FQ5011

Domestic Fire Sprinkler Systems – Report on Water Quality, Reliability and Application to Other Property

The work reported here was funded by Building Research Levy

Author: **E. Soja**
Senior Fire Engineer

Reviewer: **A. P. R. Edwards**
Fire Research Engineer

Contact: BRANZ Limited
Moonshine Road
Judgeford
Private Bag 50908
Porirua City
New Zealand
Tel: +64 4 237 1170
Fax: +64 4 237 1171
www.branz.co.nz

FUNDED BY THE BUILDING RESEARCH LEVY
BUILDING RESEARCH

Preface

This report describes research to establish whether the water quality in a Combination Domestic Fire Sprinkler System would have implications for the health of occupants, and if the combination domestic sprinkler could be used in properties other than houses.

Acknowledgments

This work was funded by the Building Research Levy. The author would like to thank Andrew Ball, ESR, Christchurch, and Rob Deacon, Environment Laboratory Services Ltd, Lower Hutt for their assistance in identifying the issues regarding sprinkler water quality and selection of determinands and testing procedures.

Note

This report is intended for:

- the Department of Building and Housing as a technical basis for reviewing the application of Domestic Sprinkler Systems
- other researchers considering the wider application of combination domestic sprinkler systems.

Domestic Fire Sprinkler Systems – Report on Water Quality, Reliability and Application to Other Property

BRANZ Report FQ5011 **E. Soja**

REFERENCE

Soja E. 2006. *Domestic Fire Sprinkler Systems – Report On Water Quality, Reliability and Application to Other Property*. BRANZ Report, Judgeford, New Zealand.

ABSTRACT

Microbial and chemical water potability tests were performed on a domestic fire sprinkler system over a period of 12 months. It was found that the microbial quality would not be hazardous to health where range pipe dead legs were up to 4.5 metres long for a water supply of equal or better quality to that used in this research. From this it is recommended that dead legs up to 3 metres could be used in Combination Domestic Fire Sprinkler Systems.

Reliability of fire sprinkler systems is investigated and it is considered that because of the lack of various features, such as a flow switch, interconnected alarms and regulated servicing interval – which are included in the more detailed fire sprinkler system standards e.g. NZS 4515 (SNZ 2003b) for residential properties and NZS 4541 (SNZ 2003a) – the reliability of a domestic fire sprinkler system is less than expected from a fully commercial one. However with some enhancements the domestic fire sprinkler system can be increased in reliability, so that the use may be extended to properties other than detached family homes.

Domestic fire sprinklers are intended for use in domestic dwellings (detached single family homes or town houses where each unit has control of its own supply). This report makes recommendations that small residential buildings – such as those offering care to people with disabilities (health or mental) and multi-residential properties which would otherwise not require a fire sprinkler system – could benefit from a system-enhanced Combination Domestic Fire Sprinkler System. In carrying out this work comparisons with NZS 4515 *Residential fire sprinkler systems* have been performed.

KEYWORDS

Fire sprinklers, houses, dead-leg, reliability, application, backflow, microbial, contaminant, determinand. E.Coli.

ES APE

Contents

Page

Figures

Page

ES APE

Tables

Abbreviations and acronyms

ATO	Concentrations of the substance at or below the health-based guideline value that may affect the water's appearance, taste or odour.
AWWA	American Water Works Association
BIA	Building Industry Authority
BCA	Building Consent Authority
cfu	colony forming units (often not specifically stated)
CCC	Christchurch City Council
DBH	Department of Building and Housing
DWSNZ	Drinking Water Standard for New Zealand (MoH 2005)
FAC	Free available chlorine
GWRC	Greater Wellington Regional Council
GV	Guideline Value
IEEE	Institute of Electrical and Electronics Engineers
KCDC	Kapiti Coast District Council
MAV	Maximum Acceptable Value
min	minutes
MoH	Ministry of Health
ml	millilitres
n/a	no measurements made
NFPA	National Fire Protection Association
NZBC	New Zealand Building Code
NZFS	New Zealand Fire Service
PB	Polybutylene
PMAV	Provisional MAV (because it is provisional in the WHO Guidelines or the WHO has no Guideline Value but the DWSNZ has retained a MAV or developed its own)
PP-R	Polypropylene
SNZ	Standards New Zealand

Definitions

Determinand	A constituent or property of the water that is determined, or estimated, in a sample
E.coli	Escherichia Coli 2
Combination Domestic Fire Sprinkler System	A sprinkler system where the house water appliances are fed from the same pipes as the fire sprinkler system

1. INTRODUCTION

1.1 Background

It has been acknowledged for a considerable time that fire sprinklers are the most effective means of controlling fires, increasing both property protection and life safety in the buildings where they are installed. In common with international statistics the majority of New Zealand casualties caused by fire occur in homes; the one occupancy where fire sprinklers are not commonly installed. In the New Zealand Fire Service Emergency Incident Statistics for 2003/2004 (NZFS 2004), analysis of the data shows that 88% of fire civilian deaths in buildings occurred in residential properties and 72% in houses (single family dwellings). The most common reason for not installing fire sprinklers in homes, particularly those most at risk, has been cost. This cost not only includes the installation but also the design and maintenance requirements.

In 2000 the New Zealand Fire Service published a report (Duncan et al 2000) on a research project, conducted by BRANZ, which investigated the idea of a cost-effective fire sprinkler system for single-family dwellings. Since that time BRANZ published a *Design Guide: Sprinklers for houses* (2002) and Standards New Zealand issued NZS 4517: 2002 *Fire sprinkler systems for houses.*

During the course of the initial research (Duncan et al 2000) it became apparent that this technology could perhaps be extended into other occupancies. There were two main issues which could potentially limit the further application of the BRANZ Combination Domestic Fire Sprinkler System (defined as one where the pipework also supplies water to the domestic appliances). First, the presence of stagnant, thus contaminated, water in 'dead legs' leading to fire sprinklers may be drawn back into the main system and so supplied to the cold water outlets. Research was therefore needed to identify what factors affect the water quality and what length of dead leg can be deemed to represent an acceptable level of risk. Secondly, reliability is an issue as residential fire sprinkler systems are installed within strict tolerances. The reliability of full fire sprinkler systems has been stated to be 99.5%. The quoted figure was based on actual fire sprinkler activations over a 100 year period to 1986, covering approximately 9000 fires in 231 different types of occupancy. Fire sprinkler standard NZS 4541 (SNZ 2003a) was written to maintain this reliability and reducing the requirements of that standard is thought to reduce the reliability of the fire sprinkler system. Previous work by BRANZ for the New Zealand Fire Service (Duncan et al 2000) assumed the reliability of a Combination Domestic Fire Sprinkler System to be 95% (this was a new type of system for which adequate historical data was not available). The work described herein was therefore proposed to define reliability in terms of fire sprinkler activation and identify domestic system failure modes.

1.2 Objectives

The objectives of this work are to provide:

- greater confidence to the fire safety community about the effectiveness of low-cost combination fire sprinkler systems, and hence increase levels of uptake of the technology
- the Department of Building and Housing (DBH) with useful information about the scope of use of Combination Domestic Fire Sprinkler Systems in the Approved Documents
- the wider building industry with information which will enable better decision making when designing fire sprinkler systems which are part of the potable water supply.

1.3 Scope of work

The proposed work was carried out in three parts:

1. Investigate the stagnant water and contamination issues by carrying out analysis of water samples taken from a representative combination system installed in the roof space of a small house.
2. Conduct a risk analysis to establish the reliability of Combination Domestic Fire Sprinkler Systems.
3. Investigate suitability of extending technology to other occupancies.

2. COMBINATION DOMESTIC FIRE SPRINKLER SYSTEM

2.1 Introduction

Before describing the research that was carried out in this project it is important to understand what a Combination Domestic Fire Sprinkler System for houses is and what it comprises. This system is unlike the type of system normally associated with fire sprinklers and has major differences which affect how it can be used.

2.2 Description

A Combination Fire Sprinkler System is a domestic plumbing system integrated with a fire sprinkler system i.e. a single system of pipe work fixtures and fire sprinkler heads that provides water supply for both domestic potable water and the fire protection. The implications of this are that:

1. All pipes must be suitable for potable water.
2. The water and flow conditions in the pipes must not be prone to contamination.
3. The system must comply with the NZBC requirements for Water Supplies, Clause G12.

Figure 1 shows an example arrangement for a ‘trunk and branch’ system and Figure 2 for a ‘loop’ system.

For both systems domestic water is taken off at any point. However for the ‘trunk and branch’ this must be as close as possible to the end of the distribution pipe, and for the ‘loop’ this must occur at least once on the ‘loop’. This is to ensure that whenever water is used in the house the main distribution pipe or loop are flushed through with fresh water as in any normal domestic water reticulation system. The issue remains of the safety of any stagnant range pipes leading off the distribution pipe and loop. This is the subject of the water analysis research described below.

The combination fire sprinkler system is further described in NZS 4517 (SNZ 2002).

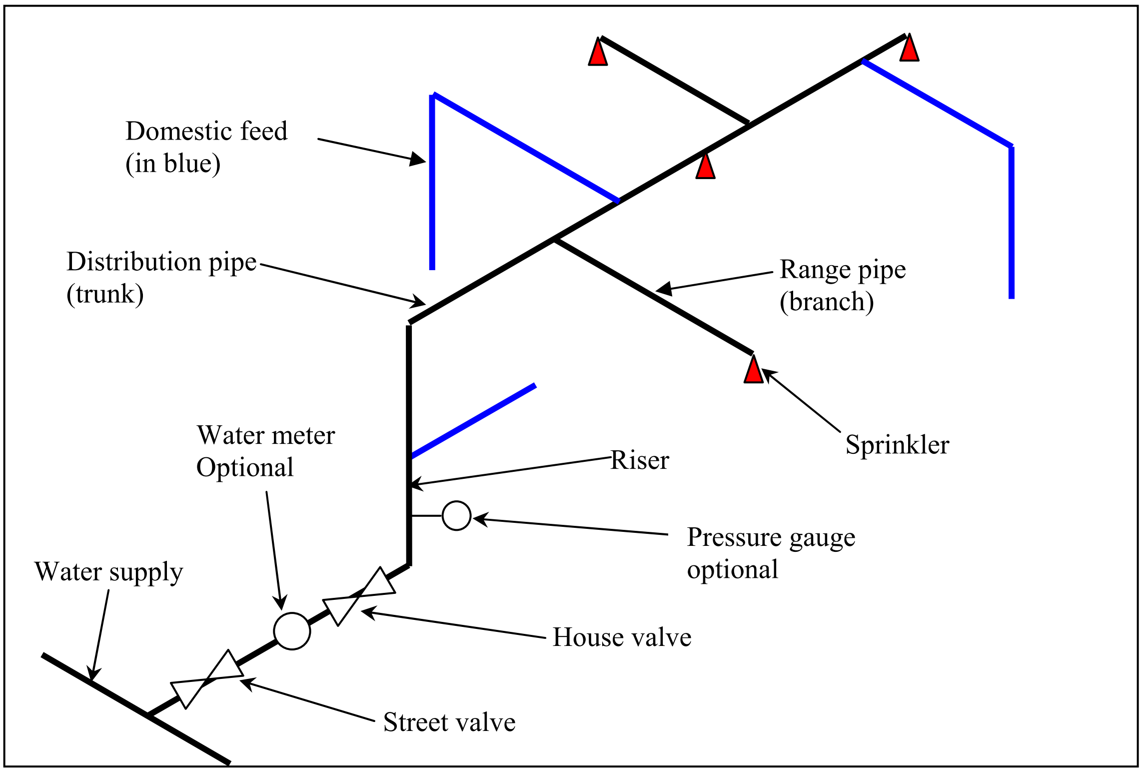

Figure 1: Schematic of an example for a trunk and branch Combination Domestic Fire Sprinkler System distribution and range pipes.

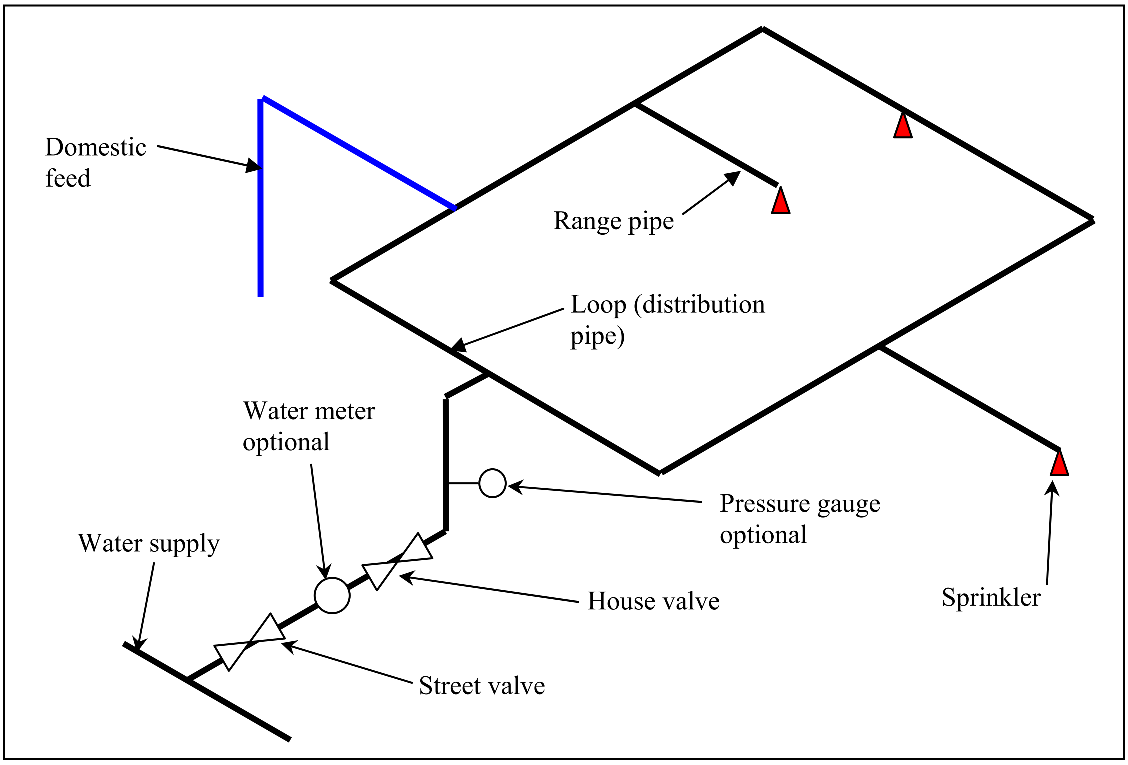

Figure 2: Schematic of an example for a loop Combination Domestic Fire Sprinkler System distribution and range pipes.

3. WATER QUALITY ANALYSIS

3.1 Introduction

There is much debate about the quality of water in fire sprinkler systems and the need, or otherwise, for backflow prevention. Water in any fire sprinkler pipes is seen by regulatory authorities and water suppliers (CCC 2005 and DBH 2005a) as a potential source of contamination. Based on a statistical study related to the failure rate of backflow prevention devices, Hart et al (1993) identified that there was a health risk from an unprotected (no backflow prevention device) water system. However the paper concluded that the risk of fire-related death and injury associated with unsprinklered dwellings is higher than the risk of illness associated with unprotected (no backflow) fire sprinkler systems.

The work carried out by Hart (1996 a,b,c) detailed the most comprehensive studies found about water quality in fire sprinkler pipe systems. From both field and laboratory samples Hart observed that:

- water deterioration in steel pipes occurred very quickly and produced the most likely hazard to health
- water deterioration (in terms of chemical changes) in CPVC pipe was much less evident than noted in both the steel and the copper pipe sections.
- flushing of pipework could increase the potential for contamination by introducing new organic matter

- for waters with high corrosion potential, the use of copper may not be suitable because of the potential for water contamination
- with no chemical corrosion reactions, the level of solids build-up was very low in CPVC pipes compared to the copper and steel pipes
- in CPVC pipes very little deterioration occurred, even after extended stagnation
- no coliforms were found in the field and laboratory samples though detectable levels of yeast, mould and heterotrophs were found
- CPVC pipes had the least substances hazardous to health when compared to copper and steel, although the copper samples had a low level of microbial determinands
- after eight months the water in copper and plastic pipes was still clear whereas in steel pipes it was black.

The work carried out by Hart was limited in its scope and essentially addressed the issues of flushing the systems, had a limited theoretical study of potential contamination and limited pipe materials.

Concerns about the health risks of a Combination Domestic Fire Sprinkler System are based on the quality of water in a standard fire sprinkler system where the water may be brackish, have unpleasant odour and be highly discoloured, even black. This gives rise to the requirement for backflow prevention where fire sprinkler systems are installed (CCC 2005 and DBH 2005a).

The requirement for backflow protection is not universal. In the USA for one- and two-family residential fire sprinkler systems, the American Water Works Association (AWWA 2004) recommends that: "Residential fire sprinkler systems do not require backflow protection on systems that are constructed of approved potable material and are designed to flow water so it does not become stagnate". In this case, the same backflow requirements for the domestic plumbing would apply to the automatic fire sprinkler system". This is also stated in the report by Hart et al (1993).

3.2 Scope of work

This part of the project investigated the quality of the water in a combination fire sprinkler system with dead legs, through bacteriological and chemical analysis.

Two aspects were investigated:

1. The likelihood of the hazard of microbial contamination of the water flowing through a Combination Domestic Fire Sprinkler System supplied with treated town water.

2. The associated length of dead leg that is likely to cause a hazard.

3.3 Approach

To determine this, tests were carried out on a mock-up Combination Domestic Fire Sprinkler System in an uninhabited house used previously by BRANZ to carry out fire tests. This is described further below.

3.4 New Zealand water supply requirements

There are two basic documents which control the potable water supply requirements in New Zealand: NZBC Clause G12 (BIA 1992) and the Ministry of Health Drinking Water Standard (MoH 2005). The compliance document G12/AS1 (DBH 2005a) provides one means of compliance with NZBC G12. G12/AS1 deals with the physical requirements for the supply of water and the Drinking Water Standard deals with the bacteriological and chemical specifications.

3.4.1 NZBC G12

The mandatory performance requirement of NZBC G12 states:

"G12.3.1 Water intended for human consumption, food preparation, utensil washing or oral hygiene must be potable.

G12.3.2 A potable water supply system shall be –

(a) protected from contamination; and

(b) installed in a manner which avoids the likelihood of contamination within the system and the water main; and

(c) installed using components that will not contaminate the water".

For the purposes of this report compliance with G12/AS1 is considered in the context of the potential for contamination due to cross-connections between the potable supply and a contaminated source attributed to the domestic sprinkler system. A "contaminated source" is defined in G12/AS1 Paragraph 3.0: Protection of Potable Water. This paragraph defines various hazard categories as follows:

"High hazard

Any condition, device or practice which, in connection with the potable water supply system, has the potential to cause death". (author's underline)

High hazard may include but is not necessarily limited to, amongst others, fire sprinkler systems and fire hydrant systems that use toxic or hazardous water.

This is not the case with the Combination Domestic Fire Sprinkler System and therefore it does not qualify as a "high hazard".

"Medium hazard

Any condition, device or practice which, in connection with the potable water supply system, has the potential to injure or endanger health". (author's underline)

Medium hazard may include but is not necessarily limited to, amongst others, fire sprinkler systems and building hydrant systems.

"Low hazard

Any condition, device or practice which, in connection with the potable water supply system, would constitute a nuisance, by colour, odour or taste, but not injure or endanger health". (author's underline)

The research described herein investigates whether a medium or low hazard definition might apply to the Combination Domestic Fire Sprinkler System.

The level of hazard determines whether a backflow protection device is required to protect the potable water supply system. Double check valves can be used to form a barrier between a medium and low hazard and the potable water supply.

3.4.2 Drinking water standard for New Zealand (DWSNZ) (MoH 2005)

The Drinking Water Standard for New Zealand gives the maximum concentrations of microbial, chemical and radiological substances in drinking water that are acceptable for public health. The maximum acceptable values (MAVs) of these substances are given in various tables in the DWSNZ (MoH 2005). The water quality standards are the yardstick by which water's suitability for drinking is assessed.

The substances are called "determinands" and are defined in the DWSNZ as a constituent or property of the water that is determined, or estimated, in a sample. Tables 1, 2 and 3 give the MAV and Guideline Value (GV) for determinands used in this study. No values are given in the DWSNZ for total coliforms, faecal coliform, yeasts and moulds, but were used in this study as indicators of water quality.

Table 1: Maximum acceptable values (MAV) for microbial determinands

Micro-organism	MAV*
E.Coli	Less than 1 cfu in 100 ml of sample

Notes: * These are MAVs for regulatory purposes. They do not represent a dose/response relationship that can be used as the basis for determining acceptable concentrations of pathogens in drinking-water.

Table 2: Maximum acceptable values (MAVs) for inorganic determinands of health significance

Determinand	MAV	Units	Comments
chlorine	5	mg/l	Free available chlorine expressed as Cl2. ATO. Disinfection must never be compromised
copper	2	mg/l	ATO

Notes: ATO-Concentrations of the substance at or below the health-based guideline value that may affect the water's appearance, taste or odour.

Table 3: Guideline values (GVs) for aesthetic determinands

Determinand	GV	Units	Comments
chlorine	0.6–1.0	mg/L	Taste and odour threshold (MAV 5 mg/L)
copper	1	mg/L	Staining of laundry and sanitary ware (PMAV 2 mg/L)

Notes: PMAV: Provisional MAV (because it is provisional in the WHO Guidelines (WHO 2004) or WHO has no guideline value, but the DWSNZ has retained a MAV or developed its own).

3.5 Selection of determinands for analysis

From discussions with water testing laboratory staff (Ball 2004, Deacon 2006) and referral to previous work on the subject of water quality in potable water supplies (Hart et al 1996 a,b,c), the following determinands were chosen to monitor the quality of water in the test pipework.

Table 4: Determinands chosen for measuring the water quality of the samples

Determinand	Test method	Detection limit
Free available chlorine (FAC)	APHA 20th edition method 4500-CL G	0.1 g/m³
Total coliforms (TC)	APHA 9222 B, MIMM 11.A3.1 LAS official test 1.1 & 1.1.1	1 cfu/100ml
Faecal coliforms (FC)	APHA 9222 D, MIMM 11.A3.1 LAS official test 1.2	1 cfu/100ml
E.Coli (EC)	MIMM 11.A3.1 LAS official test 1.8 APHA 9222 G with recovery enhancement.	1 cfu/100ml
HPC*	Heterotrophic plate count at 22°C following APHA 20th edition method 9215 B	1 cfu/ml
Yeast (Y)	Petrifilm by 3M	10 cfu/g(ml)
Moulds (M)	Petrifilm by 3M	10 cfu/g(ml)
Copper (Cu) (acid soluble)	ICP-MS following APHA 20th edition method 3125 (modified) LAS official test 5.23	0.0005 g/m³

Notes: *Heterotrophic plate count

Cryptosporidium and giardia were not monitored nor were hydrocarbons or other inorganic and organic chemicals. The above determinands were selected as being most critical to water quality, bearing in mind that a DWSNZ compliant water supply was being supplied to the test sprinkler system.

3.5.1 Free available chlorine

This was chosen to identify the FAC in the BRANZ water supply and whether any FAC was present in the dead legs to give an indication of mixing.

3.5.2 E.Coli

E.Coli is a determinand in the DWSNZ and therefore was a subject for measuring the potability of the test samples.

3.5.3 Total and faecal coliforms, heterotrophic plate count, yeast and moulds

Total and faecal coliforms are sometimes used by water supply authorities to evaluate water quality. They are not required determinands specified in the DWSNZ, but together with the heterotrophic plate count, yeast and mould, are used to assess the general health of the water system. Yeast and mould were measured in earlier fire sprinkler water quality studies (Alleman 1982, Hart 1996c).

Heterotrophic plate count (HPC) is a microbiological indicator used to determine the quality of the water in terms of its general bacterial content. This indicator is used as a supplement to the routine analysis for coliform (total and faecal) bacteria. HPC results can also be used to monitor disinfection efficiency at water treatment plants and as a measure of water quality deterioration (e.g. biofilm formation) in distribution lines and reservoirs. It is not part of the DWSNZ and therefore not a required determinand for water potability.

Previously HPC was the basic test that led public health officials and water treatment engineers to improve the quality of drinking water. HPC was rapidly replaced in most regulations by coliform testing, which provided a better indication of the sanitary quality of the water. In the early 1900s, HPC was being used only as a secondary test to further assess treatment efficiency. HPC is not used as a required determinand for water potability in New Zealand, but there are countries which do. Where they are regulated, HPC limits vary between 100 and 500 cfu/ml. For example, 500 cfu/ml is used as an indicator in New Zealand for the quality of distributed water systems (Deacon 2006). Bottled water may contain 10^5 cfu/ml (Reynolds 2005) and a study in New Zealand found in excess of 5700 cfu/ml in one product of bottled water (Kennedy and Bradshaw 2000).

3.6 Water quality test

The water quality test was carried out on a simulated fire sprinkler system using three common domestic water pipe materials: copper (Cu), polypropylene (PP-R) and polybutylene (PB). The pipework was installed in the roof space of an uninhabited test house located on the BRANZ site. Figure 3 shows the fire test house.

Figure 3: Fire test house – sprinkler pipework installed in roof space.

3.6.1 Pipework material

The pipework material was chosen to be representative of common products used in domestic water systems that are also suitable for use in a domestic fire sprinkler system. Other materials such as cross-linked polyethylene (PEX), chlorinated polyvinyl chloride (CPVC) and medium density polyethylene (MDPE PE80) may also be used but those chosen were considered to be sufficiently representative of the range of suitable materials for the purposes of this study. The pipework was all 20 mm nominal diameter.

The pipework was installed using the methods appropriate to the pipework being used in a fire sprinkler system. The jointing methods are given in Table 5.

Table 5: Pipe materials and jointing method

Pipe material	Jointing method
copper	Seal ring compression joint
polybutylene	Seal ring compression joint
polypropylene	Fusion welding

3.6.2 Pipe layout

To investigate the effect of dead leg lengths, range pipes of 1 metre, 3 metres and 4.5 metres were connected to the distribution pipe. Figure 4 shows the layout for one pipe material. A polybutylene pipe was installed from the supply into the roof space into which the three test pipe materials were connected. The different lengths were not arranged in any particular order along the distribution pipe. Valves were fitted to the range pipes so that they could be isolated from the distribution pipes for sampling.

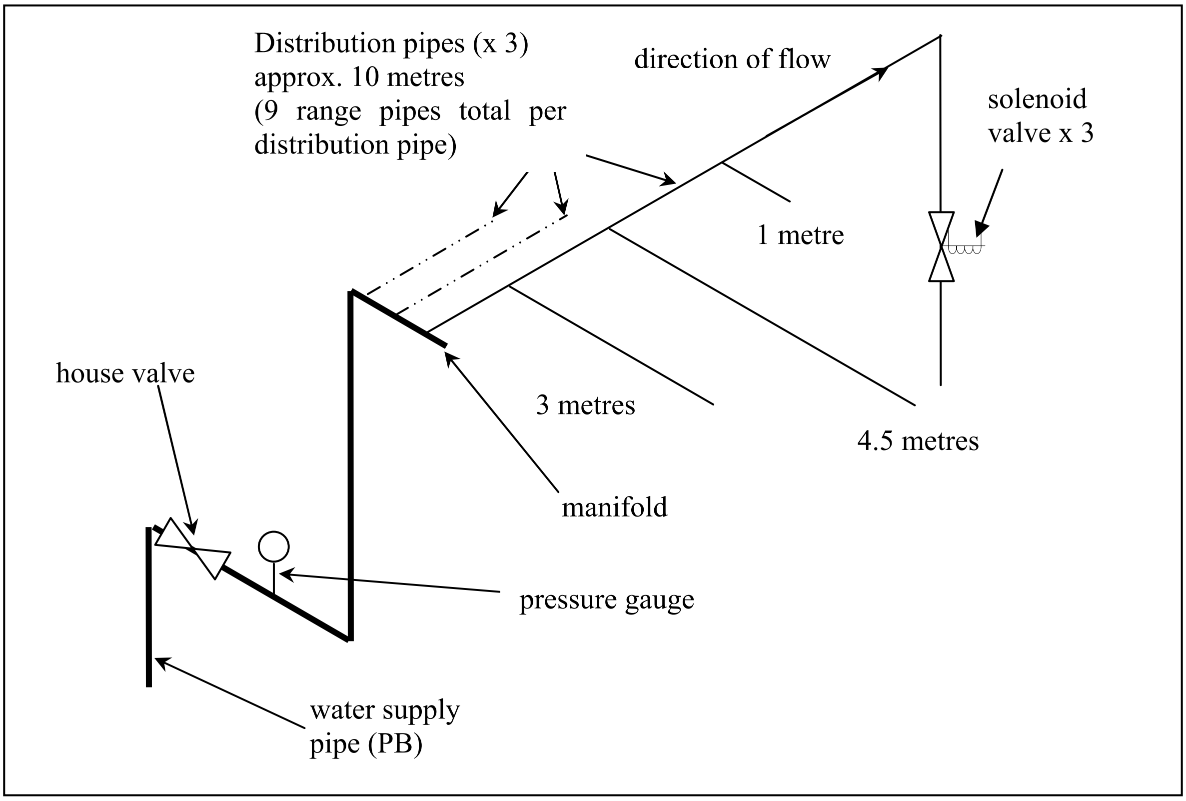

Figure 4: Schematic of the layout of test house pipework.

Figure 5 shows the water inlet to the house with the pressure gauge and shut-off valve. Figure 6 shows the outlet with the solenoid valves which was used to activate the flow at fixed times to simulate domestic usage. Figure 7 and Figure 8 show the connections of the various range pipes to the main distribution pipe. There were a total of nine range pipes connected to a distribution pipe.

In addition to the flow testing, static pipes were filled with water and left in the roof space to investigate whether there was any difference in the water quality of these and those connected to the distribution pipes. Figure 9 shows the pipes used for the static tests.

Figure 5: Inlet to house with pressure gauge.

Figure 6: Outlet of the three distribution pipes with solenoid valves.

Figure 7: Range pipe connection to main distribution pipes for PP-R (green) and PB (grey) range pipes. Cu distribution pipe between PP-R and PB pipe (red pipe not part of this study).

Figure 8: Range pipe connection to main distribution pipes for PP-R (green) and Cu (brown) range pipes. PB (gray) distribution pipe in background.

Figure 9: Pipes used for static water quality tests.

3.6.3 Water flow and flow timing

The amount of water used in a house, as given in various publications, varies from 180 litres per day per person for Auckland (Water Care 2005) to 1300 litres per day per person on the Kapiti Coast (Dominion Post 2006). Information from the Ministry of Health suggests a value of 300 litres per day per person (MoH 2004) and the Greater Wellington Council (GWRC 2005) estimated a value of approximately 400 litres per day per person. The Kapiti Coast District Council (KCDC 2002) gave a peak value of 650 litres per day per person, with a futures target of 400 litres per day per person comprising 250 for essential use and 150 for non-essential use. The Parliamentary Commissioner for the Environment identified a range for water use when looking at Kapiti Coast's water usage (OPEC 2001). This gave an average range for New Zealand of 180 to 300 litres per day per person. These figures are based on total water supplied and the population figures. The figures are gross values based on all water flow and would include leaks, garden use and outside tap use e.g. car washing. The actual water consumption therefore varies significantly and further work is being carried out at BRANZ to identify this in more detail (Heinrich 2006).

The choice of water flow and flow timing was based on a nominal flow of 6 L/min from the minimum domestic appliance usage (DBH 2005a). For two hours per day this gives a total water flow of 720 litres per day. For a four person household this gives 180 litres per day which is that given in the Water Care document (Water Care 2005) for Auckland. The flow was divided into 45 minutes in the morning (08:00 to 08:45), 30 minutes at midday (12:00 to 12:30), and 45 minutes in the evening (18:00 to 18:45). This left a no-flow period of 3¼ hours in the morning, 5½ hours in the afternoon and 13¼ hours overnight.

3.6.4 Measurements

The measurements taken included the determinands identified in Table 4 above as well as the roof space temperature.

3.6.5 Sampling

The water sampling programme was carried out 15 days after installation (only the flowing water), six months and 12 months. This gave a "four seasons" exposure of the pipework in the roof space where the temperature varied according to ambient and weather. There was no internal heating in the house.

3.6.5.1 First sample

In the first sampling, 15 days after installation, the water in the first 30 seconds and at seven minutes was sampled. This established the effect of a short-term stagnation and fresh mains water respectively. No range pipes or static pipes were sampled at this time.

3.6.5.2 Second sample at six months

All determinands were tested for in the water samples taken for a flow within 30 seconds and for the range and static pipes. Outlets were cleaned with alcohol before sampling.

3.6.5.3 Third sample at 12 months

Chlorine (FAC) was not tested for, having established that no chlorine was present after six months. Copper (Cu) was only tested for the copper pipe water samples. (The 1 metre static pipe copper was not measured).

3.6.5.4 Roof space temperature

The roof space temperature was measured at 15 minute intervals using BRANZ temperature data loggers throughout the period of the tests.

3.6.5.5 Sampling procedure

The sampling procedure consisted of closing the valves where the range pipe joined the distribution pipe and removing the pipe from the roof space. The distribution pipe connection was blanked-off.

The range pipes together with the static pipes (Figure 9) were taken to the water testing laboratory. After cleaning the outside of the valve with alcohol and flushing a small quantity of water, about 100 ml from the pipe to clear the alcohol, the sample was taken.

Samples were taken in three containers, 100 ml for FAC testing, 250 ml in a sterile container for microbial testing, and 50 ml with nitric acid to determine acid soluble copper.

The sampling of the water flowing from the outlet, outside the house from the position shown in Figure 6, was carried out within 30 seconds of initial water flow. Based on the flow rate, pipe diameters and length of pipe it takes approximately 30 seconds to fully flush the distribution pipe. The samples were taken during this time to determine whether the water in the distribution pipes had become contaminated during the period between flushes. On the day of the test the normal mid-day flushing schedule was not performed and the samples taken at 2 pm. This was to give a longer stagnation time, approximately five hours at an elevated daytime temperature for the water in the distribution pipe.

3.6.6 Results

3.6.6.1 Roof space temperature

Maximum and minimum roof space temperatures are given in Table 6.

Table 6: Minimum and maximum temperatures measured in roof space

Season	Part of season*	Maximum temperature °C	Minimum temperature °C
Summer 1 December (part) to February	Early	33	10
	Late	40	20
Autumn March to May	Early	32	9
	Late	24	3
Winter June to August	Early	15	0
	Late	20	2
Spring September to November	Early	26	2
	Late	31	5
Summer 2 December	Early	40	10

Note:* Early and late refer to parts of the season where there was a definite change in temperature.

3.6.6.2 Determinands

The results of the determinand analysis are given in Table 7, Table 8, Table 9 and Table 10.

Separate tables for E.Coli, total coliforms, faecal coliforms, yeasts and moulds are not given as these were all below the detection limit as follows:

Table 7: E.Coli, total coliforms, faecal coliforms, yeasts and moulds

Determinand	Result	Detection limit
E.Coli	<1 cfu/ml	1 cfu/100ml
Total coliform	<1 cfu/ml	1 cfu/100ml
Faecal coliform	<1 cfu/ml	1 cfu/100ml
Yeasts	<10 cfu/gm (ml)	10 cfu/gm (ml)
Moulds	<10 cfu/gm (ml)	10 cfu/gm (ml)

Note: cfu = colony forming units.

Table 8: Free available chlorine (FAC) g/m³

Flow conditions	material	Pipe length [m]	Stagnation time [months]		
			0.5*	+6	+12
Range pipe	Copper	1	N/A	<0.1	N/A
		3	N/A	<0.1	N/A
		4.5	N/A	<0.1	N/A
	PB	1	N/A	<0.1	N/A
		3	N/A	<0.1	N/A
		4.5	N/A	<0.1	N/A
	PP-R	1	N/A	<0.1	N/A
		3	N/A	<0.1	N/A
		4.5	N/A	<0.1	N/A
Static	Copper	1.5	N/A	<0.1	N/A
	PB	1.5	N/A	<0.1	N/A
	PP-R	1.5	N/A	<0.1	N/A
Initial flow (5 hours stagnation)	Copper	N/A	<0.1	0.5	0.2
	PB		0.3	0.5	<0.1
	PP-R		0.1	<0.1	N/A
Initial	Copper	N/A	0.4	N/A	N/A

flow+7 min	PB		0.4	N/A	N/A
	PP-R		0.3	N/A	N/A

Notes: N/A refers to no measurements made.
0.1 g/m³ was the detection limit.
* at 15 days.

Table 9: Heterotrophic Plate Count (HPC) cfu/ml

Flow conditions	Material	Pipe length [m]	Stagnation time [months]		
			0.5*	+6	+12
Range pipe	Copper	1	N/A	49	1400
		3	N/A	<1	<1
		4.5	N/A	49	<1
	PB	1	N/A	5	2200
		3	N/A	500	2200
		4.5	N/A	1	1500
	PP-R	1	N/A	40	230
		3	N/A	<1	5700
		4.5	N/A	230	160
Static	Copper	1.5	N/A	<1	89
	PB	1.5	N/A	5900	12700
	PP-R	1.5	N/A	9200	540
Initial flow (5 hours stagnation)	Copper	N/A	95	<1	5
	PB		640	<1	2
	PP-R		22	46	<1
Initial flow+7 min	Copper	N/A	10	N/A	N/A
	PB		32	N/A	N/A
	PP-R		12	N/A	N/A

Notes: N/A refers to no measurements made.
1 cfu/ml was the detection limit
* at 15 days.

Table 10: Copper (Cu) g/m³ (acid soluble)

Flow conditions	Material	Pipe length [m]	Stagnation time [months]		
			0.5*	+6	+12
Range pipe	Copper	1	N/A	0.679	N/A
		3	N/A	0.978	0.1020
		4.5	N/A	0.151	0.0745
	PB	1	N/A	0.118	N/A
		3	N/A	0.224	N/A
		4.5	N/A	0.122	N/A
	PP-R	1	N/A	0.089	N/A
		3	N/A	0.102	N/A
		4.5	N/A	0.135	N/A
Static	Copper	1.5	N/A	1.880	1.600
	PB	1.5	N/A	0.006	N/A
	PP-R	1.5	N/A	0.010	N/A
Initial flow (5 hours stagnation)	Copper	N/A	0.425	0.331	0.245
	PB		0.005	0.020	N/A
	PP-R		0.026	0.007	N/A

Initial flow+7 min	Copper	N/A	0.0184	N/A	N/A
	PB		0.0015	N/A	N/A
	PP-R		0.0015	N/A	N/A

Notes: N/A refers to no measurements made.
0.0005 g/m³ is the detection limit.
* at 15 days.

3.7 Analysis and discussion

3.7.1 E.Coli, total coliforms, faecal coliforms, yeasts and moulds

None of these determinands were at detectable levels from the water flow, range or static pipe tests. This is consistent with the finding of previous studies (Alleman 1982, Hart 1996 b,c). The lack of these determinands is not the only measure of water quality but the E.Coli is a major health hazard and its absence, with the other microbial determinands, indicates that the water meets the Drinking Water Standard for New Zealand (MoH 2005).

3.7.2 Chlorine FAC

Table 8 shows that chlorine dissipated rapidly with low levels after several hours of stagnation and no detectable chlorine after six months in the range pipe and static pipes. No chlorine determination was carried out at 12 months because a similar result to that at six months was expected. The absence of chlorine in the range pipes may also be indicative that no mixing took place between the range pipes and distribution pipe.

The water at BRANZ is supplied from Te Marua reservoirs in Upper Hutt. The FAC at source is between 0.6 and 0.8 g/m³ (GWRC 2006) and values measured at seven minutes flow of 0.3 to 0.4 g/m³ are consistent with that. A value of 0.5 g/m³ measured in the initial flow at six months is consistent with expectations that the sampling was delayed and the distribution pipe had been flushed through before the sample was taken.

The level of chlorine in the water supply is within those specified for MAV and GV (Table 2 and Table 3). If FAC is maintained at over 0.2 g/m³, E.Coli and coliforms are rarely present (DWSNZ 2005). This explains those microbial determinands, other than HPC, were not detected in the pipework water samples analysed in this study.

3.7.3 Heterotrophic plate count

Table 9 gives the results of the HPC analysis. The initial 30 seconds flow gave a high HPC. The HPC levels were significantly lower for the seven minute flow test and in the 6 month and 12 month initial 30 second flow. This coincided with a more rigorous sampling procedure that was established to reduce outside contamination of the sample. The results which showed values of less than 1 cfu/ml coincided with high FAC values (0.5 g/m³). This indicated a delay in the sampling may have occurred when the distribution pipe had been flushed with mains water, or that the sampling procedure had been improved to limit contamination. However the HPC would not be expected to show significant levels in the flowing water with three flushes per day.

In the range pipe water the levels of HPC in the PB and PP-R pipes increased. This may have been due to the sampling method used where the range pipes were removed from the roof space and then transported to the testing laboratory where the water was sampled. Some of the pipes were bent during transport so any HPC (or biofilm) on the pipe wall may have been dislodged. With the longer stagnation period more HPC would have formed on the pipe wall and therefore increased the measured levels. As an example the static PB pipe was damaged before a sample was taken, and even though the E.Coli and coliforms showed less than 1 cfu/100ml, the HPC was the highest recorded at 12700.

The copper range pipes, except the 1 metre length showed a decrease in HPC. This is consistent with previous work (Hart 1996b), which proposed that the copper was affecting the growth of HPC.

A WHO report (WHO 2002) states:

> *"There is no evidence, either from epidemiological studies, or from correlation with occurrence of waterborne pathogens, that HPC values alone directly relate to health risk. They are therefore unsuitable for public health target setting or as sole justification for issuing 'boil water' advisories."*

HPC is not a determinand in the Drinking Water Standards for New Zealand 2005 (MoH 2005). The WHO report (WHO 2005) further states that although an increase in HPC may be linked to an increase in E.Coli or faecal contamination, E.Coli is important in determining the quality of drinking water. As no detectable levels of E. Coli and other coliforms were found in this study, the presence of HPC is not considered significant. Tests for HPC were carried out to determine if there were likely to be any changes in the water quality, and less disruptive sampling techniques would need to be carried out to evaluate whether the HPC was in the water or solely on the pipe walls.

3.7.4 Copper

Table 10 gives the results of the copper analysis. Levels of copper in all pipes reduced with stagnation time. No samples exceeded the MAV of 2 g/m³, but the static pipe water showed levels approaching this of 1.88 and 1.6 g/m³ at six and 12 months respectively. There may be no significant difference in these numbers. At 2 g/m³ some tainting of the water would be expected (see Section 3.7.5 below).

In the plastic pipes, levels of copper were a maximum of 0.224 g/m³. The residual amount of copper was 0.0015 g/m³ as measured in the sample taken after seven minutes of initial flow water. The higher values may be explained by the presence of the brass valves and connectors used in the piping system, but even this was well below the MAV for copper. In the copper range pipes the maximum copper levels measured were 0.978 g/m³ at six months in the 3 metre pipe, though at 12 months this reduced to 0.102 g/m³. The levels of copper seem to be reducing with stagnation time and may be due to the copper reacting with the water to form insoluble compounds which were not part of the test programme. In any case, the MAV was not exceeded.

3.7.5 Colour, taste and odour

There was no discernable colour, odour or taste from the flowing water.

No colour change was observed in any of the water samples in the range and static pipes. Some small dark particles were noted in the water from copper pipes and light-coloured particles in the water from the PB and PP-R pipes. Figure 10 shows water from the static pipes at 12 months.

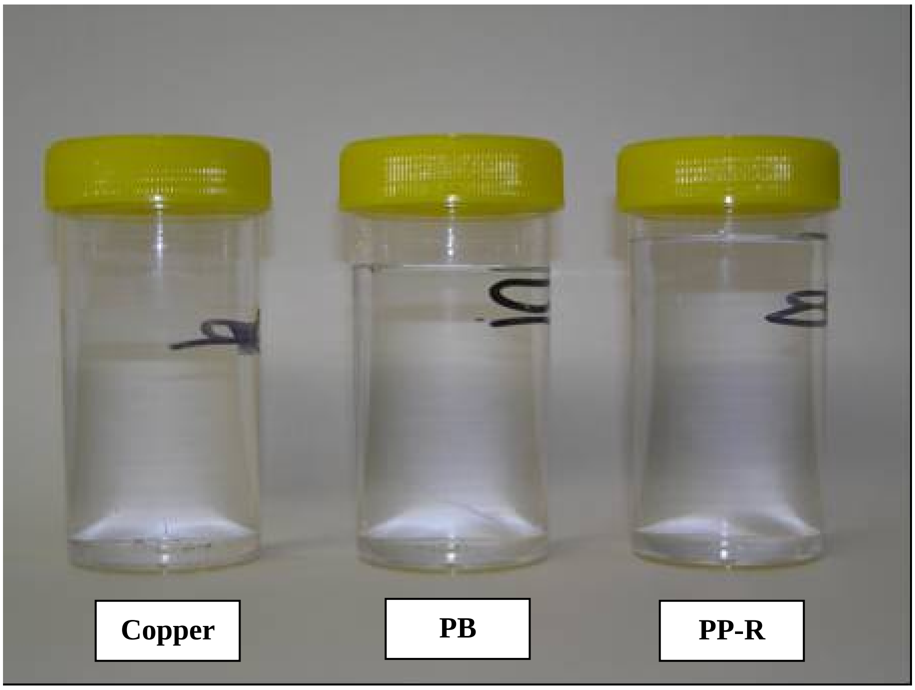

Figure 10: Water samples from static pipes at 12 months (copper, PB, PP-R).

Samples of water from the pipes were not subject to rigorous odour or taste testing. In an ad-hoc odour test, one member of a panel discerned a plastic odour from the water from the plastic range pipes and a metallic odour was noted from the static copper pipe after 12 months. At 12 months the water from the plastic range pipes had a plastic taste, but at 1:1 dilution as specified in AS-NZS 4020 (Standards Australia 2005) with chlorine-free distilled water, the taste was significantly reduced.

3.7.6 Plumbosolvency

Plumbosolvency is the ability of a water supply to dissolve lead from plumbing fixtures and has only been introduced into the DWSNZ (MoH 2005) in 2005. This effect may be important for fire sprinkler systems where the fire sprinkler itself may have lead in its composition. This study has not explored the implications of plumbosolvency.

However with a Combination Domestic Fire Sprinkler System, where water flows through the distribution pipe at each use of a plumbed appliance, plumbosolvency may offer no greater hazard to health than any other plumbing fitting.

With fire sprinklers directly attached to the distribution pipe any products of plumbosolvency would be flushed through the system and the presence of a fire sprinkler head would be no more hazardous to health than any other plumbing fitting. Where the fire sprinkler is at the end of a range pipe it is remote from the distribution pipe and under normal circumstances would not pose a hazard.

3.7.7 Contamination of mains supply

In a backflow event water may be drawn into the town mains. The water from the distribution pipe would not pose a hazard based on the range of test results and the water from the range pipes would be diluted to an extent dependent on the length of range pipe. No substances hazardous to health were found, so taste would be the only issue where the supply water is of equal or greater quality to that which was used in this research.

This study explored a maximum 4.5 metre range pipe. Whilst it would be possible to design a fire sprinkler system with such a length of range pipe it would not be a sound design (a range pipe of at most 3 metres would be applicable). In determining the potential for a dead legs to contaminate the town mains we can consider a typical domestic sprinkler design with a maximum of two 4.5 m long range pipes. With a 20 mm nominal bore for the range and distribution pipes, this would give approximately 2 litres of water. In a distribution pipe, say 10 metres long, this represents a dilution of 1:1.7. Distribution pipes are usually larger diameter than range pipes so the dilution would be significantly increased by up to 1:3. Even if the range pipe water entered the water system as a discrete volume it is considered that it would not constitute, at most, a nuisance or low hazard as defined in G12/AS1 (DBH 2005a).

3.8 General discussion and conclusion

Two questions were posed in the introduction to this part,:

1. Is the water flowing through a combination fire sprinkler system likely to be hazardous to health for a system supplied with treated town mains water, and

2. what length of dead leg would not be hazardous to health?

The results of the test showed that the levels of determinands in the flowing water did not exceed the Drinking Water Standard for New Zealand MAVs. There was also some evidence that mixing between the range pipes and distribution pipes did not occur, with no detectable chlorine in the range pipes. Any mixing would have been minimal and therefore any water from the range pipes would be significantly diluted by the flowing water, and thus have minimal effect on taste, (the only significant determinand identified).

Therefore it is concluded that the water flowing through a combination fire sprinkler system is not hazardous to health when supplied with treated mains water of equal or greater quality than used in this research.

As taste was the only determinand found in significant quantities in this study, if there is backflow into the town mains any tainted water from plastic pipes or copper would be diluted by the water in the distribution pipe and further in the town mains. The tainted water is not significant and therefore it is considered that it would not constitute a nuisance, by colour, odour or taste as defined in G12/AS1 (DBH 2005a). This means that it would not even be a low Hazard and therefore would not require a backflow device installed.

The study used a maximum dead length of 4.5 meters. However, to provide a conservative design, the length of range pipe should be kept to at most 3 metres length, notwithstanding that a sprinkler design with a 3 metre dead leg would not be an efficient design. The reason for this is that dead legs would occur in branch pipes, which are the smallest diameter pipes in the sprinkler system. Long, small diameter branch pipes would therefore produce high pressure losses which may not be compensated for by the water supply pressure. Increasing the branch pipe diameter to overcome these losses would not be an efficient design – it would be better to reduce the length of these pipes and hence the dead leg length.

3.9 Recommendations for future work

This work was limited to using town mains, which was a clean water supply complying with the DWSNZ. The results are therefore applicable to similar water supplies. However, it would be useful to undertake a study on a system whose water supply did not meet the DWSNZ and supplying that water at the upper limit of tolerance of DWSNZ compliance. This would be applicable to a wider range of water supplies to include, for instance, rural supplies using untreated tank, spring or bore water. At present such supplies, where there is some doubt about their quality, would need backflow preventers or be completely separate systems with a supply which is not shared with the domestic supply. A future study could therefore investigate the effects on water quality in a sprinkler pipework system of using water which is at the uppermost tolerance of the DWSNZ requirement.

During the study it was noted that the HPC levels increased where pipes had been damaged, and it was suspected that bending the pipes during transport may have increased HPC levels by dislodging organisms that had been attached to the inner wall of the pipe (e.g. biofilms). In discussions with the microbial test laboratory, it was suggested that swab samples from the pipe walls could be taken to determine the levels of HPC and to compare them with a standard domestic reticulation system with no sprinklers attached. It is recommended that any future study on water quality in domestic sprinkler systems include this.

4. RELIABILITY OF DOMESTIC FIRE SPRINKLERS

4.1 Introduction

Reliability is an important aspect of a fire sprinkler system. It determines the effectiveness of the fire sprinkler and controls its acceptability amongst regulators, insurance companies, the general building industry and the public. No one will gladly install a fire sprinkler system if it can't be relied on to work: most of the time. The crucial questions are will it work, and will it control (or extinguish) a fire in the early stages of growth to protect life?

For the purposes of this report reliability is used to mean an "overall" reliability and is a combination of "operational" reliability and "performance" reliability as defined by Budnick (2001). Thomas (2002) uses the term "effectiveness" which he defines as a combination of "efficacy" (performance reliability) and "reliability" (operational reliability). For the purposes of this document, the term reliability will be used to mean overall reliability in activating and controlling a fire in a domestic property within the design parameters of the sprinkler "listing".

Based on Australian and New Zealand data over the period 1886-1986 (Marryatt 1988), NZS 4541 (SNZ 2003) quotes a reliability of 99.5% for a full commercial system based on over 5000 sprinkler activations. In studies carried out in other countries fire sprinkler reliability values range from 81% to 99.4% (Koffel 2003) spanning the years 1959 to 1998. More recent studies in the USA, covering the years 1989-1998 (Rohr 2001) indicate a reliability of 74-91% in a range of occupancies. For one and two family homes the figure was 80% reliability. Rohr (2001) reported 6700 fires in sprinklered homes that resulted in 16 deaths compared with 2996 deaths in 319700 fires with no sprinklers.

This may seem low for family homes, but the figures do not include unreported fires which would increase the 80% to approximately 85% (Rohr 2001). Whilst this is not near the 99.5% reliability quoted in NZS4541, it should also be noted that even at 85% reliability, automatic fire sprinkler systems still have a significant impact on improving life and property protection in the event of a fire. A more detailed analysis of this data is given in the following sections.

4.2 Objective

This section discusses the reliability of domestic fire sprinkler systems and proposes a reliability value for use in risk analysis and/or cost-benefit studies.

4.3 Historical data

There have been many studies over the years on reliability of fire sprinkler systems. The data arising from these studies is given in Table 11 and the highest values are shown graphically in Figure 11. With the exception of the data reported by Budnick (2001) and BRANZ (2000), the reliability is based on fire sprinkler activation records. The Budnick data was a result of a reliability calculation.

Until the more recent work from the USA (Rohr and Hall 2005), previous reporting was subject to limitation such as not identifying the property or sprinkler types accurately. This makes it difficult to differentiate the different types of sprinkler systems and properties. Factors such as reporting periods, types of occupancy, and level of detail regarding types of fire incidents varied significantly and would influence the data (Holt 2005).

Table 11: Historical sprinkler system reliability data

Reference	Overall reliability %	Comments
Rohr and Hall 2005	90-100	All occupancies
Rohr and Hall 2005	94-100	Residential (100% for one or two family dwelling)
Kelly 2003	85.8	Oregon State Fire Marshal 1970 – 1978
	95.7	US Navy 1964-1977
	86.1	Factory Mutual 1970-1977
Budnick 2001	93.1-96.0	Commercial and general (excludes institutional and residential)
Duncan et al 2000 (BRANZ)	95	Estimate of domestic combination system
Ramachandran 1998	87	Increases to 94% if estimate number of fires not reported is included and based upon 33% of fires not reported to fire brigade
Linder 1993	96	
Taylor 1990	81.3	Limited data base
Kook 1990	87.6	Limited data base
Marryat 1988	99.5	Inspection, testing, and maintenance exceeded normal expectations and higher pressures
Maybee 1988	99.4	Inspection, testing, and maintenance exceeded normal expectations
Finucane et al 1987	96.9 – 97.9	
Richardson 1985	96	
Smith 1983	95	UK data
Powers 1979	98.8	Office buildings only in New York City
	98.4	Other than office buildings in New York City
	95.8	Low-rise buildings in New York City
Miller 1974	86-95.8	Commercial and general (excludes institutional and residential)
NFPA 1970	88.2 – 98.2	Data provided for individual occupancies – total for all occupancies was 96.2%
Milne 1959	96.6/97.6/89.2	Reference not sourced but given in Budnick 2001

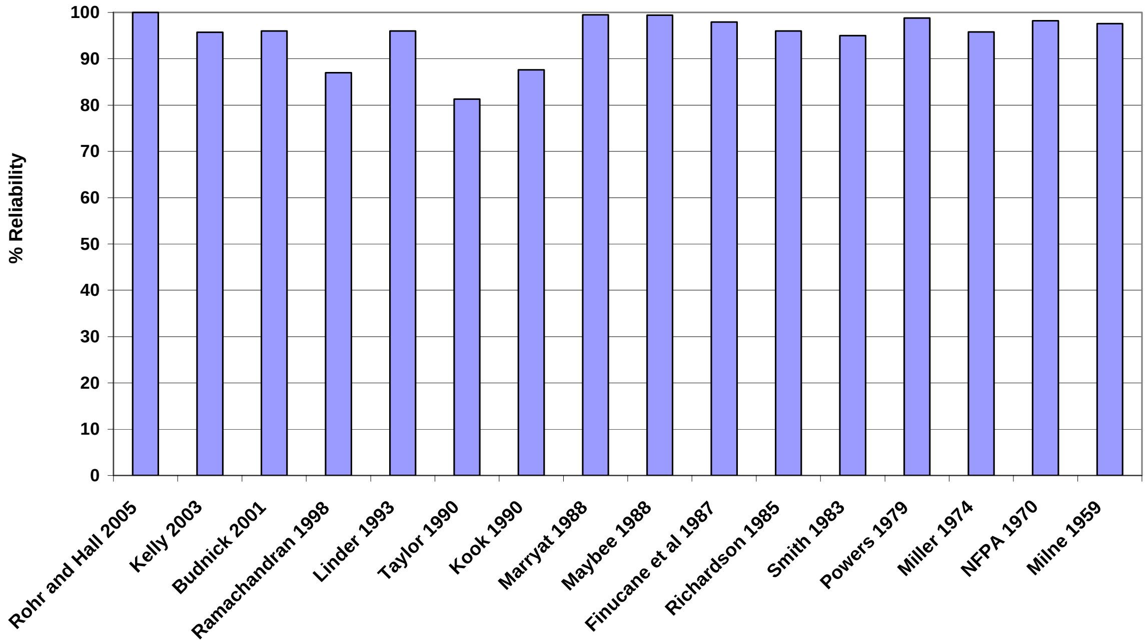

Figure 11: Historical data from Table 11 presented as a bar graph.

The data reported by Rohr and Hall (2005) was more specific in occupancy and fire sprinkler types than previous work and could be said to provide the most detailed indication of fire sprinkler reliability to date, barring the small data set for residential properties. Rohr and Hall based their analysis on a survey of 3000 US Fire Departments.

The figures from all previous work summarised here show that fire sprinklers generally have a high reliability, though there is a large spread of data from 81.3-99.5%. This range may be attributed to the methods by which the data was collected and the methods of reporting – usually from fire incident reports prepared by operational fire fighters. The lowest value (Taylor 1990) was based on a very small number of incidents and included suppression systems other than fire sprinklers. The highest value (Marryatt 1988) reflected the thoroughness of inspection, testing and maintenance of the fire sprinkler systems.

Concerns have been expressed (Budnick 2001) that levels of uncertainty in this data were not identified and that 10-15 year old data does not reflect current fire sprinkler technology. To define accurate levels of uncertainty requires a more rigorous analysis of the data than was carried out in each study, and a risk assessment approach, which has only recently been considered for use with fire sprinkler system reliability. Modern fire sprinkler technology has been devised to provide more effective life safety protection, so it could be said that the historical data underestimates the reliability of current fire sprinkler systems. The 2005 USA study (Rohr and Hall 2005) to some extent bears this out by giving higher reliability figures than previously estimated (NFPA 2005), but some sprinklers systems included in the data would have used relatively older technology.

The available historical data relates mostly to commercial properties with conventional fire sprinkler systems (Koffel 2003). No specific reliability data is currently available on Combination Domestic Fire Sprinkler Systems, though these systems are permitted by various standards such as NFPA 13D and NZS 4517. Therefore a full reliability study is needed at this time to provide estimates of reliability. This report suggests a value, but a more rigorous risk assessment needs to be carried out to determine specific values of reliability related to domestic fire sprinkler systems.

4.4 General concepts of reliability

The definition of reliability varies with the application and industry in which it is used. It may refer to something similar to 'repeatability' or 'reproducibility'. In the context of this report, the definition typically used in the electrical engineering industry (IEEE 1990) has been chosen:

> *Reliability*
> "the ability of a system or component to perform its required functions under stated conditions for a specified period of time"

Reliability can be defined in probabilistic terms as the probability of success, expressed as a percentage of the total number of activations:

$$\text{P(success)} = \frac{\text{number of successful activations}}{\text{total number of activations}}$$

Budnick (2001) defines this as the "overall" reliability and states that this can be divided into "operational" reliability and "performance" reliability. The operational reliability is a measure of the probability that the system will operate when called on to do so (i.e. will it activate?), and the "performance" reliability is a measure of the adequacy of the systems once it has activated (i.e. will it control/extinguish the fire?).

It must be remembered that the operational reliability is whether the system will operate at all within its design parameters and is dependent on the type and frequency of testing, availability of water supply and, if appropriate, the electrical power supply.

Performance reliability then depends on the system having been designed correctly and on the individual reliability of all components.

This leaves performance reliability as the main measure of effectiveness of the domestic fire sprinkler. However it may be difficult to separate the values for the two types of reliability from historical fire event data. Budnick (2001) carried out a reliability analysis but did not differentiate between the two forms of reliability. Estimates of reliability from historical data are a combination of the operational and performance reliability. Work carried out in the UK (Williams et al 2005) on the effectiveness of residential fire sprinkler systems also does not distinguish them. For the purposes of this study, an "overall" reliability is considered.

4.5 Factors affecting fire sprinkler reliability

Factors which affect fire sprinkler system operational reliability include any type of failure associated with a component, from the water supply to the fire sprinkler head. In a previous BRANZ report (Duncan et al 2004) the following factors were proposed:

1. Continued availability of water supply.
2. Functionality of valve set (determined by the level of maintenance).
3. Exposure of pipework (determined by location in relationship to a possible fire i.e. exposed or not).
4. Operation of fire sprinkler head
5. Effectiveness of fire sprinkler discharge in controlling/extinguishing the fire (dependent on the nature and location of the fire).

With a Combination domestic Fire Sprinkler System, the valve set will not exist and all pipework will be protected from the expected room of fire origin by wall linings. (The roof space is not expected to be a major source of fire (SNZ 2002).) However as not all spaces in a building are protected by a domestic fire sprinkler system, there is a possibility that a fire in an unsprinklered space will affect the pipework. The concept of reliability of a combination system must therefore take into account the fact that not all spaces are protected by the sprinkler system. Also the degree of certification and ongoing inspection is less than that of a more commercial fire sprinkler system such as NZS 4541 (SNZ 2003a) or NZS 4515 (SNZ 2003b).

Also in a domestic combination system the availability of water may not be a concern as the occupier would soon be aware that the water supply has been shut-off or disconnected when there is no water to domestic appliances.

Additional factors then to be included are:

1. Designer competence.
2. Correctness of installation.
3. Fire load (whether materials introduced not being typical of a residential occupancy).
4. Position of supply valve (e.g. possibly partially closed after maintenance but may become evident in the normal domestic water usage).
5. Interference with fire sprinkler head (painted, damaged or obstructed).

The reliability of a domestic sprinkler system associated with each of these factors could be greatly improved through the introduction of certification of designer and installers, and inspection regimes.

An estimate of reliability is given for each factor as listed in Table 12. This table gives maximum values of reliability which would give the greatest reliability, assuming a best case scenario, in an event tree. Figure 12 shows an example of part of an event tree (Duncan et al 2000) which estimates the probability of fatalities and illustrates a more detailed approach.

It should be noted that most components, pipes, valves, failure rates, etc, are given as multiples of 10^{-6} (Budnick 2001), giving a reliability of at least 99.9999% individually for each component.

Table 12: Reliability events for a Combination Domestic Fire Sprinkler System to meet its design function

Event	Reliability %	Comment
Continued availability of water supply	99.5	Duncan et al 2000
Functionality of valve set (determined by the level of maintenance). Replaced by "Operational supply valves" below	N/A	No valve set included in a domestic sprinkler system therefore not applicable
Reliability of pipework (determined by location in relationship to the fire i.e. exposed to fire, absence of fire sprinklers in areas where a fire might originate, general reliability of pipes and fittings)	98.0	Budnick 2001 Component reliability has negligible effect on overall reliability as defined here
Operation of fire sprinkler head	99.99	Mak 2006
Effectiveness of fire sprinkler discharge in controlling/extinguishing the fire (dependent on the nature and location of the fire) for which it was designed	99.99	Mak 2006 Also based on "listing" tests
Designer competence	99.9	Approved designer
Correctness of installation	99.9	Installed by approved designer or installer working under supervision
Fire load typical of residential	99.9	Estimate
Operational supply valves	99.0	Estimate
No interference with fire sprinkler head	99.0	Estimate
Overall maximum estimate of reliability	**95.0**	

All reliabilities are assumed to be mutually exclusive i.e. the reliability of one event is not affected by and does not impact on any other.

This is a rough estimate of reliability and, although based on a different approach, gives a similar result to that presented in the Duncan, Wade and Saunders report (Duncan et al 2000).

It is difficult to determine specific reliabilities for many of the factors through lack of data. Component reliabilities have previously been estimated (Budnick 2001). However, other factors that have less inherent quality control (such as design, installation and maintenance) potentially have a greater influence on the overall reliability of a fire sprinkler system than individual components. There are uncertainties in determining individual reliability values and Budnick (2001) reported a two-sided 95% confidence interval for reliability values for six existing fire sprinkler systems. That is, a range of reliability values from 66.5–99.9%. As an example, one system had a reliability of 96.3%, with 66.5% lower and 99.3% upper reliability limits at 95% confidence. This indicates a large variability in reliability.

Problems arise with small data sets and in New Zealand there is insufficient data to determine accurate reliability values as combination systems are too new for sufficient data to have been collected. In the UK (Williams et al 2005) the data on residential sprinklers, let alone combination systems, is insufficient to give reliability figures. In the USA less than 1% of the reported fires that occur in one or two family dwellings contained fire sprinklers, but the impact was shown to be high in saving lives and property (Rohr and Hall 2005).

4.6 Effectiveness and reliability

Work carried out in the UK (Williams et al 2005) assessed fire sprinkler effectiveness in protecting life by measuring the ability of fire sprinklers to control toxicity, temperature and visibility. This was defined as effectiveness in that report. Effectiveness and associated uncertainty for the addition of sprinklers were then estimated for reducing fatalities, injuries, rescues and property damage, as presented in Table 13. Whilst not within the scope of this work, the effectiveness of fire sprinklers is an important aspect of the application of fire sprinklers.

Table 13: Expected effect of the addition of fire sprinklers in all residential properties (Williams et al 2005)

Fire event outcome	% Reduction
Death	70 ±15
Injuries	30 ±15
Rescues	35 ±15 Apartments 50 ±15
Property damage	50 ±15

Similar work was carried out by Duncan, Wade and Saunders (Duncan et al 2000), but the primary focus was to address the cost-benefit of a domestic fire sprinkler system with supporting information about its effectiveness in reducing loss of life, injury and property damage as presented in Table 14. Whilst a UK-based report (Williams et al 2005) showed less effect on injuries, the effect of fire sprinklers on fatalities was in agreement with the value in the BRANZ report (Duncan et al 2000).

Table 14: Expected effect of fire sprinklers in houses (Duncan et al 2000)

Protection system	Reduction in fatalities %	Reduction in injuries %
Smoke alarms only	53	70
Fire sprinklers only	80	63
Fire sprinklers + smoke	83	75

Whilst reliability is important in risk assessment, the effectiveness of a fire sprinkler system is also a useful parameter for comparison of alternative fire protection systems.

4.7 Conclusion

It is difficult to accurately determine the reliability of a Combination Domestic Fire Sprinkler System because of lack of data due to the short histories of the new technologies involved. A simple risk analysis and a review of historical data suggests that the overall sprinkler reliability of 95% proposed in a previous BRANZ study (Duncan et al 2000) is not unreasonable. A limited data analysis conducted in the USA (Rohr and Hall 2005) indicated that as a minimum in a residential property, such as a motel, the reliability may be 94% rising to 100%, for a one or two family dwelling.

In order to determine specific values of reliability related to domestic fire sprinkler systems, future work should include a more rigorous risk assessment.

Notwithstanding the importance of reliability in risk assessment, the effectiveness of a domestic fire sprinkler system in saving life and property should not be underestimated. This has been described more fully in other reports (Williams 2005 and Duncan et al 2000).

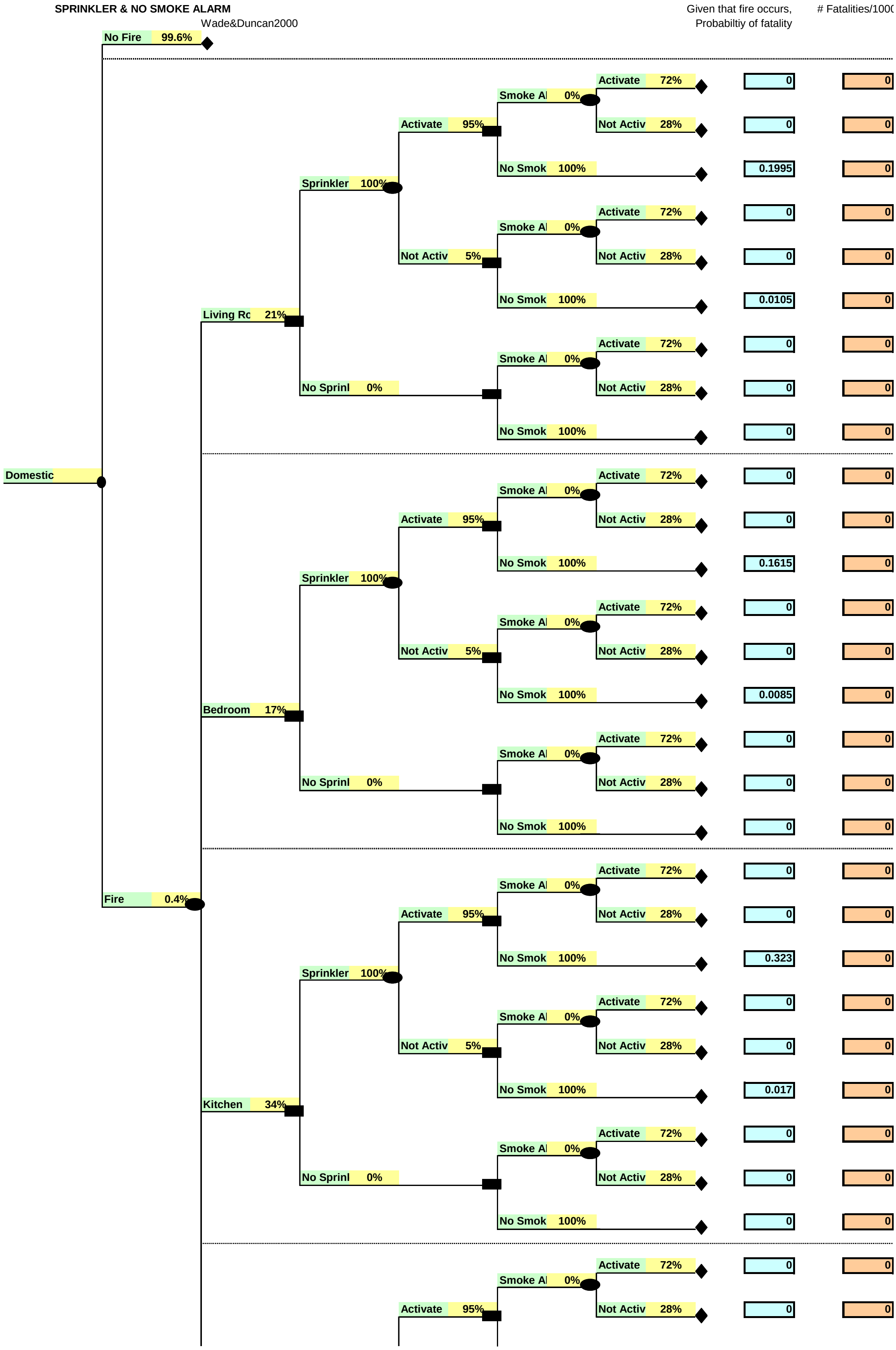

Figure 12: Example of an event tree extracted from Duncan et al (2000).

5. APPLICATION TO OTHER PROPERTY

5.1 Introduction

The objective of this part is to determine where domestic fire sprinklers could be introduced in the Compliance Documents for fire safety to the NZBC to improve life safety. In particular, Acceptable Solution C/AS1 (DBH 2005b) and whether there is a technical basis to extend the applicability of Combination Domestic Fire Sprinklers to properties other than single family dwellings.

Currently the only fire sprinkler systems referenced in C/AS1 (DBH 2005b) are, NZS 4541 (SNZ 2003b) *Automatic fire sprinkler systems* and NZS 4515 (SNZ 2003a) *Fire sprinkler systems for residential occupancies*.

Types of property which may benefit from a domestic fire sprinkler system are those which might otherwise not require a fire sprinkler system. However if sprinklers are voluntarily installed in these properties, or where the activity or nature of occupant (purpose group as defined in C/AS1 (DBH 2005b)), this is subject to discussion. For example, whether a residential property is a care facility or accommodation, they may be required to have at least an NZ 4515 system. Properties which may benefit from a domestic fire sprinkler system but which might otherwise not require one include, but are not limited to:

- backpackers accommodation (SA purpose group)
- small residential care homes (SC or SA)
- wharenui and marae (SA).

The definition of the purpose groups SC, SA and SR are given in Table 15.

The following is a discussion on these issues and terminology, and concepts from C/AS1 (DBH 2005b) will be used.

5.2 C/AS1 requirements

C/AS1 requires fire sprinklers to be installed in residential (sleeping occupancies) as follows:

- in all SC and SD purpose groups
- in all SA and SR purpose groups:
  - over 25 m escape height
  - over 10 m escape height with single means of escape
- firecells directly below purpose groups SC and SD.

A single fire sprinkler head is required at the top of protected shafts, but compliance with a standard is not required, except for coverage within the shaft which has to meet NZS 4541 or NZS 4515 as applicable. Residual pressure and pipe diameter are also specified.

Fire sprinklers can be used to provide concessions for various building parameters such as increases in open path lengths (C/AS1, Paragraph 3.5), increase in number of bed spaces (C/AS1 Part 6), and increase in unprotected areas or decrease in distance to the boundary (C/AS1 Part 9).

This leaves the following occupancies which, although are not required to have fire sprinklers, may benefit from a fire sprinkler system:

- in all SA and SR purpose groups less than 25 m escape height and less than 10 m escape height with single means of escape.

Considering the nature of a NZS 4517 system, and with additional safeguards and features, the following properties could have an enhanced NZS 4517 system without reducing the life safety performance of the building:

This includes properties such as described in the introduction:

- small backpackers
- small motels
- wharenui
- residential care with occupants requiring little assistance (ambulatory and of a lesser mental disability than may be for an SC occupancy).

Working and crowd occupancies are not considered suitable for a sprinkler system based on NZS 4517 because that standard essentially uses sprinkler heads designed for residential type occupancies.

Table 15: Purpose groups (extracted from C/AS1 (DBH 2005b))

Purpose group	Description	Some examples (not a complete list)	Fire hazard category
SC	Spaces in which principal users because of age mental or physical limitations require special care or treatment	Hospitals, care institutions for the aged, children, people *with disabilities*	1
SA	Spaces providing transient accommodation, or where limited assistance or care is provided for principal users	Motels, hotels, hostels, boarding houses, clubs (residential), boarding schools, dormitories, halls, wharenui, community care institutions	1
SR	Attached and multi-unit residential dwellings	Multi-unit dwellings or flats, apartments and includes household units attached to the same or other purpose groups such as caretakers' flats and residential accommodation above a shop. Household unit firecells may contain garages which are used exclusively by the occupants of that household unit	1
SH*	Detached dwellings where people live as a single household or family	Dwellings, houses, being household units, or suites in purpose group SA, separated from each other by distance. Detached dwellings may include attached self-contained suites such as granny flats when occupied by a member of the same family, and garages whether detached or part of the same building and are primarily for storage of the occupants' vehicles, tools and garden implements	1

Note: *A domestic fire sprinkler system to NZS 4517 may be used in purpose group SH.

5.3 Choice of fire sprinkler standards

The choice of which fire sprinkler standard applies is determined by the standards. The application of a standard is given in its scope. The scope to NZS 4515 restricts the fire sprinkler system to residential properties with limits to floor area and number of storeys.

Residential properties are defined in NZS 4515 as:

"*RESIDENTIAL OCCUPANCIES. Rooms arranged for the purposes of habitation or co-habitation, other than those defined as a domestic occupancy. These include hospital ward areas, rest homes, care institutions, prisons, police cells, motels, hotels, hostels, residential boarding schools, flats and apartments".*

It should be noted that a domestic occupancy is excluded. This is defined as:

"*DOMESTIC OCCUPANCY. A domestic occupancy is the home of not more than one household and includes any attached self-contained unit (e.g. granny flat). Multiple adjoining occupancies are considered to be included provided they are separated by fire-rated walls (e.g. townhouses)".*

Domestic occupancies are not required to have a fire sprinkler system and this definition has similarities to that of an SH purpose group.

The limits for floor area and storeys are given in Table 16.

Table 16: Scope of application for NZS 4515

Conditions	**Total area of all floors m^2**	**Number of storeys**
None	≤ 500	≤ 3
Fire sprinkler water supply > 60 min duration Fire brigade alarm Fire sprinkler inlet	≤ 2000	≤ 4

For the purposes of this report, as most New Zealand buildings would fall into the first category of not more than 500 m^2 nor greater than 3 storeys, a comparison of NZS 4517 with NZS 4515 is appropriate.

NZS 4541 applies to any building, and provision is made in the standard for residential properties which would have an Extra Light Hazard (ELH) classification.

5.4 Comparison between NZS 4515 and NZS 4517

A comparison between NZS 4515 and NZS 4517 for properties of not more than 500 m² of floor area nor greater than 3 storeys is made under the following headings:

- Scope of application
- Number of fire sprinklers activating
- Water discharge density
- Water demand
- Duration of fire sprinkler action
- Alarms
- Fire sprinkler valve installation
- Verification of design
- Inspections
- Listing requirements. “Listed” means that the item has been examined by the fire sprinkler system certifier and found to meet relevant standards and/or has otherwise been demonstrated to be adequate for the intended application

  Examples of test and approval bodies are Verifire, Factory Mutual (FM), Loss Prevention Council (LPC), and Underwriters Laboratories (UL). Verifire hold a register of listed equipment, components and materials. Equivalent organisations may be used if they have been independently accredited by an internationally recognised accreditation body to AS/NZS ISO/IEC 17020 as competent to certify to the appropriate fire sprinkler standard
- Installer requirements
- Pipework
- Provision for external exposure risk.

These features are considered to be the most significant of a fire sprinkler system which can affect the cost and acceptability of a system. Table 17 gives a summary of the comparison.

The greatest impact on a fire sprinkler design will be the water supply requirements. It is feasible that a house may have a room with four fire sprinklers, such as a family/lounge kitchen/dining area. For compliance with NZS 4515 this would require say 256 L/min, whereas according to NZS 4517 the requirements would be 132 L/min. The required higher flow can have a significant effect on the dynamic pressure losses and hence fittings (e.g. water meters, flow check valves) and pipe sizes and hence cost of installation. A property that can have four fire sprinklers in one room can include any of the properties to which an NZS 4515 system would apply, such as a residential care facility, rest home or motel.

Discharge density of water is the same in both cases.

Other aspects (such as design and installation verification, six monthly and annual inspection by a listed contractor, flow alarms and associated alarm equipment) are significant variations to NZS 4517..

Table 17: Comparison between NZS 4515 and NZS 4517 for types of property considered in this report

Feature	NZS 4515	NZS 4517
Scope of application	See Section 5.3 and Table 16	Single family dwellings or multiple adjoining occupancies separated by fire-rated walls e.g. townhouses with their own independent water supply
Maximum number of fire sprinklers activating	Three at 110% of pressure	2
Extent of fire sprinkler protection	Entire building	Sprinklers may be omitted from some areas
Maximum water demand	Approximately 180 L/min for three fire sprinklers operating + 76$ L/min for domestic demand (total 256 L/min)	Approximately 120 L/min for two fire sprinklers operating + 12 L/min for domestic demand (total 132 L/min)
Duration of fire sprinkler action	20 minutes	10 minutes
Alarms	Fire sprinkler operating alarm and an evacuation alarm	Smoke alarms. No connection to fire service
Fire sprinkler valve installation	Installation control valves as per Figure 3.1 of NZS 4515	Standard ball valve or similar. No special requirements. No drain valve, test valve, water flow and pressure detectors, upstream pressure gauge
Verification of design	By fire Sprinkler System Certifier (SSC)	None, but a peer review sometimes requested
Verification of installation	By SSC	On commissioning by installer, thereafter owner's responsibility
Inspections*	Monthly by owner Six monthly and annually by listed contractor	No formal requirements. Annual owner's inspection recommended yearly
"Listing" requirements	Including but not limited to: Pipework Isolating valves Water flow detector Low water pressure detector Alarm equipment Pumps and components	Fire sprinkler heads only
Installer requirements	Listed contractor	None
Pipework	Mild steel Copper CPVC Stainless steel Any other pipe listed and meeting the requirements of AS 4118.2.1	Any pipe appropriate for domestic water reticulation but must be protected.
Provision for external exposure risk	Additional where within 3 metres if domestic or within 10 metres if industrial, commercial etc	None

Notes: $ Based on 12 fixture load units – Bathroom group (washbasin, water closet, bath and shower) 6, dishwasher 1, washing machine 2, kitchen sink 2, garden hose 1.
* If installed in a single family residence a Compliance Schedule would not be required therefore an IQP report would not be necessary.

Based on this comparison, with appropriate design considerations, there is no reason why the technical requirements of NZS 4517 cannot be used in place of a NZS 4515 system for the range of properties considered here. However aspects to be resolved are:

- reliability
- location of fire sprinklers
- domestic water demand
- alarm systems
- verification of design and installation
- inspection regimes
- type of property.

If these cannot be resolved then a NZS 4515 system must be installed.

5.5 Reliability

As discussed in Part 2 of this report the reliability of a domestic fire sprinkler system is less than that of a NZS 4515 or NZS 4541 fire sprinkler system. The main reason for this is that the verification of the design and installation, inspection and maintenance regime for those systems is rigorous. Therefore to improve the reliability of a NZS 4517 system it is recommended that a system of design verification and inspection be put in place (see below).

5.6 Location of fire sprinklers

The NZS 4517 system has been developed by excluding fire sprinklers from spaces considered to be low fire risk, based on New Zealand Fire Service statistics and commensurate with overseas practice e.g. NFPA 13D. Notwithstanding these fire sprinklers are required in low risk areas such as laundries, stairs and hallways, which although not giving high percentages of fatalities may constitute either a future hazard, e.g. clothes driers in laundries, or are an important part of escape routes. The location of fire sprinklers in accordance with NZS 4517 is therefore considered sufficient to meet life safety requirements for occupants in domestic occupancies.

5.7 Domestic water demand

NZS 4517 requires a minimum domestic water demand of 12 L/min to be used in the sprinkler system calculations, but also requires that any high demand appliances be taken into account. This demand can be included in the design calculation where it arises or included with the sprinkler head requirement. Although not as demanding as required by NZS 4515, this is considered sufficient to enable a higher value than 12 L/min to be factored into the fire sprinkler design.

5.8 Alarm systems

NZS 4515 requires a dedicated sprinkler alarm system, using a flow switch to initiate an alarm. This is also proposed for the enhanced NZS 4517 fire sprinkler system.

5.9 Verification of design and installation

NZS 4517 does not require a rigorous design verification system, although a final commissioning test is needed to validate the design. This test is not required by NZS 4515 (nor NZS 4541). In NZS 4515 and NZS 4541 it is sufficient for the design to be peer reviewed. The commissioning test is a valid method of ensuring compliance with the Standard but must be recorded and become part of the compliance documentation.

5.10 Inspection regimes

NZS 4517 deems the owner as wholly responsible for inspecting and maintaining the fire sprinkler system. Where the use of this standard is extended to properties other than single family homes, then the inspection regimes must be more structured and documented. This is achieved by including the fire sprinkler system in the Compliance Schedule and requiring regular inspection. Whereas NZS 4515 requires monthly inspection and testing, annual inspections by a competent person are recommended for the system proposed in this report.

The inspections should include:

- main stop valve(s) open
- operation of electrical pumps satisfactory
- water pressure check (on pressure gauge) – the owner is encouraged to check this regularly e.g. monthly
- alarm valve operational
- general overall system check to ensure fire sprinkler heads are clear and no additions have been made to the system.

This is in general agreement with NZS 4515, but with variations to take into account a smaller fire sprinkler system.

5.11 Type of property

For the purposes of this report comparison with a residential property (as given in NZS 4517 which limits the floor area to less than 500 m² and 3 storeys high) is being made. Whilst this floor area is greater than a typical large family home, which may be 250 m² to 300 m², it would include larger residential properties such as motels and backpackers.

It has been suggested that an enhanced NZS 4517 fire sprinkler system could be used in properties classified as SC. These properties include a wide range of occupants with the degree of care ranging from day care and ambulant occupants to 24 hour care and bedridden occupants. At the lower level of care it may be possible, by agreement with the BCA, to classify such properties as SR or SA, in which case an NZS4517 may be applicable. It is not the purpose of this report to explore the amount of care occupants require and therefore if a low level of care, or "limited assistance or care" as stated in C/AS1, Table 2.1 for an SA purpose group is provided, then an enhanced NZS 4517 system would be applicable. The decision to classify such a property as SA would be reached in discussion between the designer and Building Consent Authority (BCA).

Occupant load is an important part of the fire safety in a building. NZS 4515 gives no limits for occupant load. For SA or SR purpose groups a limit of 40 is given in C/AS1, or 160 in a group sleeping area if a smoke detection system and fire sprinklers are installed in accordance with at least NZS 4515.

The proposed fire sprinkler system is not fully complaint with NZS 4515, therefore the increase in occupant load is not justified. An SA and SR property within the design parameters of 500 m² floor area and 3 storeys would not need a fire sprinkler system, therefore the proposed enhanced fire sprinkler system for houses would be suitable for such properties.

5.12 Determination of compliance

NZS 4515 Appendix A gives information on the determination of compliance for a residential fire sprinkler system. This states that the fire sprinkler system is deemed to comply with NZS 4515 when an appropriately qualified contractor has issued a Certificate of Compliance stating:

a) The design of the system has been documented and shown to conform to this Standard.
b) All components which are required to be listed have been verified.
c) The physical installation complies in all aspects.
d) The water supply and components have been tested and shown to comply.
e) The flow switch, and other alarm and monitoring functions, operate correctly.
f) There is evidence of ongoing testing, servicing and surveying arrangements and that these comply.

The form of Certificate of Compliance is that set out in Appendix D (of NZS 4515) and a copy should be displayed adjacent to the system control valves.

All these items are recommended to be included in the proposed enhanced NZS 4517 system. This information will be included in the owner's manual in addition to that required by NZS 4517 if not already included.

The above items can be considered completed as follows:

a) Fire sprinkler layout on a floor plan, hydraulic calculation sheets, and verification by peer review.

b) Fire sprinkler data sheet provided.

c) Sign-off of installation by a competent person.

d) Water supply graph included in owner's manual.

e) Sign-off of flow switch operation.

f) Testing and servicing arrangements included in owner's manual.

In addition, the commissioning flow test will be included and all documents lodged with the BCA who issue the Compliance Schedule.

5.13 Conclusion

It is considered that a domestic fire sprinkler system in accordance with NZS 4517 could be installed in properties other than houses (SH purpose group) with the following conditions:

5.13.1 Property definition

- Residential (SR, SA, residential care not classified as SC, and Wharenui sleeping areas with not more than 40 sleeping spaces).
- Not more than 25 m escape height or 10 m escape height with single means of escape.
- Not more than 3 storeys.
- Not more than 500 m² total floor area.
- Occupant load not exceeding 40.
- Smoke alarms installed as required by NZBC Clause F7.

5.13.2 Fire sprinkler specification

- Domestic water supply to be taken as 12 L/min unless it can be shown that there is a greater demand (evidence to be supplied of reason for choice of domestic demand).
- Evidence of water supply characteristics to be provided.
- Design to be reviewed by a person with qualifications and experience of fire sprinkler design.
- Flow switch to alarm in fire sprinkler pipework
- Water supply to provide 20 minutes fire sprinkler activation.
- Installation to be approved and final commissioning test witnessed by the BCA or agent.
- Inspection and maintenance carried out annually by a competent person.
- Compliance Schedule to be issued.
- Owner's manual and all compliance documents copied to the BCA and owner.

6. REFERENCES

Alleman JE, Milke JA and Hickey HE. 1982. 'An Investigation of the Water Quality and Condition of Pipes in Existing Automatic Sprinkler Systems for the Analysis of Design Options With Residential Sprinkler Systems'. *NBS-GCR-82-399*. (August 1982, NBS Grant NB80NADA1011) University of Maryland Dept. of Fire Protection Engineering and Civil Engineering College Park, MD, USA.

American Water Works Association. 2004. *Recommended Practice for Backflow Prevention and Cross-Connection Control*. (Third Edition, ISBN 1583212884, Catalogue Number 30014) AAWA, Denver, CO, USA.

Ball A. 2004. Personal Communication, Environmental Science and Research Ltd (ESR) Christchurch, New Zealand.

BRANZ Ltd. 2002. *BRANZ Design Guide Sprinklers for Houses*. Judgeford, New Zealand.

Budnick EK. 2001. 'Automatic Sprinkler System Reliability'. *Fire Protection Engineering* (Winter 2001). Society of Fire Protection Engineers.

Bukowski RW, Budnick EK and Schemel CF. 1999. *Estimates of the Operational Reliability of Fire Protection Systems*. International Association of Fire Safety Science (IAFSS), October 4–8, Chicago, IL, Society of Fire Protection Engineers, Boston, MA, USA.

Christchurch City Council. 2004. *Environmental Services Unit – Building Control Domestic Fire Sprinkler Systems for Houses Information Sheet IS24.* CCC, Christchurch, New Zealand.

Deacon R. 2006. Personal Communication, Environment Laboratory Services Ltd (ESR), Lower Hutt, New Zealand.

Department of Building and Housing (DBH). 1992. *The Building Regulations 1992, First Schedule, The Building Code*. Ministry of Internal Affairs, Wellington, New Zealand.

Department of Building and Housing (DBH). 2005a. *Compliance Document for New Zealand Building Code Clause G12, Acceptable Solution G12/AS1*. (Second Edition, ISBN 0-477-01606-5) Wellington, New Zealand.

Department of Building and Housing (DBH). 2005b. *Compliance Document for New Zealand Building Code Clauses C1, C2, C3, C4, Acceptable Solution C/AS1*. (Second Edition, ISBN 0-477-01606-5) Wellington, New Zealand.

Dominion Post. 2005. *Kapiti is Parched. Despite a New $13m Borefield, They Still Can't Turn On Their Sprinkler.* 3 December 2005 (Weekend Edition E4–E5). Wellington, New Zealand.

DuBay C and Kelly K. 2004. *Automatic Fire Sprinkler Systems and Backflow – Where Are We and What Should We Do?* www.pmengineer.com/CDA/Archives/0a2c8864da298010VgnVCM100000f932a8c0 (accessed on 29 March 2006).

Duranceau SJ, Foster JV and Poole J. 1998. *Impact of Wet-Pipe Fire Sprinkler Systems on Drinking Water Quality*. (ISBN: 0898679435) AWWA.

Duncan CR, Wade CA and Saunders NMS. 2000. *Cost-Effective Domestic Fire Sprinkler Systems.* NZ Fire Service, Wellington, New Zealand. www.fire.org.nz/research/reports/reports/report_1.htm (accessed on 30 March 2006).

Finucane M and Pickney D. 1987. *Reliability of Fire Protection and Detection Systems*. UK Atomic Energy Authority, University of Edinburgh, Scotland.

Greater Wellington Regional Council. 2005. *Water Supply Annual Report For the Year Ended 30 June 2005*. GWRC, Wellington, New Zealand.

Greater Wellington Regional Council. 2006. *Chlorination Questions and Answers*. www.gw.govt.nz/section670.cfm (accessed 3 April 2006).

Hart FL, Till R, Nardini C and Bisson D. 1993. *The Need for Backflow Protection When Installing Residential Fire Sprinklers.* USFA, FEMA, Grant No. GMW-93-G-4191, June 1993.

Hart FL, Anderson L and Murawski J. 1996a. *The Impact of Stagnation on Water Quality in Wet Pipe Fire Sprinkler Systems*. Presented at 1996 AWWA Conference, Toronto, Canada.

Hart FL, Anderson L and Murawski J. 1996b. *Laboratory Study – Water Deterioration From Extended Stagnation Conditions in Steel, Copper and CPVC Pipes*. USFA, FEMA, Grant No. EMW-94-G-4521, February 1996.

Hart FL, Anderson L and Murawski J. 1996c. *Field Sampling Data of Water Taken From Fire Sprinkler Systems*. USFA, FEMA, Grant No. EMW-94-G-4521, May 1996.

Heinrich M. 2006. 'Residential Water End Use Literature Survey'. *BRANZ Study Report 149*, BRANZ Ltd, Judgeford, New Zealand.

Henderson D. 2006. 'Is the Sprinkler Lobby all Wet?' *Ontario Home Builder* (Winter 2006)

Holt I. 2005. Personal Communication, Promat International (Asia Pacific) Ltd, Malaysia, New Zealand.

Institute of Electrical and Electronics Engineers. 1990. *IEEE Std 610 Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries.* IEEE, New York, USA.

Kapiti Coast District Council (KCDC). 2002. *Water Matters: Kapiti Coast District Sustainable Water Management Strategy*. www.kapiticoast.govt.nz/NR/rdonlyres/F18FA9A0-E426-45C1-BB18-50C4BF8854E8/8077/WaterMatterscomplete.pdf (accessed on 15 March 2006).

Kelly KJ. 2003. 'Trade Ups'. *Sprinkler Quarterly* (Summer).

Kennedy M and Bradshaw K. 2000. 'Public Perception of Water Quality' *Report No. 00.210 to the Utility Services Committee of the Greater Wellington Council*. Wellington, New Zealand.

Koffel W. 2003. 'Reliability of Automatic Sprinkler Systems'. *Alliance for Fire Safety, October 2003.* Koffel Associates Inc. www.afscc.org/AFSCCTechnicalPapers.htm (accessed 10 January 2006).

Kook KW. 1990. *Exterior Fire Propagation in a High-Rise Building.* Master's Thesis, Worcester Polytechnic Institute, Worcester, MA, USA.

Linder KW. 1993. 'Field Probability of Fire Detection Systems.' *Balanced Design Concepts Workshop, NISTIR 5264.* RW Bukowski (ed), Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, Maryland, USA.

Mack C. 2005. Personal Communication, Tyco Fire & Security, Auckland, New Zealand.

Marryatt HW. 1988. *Fire-Automatic Sprinkler Performance in Australia and New Zealand, 1886-1986* (Revised Edition). Australian Fire Protection Association, North Melbourne, Australia.

Maybee WW. 1988. *Summary of Fire Protection Programs in the US Department of Energy – Calendar Year 1987*. US Department of Energy, Frederick, MD, USA.

Miller MJ. 1974. *Reliability of Fire Protection Systems*. Loss Prevention ACEP Technical Manual 8.

Milne WD. 1959. 'Automatic Sprinkler Protection Record'. *Factors in Special Fire Risk Analysis* (Chapter 9: 73-89).

Ministry of Health. 2004. *Household Drinking Water Supplies, The Selection, Operation, And Maintenance of Individual Household Water Supplies*. MoH, Wellington, New Zealand. www.healthed.govt.nz/upload/pdf/4602.pdf (accessed on 30 March 2006).

Ministry of Health. 2005a. *Drinking-Water Standards for New Zealand 2005*. MoH, Wellington, New Zealand.

National Fire Protection Association (NFPA). 1970. 'Automatic Sprinkler Performance Tables' (1970 Edition). *Fire Journal* (July: 35-39).

National Fire Protection Association (NFPA). 2005. 'NFPA Report Finds Higher Estimated Reliability Of Sprinkler Systems and Reaffirms Their Life-Saving Impact, Especially In Homes'. *News Release* (9 September 2005).

New Zealand Fire Service. 2006. *Emergency Incident Statistics 2003-2004.* NZFS, Wellington, New Zealand.

Parliamentary Commissioner for the Environment. 2001. *Whose Water Is It? The Sustainability of Urban Water Systems on the Kapiti Coast.* PCE, Wellington, New Zealand.

Powers RW. 1979. 'Sprinkler Experience in High-Rise Buildings (1969-1979)'. *SFPE Technology Report 79-1*. Society of Fire Protection Engineers, Boston, MA, USA.

Ramachandran G. 1998. *The Economics of Fire Protection*. E & FN Spon: New York, London.

Reynolds K. 2005. 'On Tap: The Microbial Quality and Safety of Bottled Water'. *Water Conditioning & Purification Magazine* (September). Tucson, Arizona, USA.

Richardson JK. 1985. 'The Reliability of Automatic Sprinkler Systems'. *Canadian Building Digest* (July: Vol. 238).

Rohr KD. 2001. *US Experience With Sprinklers*. National Fire Protection Association, Quincy, Massachusetts, USA.

Rohr KD and Hall JR. 2005. *US Experience With Sprinklers And Other Fire Extinguishing Equipment*. Fire Analysis and Research Division, National Fire Protection Association, Quincy, Massachusetts, USA.

Smith F. 1983. 'How Successful are Sprinklers?' *SFPE Bulletin (*April: Vol. 832: 23-25).

Standards Australia. 2005. *AS-NZS 4020 Testing of Products For Use in Contact with Drinking Water.* Sydney, Australia.

Standards New Zealand. 2002. *NZS 4517:2002 Fire Sprinkler Systems for Houses*. SNZ, Wellington, New Zealand.

Standards New Zealand. 2003a. *NZS 4541:2003 Automatic Fire Sprinkler Systems*. SNZ, Wellington, New Zealand.

Standards New Zealand. 2003b. *NZS 4515:2003 Fire Sprinkler Systems for Residential Occupancies.* SNZ, Wellington, New Zealand.

Taylor KT. 1990. 'Office Building Fires … A Case for Automatic Fire Protection'. *Fire Journal* (January/February 84(1): 52-54).

Thomas IR. 2002. 'Effectiveness of Fire Safety Components and Systems'. *Journal of Fire Protection Engineering* (May: Vol. 12).

Water Care. 2004. *From the Sky to the Sea.* Auckland Water Management Plan, Auckland, New Zealand.

Williams C, Fraser-Mitchell J, Campbell S and Harrison R. 2005. 'Effectiveness of Sprinklers in Residential Premises'. *Project Report Number 204505*. Building Research Establishment Ltd, Watford, UK.

World Health Organization. 2002. *Heterotrophic Plate Counts and Drinking-Water Safety. The Significance of HPCs for Water Quality and Human Health*. WHO, Geneva, Switzerland.

World Health Organization. 2004. *Guidelines for Drinking-Water Quality* (Third Edition, Volume 1, Recommendations). WHO, Geneva, Switzerland.