Fire Research Report

Risk Assessment & Cost Benefit Analysis of Corridor Smoke Detectors in Rest Homes

Caldwell Consulting

August 2000

A computer fire model was used to carry out fire growth and smoke development calculations to determine when the smoke detectors and sprinklers activate and when conditions become untenable for life in the means of egress in a rest home. It was assumed that there are smoke detectors which are operational in the bedrooms and that there is an operational sprinkler system throughout the rest home. Fifty-six variations to this base case were considered, incorporating differences in the location and growth rate of the fire, and the location and response of smoke detectors and sprinklers. The probability of occupants being exposed to untenable conditions was determined by calculating the time required to escape with the time available to escape.

Deborah Palmer, Carol Caldwell & Dr Charley Fleischmann
New Zealand Fire Service Commission Research Report Number 4
ISBN Number 0-908-920-46-6

RISK ASSESSMENT AND COST BENEFIT ANALYSIS OF CORRIDOR SMOKE DETECTORS IN REST HOMES

New Zealand Fire Service Contestable Research Fund

Prepared By: Deborah L. Palmer
ME Dist. (Fire)
3rd December 1999

Reviewed By: Carol Caldwell
MIPENZ, MSFPE
Director

Dr Charley Fleischmann
PhD

CONTENTS

1.0 Executive Summary

The purpose of this research is to determine if smoke detectors in the corridors of rest homes have a cost benefit.

A cost benefit analysis was performed by combining rest home and rest home fire statistics, results of computer modelling, evacuation analysis and costs of fire protection systems. Ten comparisons were made in the cost benefit analysis to determine which fire protection systems have the best cost benefit in a rest home.

A generic rest home model was used with 12 occupants in the firecell and either one or two staff. The rest home bedrooms were considered to already be protected with smoke detectors and sprinklers. The entire rest home was assumed to have sprinklers installed, either standard or fast response sprinklers.

The cost benefit analysis showed that replacing standard response sprinklers with fast response sprinklers had the best cost per life saved ($449,125). The next best cost per life saved when standard response sprinklers are installed is to install a conventional smoke detector in the lounge ($1.69 million). When fast response sprinklers are installed there is no good cost benefit to install smoke detectors in the rest home. There is also no good cost benefit to install smoke detectors when two staff are required to be on duty, this is based upon 12 occupants in the firecell. A comparable cost benefit is the cost per life saved to determine roading improvements ($2.0 million).

2.0 Introduction

The purpose of this research is to determine if smoke detectors in the corridors of rest homes have a cost benefit.

Safe evacuation routes are important especially in rest homes because of the often frail characteristics of the building occupants. Smoke detectors in corridors can provide a faster warning time than if the smoke detectors are only installed in the bedrooms. The question is, are the smoke detectors in the corridors much better for life safety and what is the cost benefit or cost per life saved of them in corridors.

The research assumes a base level of fire protection in the rest homes including a sprinkler system and smoke detectors in bedrooms.

3.0 Background / Literature Review

A background to various part of the research is provided here. It outlines the fire protection requirements of rest homes, provides information about rest homes in New Zealand and also gives information about possible installed fire protection systems in rest homes.

3.1. BIA Acceptable Solution Requirements for Rest Homes

The BIA Acceptable Solutions class rest homes in a SC purpose group, sleeping care. The requirements for a SC purpose group vary depending on the number of beds and the height of the building. The fire safety precautions for table B1 of the Fire Safety Annex give the following general requirements:

- Smoke detectors in bedrooms only for rest homes when sprinklers installed (Type 6)
- Full smoke detection for rest homes with greater than 40 beds for single storey rest homes (rest homes two floors and greater do not require full smoke detection – this is not consistent with the single storey requirement) (Type 7)
- Sprinkler systems for single storey rest homes greater than 20 beds
- Sprinkler systems for two-storey rest homes greater than 10 beds
- Emergency Lighting throughout the rest home
- Each sleeping area shall be fire separated from every other sleeping area with a fire separation of 30/30/30.

The proposed revised BIA Acceptable Solutions that were issued for public comment in July 1999 have the following requirements for rest homes, SC purpose group.

- Sprinklers in all rest homes - no minimum bed number
- Smoke Detectors in all rest homes - throughout entire building full Type 7 system
- Emergency lighting throughout the rest home

3.2. US Requirements for Rest Homes

The United States of America has the following requirements for new healthcare facilities and nursing homes as per NFPA 101 Life Safety Code. The requirements are taken as direct quotes, attached is a copy of the page with these requirements.

12-2.9.1 Emergency lighting shall be provided in accordance with Section 5-9.

12-3.4.5.3 Nursing Homes* An approved, automatic smoke detection system shall be installed in corridors throughout smoke compartments containing patient sleeping rooms and in spaces open to corridors as permitted in nursing homes by 12-3.6.1.

Exception No. 1: Corridor systems shall not be required where each patient sleeping room is protected by an approved smoke detection system.

Exception No. 2: Corridor systems shall not be required where patient room doors are equipped with automatic door-closing devices with integral smoke detectors on the room side installed in accordance with their listing, provided that the integral detectors provide occupant notification.

12-3.5.1* Buildings containing health care facilities shall be protected throughout by an approved, supervised automatic sprinkler system installed in accordance with Section 7-7.

Excepion: In Type I and Type II construction, where approved by the authority having jurisdiction, alternative protection measures shall be permitted to be substituted for sprinkler protection in specified areas where the authority having jurisdiction has prohibited sprinklers, without causing a building to be classified as nonsprinklered.

12-3.5.2* Listed quick response or listed residential sprinklers shall be used throughout smoke compartments containing patient sleeping rooms.

12-3.6.1 Corridors shall be separated from all other areas by partitions complying with 12-3.6.2 through 12-3.6.5 *(see also 12-2.5.8).*

Exception No. 1: Spaces shall be permitted to be unlimited in area and open to the corridor, provided that

(a) The spaces are not used for patient sleeping rooms, treatment rooms, or hazardous areas; and

(b) The corridors onto which the spaces open in the same smoke compartment are protected by an electrically supervised, automatic smoke detection system installed in accordance with 12-3.4, or the smoke compartment in which the space is located is protected through-out by quick response sprinklers; and

(c) The open space is protected by an electrically supervised, automatic smoke detection system installed in accordance with 12-3.4, or the entire space is arranged and located to permit direct supervision by the facility staff from a nursing station or similar space; and

(d) The space does not obstruct access to required exits.

Exception No. 2………etc……….

3.3. Smoke Detection Systems

Smoke detection systems are an integral part of the fire protection in a rest home. Smoke detection provides early warning of a fire to enable evacuation to begin when the fire is small.

There are many different types of smoke detection systems available on the market. Two such systems that are typically installed in rest homes are a conventional smoke detection system or an analogue addressable smoke detection system.

A conventional smoke detection system consists of either ionisation or photoelectric smoke detectors installed in zones in the rest home. The number of zones is dependant on the fire alarm panel and system design. When a smoke detector activates it will activate alarms either locally or throughout the rest home. The zone in which the smoke detector activated will be displayed on the fire alarm panel so that staff are able to determine the location and investigate the cause of the alarm. The smoke detectors in the conventional system require regular cleaning to avoid problems of false activation.

Addressable analogue smoke detection systems are more advanced than conventional smoke detection systems and are more expensive. Each smoke detector in this system has an 'address'. The address of the smoke detector is displayed on the fire alarm panel when it activates so that staff are able to go directly to the room of smoke detector activation and investigate the cause of the alarm. Analogue addressable smoke detectors are able to tell the fire alarm panel that there is a problem in the detector that needs to be fixed. eg. It is displayed when the smoke detector requires cleaning.

3.4. Automatic Sprinkler Systems

Automatic sprinkler systems are the best fire protection system available for life safety and property protection. They not only detect the fire but they control/suppress it. There are two New Zealand standards to which a sprinkler system can be installed in a rest home. They are:

- NZS 4541 Automatic Fire Sprinkler Systems
- NZS 4515 Fire Sprinkler Systems for Residential Occupancies

The residential sprinkler standard can only be used in rest homes of area less than $2000m^2$ if there is a brigade inlet, a 60 minute water supply and a brigade alarm. The main differences between NZS 4515 (residential) and NZS 4541 are the design density and the valve set. NZS 4515 (residential) has a reduced design density, this in turn can reduce the pipe sizes required.

As well as there being two different sprinkler standards there are different types of sprinkler heads that can be installed, they are:

- Standard Response Heads
- Fast Response Heads
- Residential Heads

Standard response heads are typically found in older sprinkler systems. They have a 5mm bulb and a typical RTI (Response Time Index) of 150 $m^{½}s^{½}$. Fast response heads have smaller bulbs (3mm) and a typical RTI of 50 $m^{½}s^{½}$. Both standard and fast response heads have similar spray patterns, they typically spray water down onto the fire.

Residential sprinklers use a fast response bulb (3mm) but have a different spray pattern. Residential heads not only spray water down onto the fire they have greater coverage and spray water further horizontally onto wall etc. Other advantages to residential heads are that they are cheaper and have a lower water demand. Residential heads can be used in both NZS 4515 and NZS 4541 systems.

The effectiveness of sprinkler systems in residential type buildings at preserving life when an occupant is in the same room as the fire has been well documented by H.W. Marryatt in his book " Fire - A Century of Automatic Sprinkler Protection in Australia and New Zealand". As noted in the book, 'An important question raised by the fire fatalities in the U.S.A. in 1985 is whether sprinkler operation in a single room fire, *as in a hotel or hospital* would be fast enough to prevent the asphyxiation of an occupant smoking in bed for example.' It goes on to evaluate the fatalities in 79 single room fires, there were only two; one person whose clothes were on fire who ran from the room and one whose bedding ignited. These were all ***standard response*** sprinklers not fast response. The statistics show that in 389 documented fires in which sprinkler systems in residential buildings activated there have been only three fatalities. The majority of these residential sprinkler systems have been provided with ***standard response*** sprinklers not residential sprinklers that use a quick response activating element. The fatalities occurred when the occupant was intimate with the fire origin:

- An elderly woman dropped a cigarette onto the rubber upholstered chair on which she was sitting.
- An elderly woman sustained fatal burns when her bedding caught fire when the overhead fluorescent lights burst and hot metal ignited her bed covers.
- A young woman in a mental hospital ignited her clothing while smoking and suffered fatal burns.

In each of the described fatality scenarios the ***standard response*** sprinklers activated and prevented danger to other occupants of the buildings. In all other documented fires where residential type sprinkler systems were installed the sprinklers activated and either suppressed the fire or controlled it until the fire service was able to intervene. The documented situations Marryatt's book show residential sprinkler systems are capable of saving the lives of occupants directly exposed to the fire. In some cases the sprinkler system has saved the lives of occupants who have *deliberately started fires* in their room (Marryatt 1988).

Sprinkler systems in New Zealand have a high reliability and effectiveness. H.W. Marryatt in his book gives the reliability of sprinkler systems in New Zealand as 99.46%.

There is only one known case in New Zealand where a person has died in a rest home fire that was protected by sprinklers. This occurred in a fire where the person who died accidentally dropped embers from his pipe onto his tracksuit. The tracksuit smouldered and when the person stood up it burst into flames. The sprinkler system activated saving others in the room but could not save the life of the man intimate with the fire.

3.5. New Zealand Fire Service

Discussions with various personnel of the New Zealand Fire Service were held to gauge their views on rest home corridor smoke detectors.

The following points are some of the issues that were raised:

- Many fires originated in the residents room. These are mainly caused be carelessness (smoking materials) or from malfunctioning of electrical appliances eg. heaters and electric blankets.
- Smoke detectors should be required in bedrooms and in exitways/corridors (escape routes) because occupants and staff need to know about a fire early so that when evacuating, smoke is not harmful to the residents and staff going back and forth evacuating residents. It is believed that if smoke detectors are provided in corridors there could be less smoke in the corridor when occupants are being evacuated.
- Smoke detectors and sprinklers should be installed throughout the building because nursing homes never have more than the minimum staff required. Minimum staffing is acceptable for normal day to day running of the home but when there is a problem such as full evacuation required minimum staffing is often not enough. Therefore the fire service tend to rely more on the systems provided in facility (sprinkler and smoke) rather than on the staff. Often it is better for rest homes to put in active systems than to hire and pay extra staff if the Fire Service recommend it.
- Two main problems were identified with the proposal not to install smoke detectors in corridors of rest homes.

1. It does not comply with the New Zealand standard for smoke detector installation (NZS 4512 Fire Alarm Systems in Buildings)
2. Often rest home doors close upon activation of an adjacent smoke detector. If this can't happen because there are no corridor smoke detectors and doors close on activation of any smoke detector activating then evacuation can be made difficult. Older people need management to get out and if many doors close then need more help to get out.

3.6. Ministry of Health / NZFS Requirements

The New Zealand Fire Service encourage sprinklers and smoke detectors to be installed when applying for evacuation scheme approval. An evacuation scheme is required for the rest home so that funding and licensing is available from the Ministry of Health. The New Zealand Fire Service, in co-operation with the Ministry of Health, has distributed for public comment a draft Code of Practice for Fire Safety and Evacuation in Health Care Facilities. The draft Code of Practice will be used in conjunction with the New Zealand Building Code and the Fire Safety and Evacuation of Buildings Regulations 1992. The draft Code specifies objectives and compliance methods in four main areas:

- Fire Protection Systems and Features (Full Type 7 system)
- Fire Safety Management
- Fire Safety Training
- Evacuation Schemes

Care providers are required to meet and maintain the objectives and compliance methods in each part of the draft Code in a specified time frame. The New Zealand Fire Service and Ministry of Health have said that to get evacuation scheme approval and therefore funding rest homes must have sprinklers and smoke detectors installed in the rest home. A 12-18 month period of grace is given for the installation of the systems before funding is stopped.

The draft Code of Practice was distributed for public comment in July 1999, comments were received in August 1999, the code has not yet been adopted.

3.7. Rest Homes in NZ

A book published by Statistics New Zealand titled "*New Zealand Now, 65 Plus*" details the statistics of New Zealand elderly population. Most of the statistics are sourced from the 1996 Census. The book details the living arrangements of elderly people, classified as those people over the age of 65. The results of the section on elderly in non-private dwellings are summarised here.

At the 1996 Census 28,293 elderly people identified their usual residence as a non-private dwelling. Non-private dwellings are those where a number of generally unrelated people live. Residential homes for the elderly and hospitals are two main types of non-private dwellings. In 1996 around 19,926 people, or slightly less than 5%, were living in residential homes for the elderly, and a further 5,124 or 1.2% were in public or private hospitals.

The median age of elderly people in residential homes was 84, which is much higher than the median age of the total elderly population, which is 73. Of the total population the number of elderly in residential homes according to age is as follows:

- Age 65 to 74 – 1.3%

- Age 75 to 84 – 5.7%
- Age 85 and older – 24.5%

Almost half of all residents in residential homes in 1996 were 85 years or older. The number of elderly people in hospitals has declined in recent decades as residential homes have taken the place of hospitals in providing long-term care. As mentioned earlier slightly less than 5% of elderly live in residential homes and only 1.2% in public or private hospitals. This is very different from the 1966 statistics where 4.3% were in hospitals and less than 2% in residential homes.

Information was sourced from Ministry of Health on the number of rest homes and number of people in licensed rest homes in New Zealand. As at October 1999 the details are:

- 528 fully licensed old people homes in NZ
- 15699 fully licensed old people homes beds in NZ

The difference in the number of people living in residential homes (19,926) and rest homes (15,699) is unknown. The Census information is for non-private residential homes for the elderly. The Ministry of Health information is for fully licensed old people homes, this does not include geriatric homes for the elderly. It is possible that the discrepancy in the number of people living in rest homes is because not all rest homes would be fully licensed to the Ministry of Health. For the purposes of this research the data used is from the 1996 Census which gives the number of elderly living in residential homes for the elderly as 19,926 people. Using the higher number reduces the expected number of fires per person per year. This in turn increases the cost per life saved.

3.8. Typical Protection in a Rest Home

The typical protection in rest homes was discussed with personnel from the New Zealand Fire Service. The approximate details on fire protection systems in rest homes is given below:

- Approximately 80 - 90% of rest homes have sprinklers installed. This does not necessarily mean that they also have smoke detectors installed.
- Other rest homes only have smoke detectors or heat detectors or sometimes only manual call points.

A recent presentation given by the New Zealand Fire Service and the Ministry of Health regarding the Draft Code of Practice for Fire Safety and Evacuation in Health Care Facilities gave the following statistics about rest homes in New Zealand.

- Three years ago 360 rest homes out of 810 had no sprinkler systems installed.
- Today, only two dozen do not have a sprinkler system installed or a management system in place to get a sprinkler system installed.

The differences in numbers between the above 810 rest homes and the Ministry of Health figures of 528 fully licensed old people homes is unresolved. Possible reasons are that not all rest homes are fully licensed, or some rest homes have gone out of business.

These statistics and information show that most rest homes in New Zealand have a sprinkler system installed. Information of smoke detectors in rest homes is not accurately known.

4.0 Statistics

There are many sources for statistics and information about fires in rest homes. References such as the census data (1996) and working group findings (WG10) have been used as well as New Zealand Fire Service FIRS database statistics.

4.1. NZFS Fire Incident Reporting Statistics

Information from the Fire Incident Reporting Statistics database (FIRS) for rest homes was obtained from the New Zealand Fire Service for the following categories on the FIRS incident reporting form:

- Date and day of week of incident
- Specific Property Use (Resthome)
- Incident Type
- Location of fire origin
- Alarm time
- Evacuation
- Supposed Cause
- Object and material type fire started on
- Detector Type
- Detector Performance
- % of property saved
- No. of casualties
- Type of Injury
- Severity of Injury

The statistics were obtained for the period from 1990 to the end of April 1999. The number of statistics obtained for 1990 – 1995 were very small. The reason for this is unknown and is unresolved with The New Zealand Fire Service. Further information was requested from The New Zealand Fire Service regarding the period 1990 – 1995. The information received had not been screened, was difficult to use and did not include fatality information. Further statistics were requested for fatality information in rest home fires. Fatality statistics for the period 1985/86 through to 98/99 were received and the total number of fatalities in rest home fires was determined for this period.

The number of structural fires that occurred in rest homes in the period 1985/86 through to 1998/99 is 455. In this time there were 15 recorded fatalities.

Ministry of Health statistics given at a presentation on the Draft Code of Practice for Fire Safety and Evacuation in Health Care Facilities had slightly different statistics. The data they obtained (recorded since 1986) gave 221 fires that had structural damage and 16 fatalities. The data used by the Ministry of Health used fires that had structural damage, the statistics used in this research is for any structural fire - damage or no damage. Other fires on the FIRS database that were not included in this research were fires such as rubbish fires and false alarms.

It is not possible to differentiate between sprinklered rest homes and non-sprinklered rest homes in the statistics. To date there is only one fatality in a sprinklered rest home in New Zealand, this occurred in 1996 when a man smoking a pipe had hot ash falling on his polyester track suit. It smouldered and when he stood up it burst into flames. Everyone else in the room survived the fire.

Expected number of fatalities in rest homes now is likely to be less than the statistical information here because of the recent trend towards providing sprinklers in rest homes.

The following statistics and graphs are based on the initial statistics received from the New Zealand Fire Service for the period 1990 to the end of April 1999. The statistics analysed have been used to determine the scenarios modelled or have been used in the cost benefit analysis.

The following graph (Figure 1), shows the most likely location of fire origin for a rest home fire. The largest number of fires start in the kitchen with 71 fire starts, the bedroom has 32 and the lounge 22 fire starts.

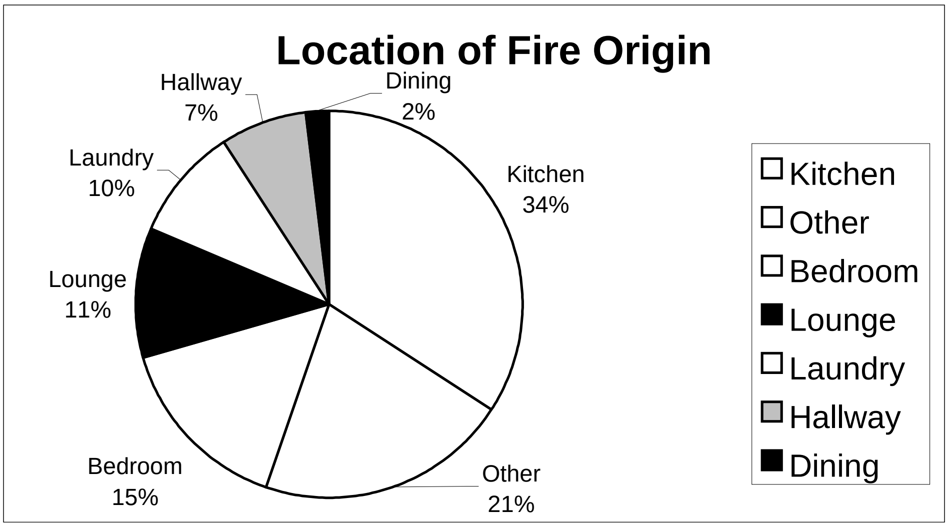

Figure 1, Location of Fire Origin – FIRS database 1990 – April 1999

The FIRS database gives many different causes of fire start. The following graph, figure 2, details the supposed causes of fire as filled out on the FIRS incident form.

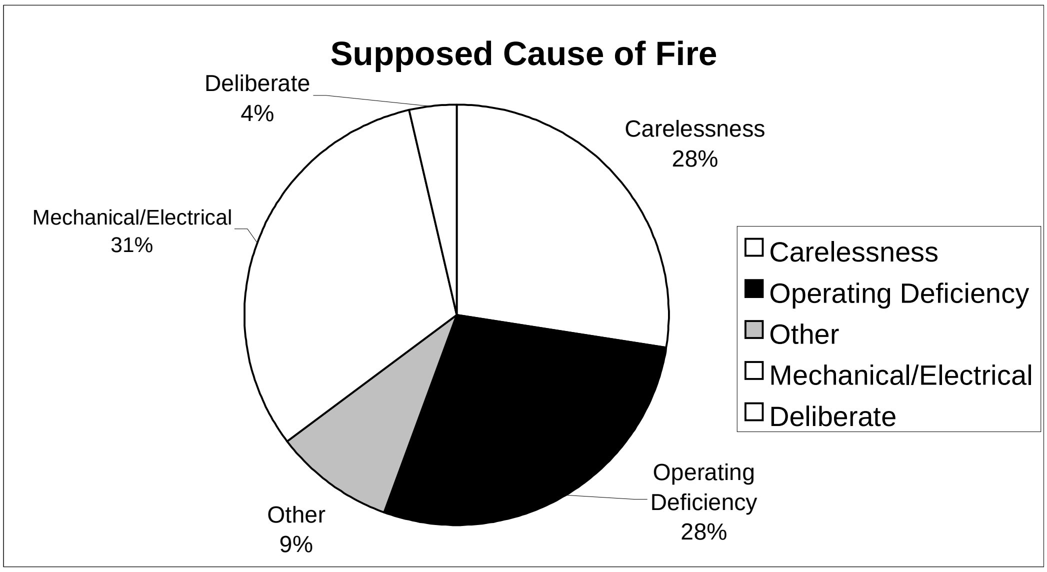

Figure 2, Supposed Cause of Fire – FIRS database 1990 – April 1999

Other common causes of fire starts in rest homes have been determined by speaking to personnel from the New Zealand Fire Service and from the BIA Working Group document (WG10). Common causes are:

- Electric blankets bunched up or faulty old electric blankets
- Faulty electrical appliances
- Fallings asleep while smoking
- Carelessly discarding smoking materials

The detector type that may have alerted occupants to the fire is shown below in figure 3. Not all of the fires had an entry for the detector type, only 81 of the 216 statistics had an entry. A smoke detector was the most common detector, with sprinklers the next common and then heat detectors.

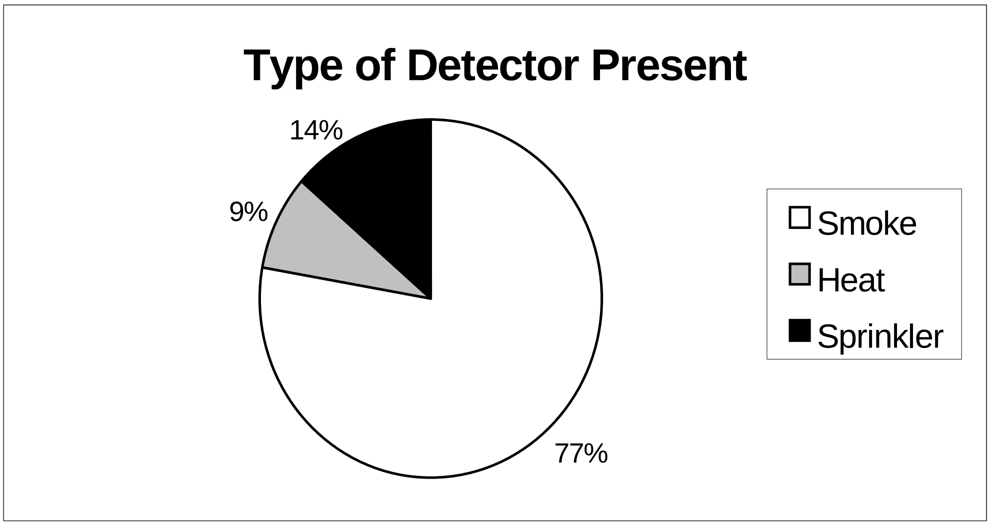

Figure 3, Type of detector present - FIRS database 1990 – April 1999

The object that the fire first started on is shown in figure 4. These statistics were used to determine the probability of an ultra fast fire occurring. This information was required for the cost benefit analysis. The probability of an ultra fast fire occurring was assumed to be 50% of the percentage of fires starting on soft furnishings and upholstered furniture. The figure 50% was used because it was expected that furnishings in rest homes are likely to be of a better quality and are less likely to result in an ultra fast fire than cheaper furnishings. The cost benefit analysis therefore used a figure of 8.5% for the percentage of fires assumed to result in an ultra fast fire.

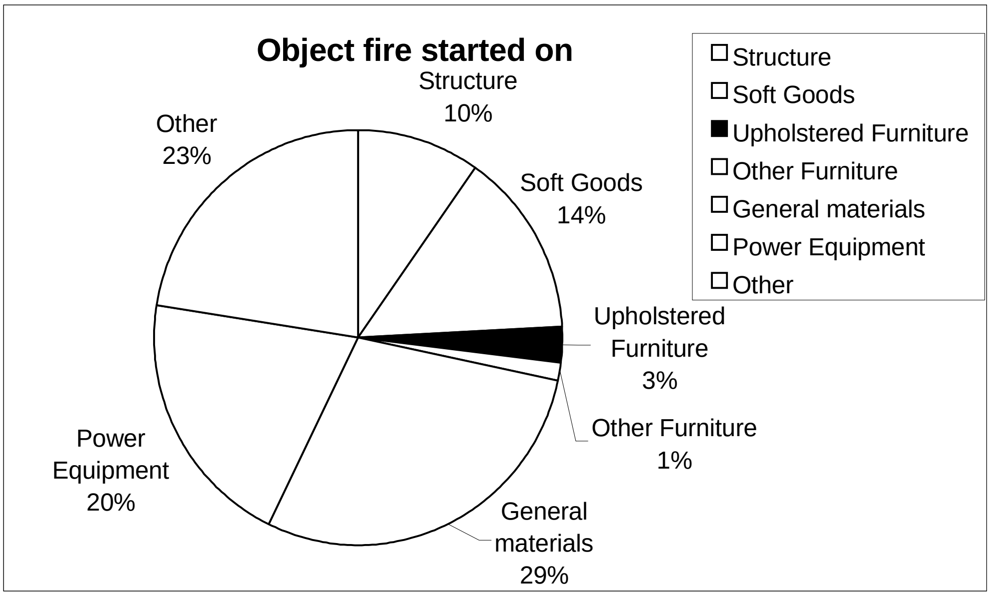

Figure 4, Object that fires started on - FIRS database 1990 – April 1999

The number of fatalities in the years 1985/86 through to April 1999 were found from the fatality statistics received from the New Zealand Fire Service. The total number of fatalities for rest home fires for the 14 years is 16, this is for a total of 455 rest home fires. This gives the expected number of fatalities per fire as 0.03516.

The expected number of fatalities in the United States and Australia (Zhao) can be compared with the New Zealand information in figure 5. The expected number of fatalities from the United States has been determined from a far larger number of statistics than the New Zealand expected number of fatalities.

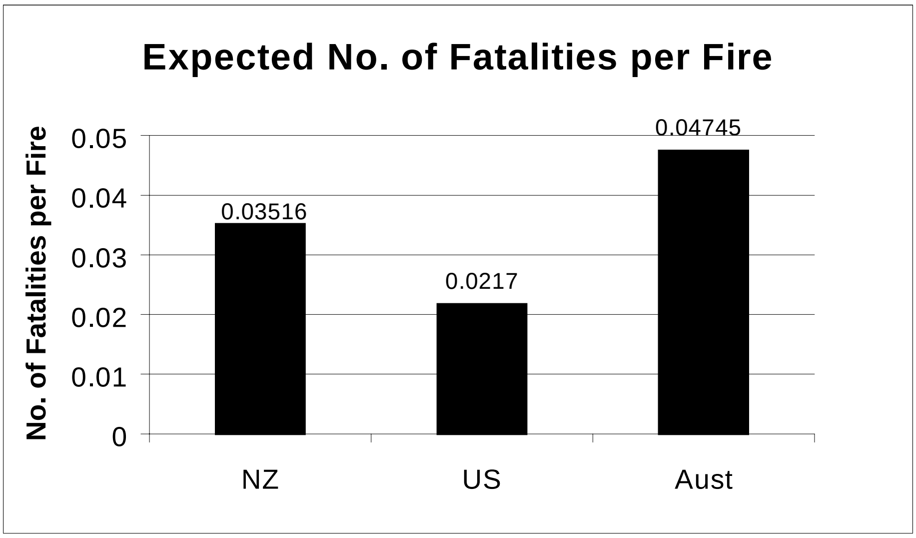

Figure 5, Expected Number of Fatalities per Fire – FIRS Fatality Information (85/86 – 98/99) and Zhao.

4.2. BIA Working Group

A report written by a working group for the BIA (WG10) investigated significant risk in fire. The objectives of the report were to;

(a) define significant risk;
(b) develop appropriate criteria for the classification of residential buildings as "significant risk". The criteria is to have practical application for the assessment of residential buildings in order that requirements for appropriate fire safety precautions may be made for existing residential buildings;
(c) review the fire safety precautions in the Approved Documents for residential Purpose Groups;
(d) consider whether automatic fire alarms should be installed in residential occupancies where significant risk areas;
(e) relate the work to other work carried out for the Building Industry Authority on risk assessment;
(f) relate the work to Section 64 of the Building Act such that if accepted the recommendations for the significant risk criteria can be included in Section 64 as a basis for deeming a building to be dangerous.

The working group investigated the risk of rest homes in relation to fire. They used information from the New Zealand Fire Service relating to people 65 years and older and rest homes occupancies. The working group found that the societal risk and the individual risk, that was based on past trends, was higher than the acceptable risk. Therefore they concluded that (generically) the fire risk in rest homes is significant.

The high fire risk was determined for all rest homes – both old and new. It is likely that newer rest homes will have better fire safety precautions than older rest homes and will not pose such a significant risk. The working group decided that further research is required regarding newer rest homes to determine where the risk is. If newer rest homes are not a significant risk then older rest homes may be a very high significant risk.

The risk was evaluated on the basis of deaths/100 fires. Purpose groups SC/SA (rest homes) had the highest fatality rate per 100 fires, 6.8 fatalities/100 fires. This fatality rate is high compared with the fatality statistics determined from the NZFS FIRS database. It is possible that the fatality rates are higher because the statistics used by WG10 are for the period 1986 – 1993 in which the majority of fatalities occurred.

The working groups recommendations were that smoke detectors should be installed in and around the sleeping areas of all SC rest homes regardless of the number of beds (current requirement is smoke detectors for 6 beds or more). They also recommended that sprinklers should be installed in all SC rest homes of 6 beds or more, regardless of the building height (current requirement is 6, 11, or 21 beds depending on the height of the building) and that the sprinklers should be fitted with quick response heads.

5.0 Scenarios

There are many possible scenarios that could occur when a fire breaks out in a rest home. For the purpose of this research the determination of the scenarios have been divided into the fire scenario and the physical scenario. The fire scenario deals with the properties of the fire. The physical scenario details the physical situation of the rest home. Fifty six different scenarios were determined by combining the fire scenarios and physical scenarios. These fifty six scenarios have been arranged in an event tree so that all of the scenarios are easy to determine. The event tree can be seen in Appendix One.

5.1. Fire Scenario

The number of fire scenarios that could occur in a rest home is limitless. For the purposes of this research the fire scenarios need to be limited to the most likely fire scenarios. The limitations that have been put on the fire scenarios are:

- Location of fire origin, either in the corridor or exposing the corridor (lounge)
- If exposing the corridor then fire either in the bedroom or the lounge
- Type of fire, either flaming or smouldering
- If a flaming fire then either slow, medium, fast or ultra fast growth

The location of the fire origin was further reduced by not considering the bedroom. The bedroom already has sprinklers and smoke detectors installed. With these fire protection features a fire starting in the bedroom is not expected to be a concern to life safety for other occupants of the rest home.

A flaming ultra fast fire was not considered appropriate for the corridor. With the expected furnishings in the rest home corridor to be sparse it was not considered likely that an ultra fast fire would develop.

5.2. Physical Scenario

The physical situation of the building is different from the fire scenario. The physical situation deals with aspects of the building such as the size of the rooms, situation of the doors between rooms and installed fire protection features. As stated above in the fire scenario, the bedroom is not being considered because it has a smoke detection and sprinkler system installed. For the purposes of this research the scenarios have been limited to a typical rest home with the following features:

- Corridor dimensions 1.5m x 24m x 2.4m high
- Lounge dimensions 8m x 9m x 2.4m high
- Lounge door to corridor always open, opening of 1.4m x 2.1m high
- Sprinklered building with either fast response or standard response sprinklers
- Smoke detector location either in the corridor or lounge.

5.3. Assumptions

The assumptions made in the scenarios and the computer modelling are given below. Many of the assumptions are made so that the computer modelling is representative of actual situations in rest homes in New Zealand.

- The sprinkler system and any installed smoke detection system is assumed to be operational and effective in detecting the fire and controlling the fire. This is generally accepted practice in New Zealand.
- An ultra fast fire is not likely to occur in the corridor.
- Smouldering fires are not able to be modelled accurately using FASTLite because accurate heat release rate data is not available. Smouldering fires do not create untenable conditions in the timeframe being considered for evacuation. Information from Quintere *et. al.* (1982) was used to determine the time when a smouldering fire may become untenable. Quintere *et. al.* determined that smouldering fires may cause hazardous conditions due to Carbon Monoxide in approximately 50 – 150 minutes. The experiments were done in a closed room, 2.44m high and a floor area of $8.83m^2$

with a small horizontal slit opening at the floor. Section 2-11, page 177 of The SFPE Handbook of Fire Protection Engineering gives the time to either lethal CO concentrations or transition to flaming combustion for smouldering bedding or upholstery as 65 to 80 minutes for a closed room. These time frames are not a concern as occupants or staff are expected to be aware of a smouldering fire and able to evacuate to a safe place in less than 50 minutes.

- Sprinkler activation will control the fire. When the sprinkler activates the heat release rate will remain steady and will not be suppressed by the sprinkler. This is a very conservative approach to the modelling.
- Untenable conditions are assumed to occur in the corridor when the Carbon Monoxide (CO) concentration reaches 27,000 ppm.min (for information regarding this see Section 6.2 Untenable Conditions Results).
- Fire service intervention is not considered in the modelling, that is, the impact of fire service on life safety is the same regardless whether smoke detectors are installed in corridor or not. Is assumed fire service are not notified automatically about a smoke detector activating. Either a manual call point or sprinkler activation will notify the fire service of a fire therefore smoke detectors only notify occupants and staff.
- There are six bedrooms on either side of the corridor each with one occupant, therefore there are 12 occupants being considered in the research.
- It is assumed that evacuation is staff assisted therefore the state of the person (asleep or awake) is not important.
- The evacuation is assumed to progress with one person evacuated per minute per staff member. Therefore with only one staff member it takes 12 minutes to evacuate the 12 patients from the area.

6.0 Computer Modelling

The fire modelling printouts are not included here, for reasons of space.

6.1. Set up on FASTLite

FASTLite is a computer program developed by the National Institute of Standards and Technology in the United States of America that is used as an "Engineering Tools for Estimating Fire Growth and Smoke Transport". FASTLite is used in this research to determine when the smoke detectors and sprinklers activate and when conditions become untenable in the means of egress.

FASTLite was used to set up the base case modelling. Variations to the base case were modelled so that all of the events in the event tree were covered in the modelling. The variations to the base case include the location of the fire starting, type of fire and the position of the smoke detector. All of the scenarios have been modelled with the sprinklers and smoke detectors, vents and fire locations in the same positions in each room and the same room sizes.

The printouts from FASTLite can be seen in Appendix Two.

Detailed below are the variables, data and other information that was entered into FASTLite to perform the modelling of the scenarios.

Rooms and Dimensions

The modelling uses two rooms, the corridor and lounge. The basic arrangement of the rooms is as shown in figure 6.

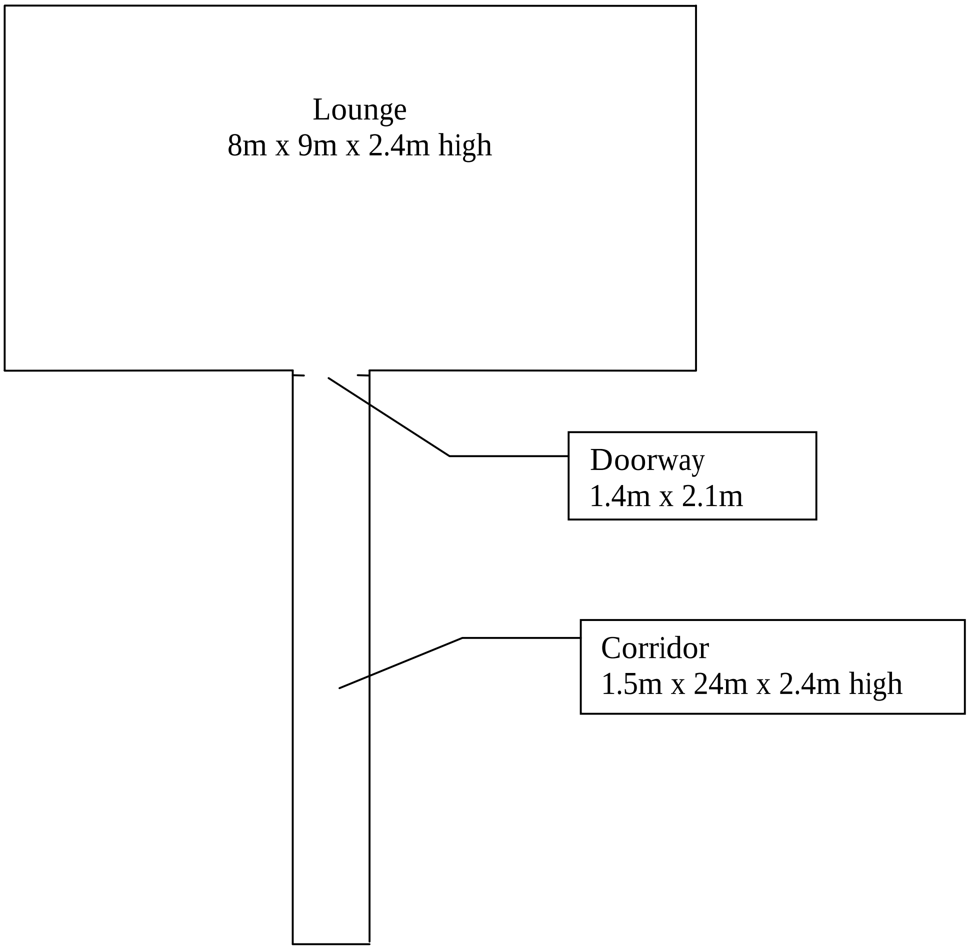

Figure 6, Layout and Dimensions of Rest Home used in FASTLite – (not to scale)

Type of Fires Modelled

The four different fires, slow, medium, fast and ultra-fast were used to demonstrate the variety of fires that can occur, an ultra fast fire was not modelled in the corridor. A slow fire may occur in a corridor where there are few combustibles. An ultra fast fire may occur in a lounge where a chair or couch made with a polyurethane foam and a polyester covering may catch fire and burn extremely quickly.

The Carbon Monoxide concentration was used to determine when conditions become untenable. To determine the Carbon Monoxide concentration the species information is required as an output from FASTLite. To get the species output the following species ratios are required to be entered into the modelling. The ratios are determined from The SFPE Handbook of Fire Protection Engineering, section 3-4 (pages 78 and 89) for GM27 polyurethane flexible foam.

- Hydrogen (H) to Carbon ratio (C) = 2:1
- Carbon Monoxide (CO) to Carbon Dioxide (CO_2) ratio = 0.03
- Carbon to Carbon Dioxide ratio = 0.13

Vents

There is a permanent opening between the lounge and the corridor, this is the set of double doors. A window was assumed open in the modelling, it was located in the room that did not have the fire. This was done so that the fire did not have a limited air supply and so that it did not affect the upper layer in the room of fire origin. Providing a window is representative of an actual situation where either a window or door is likely to be open in the rest home. The window size modelled is 0.5m wide and 1m high and is situated 1m off the ground. In the ultra fast fire cases the vents were not large enough for the modelling and FASTLite crashed. The window was increased in size slightly so that the modelling could continue.

Leakage to the outside was also modelled. The rest home was assumed to be of average construction. Using Table 4.3 from Klote and Milke (1992) the area ratio (area of leakage through the wall divided by the total wall area) for average tightness is 0.21×10^{-3}. The area of leakage to the outside was determined and was converted into a vent the total height of the room with a narrow width.

Sprinklers

Sprinklers were modelled throughout the space. The sprinkler suppression algorithm was not used as it was assumed that the heat release rate was kept steady at the rate when the sprinkler activated. Keeping the heat release rate steady when the sprinkler activates assumes that the sprinkler only controls the fire and does not suppress it. This is a very conservative approach to take because in New Zealand it is generally accepted that sprinklers will suppress the fire.

DETACT, was used to predict the time and heat release rate when the sprinkler activated. DETACT is a computer model used to predict the thermal response of a detector or sprinkler head located near the ceiling. The inputs for DETACT include the room dimensions, response time index (RTI) of the sprinkler and the activation temperature of the sprinkler.

The time and heat release rate when the sprinkler activated from the DETACT modelling were entered into the FASTLite modelling.

The scenarios identified in the section above use both fast response sprinklers and standard response sprinklers. The typical response time index (RTI) of the two types of sprinklers is shown below:

- Standard Response RTI = 150 $m^{1/2}s^{1/2}$
- Fast Response RTI = 50 $m^{1/2}s^{1/2}$

The typical activation temperature of the sprinklers installed in rest homes was found from the Reliable Sprinkler manufacturers listing of various sprinkler heads, the activation temperature used for both fast response and residential sprinklers modelled in the rest home is typically 68°C.

Because the fire was only being controlled at a steady heat release rate and not suppressed the sprinkler suppression algorithm in FASTLite was not used. The sprinkler suppression algorithm uses the spray density of the sprinklers as well as the RTI and activation temperature.

Smoke Detectors

Smoke detectors were modelled as per the scenarios where either a smoke detector is provided:

- in the corridor only;
- in the lounge only or;
- in the corridor and lounge.

Note: The scenarios were also modelled with no smoke detector in the corridor and lounge.

Smoke detectors were modelled in FASTLite. They are modelled to activate at a specified temperature because it is not possible to accurately predict smoke detector activation. The default temperature of activation in FASTLite was used, this is 31°C which is 11°C above ambient.

The time at which the smoke detector activates and the room in which it activates can be determined from the FASTLite printout included in Appendix Two.

6.2. Untenable Conditions Results

The time at which untenable conditions occur is the time at which the Carbon Monoxide concentration in the corridor reaches 27,000 ppm.min. This limit for untenable conditions was determined from various sources such as the Fire Engineering Design Guide (NZ), the Fire Engineering Guidelines (Aust.) and CIBSE – Fire Engineering (UK) that gave the time that occupants could be exposed to certain concentrations of Carbon Monoxide before it became incapacitating. These references used similar data to the SFPE Handbook of Fire Protection Engineering where the time to incapacitation in active monkeys is given. For CO concentrations between 1000 and 8000 ppm the time to incapacitation ranged between 26.6 minutes and 3.3 minutes respectively. The concentration multiplied by the time (Ct) for these values equal approximately 27,000 ppm.min.

There are other options to use to define the time at which untenable conditions occur. Two possible points for untenable conditions is the time at which the layer height drops to 1.5m or the time when the temperature in the upper layer reaches 200°C. Both of these are not appropriate to use in the research. The layer height drops very quickly in the modelling. Using the time at which the layer height reaches 1.5m is not appropriate because the smoke at this time is cool, and with the sprinkler system operating is not likely to be hazardous to occupants. With the installation of the automatic sprinkler system temperatures in the upper layer in an actual fire with sprinklers operating are not likely to reach 200°C. This was found in some initial modelling performed using FASTLite with the sprinkler suppression algorithm on.

The Carbon Monoxide levels in the corridor are given in the species output from FAST, the output is converted into an Excel spreadsheet. The Carbon Monoxide levels (in ppm) are multiplied by the time (in minutes) to give ppm.min.

When this value reaches 27,000 ppm for the corridor this is the time at which conditions were considered untenable.

The time to untenability is used to determine the probability of occupants being exposed to untenable conditions (see section 7.2) in the corridor.

6.3. Sprinkler / Smoke Detector Activation Results

The time that the smoke detector activates in a compartment is found in the results of the FASTLite modelling. The sprinkler system activation time was determined using DETACT. The results of the DETACT modelling for sprinkler activation were used in the FASTLite modelling.

The results of the smoke detector activation times and sprinkler activation times are used to determine the probability of occupant being exposed to untenable conditions in the corridor.

In some of the scenarios where fast response sprinklers are installed in the building there is only a small difference in time between the activation of the smoke detector and the sprinkler. In one case, a fast fire in the corridor and a smoke detector in the lounge, there is only a difference of 40 seconds between the two detectors activating. This is due somewhat to the artificial nature of smoke detector activation that does not easily take into account smouldering fires.

The activation times of the various detectors can be seen in Appendix Three.

7.0 Cost Benefit Analysis

The cost benefit analysis combines the computer modelling results with some of the statistics analysed. The computer modelling results that determined time to untenable conditions and alarm activation time are combined to determine a probability of being exposed to untenable conditions.

7.1. Evacuation Analysis

The rest home being analysed in this research has sprinklers installed throughout the building and smoke detectors in the bedrooms. The scenarios that were modelled were to install smoke detectors in the corridor, in the lounge, in the corridor and lounge, or not installing them in the corridor or lounge.

There are 12 bedrooms being considered in the analysis each with one occupant. At night time it is likely that there will be a low level of staffing, one or two staff members is often the minimum requirement as per Ministry of Health standards. In the cost benefit analysis both one or two staff members are considered.

Upon activation of either the smoke detector or sprinkler, evacuation begins to occur. It was assumed that it would take one staff member one minute to evacuate one patient to a safe place. Using this value the total time required to evacuate the 12 occupants if there is only one staff member is 12 minutes. An investigation time was not used because the one minute evacuation time was considered long enough to include investigation time for the staff.

7.2. Probablity of Being Exposed to Untenable Conditions

The cost benefit analysis requires a probability of being exposed to untenable conditions. For the analysis it was assumed that this probability was determined by comparing the time available to escape with the time required to escape. The time available to escape is the time between when the alarm activates and when conditions become untenable. The time required to escape is the time taken for one or two staff members to evacuate the 12 occupants (either 12 or 6 minutes). The number of occupants that were not evacuated in the time available to escape was divided by the total number of occupants (12) to obtain the probability of being exposed to untenable conditions.

Example. If the alarm activates at 2 minutes and conditions become untenable in 10 minutes the time available to escape is 8 minutes. If there is only one staff member on duty he/she will only be able to evacuate 8 patients, 4 will be left in the building. Therefore the probability of being exposed to untenable conditions is 4/12 = 33%.

This calculation was performed for all of the scenarios, the results from the calculations can be seen in Appendix Four.

7.3. Statistics Information Used in the Analysis

The main statistics required to be used in the cost benefit analysis are:

- Expected number of fires per person per year
- Expected number of fires per person per year (ultra fast only)
- Expected number of fatalities per fire

The expected number of fires per person per year can be determined by dividing the total number of rest home fires that occurred by the number of years and the number of people residing in rest homes. In the 14 years from 1985/86 to 1998/99 the total number of structural rest home fires that occurred is 455. The number of people in rest homes as determined from the 1996 Census information as discussed in Section 3.7, Rest Homes in NZ, is 19,926. The expected number of fires per year per person is therefore 0.00163. As discussed in Section 3.7, using the higher number of people in rest homes reduces the expected number of fires per person per year which then increases the cost per life saved.

The expected number of fires per person per year for ultra fast fires only can be determined by multiplying the probability of an ultra fast fire occurring by the total expected number of fires per person per year (as above). The probability of an ultra fast fire occurring was discussed in Section 4.1 NZFS Fire Incident Reporting Statistics and was determined to be 8.5%. Therefore the expected number of ultra fast fires per person per year is 0.00014.

The expected number of fatalities per fire was discussed in Section 4.1, NZFS Fire Incident Reporting Statistics and is given as 0.03516. The statistics used were for all rest home fires, this includes those rest homes that were sprinklered as well as unsprinklered rest homes. It was not possible to use statistics for sprinklered rest homes only because this information is not known from the FIRS database. Information is not readily available to determine if the rest home was sprinklered at the time of the fire. It may have been possible to investigate each incident further by calling the rest home to determine if sprinklers are installed and when they were installed.

This would be a very time consuming and not necessarily productive task. Using the expected number of fatalities per fire for all structural rest home fires makes the cost benefit analysis appear better than it is, ie. the cost benefit is reduced.

In summary the statistics used in the cost benefit analysis are shown in Table 1.

Table 1 Statistics used in Cost Benefit Analysis

Statistic Used	Value
Expected no. of fires per year per person	0.00163
Expected no. of ultra fast fires per year per person	0.00014
Expected no. of fatalities per fire	0.03516

7.4. Cost of Fire Protection Systems

Three fire protection contractors were approached to provide the cost to install smoke detectors in a rest home assuming an existing smoke detection system was already installed in the bedrooms. Two costs were requested, one for a conventional smoke detection system and one for an analogue smoke detection system. The costs were approximately the same for all three contractors and included the smoke detector, cabling and labour, the following costs were used in the cost benefit analysis:

- Cost to install conventional smoke detection system (per detector) = $120.00
- Cost to install analogue smoke detection system (per detector) = $180.00

Three smoke detectors are required in the corridor and one in the lounge room to meet the spacing and location requirements of NZS 4512 Fire Alarm Systems in Buildings. The cost to install smoke detectors is therefore:

- In the corridor only = $360.00 or $540.00
- In the lounge only = $120.00 or $180.00
- In the corridor and lounge = $480.00 or $720.00

The expected lifetime of the smoke detectors is approximately 8 years, this is the life used in the cost benefit analysis.

The cost to convert the sprinkler system from standard response sprinklers to fast response sprinklers was determined by speaking to fire protection contractors. The total cost, including labour, per sprinkler is approximately $35.00 per sprinkler. As per NZS 4541 Automatic Fire Sprinkler Systems requirements the total number of sprinklers in the corridor and lounge is nine. The total cost to convert from standard response sprinklers to fast response sprinklers is $315.00.

The expected life of the sprinklers as used in the cost benefit analysis is 50 years.

The cost to employ an extra staff member for 12 hours at night for every day of the year for 8 years is required for the cost benefit analysis. The cost for 8 years is required because that is the expected life of a smoke detector. Assuming the staff member is paid $10.00 per hour, the total cost to employ an extra staff member is $350,400.00.

7.5. Cost Benefit Comparisons

To enhance the output of the project ten comparisons were made for the cost benefit analysis. This was made possible by the fifty six scenarios analysed in the computer modelling. The cost benefit for smoke detectors in corridors versus no smoke detectors was only one of many cost benefits analysed as shown below:

1. No smoke detectors vs smoke detectors in corridor – standard response sprinkler
2. No smoke detector vs smoke detector in lounge – standard response sprinkler
3. No smoke detector vs smoke detector in corridor and lounge – standard response sprinkler
4. No smoke detector vs smoke detector in corridor – ultra fast fire only – fast response sprinkler
5. No smoke detector vs smoke detector in lounge – ultra fast fire only – fast response sprinkler
6. No smoke detector vs smoke detector in corridor and lounge – ultra fast fire only – fast response sprinkler
7. No smoke detector and two staff vs smoke detector in corridor and one staff – standard response sprinkler
8. No smoke detector and two staff vs smoke detector in corridor and one staff – fast response sprinkler
9. No smoke detectors standard response sprinklers vs no smoke detectors fast response sprinklers
10. No smoke detector and 2 staff vs smoke detector in corridor and 2 staff – standard response sprinklers

The number listed above is referred to later as the ‘case’ number.

Other comparisons were not made in some cases because the installation of smoke detectors made no difference to the probability of being exposed to untenable conditions because the probability was already zero. This occurred most often in fires where fast response sprinklers were installed and the installation of smoke detectors did not provide any benefit to the occupants. Some of the cases where this occurred is:

- Slow, medium and fast fires for no smoke detector vs smoke detectors (anywhere) when fast response sprinklers are installed.
- No smoke detector and 2 staff vs smoke detector in corridor and 2 staff – fast response sprinklers

All but three of the ten cost benefit comparisons analysed the seven types of fires that were modelled in FASTLite. In summary these seven fires are:

- Slow, medium and fast fires starting in the corridor (3)
- Slow, medium, fast and ultra fast fires starting in the lounge (4)

The three cost benefit comparisons that did not use the seven types of fires are cases four, five and six. Only an ultra fast fire in the lounge was analysed in these cases because it is the only type of fire that installing smoke detectors made a difference to. The expected number of fires per person was altered in these cases to include only ultra fast fires.

Cases seven and eight can be analysed in two different ways, one way is assuming that two staff members were already required at night in the rest home and the other way by assuming that only one staff member is required at night. Where two staff members are already required the cost benefit is not analysed because the probability of being exposed to untenable conditions increases by having only one staff member and smoke detectors. In other words there is no benefit in installing smoke detectors when there are already two staff on duty. Where two staff members are not already required the cost benefit can be analysed to include the cost to employ an extra staff member at night for 12 hours every day. Because the life of the smoke detector is taken as 8 years, the cost to employ a staff member for 8 years is analysed.

7.6. Cost Benefit Analysis and Results

The following table, table 2, shows the calculations performed in the cost benefit analysis. The first three columns is the cost benefit analysis, the fourth column is how the number or calculation was determined:

Table 2 Sample cost benefit analysis for case one

	No Smoke Detector Std Response	Smoke Detector in Corridor Std Response	Explanation
Probability Exposed to Untenable Conditions	32.1	16.1	From calculations performed as per section 7.2
Expected no. fires per person per year	0.00163	0.00163	From section 7.3
Expected no. of fires of concern per person per year	0.00052	0.00026	Expected no. of fires per person per year X Probability Exposed
Expected no. of fatalities per fire	0.03297	0.03516	From section 7.3
Expected no. of lives saved per year		9.23E-06	=(0.00052 – 0.00026) *0.03516
Expected no. of lives saved in 8 years		7.39E-05	Expected no. of lives saved per year X 8
Cost of Analogue Smoke Detection System		$540.00	From section 7.4
Cost of Conventional Smoke Detection System		$360.00	From section 7.4
Cost per life saved – analogue		$7,311,071.00	Cost of smoke detector / expected no. of lives saved in 8 years
Cost per life saved - conventional		$4,874,047.00	Cost of smoke detector / expected no. of lives saved in 8 years

The calculations performed for the 10 cases can be seen in Appendix Five.

The following table, table 3, summarises the cost benefits for the 10 cases analysed as listed in section 7.5 Cost Benefit Comparisons.

Table 3 Summary of Cost Benefits for 10 cases

Case Number	Cost Per Life Saved
1	$7,311,071 Analogue Smokes $4,874,047 Conventional Smokes
2	$2,376,677 Analogue Smokes $1,584,451 Conventional Smokes
3	$8,617,881 Analogue Smokes $5,745,254 Conventional Smokes
4	$214,384,099 Analogue Smokes $142,922,732 Conventional Smokes
5	$48,298,743 Analogue Smokes $32,199,162 Conventional Smokes
6	$197,207,925 Analogue Smokes $131,471,950 Conventional Smokes
7	$5,749,831,005 Conventional Smokes, extra staff
8	$24,998,208,756 Conventional Smokes, extra staff
9	$420,992 (Changing to fast response heads)
10	$71,206,147 Analogue Smokes $47,470,765 Conventional Smokes

Table 3 shows the various cost benefits for the ten cases. The lowest cost benefit is to replace standard response sprinklers with fast response sprinklers when no smoke detectors are installed in the corridor or lounge. The next best cost benefit is to install a conventional smoke detector in the lounge if the rest home has standard response sprinklers installed.

These cost benefits can be based upon other known cost benefits for other fire protection equipment. The cost per life saved for residential smoke alarms is $1.2 million and about $2.7 million for a sprinkler system (Zhao). Other cost benefits that are analysed before work proceeds is the cost per life saved for road improvements which is $2.0 million (BIA WG10).

Considering these other cost benefits the only possible cost benefits are to either install fast response sprinklers instead of standard response sprinklers in the corridor and lounge or install a conventional smoke detector in the lounge if the rest home has standard response sprinklers.

The cost benefit analysis has not taken into account a distribution of costs over time, nor has it allowed for the costs associated with maintenance of the smoke detectors. It is possible that the maintenance costs of a conventional smoke detection system is greater than an analogue smoke detection system.

8.0 Discussion

The computer modelling and subsequent cost benefit analysis were performed for fifty six scenarios. Many problems were encountered and assumptions were made so that the modelling and analysis could proceed.

8.1. Statistics

As discussed in Section 4.0 Statistics, there were a few different sources to get the required statistics for the computer modelling and cost benefit analysis. There was some difficulty in getting information from the NZFS Fire Incident Reporting Statistics (FIRS) database. Initial information from the FIRS database did not have the full amount of statistics for the years 1990 – 1995. Further statistics that were requested were not useful as they had not been screened for false alarms and other miscellaneous fires and did not have fatality information. Fatality statistics were then requested and obtained for all types of fires, it was relatively easy to determine the number of fatalities for rest home fires only. The statistics used in the cost benefit analysis to determine the expected number of fires per year were sourced from the unscreened statistics for structural rest home fires only. Other statistics such as the origin of fire location, object fire started on etc. were determined from the original statistics received. Information on the number of elderly in rest homes was found from information sourced from the 1996 Census. This was used instead of the Ministry of Health information which was only for fully licensed old people homes.

8.2. Computer Modelling

A great deal of initial computer modelling was performed which was ultimately not used in the research. The computer modelling was performed for three rooms, the bedroom, corridor and lounge and was done for basically the same scenarios except a fire could start in the bedroom and the sprinkler suppression algorithm was used. Using the sprinkler suppression algorithm meant that the heat release rate of the fire decreased when the sprinkler activated. Using the sprinkler suppression algorithm created difficulties in defining the time when untenable conditions occur. The layer height dropped very quickly in these scenarios and was not a realistic criteria to use for the time to untenable conditions. Because the sprinkler suppression algorithm was operating the temperature criteria could not be used because high enough temperatures were not reached.

It was decided to perform more modelling for slightly different scenarios to obtain a better way to find untenable conditions and to create scenarios that could be compared against each other in the cost benefit analysis. This modelling is described in Section 6.0 Computer Modelling.

The 56 scenarios analysed did not include the rest home bedrooms. This is because it was assumed that the rest home bedroom already had sprinklers and smoke detectors installed. The bedroom was not considered a concern and instead more emphasis was placed on the corridor and lounge. Slow, medium, fast and ultra fast fires were modelled for a fire in the lounge. The same fires were modelled for a fire in the corridor except an ultra fast fire was not modelled because it was not considered likely to occur given the likely furnishings in the corridor. Both standard response and fast response sprinklers were modelled in the rest home.

One main assumption in the modelling in FASTLite was the heat release rate of the fire. The sprinkler suppression algorithm was not used and instead the heat release rate was kept steady at the rate when the sprinkler activated. This is a very conservative approach to take. The sprinklers are assumed to only control the fire and not suppress the fire.

Many of the assumptions made in the computer modelling such as vents, room dimensions etc. are not important because the results of the computer modelling are compared relatively. Any effects of the assumptions are cancelled out when comparing relatively. The windows situated in the modelling were located and placed in such a way that they did not effect the upper layer in the compartment therefore allowing the upper layer to be used for analysis.

The criteria for untenable conditions to occur in the research is when the Carbon Monoxide (CO) concentration reaches 27,000ppm.min. This was determined from the output of FASTLite. Using this criteria is the most effective way to determine untenable conditions because both the layer height and temperature are not appropriate to use.

8.3. Cost Benefit Analysis

The cost benefit analysis was based upon the probability of occupants being exposed to untenable conditions. This was determined by finding the time available to escape and the time required to escape and then determining the number of people who did not escape. The time available to escape was determined from the FASTLite modelling and the time required to escape was determined from evacuation calculations. The evacuation was assumed to take one minute per occupant when one staff member is on duty. This was considered a reasonable time for a staff member to wake an occupant, help them out of bed and assist them to a safe place.

The probability of occupants being exposed to untenable conditions was calculated for the example where there are 12 occupants in the firecell and either one or two staff. The cost benefit is based upon these numbers. Where there are greater than 12 occupants in the firecell the cost benefit may be different.

The costs to install smoke detectors or replace sprinklers were determined from discussions with three different fire protection contractors. The values used were approximate figures as estimated by all three contractors. The costs benefit analysis did not take into account any associated maintenance costs for the fire protections systems.

The ten comparisons made in the cost benefit analysis are useful to determine which fire protection systems would have the best cost benefit in the rest home. The analysis showed that replacing standard response sprinklers in the corridor and lounge with fast response sprinklers had the best cost per life saved ($449,125). The next best cost per life saved when standard response sprinklers are installed is to install a conventional smoke detector in the lounge ($1.69 million). When fast response sprinklers are installed there is no good cost benefit to install smoke detectors in the rest home. There is also no good cost benefit to install smoke detectors when two staff are required to be on duty. A comparable cost benefit is the cost per life saved to determine roading improvements ($2.0 million).

The cost per life saved to replace standard response sprinklers with fast response sprinklers has been shown to be the best cost benefit. Replacing standard response sprinklers with fast response sprinklers is consistent with the US approach where exceptions are given if a space is protected with either fast response sprinklers OR smoke detectors. For example, spaces such as lounges are permitted to be open to the corridor if protected with either fast response sprinklers or smoke detectors.

The cost per life saved results appear better than they probably are because the fatality statistics used in the analysis was for all rest home fires. No consideration was taken for a sprinklered rest home because the statistical information was not available and would be very minimal. If only sprinklered fire fatality information was able to be used it is expected that the cost per life saved would increase. There has only been one known case where a person died in a sprinklered rest home fire in New Zealand. The cost benefit analysis used the higher value as determined from the 1996 Census information for the number of elderly residing in rest homes. This reduces the expected number of fires per person per year which then increases the cost per life saved. This increase in cost per life saved is expected to be somewhat offset by using fatality information for all fires which decreases the cost per life saved.

9.0 Conclusion

The ten comparisons made in the cost benefit analysis are useful to determine which fire protection systems would have the best cost benefit in the rest home. The analysis showed that replacing standard response sprinklers with fast response sprinklers had the best cost per life saved ($449,125). The next best cost per life saved when standard response sprinklers are installed is to install a conventional smoke detector in the lounge ($1.69 million). When fast response sprinklers are installed there is no good cost benefit to install smoke detectors in the rest home. There is also no good cost benefit to install smoke detectors when two staff are required to be on duty, this is based upon 12 occupants in the firecell. A comparable cost benefit is the cost per life saved to determine roading improvements ($2.0 million).

The cost per life saved to replace standard response sprinklers with fast response sprinklers has been shown to be the best cost benefit. Replacing standard response sprinklers with fast response sprinklers is consistent with the US approach where exceptions are given if a space is protected with either fast response sprinklers OR smoke detectors. For example, spaces such as lounges are permitted to be open to the corridor if protected with either fast response sprinklers or smoke detectors.

10.0 References

BIA, *Significant Risk in Fire – Working Group 10*, 1997.

BIA Acceptable Solutions, *Approved Documents*, 1992.

Buchanan, A.H., *Fire Engineering Design Guide*, Centre for Advanced Engineering, University of Canterbury, 1994.

CIBSE Guide E, UK, *Fire Engineering.*

Fire Engineering Guidelines, Aust, 1st Edition 1996.

Klote, J.W., Milke, J.A., *Design of Smoke Management Systems*, 1992.

Marryatt, H.W., *Fire – A Century of Automatic Sprinkler Protection in Australia & New Zealand 1886-1986*, 2nd Edition 1988.

NFPA 101, *Life Safety Code*, 1997 Edition.

Quintiere, J.G., Birky, F., Smith, *An Analysis of Smouldering Fires in Closed Compartments and their Hazard Due to Carbon Monoxide*, Fire and Materials, Vol.6, Nos 3 and 4, 1982.

NFPA, *The SFPE Handbook of Fire Protection Engineering*, 2nd Edition, NFPA, Quincy, M.A., USA, 1995.

Statistics New Zealand, *New Zealand Now, 65 Plus*, 1998 Edition, Published June 98 by Statistics NZ, Wellington, New Zealand.

Zhao, L., He, Y., Beck, V., *The Protection of Corridors in Sprinklered Residential Aged Care Building.*

11.0 Appendix One

Following this page is the event tree showing the 56 scenarios modelled.

12.0 Appendix Two

The computer modelling results for the 14 cases modelled which depict the 56 scenarios follow this page.

13.0 Appendix Three

The detection and activation times of the smoke detectors and sprinklers as determined in the computer modelling are shown in the following table. The time to untenable conditions is also given, a calculation to determine the time available to escape is shown. Also included is a table giving the time required to escape and the calculation determining the probability of being exposed to untenable conditions.

14.0 Appendix Four

The cost benefit calculations for the 10 cases used for comparison are following this page. The 10 cases are numbered as per the report.