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Cost-Effective Domestic Fire Sprinkler Systems

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COST-EFFECTIVE DOMESTIC FIRE SPRINKLER SYSTEMS

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ABSTRACT

The objective of this project was to propose an inexpensive domestic fire sprinkler system design, with supporting information about its effectiveness in reducing loss of life, injury and property damage due to fires in houses. This paper outlines a low-cost, multi-purpose sprinkler system that fulfils these objectives in a more cost-effective manner than the systems presently available. The proposed sprinkler system varies from the requirements of the current New Zealand Standard, NZS 4515:1995 *Fire Sprinkler Systems for Residential Occupancies (including Private Dwellings)* in that it is not a stand-alone system, rather it is integrated with the domestic plumbing. The proposed design is based on the requirements of the National Fire Protection Association's residential sprinkler standard NFPA 13D:1999 (NFPA, 1999) and incorporates aspects of the Australian Standard, AS 2118.5:1995 (Standards Australia, 1995), for domestic sprinkler systems. These Standards were used as verification for engineering assumptions.

The system omits sprinkler heads from the bathroom, toilet, wardrobe/cupboard spaces and ceiling cavity where few fatal fires occur. Almost 90% of fatal fires originate in bedrooms, lounge/dining rooms and kitchens. Installation is by approved plumbers or sprinkler contractors and the system requires no control valveset or backflow prevention. The system does not have a sprinkler operating alarm, but does recommend the installation of smoke alarms to provide early warning of the fire. There are no requirements for annual maintenance.

The marginal cost of installing this system into a very simple, single-level three-bedroom new house was found to be approximately NZ$1000. Cost-benefit analysis showed the proposed system achieves a cost per life saved competitive with that of domestic smoke alarms, however it would be more effective in saving lives and property. For the installation of the multi-purpose sprinkler system alone, the cost per life saved on a national basis was found to be less than NZ$900,000. Installing four battery-powered smoke alarms in conjunction with a multi-purpose sprinkler system increases the cost per life saved to around NZ$2.8 million, similar to the Transit New Zealand criterion for value of human life.

KEYWORDS

Sprinkler; Domestic; Fire

INTRODUCTION

The objective of this project was to propose an inexpensive domestic sprinkler system design, with supporting information about its effectiveness in reducing loss of life, injury and property damage due to fires in domestic dwellings.

The research highlights where sprinklers can be targeted within a dwelling to achieve effective protection and coverage. This paper outlines a low-cost sprinkler system that will result in fewer fatalities and injuries and less property damage in a more cost-effective manner than is presently available.

Preliminary investigation into the cost and cost-effectiveness of domestic sprinkler systems concludes that sprinkler systems built to the current New Zealand Standard (NZS 4515:1995 [SNZ, 1995]) are not cost-effective, with an estimated cost per life saved of about NZ$35 million.

It was also found:

- There is scope to reduce the cost of the domestic sprinkler system. The scope comes predominantly from legislation, competition and design requirements.
- A risk assessment approach, where reductions in effectiveness are offset against increased numbers of sprinkler system installations in the home, appears to offer possibilities for providing options to reduce the cost of the sprinkler system.
- Inconsistencies exist when considering the costs for installing the sprinkler system. For example, it costs more to connect to the water mains to serve the sprinklers than it does to install the sprinkler system.
- Compulsory requirements for sprinkler systems in homes have been successful in the USA at reducing the costs of the system (Home Fire Sprinkler Association, 1997).

The review of literature and international sprinkler standards indicated that a multi-purpose sprinkler system offers significant cost reductions. A multi-purpose sprinkler system shares the same pipes as the domestic plumbing system. Using the same pipe for both systems means less pipe and less fittings. This approach is currently permitted by NFPA 13D (NFPA, 1999).

This paper gives a description of a proposed multi-purpose sprinkler system in New Zealand. A risk assessment approach, where the influence on expected numbers of injuries and fatalities caused by a reduction in sprinkler coverage is assessed, and a cost-benefit analysis, based on the costs to install the proposed multi-purpose sprinkler system, is used to analyse the cost-effectiveness of the system. The risk assessment and cost-benefit analysis are outlined.

SPRINKLER SYSTEM PROPOSAL

The proposed design for the multi-purpose domestic sprinkler system is based on the requirements of the National Fire Protection Association's residential sprinkler standard, NFPA 13D:1999 (NFPA, 1999) and incorporates aspects of the Australian Standard, AS 2118.5:1995 (Standards Australia, 1995), for domestic sprinkler systems.

In summary, the specific details of the proposed multi-purpose sprinkler system are:

- A single mains connection feeds both the sprinkler system and the domestic water supply.
- Design pressure from the mains was taken to be 500 kPa (a typical mains pressure for residential areas in New Zealand) and hence a 25 mm diameter feed from the mains to the house was required to achieve the design pressures at the sprinkler heads.
- The domestic load for the hydraulic design of the combined plumbing and sprinkler system was taken to be 12 litres per minute, in accordance with AS 2118.5 (Standards Australia, 1995).
- The main run of water supply pipe is 25 mm diameter; the pipe branches serving the sprinklers are 20 mm diameter; the pipe branches supplying the domestic services are 15 mm diameter.
- The sprinkler heads are of residential listing and installed in accordance with the listing.
- The hydraulic calculations are based on a maximum of two sprinkler heads operating.

The above parameters were used for the design of the combined sprinkler/plumbing system for the dwelling subsequently used in a cost-benefit analysis. The design would not be appropriate in any cases where the minimum specified mains pressure was found to be not available.

The proposed multi-purpose sprinkler system varies in the following ways from the current requirements of NZS 4515:1995 (SNZ, 1995) for the installation of domestic fire sprinkler systems:

1. NZS 4515:1995 (SNZ, 1995) requires the domestic sprinkler system to be a stand-alone system. The current New Zealand sprinkler standard has no provisions for alternatives to the stand-alone system. The concept of the multi-purpose system, whereby the sprinkler system is integrated with the domestic plumbing, arises from the National Fire Protection Association Standard, NFPA 13D:1995 (NFPA, 1995).
2. A control valveset is not a requirement for the multi-purpose sprinkler system. The function of the control valveset as backflow prevention, pressure sustaining valve and sprinkler system isolation valve is not required where the sprinkler system is integrated with the plumbing and water is regularly flowing through.
3. An alarm indicating sprinkler operation or requirement to evacuate is not included in the multi-purpose system. In the case of a stand-alone sprinkler system designed to NZS 4515:1995 (SNZ, 1995), a flow switch would trigger an alarm to indicate that the sprinkler system was operating. In the case of the multi-purpose system, where water is regularly flowing through it, a flow switch would not be an appropriate alarm mechanism. It is recommended that domestic smoke alarms be installed along with the multi-purpose system.
4. The design excludes sprinkler heads from the bathroom, toilet, wardrobe/cupboard space and the ceiling cavity. The statistical analysis indicates that the likelihood of a fire originating in these areas is minimal. All sprinkler heads are required to be listed and be installed in accordance with the listing.
5. The domestic load for the hydraulic design is taken to be 12 litres per minute. This design flow is based on the requirements of AS 2118.5:1995 (Standards Australia, 1995). This figure has been used on the basis of evidence presented by Beever and Britton (1999) indicating that the average demand per household unit in Australia peaks at six litres per minute.
6. It is assumed that the installation will be carried out by approved plumbers, sprinkler contractors or others who have demonstrated competency to carry out the work.
7. The integrated sprinkler and domestic plumbing system has no specific ongoing maintenance requirements. The maintenance requirements are normally specific to the control valveset. The proposed multi-purpose sprinkler system does not require a control valveset and subsequently no annual maintenance requirements are necessary. With the sprinkler system integrated with the domestic plumbing, the possibility of unintentional shut off of the water supply is minimised.
8. The proposed multi-purpose sprinkler system does not need to be connected to the fire service.

RISK ASSESSMENT

A risk assessment approach, whereby the influence on expected numbers of injuries and fatalities caused by a reduction in sprinkler coverage is assessed, was carried out to evaluate options for alternative sprinkler system designs.

The risk assessment objectives were to:

1. Investigate the number and location of injuries and fatalities as a result of domestic fires in New Zealand.
2. Determine the impact on the number of injuries and fatalities as a result of installing combinations of domestic smoke alarms and sprinklers.
3. Assess the impact on the number of injuries and fatalities as a result of omitting sprinkler heads from the ceiling space, bathroom, toilet and wardrobe/cupboard spaces.

The risk assessment was undertaken through use of event tree analysis. An event tree is a logic diagram which predicts the possible outcomes from an initial event (Charters, 1999). The risk assessment analysed four options of sprinkler system and smoke alarm combinations: sprinkler and smoke alarm, smoke alarm only, sprinkler only, neither sprinkler nor smoke alarm. Figure 2 shows the structure of the event tree used for the analysis.

For analysis, probabilities are associated with each chance event. The likelihood of fire occurring per room is multiplied by the reliability of the sprinkler system, then multiplied by the reliability of the smoke alarm, to achieve an estimate of the likelihood of this sequence of events occurring. The likelihood of this event sequence is in turn multiplied by the consequence (expected number of injuries and fatalities associated with the sprinkler and smoke alarm combinations) to provide an expected number of injuries and fatalities. The expected number of injuries and fatalities is multiplied by the probability of fire occurrence to determine the expected annual number of injuries and fatalities as a result of the sprinkler and smoke alarm combinations.

Conditional probabilities are associated with each chance event in the event tree. The probabilities are derived from New Zealand and international domestic fire statistics. The statistics are compared with international fire incident statistics to ensure any assumptions made were appropriate. The risk analysis required the input of the following statistics: probability of fire occurrence, areas of fire origin which resulted in injuries and fatalities, smoke alarm reliability, sprinkler system reliability, fatality rates and injury rates.

The event tree was calibrated to agree with the assumptions in Table 1, assuming full sprinkler coverage. Background and basis of these assumptions are discussed by Duncan et al (2000). The smoke alarm was taken to be 74% reliable, which is the probability that the alarm will operate and be effective in providing early warning. The reliability of the sprinkler system for use in the risk assessment was taken to be 95%, which is the probability that the sprinkler will activate and be effective in controlling the fire, given the sprinkler is located in the room of fire origin. Given the uncertainty in the reliability, Figure 1 indicates the effect reliability has on the number of deaths per year.

Table 1: Fatality and injury rates used in risk assessment

Option	**Consequence – expected deaths per 1000 house fires**	**Consequence – expected injuries per 1000 house fires**
No smoke alarm / no sprinkler	6	40
Smoke alarm / no sprinkler	2.8	12
No smoke alarm / sprinkler	1.2	15
Smoke alarm / sprinkler	1	10

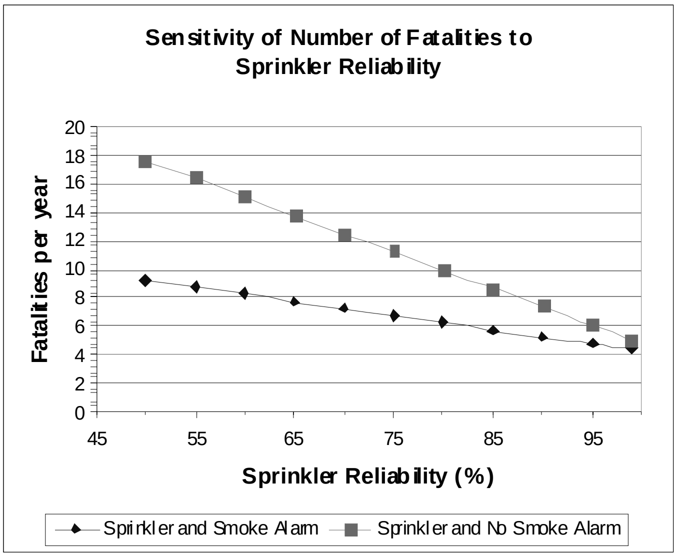
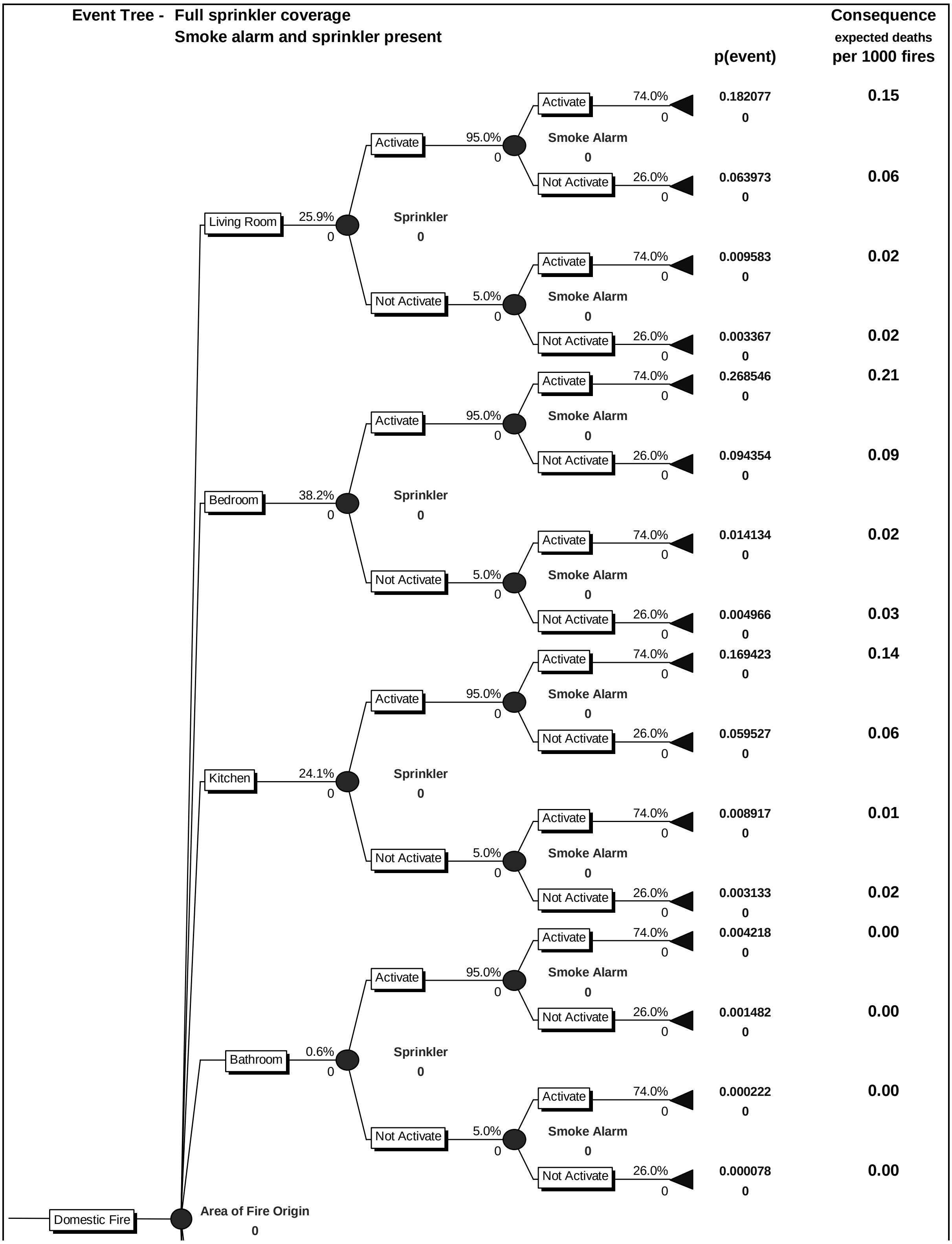


Figure 1: Influence on number of fatalities as a result of reduction in sprinkler reliability



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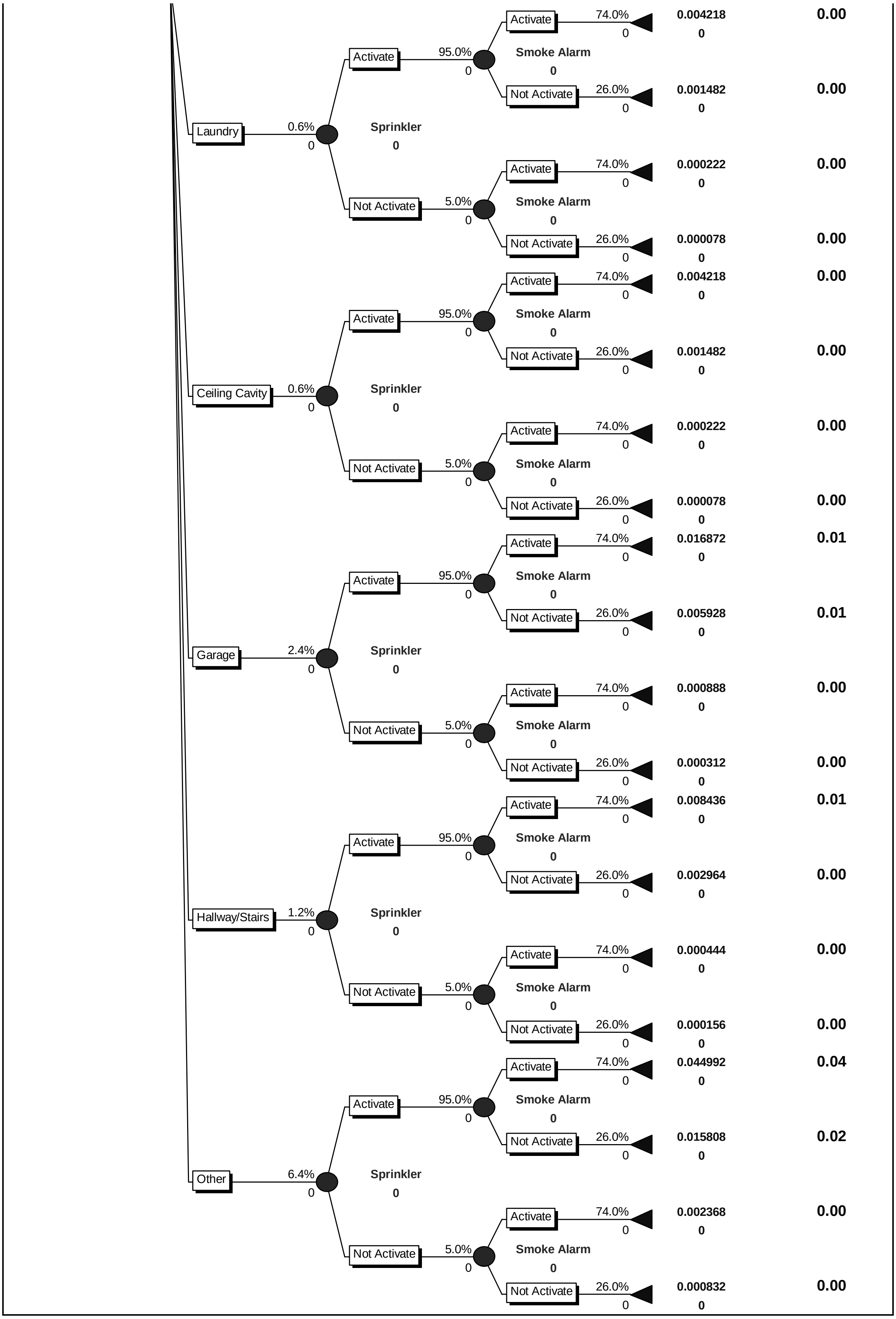

Figure 2: Example event tree

Outcomes from risk assessment

Outcomes from the risk assessment analysis show:

- The majority of fatalities and injuries occur as a result of fires originating in the living room, bedroom or kitchen. The risk analysis shows that injuries and fatalities are less likely to occur from fires originating in the bathroom and ceiling cavity.
- Results show that the combination of the multi-purpose sprinkler system with the smoke alarms is the most successful at reducing the number of injuries and fatalities in a domestic fire. The proposed multi-purpose sprinkler system alone is estimated to reduce the number of injuries by approximately 55% and the number of fatalities by approximately 72%.
- For the option of the combined multi-purpose sprinkler system and smoke alarm, removal of sprinkler heads from the ceiling space, bathroom/toilet and wardrobe/cupboard space increases the expected number of fatalities per year from 4.8 to 5.7 (16%). Removal of sprinkler heads from these spaces increases the expected number of injuries per year from 27.3 to 31.5 (13%).

Table 2 indicates the influence that removing sprinkler heads from bathroom/toilet, wardrobe/cupboard space and the ceiling cavity has on the expected numbers of fatalities and injuries.

Table 2: Comparison of full sprinkler coverage with reduced sprinkler coverage (combined system)

	Fatalities/Year in New Zealand		**Injuries/Year in New Zealand**	
Option	**Full Coverage Sprinkler System**	**Reduced Coverage Sprinkler System**	**Full Coverage Sprinkler System**	**Reduced Coverage Sprinkler System**
Sprinkler/Smoke Alarm	4.8	5.7	27.3	31.5
Sprinkler/No Smoke Alarm	6.1	8.5	76.1	92.0
No Sprinkler/ No Smoke Alarm	30.5		203.0	

COST BENEFIT ANALYSIS

Methodology

The methodology for the cost-effectiveness study followed that carried out by Beever and Britton (1999) in a study undertaken for the Building Control Commission of Victoria, Australia. The study involved cost-benefit modelling to determine a dollar cost per life saved for the installation of specified fire safety measures. The cost per life saved was determined by calculating:

$$\text{Cost per life saved} = \frac{\text{(installation costs + maintenance costs - savings in injury costs - savings in property losses)}}{\text{expected number of lives saved}}$$

Each variable for the cost per life saved equation was derived from New Zealand Fire Service statistics and commercial costs, or other international data where local data was inadequate or unavailable. For details see Wade and Duncan (2000).

For each fire safety measure, a net present cost was calculated by subtracting the net present value of savings (such as injuries avoided and direct loss of property) from the net present value of the purchase, installation and maintenance costs. The net present value (NPV) per household for the fire safety measure was calculated using the formula:

$$\text{NPV} = \sum_{t=1}^{n} \frac{\text{Net yearly cost}}{(1 + \text{discount rate})^{t}}$$

Where t = time (years) n = number of years

For analysis, a nominal discount rate of 8% and an inflation rate of 2% was used with an analysis period of twenty years. Where components of the safety measures had a different working life, the replacement costs were incorporated at the appropriate time during the analysis period.

A cost-effectiveness analysis was undertaken for the following fire sprinkler options:

- A fire sprinkler system installed in a new dwelling to the requirements of NZS 4515:1995 (SNZ, 1995).
- The proposed multi-purpose fire sprinkler system, with reduced coverage, installed in a new dwelling.

The results from the analysis of the cost-effectiveness of the sprinkler systems were compared with an analysis by Wade and Duncan (2000) considering the cost-effectiveness of installing domestic smoke alarms.

A low-cost three-bedroom home was used as the design home for the sprinkler installations. The three-bedroom design home was used as representative of a standard, low-cost family home. It was assumed that the home is located in the suburbs, with access to water services and public amenities such as fire hydrants. The home is a single level dwelling constructed of timber frame with corrugated galvanised steel roof, weatherboard exterior walls, aluminium windows and interior lining of gypsum plasterboard walls with particleboard finished floors. Costs for the fire safety measures were market value, in-situ prices provided by sprinkler contractors and plumbers. Figure 3 shows the layout of the design home and overlays the plan of the multi-purpose sprinkler system.

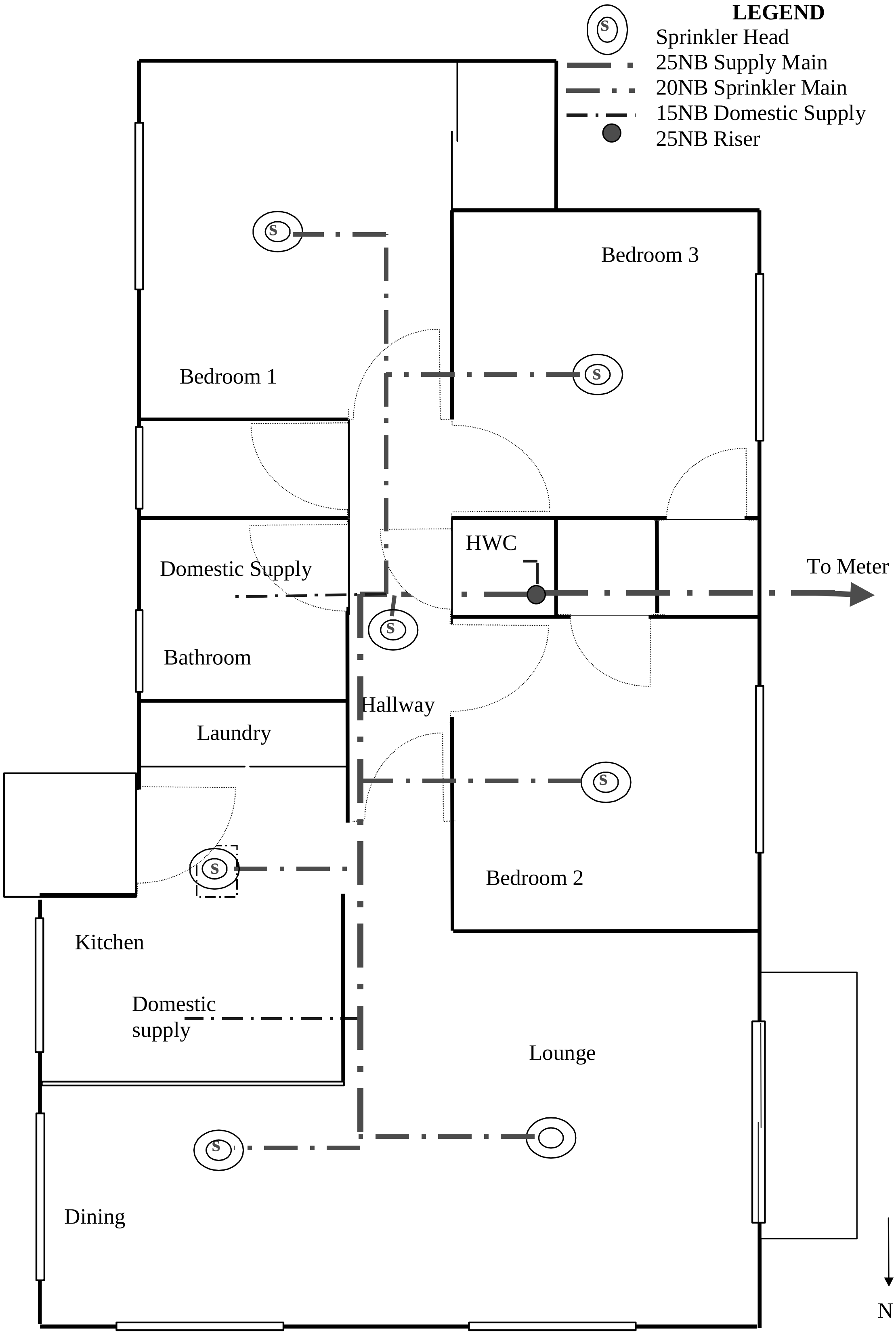

Figure 3: Plan view of multi-purpose sprinkler system
(Source – P. Downey, Hydraulic Services Consultants)

Cost-benefit analysis results

Table 3 shows a summary of the results of the cost-benefit analysis.

Table 3: Results of cost-benefit analysis

	Installation costs (NPV $NZ)	**Maintenance costs over 20 years (NPV $NZ)**	**Savings on injuries and property loss ($NZ)**	**Net cost per household ($NZ)**	**Deaths per household**	**Expected deaths per year**	**Lives saved per year**	**$NZ net cost per life saved**
Four stand-alone ionisation 1 year battery	212	973	405	780	0.000224	14.2	16.2	$3 million
Four stand-alone ionisation 10 year battery	340	741	414	667	0.0002	12.7	17.8	$2.4 million
Four battery powered smoke alarms (1 year battery) and multi-purpose sprinklers*	1180	973	1065	1,088	0.0000896	5.7	24.8	$2.8 million
Multi-purpose sprinklers only*	968	0	660	308	0.0001344	8.5	21.9	$891,000
NZS4515:1995 complying domestic sprinkler system	6700	7353	693	13,361	0.000096	6.1	24.4	$34.8 million
No system	0	0	0	0	0.00048	30.5		

*assumes sprinklers omitted from bathrooms, ceiling spaces, wardrobes etc.

The cost per life saved for installation of the proposed multi-purpose sprinkler system was found to be NZ$891,000. This cost per life save is a fraction of the cost per life saved for a new sprinkler system installed to the current New Zealand Standard, NZS 4515:1996 (SNZ, 1995). The comparison of these results show the proposed multi-purpose sprinkler system to be considerably more cost-effective than domestic sprinkler systems installed to current standards.

Reducing the cost of the domestic sprinkler system has achieved a cost-effectiveness in the range close to that of a domestic smoke alarm. The cost per life saved for the multi-purpose sprinkler system is considerably less than that of multiple smoke alarms.

Considering the net cost per life saved, the option of a multi-purpose sprinkler system offers the most cost-effective solution. Combination of the smoke alarm with the sprinkler system has the greatest effect in reducing the number of expected deaths per year. The smoke alarm plus sprinkler option potentially saves 25 lives per year. The cost per life saved for this option is NZ$2.8 million, similar to the Transit New Zealand criterion for value of human life.

CONCLUSION

Domestic fire sprinkler systems built to current New Zealand standards are not cost-effective. The multi-purpose sprinkler system, where the sprinkler system is integrated with the domestic plumbing, is a more cost-effective option for installing sprinklers in homes.

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