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Phase 1 report

Title: Investigation of the suitability of the Actual Delivered Density Apparatus (ADD) for the performance evaluation of standard sprinklers as described in Insurance Services project proposal no. 12192

Project no. TE 91014 - 19

Client: Insurance Services
The Loss Prevention Council
On behalf of The Association of British Insurers

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1. Introduction

No fire tests are conducted on sprinklers during the approval process in Europe and this is considered to be a serious omission. The Actual Delivered Density (ADD) equipment is a low running-cost apparatus specifically developed to fire test ESFR sprinklers and is referred to in ISO 6182-7 [10.1]. This project sets out to develop the apparatus and methodology for testing all sprinkler types. No data is available on the performance evaluation of standard sprinklers using the (ADD) apparatus; the project will therefore establish a methodology that will yield similar results to the established ISO 6182-1 [10.2] wood crib fire test used for testing standard K80 and K115 sprinklers.

As outlined in LPC Insurance Services project proposal no. 12192 [10.3], an ADD apparatus was constructed at the Special Projects Group of LPC Laboratories on behalf of Insurance Services representing the Association of British Insurers. This report sets out to provide the information required to establish suitable performance criteria limits for K115 (and K80) sprinklers.

2. Sprinkler selection

Four K115 sprinkler were selected for ADD and wood crib fire testing as follows:

Company	K-factor	Model	Style/position
GW	115	DD1 (SSU)	Upright
GW	115	DD1 (SSP)	Pendent
Star	115	SG (SSU)	Upright
Star	115	SG (SSP)	Pendent
Viking	115	M (SSU)	Upright
Viking	115	M (SSP)	Pendent
Wormald	115	A (C/UP)	Upright
Wormald	115	A (C/UP)	Pendent

Table 1 – Selected K115 sprinklers

Additionally two K80 were selected for ADD testing only:

Company	K-factor	Model	Style/position
Star	80	SG (SSU)	Upright
Star	80	LD2 (SSP)	Pendent

Table 2 – Selected K80 sprinklers

Photographs of these sprinklers are shown in Figures 1 to 9

Figure 1 - GW DD1 K115 pendent sprinkler head

Figure 2 – GW DD1 K115 upright sprinkler head

Figure 3 - Star SG K115 pendent sprinkler head

Figure 4 – Star SG K115 upright sprinkler head

Figure 5 - Viking M K115 pendent sprinkler head

Figure 6 – Viking M K115 Upright sprinkler head

Figure 7 - Wormald A K115 (C/UP) sprinkler head

Figure 8 - Star LD2 K80 pendent sprinkler head

Figure 9 – Star SG K80 upright sprinkler head

3. Factory Mutual wood crib test results (ISO 6182-1)

All the K115 sprinklers were subjected to the wood crib fire test described in ISO 6182-1 and Factory Mutual (FMRC Approval Standard Class Series 2000, December 1983). The wood crib is located centrally 2.5 metres below an array of 4 sprinklers, and sprayed from below with heptane. Evaluation is based upon the mass loss from the crib during the test. Sprinklers that allow the consumption of more than 20% of the crib's mass, or enable ceiling temperatures to be achieved that threaten the structure of the test rig, will fail to meet the appraisal criteria.

Figure 10 shows the experiment configuration and Table 3 shows the FMRC results [10.4] of these tests that were conducted at a flow rate of 100 $l.min^{-1}$ per sprinkler.

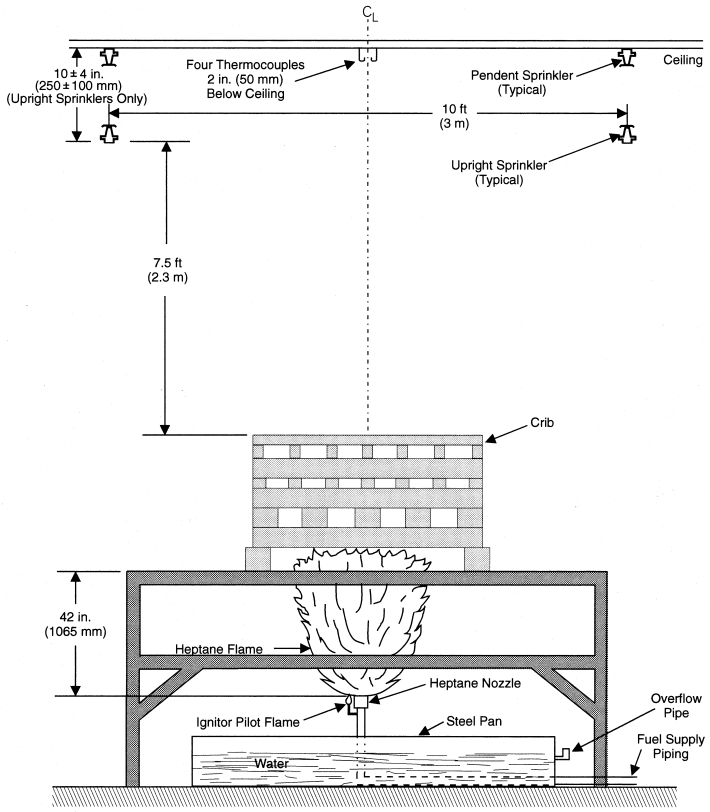

Figure 10 – The ISO 6182-1 test configuration

Company	Model	Orient ation	Pre-fire crib weight Pounds	Pre-fire crib moisture %	Pre-fire bone dry weight Pounds	Post fire crib weight Pounds	Post fire crib moisture %	Post fire bone dry weight Pounds	Crib weight loss %
GW	DD1	Upright	320.0	8.10	294.1	286	5.75	269.5	8.36
GW	DD1	Pendent	327.0	8.41	299.5	240	3.50	231.6	22.67**
Star	SG	Upright	318.0	7.70	293.5	290	6.50	271.2	7.60
Star	SG	Pendent	323.0	7.27	299.5	301	5.10	285.6	4.64
Viking	M	Upright	327.0	7.40	302.8	285	4.40	272.5	10.00
Viking	M	Pendent	333.0	8.90	303.4	305	5.60	287.9	5.11
Wormald	A	Upright	318.0	8.52	290.9	223*	3.70	214.7*	26.19*
Wormald	A	Pendent	321.0	8.48	293.8	268	3.25	259.3	11.74

* Test terminated at 8 minutes due to excessive ceiling temperatures, sustained burning of crib, and endangerment of facility

** Exceeds the FMRC requirement for maximum crib weight loss of 20 %

Table 3 – Summary of FMRC wood crib fire test results

The order of performance starting with the best is as follows: (1) Star Pendent, (2) Viking Pendent, (3) Star Upright, (4) GW Upright, (5) Viking Upright, (6) Wormald Pendent, (7) GW Pendent, (8) Wormald Upright, of which (7) and (8) did not satisfy the test criteria. One test, (8) Wormald Upright was terminated after eight minutes due to an excessive rate

of burning and high ceiling temperature. Had the test continued for 30 minutes the crib weight loss would have been greater.

It is recommended that these tests form the basis of the ADD approval criteria. Annex F details ADD

4. The Actual Delivered Density rig

The Actual Delivery Density Apparatus (ADD) used for the performance evaluation of ESFR sprinkler types is fully described in ISO/DIS 6182-7:1996(E) “Fire protection – Automatic sprinkler systems – Part 7: *Requirements and test methods for Early Suppression Fast Response (ESFR) sprinklers*”. The ADD apparatus enables the measurement of water densities in the presence of a fire. Fire will modify the ‘cold’ coverage by evaporating water droplets and/or displacing them. A brief description of the LPC ADD apparatus is given below.

The equipment is in two parts:

- a ceiling 6m x 6 m in area whose height can be adjusted up to 7 metres. A high volume water supply is connected to a pipe network suspended under the ceiling which is capable of 3m x 3m, 4m x 3m, and 4m x 4m sprinkler arrays as well as single and double head configurations.
- a set of collection pans configured to mimic palletised storage (a 2 x 2 array with gaps in between). Water falling into the pans is piped away to collection bins that are mounted on load cells so that ‘real-time’ measurement of the water densities is possible. Eight burners mounted on a ring over the collection pans and an additional central one enable a heptane spray fire up to 7 MW in size to be produced. Air is blown up the centre of the collection array to aerate the fire and produce representative flue gas velocities.

Figures 11 to 15 show the collection array, control program and ADD rig, respectively

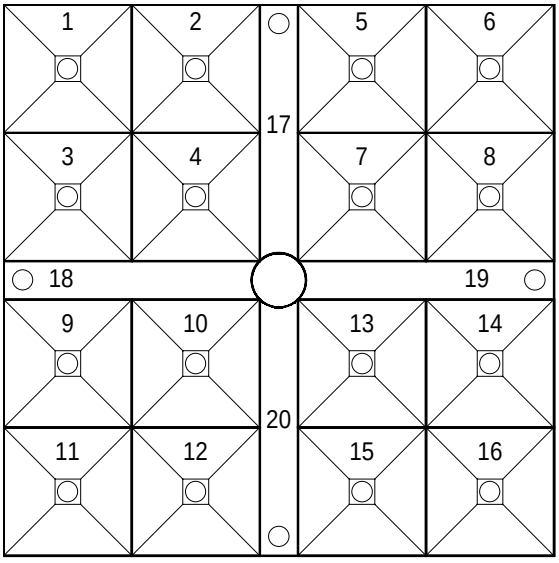

Figure 11 – The ADD collection pan array

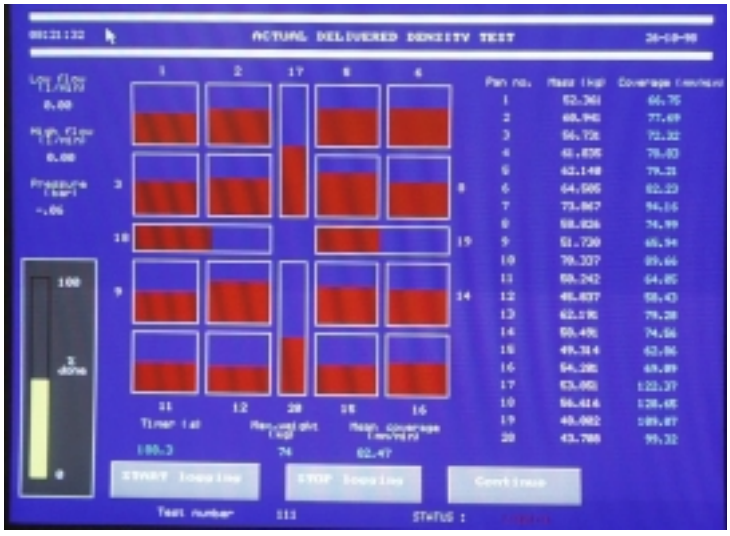

Figure 12 – The ADD control program display

Figure 13 – The ADD rig

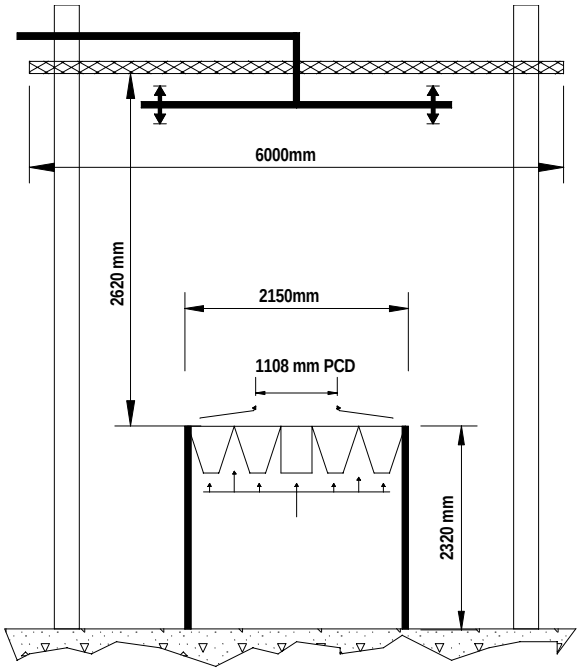

Figure 14 – Side elevation of the ADD rig

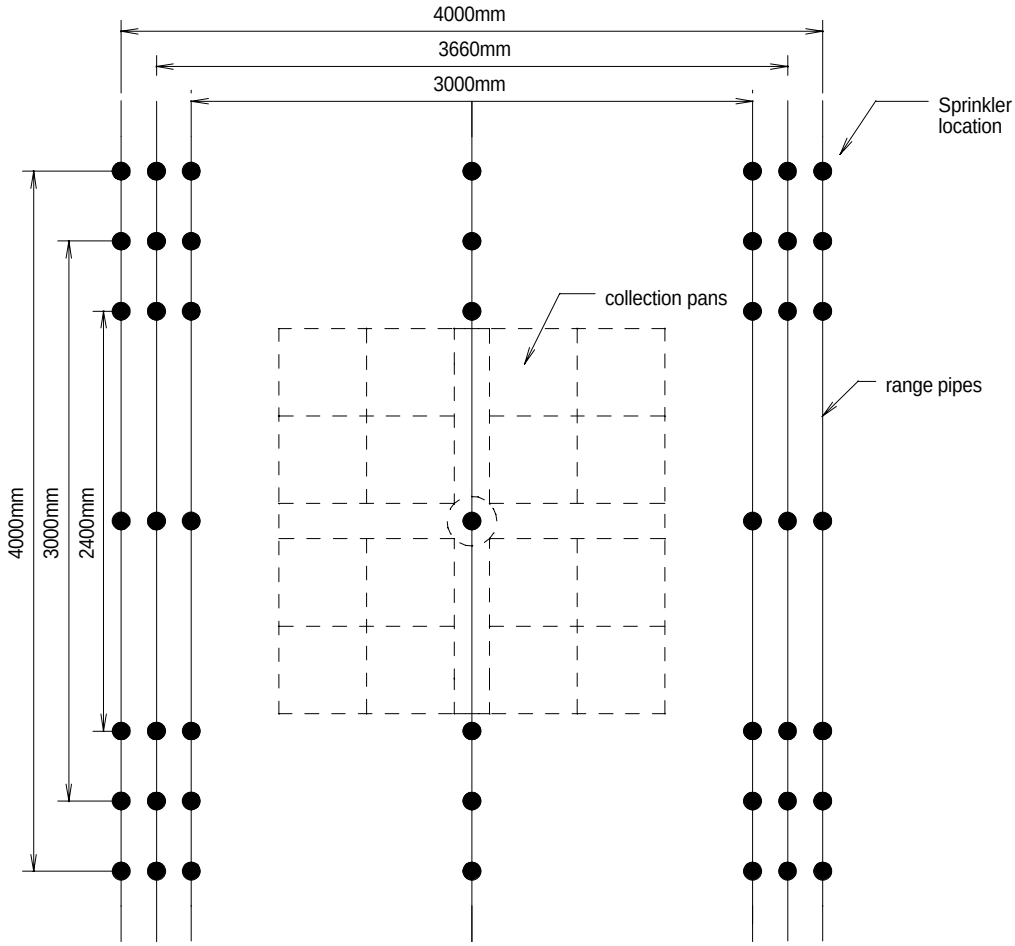

Figure 15 - Plan view of sprinkler locations

The operational test parameters are as follows:

Parameter		Unit
Ceiling height above top of pans	2.6	m
Water flow rate per sprinkler	100±5 (1)	l min^{-1}
Fire size	1.3	MW
Range pipe DN	32	mm
Air flow rate		m^3 s^{-1}
Range pipe centre line to ceiling distance	225 ± 5	mm
Pendent sprinkler deflector to ceiling distance	340 (nominal)	mm
Upright sprinkler deflector to ceiling distance	110 (nominal)	mm
Pan height above floor	2.32	m
Hopper pan dimensions	(500 ± 5)x(500 ± 5)	mm
Gap pan dimensions	(150 ± 5)x(1000 ± 5)	mm
Air duct diameter	210 ± 5	mm
Number of Hopper pans	16	
Number of gap pans	4	
Total collection area	4.46	m^2
Ceiling dimensions	6.0 x 6.0	m
Ceiling to pan height – low	2.62	m
Ceiling to pan height - high	4.94	m
Number of heptane burners	9	
Circle diameter of 8 equally spaced burners	1108	mm
Burner model	Delevan (0.5678 l.min^{-1} @ 6.895 bar)	
Burner cone angle	80°	
Burner height above pans	150	mm
Burner inclination	45°	
NOTE (1): flow rate of 100 L.min^{-1} per sprinkler equivalent to a nominal discharge density of 11.1 mm/min for sprinkler spacing of 9 m^2 per sprinkler.		

Table 4 – ADD operational test parameters

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5. The ADD test programme

All sprinklers described in Section 2 were tested in accordance with the criteria set out in Section 4. The configurations were as follows:

- 4 sprinklers — Separation 3 metres
  Sprinkler arms in line with pipe work
  Upright and pendent positions
  ADD located centrally under array
- 2 sprinklers — Separation 3 metres
  Sprinkler arms in line with pipe work
  Upright and pendent positions
  ADD located centrally between sprinklers
- 1 sprinkler — Sprinkler arms in line with pipe work
  Upright and pendent positions
  ADD located centrally underneath sprinkler

All test arrangements were conducted with (hot) and without (cold) the fire in operation, and the results compared.

6. Test results

The test results presented in tables have been averaged in a number of ways to aid interpretation of the data. ‘Hoppers’ is the term used to identify the 0.5m x 0.5m collection pans, four of which simulate a storage pallet. ‘Gap’ is the term used to identify the four 0.15m x 0.5m pans used to simulate the space between the stacked pallets.

The averaging system is as follows:

Mean description	**Included collectors**	**Definition**
Hoppers and gap	1 – 20	All water collected in ADD
Hoppers only	1 – 16	Water collected in 0.5m x 0.5m pans only
Gap only	17 – 20	Water collected in 0.15m x 1m pans only
Hoppers and non-aligned gap	1 – 16 + 17 + 20	Excludes pipe run off (single head tests)
Aligned gap	18 + 19	Pipe runs off (single head tests only)
Inner hoppers	4 + 7 + 10 + 13	Inner ‘circle’ of 0.5m x 0.5m pans
Middle hoppers	3 + 2 + 5 + 8 + 14 + 15 + 12 + 9	Middle ‘circle’ of 0.5m x 0.5m pans
Outer hoppers	1 + 6 + 16 + 11	Outer ‘circle’ of 0.5m x 0.5m pans

*Numbering system given in Figure 11.

6.1. ADD 4 sprinkler array tests

Full details of the measurements made during testing of the sprinklers in an array of 4 are given in Appendix A. Tables 5 and 6 summarise the water density, and collection percentage results respectively, from the 4 pendent sprinkler array on a 3 m x 3 m spacing.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
GW Pendent	Cold	(mm/min)	11.59	11.39	13.02	11.68	10.41	12.97	11.69	9.20
	Hot	(mm/min)	8.25	8.37	7.48	8.42	5.84	7.20	8.70	8.86
Star Pendent	Cold	(mm/min)	13.45	13.03	16.32	13.31	15.53	17.52	12.17	10.28
	Hot	(mm/min)	11.81	11.72	12.44	11.76	12.60	13.41	11.70	10.07
Viking Pendent	Cold	(mm/min)	11.79	11.54	13.47	11.64	13.97	13.91	11.46	9.34
	Hot	(mm/min)	9.65	9.70	9.37	9.69	9.18	8.90	10.24	9.40
Wormald Pendent	Cold	(mm/min)	9.67	9.63	9.93	9.66	9.83	9.42	10.20	8.71
	Hot	(mm/min)	7.83	7.89	7.41	7.86	7.43	6.63	8.67	7.60

Table 5 – Water density measurements for pendent sprinklers in an array of 4

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
GW Pendent	[(1)]Cold	(%)	13.22	11.32	1.90	12.46	0.76
	[(2)]Hot	(%)	9.38	8.29	1.09	8.96	0.42
	[(3)]H/C	(%)	70.94	73.23	57.26	71.85	55.92
Star Pendent	Cold	(%)	15.49	13.08	2.41	14.34	1.14
	Hot	(%)	13.40	11.60	1.81	12.49	0.92
	H/C	(%)	86.56	88.66	75.14	87.09	79.96
Viking Pendent	Cold	(%)	13.34	11.39	1.95	12.33	1.01
	Hot	(%)	11.08	9.70	1.38	10.41	0.67
	H/C	(%)	83.06	85.20	70.53	84.40	66.67
Wormald Pendent	Cold	(%)	11.08	9.62	1.46	10.36	0.72
	Hot	(%)	8.86	7.79	1.07	8.32	0.54
	H/C	(%)	79.99	80.93	73.75	80.36	74.69

NOTE
(1) Cold % = (4 x total water volume collected cold / total water volume discharged cold) x 100
(2) Hot % = (4 x total water volume collected hot / total water volume discharged hot) x 100
(3) H/C = (Hot % / Cold %) x 100 ≈ (Hot [mm/min]/ Cold [mm/min]) x 100

Table 6 – Water collection measurements for pendent sprinklers in an array of 4

Tables 7 and 8 summarise the water density and collection percentage results respectively, from the upright 4-sprinkler array on a 3 m x 3 m spacing.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
GW Upright	Cold	(mm/min)	9.39	9.33	9.79	9.47	8.25	11.41	8.38	9.16
	Hot	(mm/min)	8.25	8.29	7.96	8.36	6.63	8.95	8.04	8.13
Star Upright	Cold	(mm/min)	13.54	12.93	17.71	13.31	16.93	16.23	14.00	7.48
	Hot	(mm/min)	11.60	11.33	13.39	11.47	13.40	12.51	12.31	8.21
Viking Upright	Cold	(mm/min)	11.14	11.05	11.82	11.14	11.26	10.89	11.40	10.50
	Hot	(mm/min)	8.97	9.05	8.45	9.01	8.44	6.87	9.46	10.41
Wormald Upright	Cold	(mm/min)	9.75	10.07	7.64	9.93	7.18	6.88	10.63	12.13
	Hot	(mm/min)	5.14	5.35	3.76	5.26	3.41	2.62	5.67	7.43

Table 7 – Water density measurements for upright sprinklers in an array of 4

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
GW Upright	Cold	(%)	10.82	9.38	1.44	10.21	0.61
	Hot	(%)	9.43	8.26	1.16	8.94	0.49
	H/C	(%)	87.11	88.11	80.61	87.55	79.70
Star Upright	Cold	(%)	15.48	12.88	2.59	14.24	1.24
	Hot	(%)	13.20	11.25	1.95	12.23	0.98
	H/C	(%)	85.31	87.32	75.31	85.87	78.86
Viking Upright	Cold	(%)	12.71	10.99	1.73	11.89	0.82
	Hot	(%)	10.22	8.99	1.23	9.60	0.62
	H/C	(%)	80.38	81.79	71.42	80.76	74.84
Wormald Upright	Cold	(%)	11.22	10.09	1.12	10.69	0.53
	Hot	(%)	5.82	5.27	0.54	5.57	0.25
	H/C	(%)	51.87	52.25	48.44	52.12	46.80

Table 8 – Water collection measurements for upright sprinklers in an array of 4

6.2. ADD 2 sprinkler array tests

Full details of the measurements made during testing of the sprinklers in an array of 2 are given in Appendix B. Tables 9 and 10 summarise the water density, and collection percentage results respectively, from the pendent 2 sprinkler array on a 3 m spacing.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
GW Pendent	Cold	(mm/min)	5.86	5.77	6.48	5.87	5.68	6.34	5.46	5.80
	Hot	(mm/min)	3.32	3.29	3.51	3.33	3.16	3.03	3.36	3.48
Star Pendent	Cold	(mm/min)	7.93	7.84	8.56	7.86	9.07	8.10	7.99	7.29
	Hot	(mm/min)	4.99	5.13	4.06	4.97	5.32	3.54	5.31	6.35
Viking Pendent	Cold	(mm/min)	7.09	6.96	8.00	7.00	8.37	7.74	6.82	6.44
	Hot	(mm/min)	4.60	4.64	4.34	4.57	5.03	3.89	4.84	5.00
Wormald Pendent	Cold	(mm/min)	6.03	5.97	6.41	5.98	6.74	7.23	5.39	5.88
	Hot	(mm/min)	4.36	4.45	3.73	4.36	4.35	4.09	4.48	4.76

Table 9 – Water density measurements for pendent sprinklers in an array of 2

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
GW Pendent	Cold	(%)	13.05	11.20	1.85	12.24	0.81
	Hot	(%)	7.46	6.44	1.01	7.00	0.45
	H/C	(%)	57.14	57.55	54.69	57.21	56.10
Star Pendent	Cold	(%)	18.13	15.63	2.50	16.80	1.33
	Hot	(%)	11.12	9.96	1.16	10.36	0.76
	H/C	(%)	61.32	63.73	46.22	61.64	57.22
Viking Pendent	Cold	(%)	16.19	13.85	2.34	14.96	1.22
	Hot	(%)	10.20	8.97	1.23	9.49	0.71
	H/C	(%)	63.05	64.80	52.66	63.43	58.39
Wormald Pendent	Cold	(%)	13.32	11.51	11.51	12.37	0.95
	Hot	(%)	9.82	8.75	8.75	9.20	0.63
	H/C	(%)	73.76	76.03	76.03	74.37	65.79

Table 10 – Water collection measurements for pendent sprinklers in an array of 2

Tables 11 and 12 summarise the water density and collection percentage results respectively, from the upright 2 sprinkler array on a 3 m spacing.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
GW Upright	Cold	(mm/min)	5.01	5.09	4.46	5.06	4.36	4.41	5.26	5.44
	Hot	(mm/min)	3.74	3.93	2.44	3.78	3.05	1.94	4.28	5.21
Star Upright	Cold	(mm/min)	9.41	8.91	12.79	8.81	18.18	12.82	8.75	5.32
	Hot	(mm/min)	6.89	6.69	8.23	6.47	12.96	6.79	7.28	5.41
Viking Upright	Cold	(mm/min)	7.95	7.92	8.22	7.88	9.11	8.93	7.41	7.92
	Hot	(mm/min)	5.72	5.82	5.06	5.75	5.35	4.79	6.08	6.33
Wormald Upright	Cold	(mm/min)	8.10	8.26	6.99	8.22	6.28	9.78	6.80	9.68
	Hot	(mm/min)	3.93	4.05	3.14	4.09	1.66	2.30	4.46	4.99

Table 11 – Water density measurements for upright sprinklers in an array of 2

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
GW Upright	Cold	(%)	11.10	9.84	1.27	10.48	0.62
	Hot	(%)	8.29	7.60	0.69	7.86	0.43
	H/C	(%)	74.72	77.30	54.72	74.99	70.25
Star Upright	Cold	(%)	20.89	17.25	3.64	18.31	2.58
	Hot	(%)	15.72	13.32	2.40	13.83	1.89
	H/C	(%)	75.26	77.18	66.13	75.53	73.32
Viking Upright	Cold	(%)	17.50	15.18	2.31	16.21	1.28
	Hot	(%)	12.67	11.23	1.44	11.91	0.76
	H/C	(%)	72.40	73.98	62.02	73.45	59.12
Wormald Upright	Cold	(%)	17.97	15.99	1.99	17.08	0.89
	Hot	(%)	8.71	7.82	0.89	8.48	0.24
	H/C	(%)	48.48	48.94	44.78	49.64	26.43

Table 12 – Water collection measurements for upright sprinklers in an array of 2

6.3. ADD single sprinkler tests

Full details of the measurements made during testing of single sprinklers are given in Appendix C. Tables 13 and 14 summarise the water density and collection percentage results respectively, from centrally mounted single pendent sprinkler.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
GW Pendent	Cold	(mm/min)	1.52	1.45	2.01	1.51	1.73	1.04	1.71	1.34
	Hot	(mm/min)	0.86	0.79	1.36	0.82	1.53	0.35	1.07	0.68
Star Pendent	Cold	(mm/min)	2.05	2.07	1.89	2.01	2.57	1.02	2.20	2.86
	Hot	(mm/min)	0.88	0.85	1.14	0.82	1.89	0.31	0.94	1.22
Viking Pendent	Cold	(mm/min)	2.86	2.86	2.88	2.83	3.32	2.07	3.21	2.93
	Hot	(mm/min)	1.26	1.22	1.49	1.21	1.86	0.66	1.45	1.32
Wormald Pendent	Cold	(mm/min)	3.30	2.91	5.98	2.86	9.87	2.22	2.98	3.47
	Hot	(mm/min)	1.46	1.17	3.47	1.13	6.28	0.30	1.41	1.56

Table 13 – Water density measurements for pendent single sprinkler

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
GW Pendent	Cold	(%)	6.59	5.47	1.11	6.11	0.48
	Hot	(%)	3.60	2.87	0.73	3.19	0.41
	H/C	(%)	54.67	52.50	65.34	52.26	85.45
Star Pendent	Cold	(%)	9.26	8.17	1.09	8.52	0.74
	Hot	(%)	3.80	3.18	0.63	3.28	0.52
	H/C	(%)	41.07	38.90	57.34	38.56	69.89
Viking Pendent	Cold	(%)	13.08	11.40	1.69	12.11	0.97
	Hot	(%)	5.72	4.85	0.87	5.18	0.54
	H/C	(%)	43.71	42.57	51.42	42.74	55.81
Wormald Pendent	Cold	(%)	14.30	10.98	3.31	11.56	2.74
	Hot	(%)	6.31	4.39	1.92	4.58	1.73
	H/C	(%)	44.14	40.01	57.85	39.58	63.41

Table 14 – Water collection measurements for pendent single sprinkler

Tables 15 and 16 summarise the water density and collection percentage results respectively, from the single upright sprinkler.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
GW Upright	Cold	(mm/min)	1.94	0.74	10.13	0.72	19.85	0.64	0.66	1.00
	Hot	(mm/min)	1.43	0.68	6.51	0.65	12.84	0.97	0.61	0.55
Star Upright	Cold	(mm/min)	2.81	1.48	11.88	1.42	23.24	0.78	1.35	2.45
	Hot	(mm/min)	2.05	1.36	6.74	1.28	13.30	1.26	1.45	1.29
Viking Upright	Cold	(mm/min)	3.93	2.88	11.10	2.79	20.60	1.42	2.97	4.16
	Hot	(mm/min)	2.66	2.01	7.09	1.95	12.98	1.94	1.80	2.49
Wormald Upright	Cold	(mm/min)	6.37	6.09	8.05	5.86	13.35	3.39	7.73	5.49
	Hot	(mm/min)	2.45	2.08	4.90	1.99	9.03	0.95	2.21	2.97

Table 15 – Water density measurements for upright single sprinkler

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
GW Single Upright	Cold	(%)	8.60	2.86	5.74	2.97	5.63
	Hot	(%)	6.30	2.62	3.67	2.68	3.62
	H/C	(%)	73.18	91.78	63.93	89.99	64.31
Star Single Upright	Cold	(%)	12.46	5.72	6.74	5.87	6.59
	Hot	(%)	8.97	5.19	3.77	5.24	3.72
	H/C	(%)	71.93	90.78	55.94	89.30	56.45
Viking Single Upright	Cold	(%)	17.45	11.14	6.31	11.60	5.85
	Hot	(%)	11.95	7.87	4.08	8.21	3.74
	H/C	(%)	68.46	70.61	64.67	70.81	63.82
Wormald Single Upright	Cold	(%)	28.24	23.65	4.59	24.43	3.81
	Hot	(%)	11.29	8.39	2.90	8.62	2.67
	H/C	(%)	40.00	35.49	63.19	35.30	70.12

Table 16 – Water collection measurements for upright single sprinkler

6.4. ADD testing of Star LD2 K80 Pendent and Star SG K80 Upright sprinkler

Full details of the measurements made during testing of the K80 sprinklers are given in Appendix D. Tables 17 and 18 summarise the water density and collection percentage results respectively, from the two K80 sprinklers.

Coverage			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap	Inner hoppers	Middle hoppers	Outer hoppers
Star LD2 K80	Cold	(mm/min)	13.34	13.06	15.23	13.11	16.76	16.46	12.62	10.54
Pendent	Hot	(mm/min)	11.99	11.99	12.01	11.93	12.91	12.94	12.47	10.10
Star SG K80	Cold	(mm/min)	13.85	13.27	17.80	13.71	15.86	18.13	13.15	8.64
Upright	Hot	(mm/min)	10.79	10.75	11.06	10.82	10.35	10.91	11.66	8.76
Star LD2 K80	Cold	(mm/min)	11.10	10.98	11.94	10.94	13.47	13.85	10.16	9.76
Pendent	Hot	(mm/min)	7.39	7.49	6.71	7.32	8.41	6.67	7.33	8.63
Star SG K80	Cold	(mm/min)	7.70	7.51	8.98	7.42	11.82	7.79	7.68	6.92
Upright	Hot	(mm/min)	5.32	5.52	3.94	5.28	5.87	3.24	6.38	6.07
Star LD2 K80	Cold	(mm/min)	5.11	5.14	4.90	4.99	6.95	3.67	5.24	6.44
Pendent	Hot	(mm/min)	2.03	1.99	2.36	1.91	3.90	0.88	2.09	2.89
Star SG K80	Cold	(mm/min)	3.19	2.23	9.74	2.14	18.50	1.77	2.11	2.94
Upright	Hot	(mm/min)	2.20	1.64	6.05	1.56	11.59	1.92	1.40	1.83

Table 17 – Water density measurements for upright single sprinkler

Collection			Hoppers & gap	Hoppers	Gap	Hoppers & non-aligned gap	Aligned gap
Star LD2 K80	Cold	(%)	15.31	13.07	2.24	14.08	1.23
Pendent	Hot	(%)	13.81	12.03	1.77	12.85	0.95
Array of 4	H/C	(%)	90.17	92.07	79.11	91.31	77.24
Star SG K80	Cold	(%)	15.95	13.32	2.62	14.78	1.17
Upright	Hot	(%)	12.45	10.81	1.63	11.68	0.76
Array of 4	H/C	(%)	78.06	81.17	62.26	79.06	65.39
Star LD2 K80	Cold	(%)	24.75	21.34	3.41	22.83	1.92
Pendent	Hot	(%)	17.05	15.07	1.98	15.81	1.24
Array of 2	H/C	(%)	68.90	70.61	58.15	69.26	64.62
Star SG K80	Cold	(%)	17.77	15.11	2.65	16.02	1.75
Upright	Hot	(%)	12.25	11.09	1.16	11.39	0.87
Array of 2	H/C	(%)	68.97	73.39	43.82	71.08	49.62
Star LD2 K80	Cold	(%)	22.68	19.90	2.78	20.71	1.97
Pendent	Hot	(%)	9.09	7.74	1.35	7.98	1.11
Single head	H/C	(%)	40.08	38.91	48.46	38.52	56.41
Star SG K80	Cold	(%)	14.23	8.67	5.56	8.95	5.28
Upright	Hot	(%)	9.92	6.43	3.48	6.58	3.34
Single head	H/C	(%)	69.71	74.20	62.70	73.55	63.22

Table 18 – Water collection measurements for upright single sprinkler

6.5. Single sprinkler distribution tests

Figure 16 shows the collector array used for the evaluation of spray distributions from all of the K115 and K80 sprinklers under test. Tests were conducted for upright and pendent sprinkler configurations for both sprinkler frame arm positions.

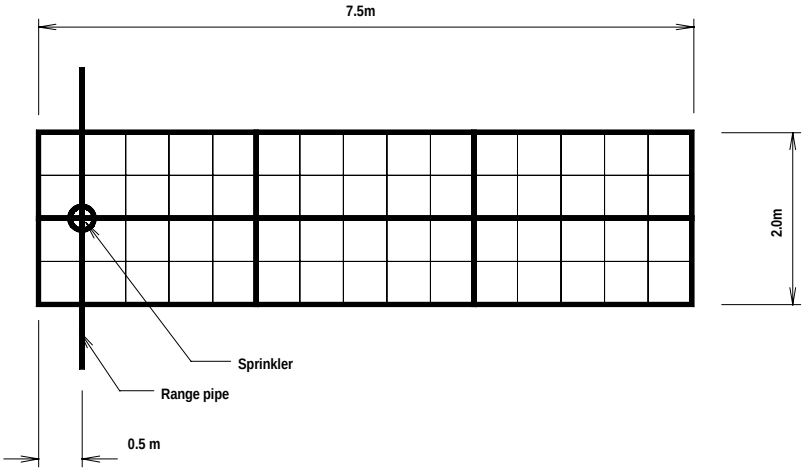

Figure 16 – Single sprinkler distribution collection array

6.5.1. GW DD1 K115

The distribution profiles for the GW DD1 K115 sprinkler are shown in figures 17 to 20.

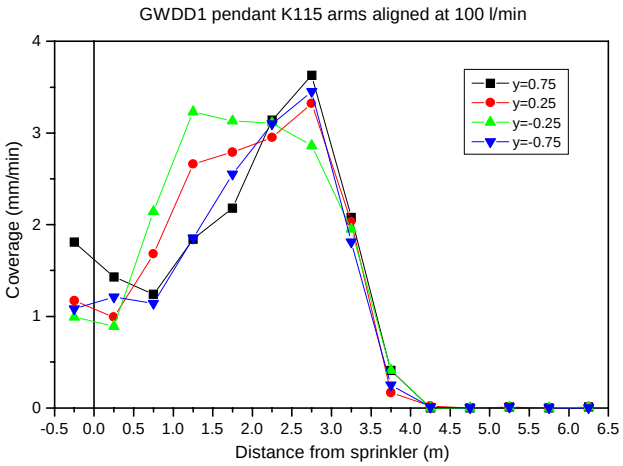

Figure 17 - GW DD1 K115 pendent sprinkler arms in-line with pipe

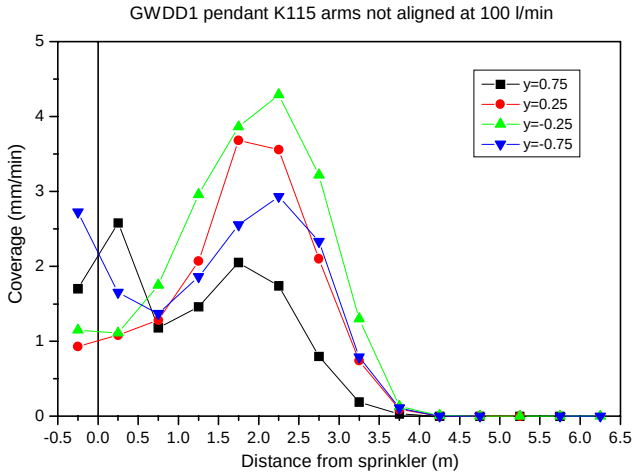

Figure 18 - GW DD1 K115 pendent sprinkler arms at 90° to pipe

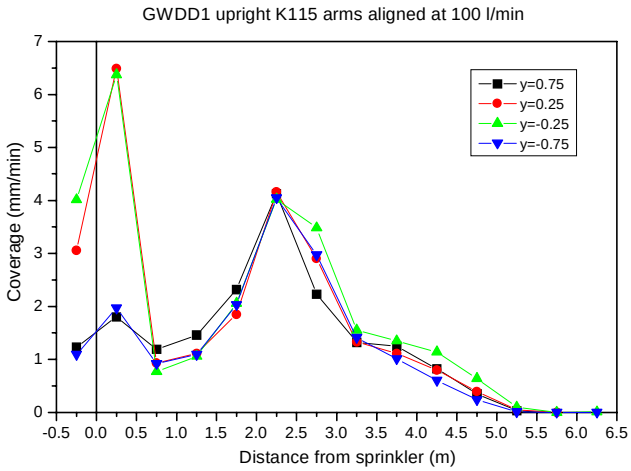

Figure 19 - GW DD1 K115 upright sprinkler arms in-line with pipe

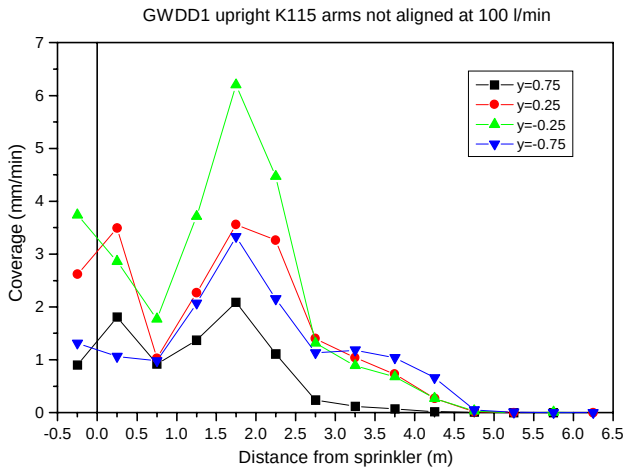

Figure 20 - GW DD1 K115 upright sprinkler arms at 90° to pipe

6.5.2. Star SG K115

The distribution profiles for the Star SG K115 sprinklers are shown in figures 21 to 24.

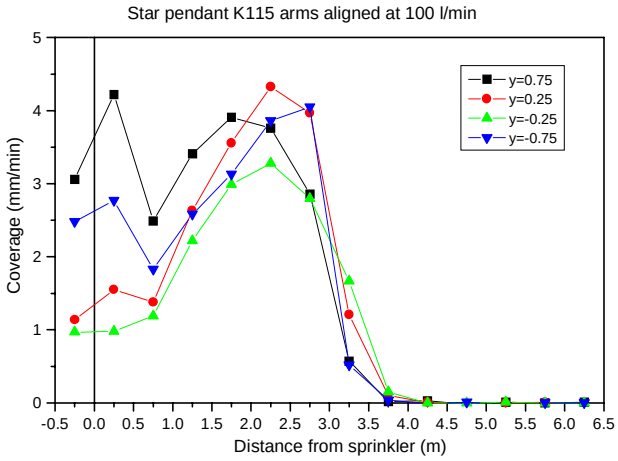

Figure 21 – Star SG K115 pendent sprinkler arms in-line with pipe

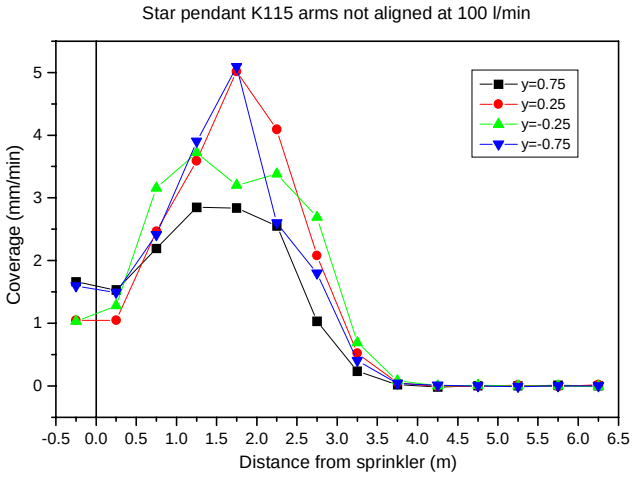

Figure 22 - Star SG K115 pendent sprinkler arms at 90° to pipe

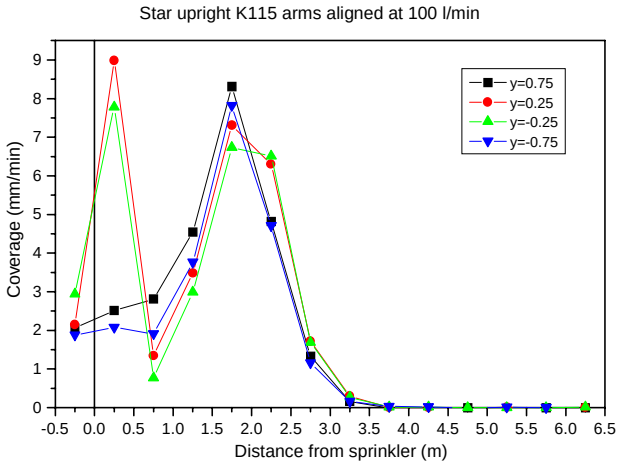

Figure 23 - Star SG K115 upright sprinkler arms in-line with pipe

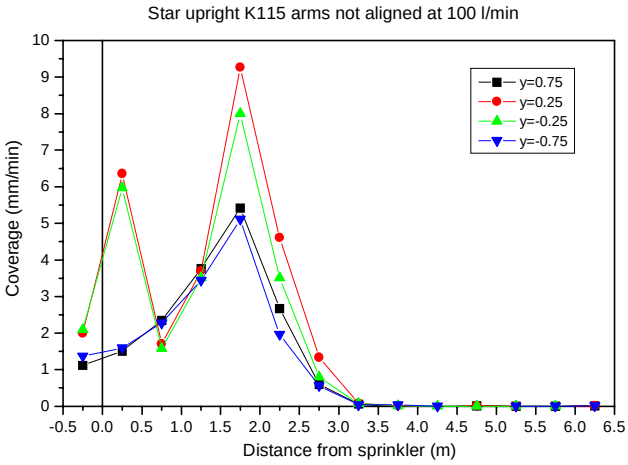

Figure 24 - Star SG K115 upright sprinkler arms at 90° to pipe

6.5.3. Viking M K115

The distribution profiles for the Viking M K115 sprinklers are shown in figures 25 to 28.

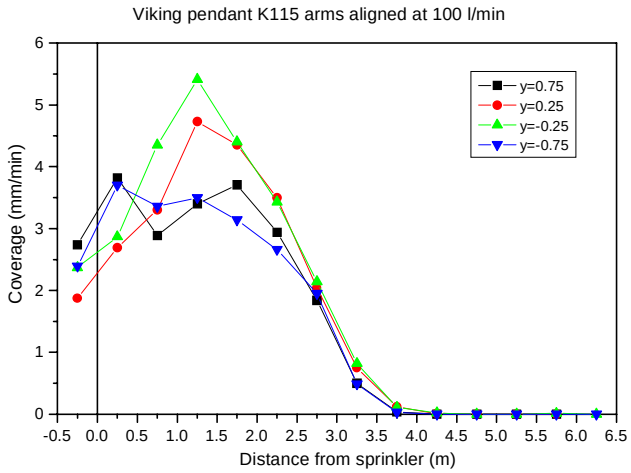

Figure 25 - Viking M K115 pendent sprinkler arms in-line with pipe

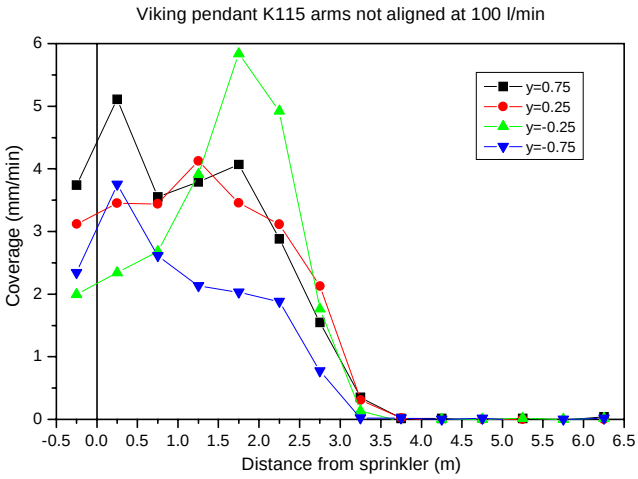

Figure 26 - Viking M K115 pendent sprinkler arms at 90° to pipe

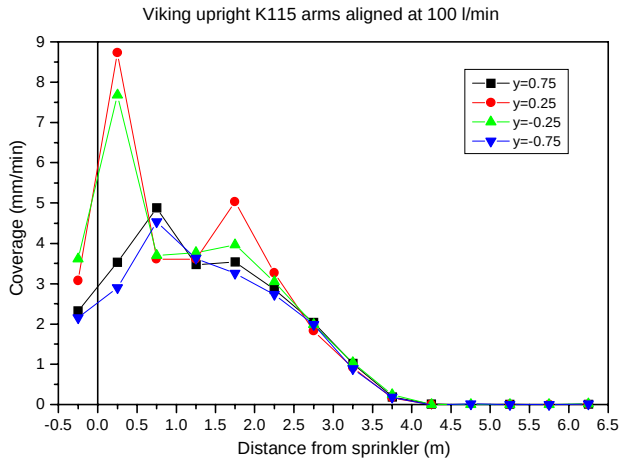

Figure 27 – Viking M K115 upright sprinkler arms in-line with pipe

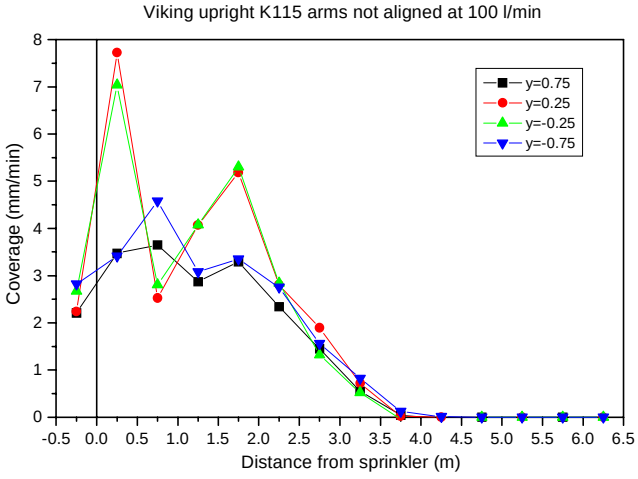

Figure 28 – Viking M K115 Upright sprinkler arms at 90° to pipe

6.5.4. Wormald 'A' K115

The distribution profiles for the Wormald 'A' sprinklers are shown in figures 29 to 32.

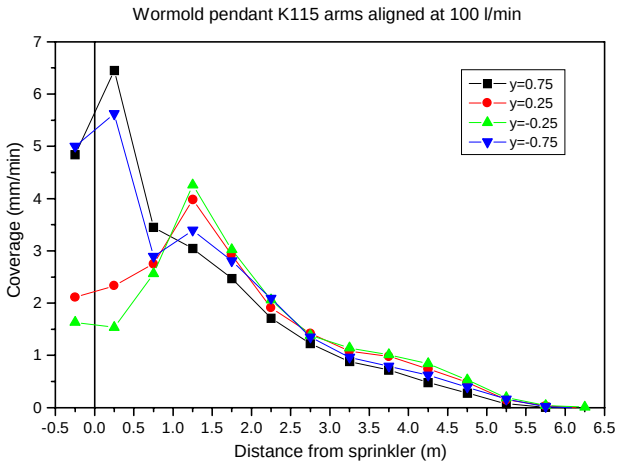

Figure 29 – Wormald A K115 (C/UP) pendent sprinkler arms in-line with pipe

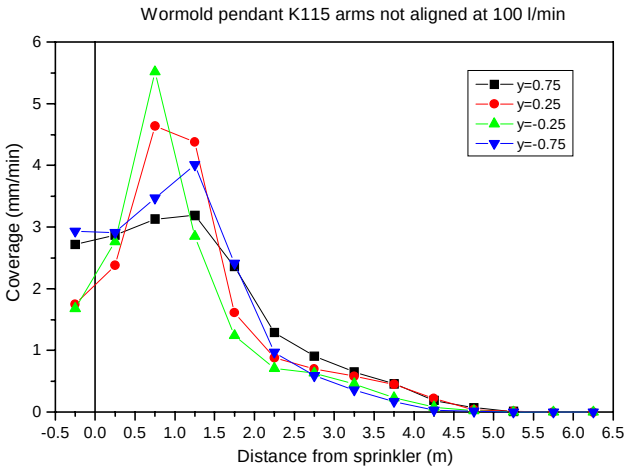

Figure 30 - Wormald A K115 (C/UP) pendent sprinkler arms at 90° to pipe

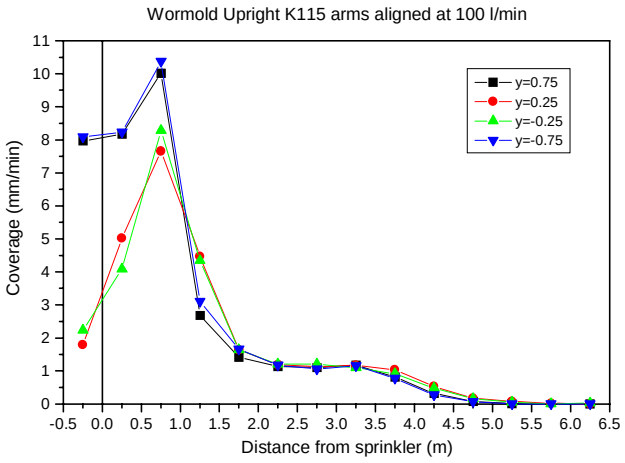

Figure 31 – Wormald A K115 (C/UP) upright sprinkler arms in-line with pipe

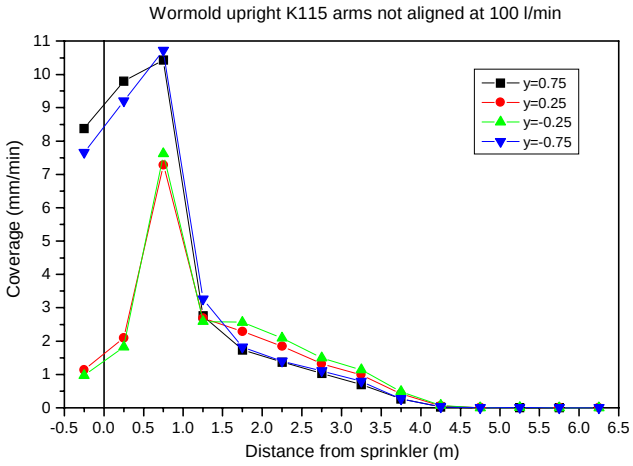

Figure 32 - Wormald A K115 (C/UP) upright sprinkler arms at 90° to pipe

6.5.5. Star LD2 K80

The distribution profiles for the Star LD2 K80 sprinkler are shown in figures 33 to 36.

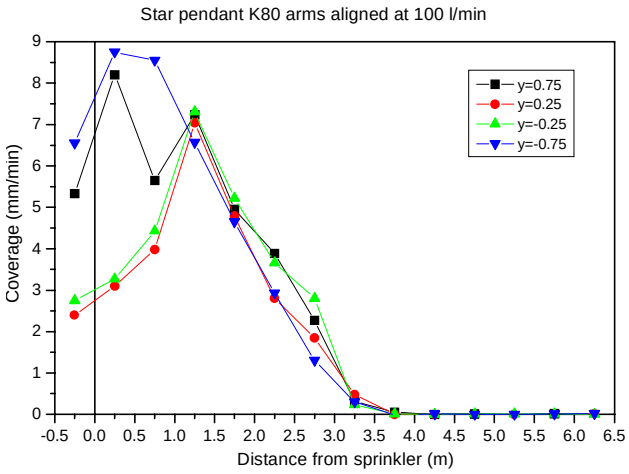

Figure 33 – Star LD2 K80 pendent sprinkler arms in-line with pipe

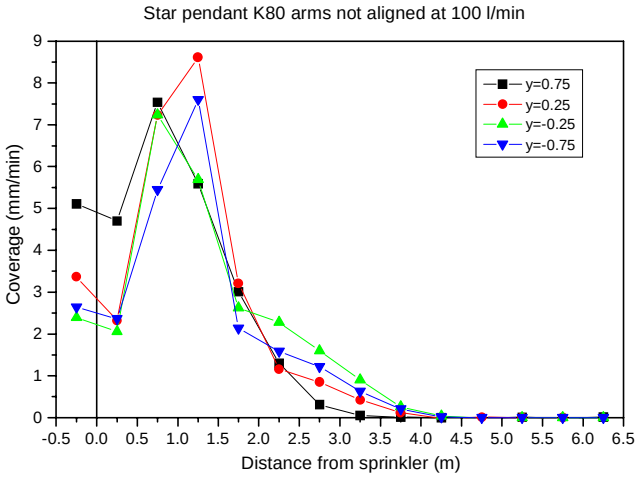

Figure 34 – Star LD2 K80 pendent sprinkler arms at 90° to pipe

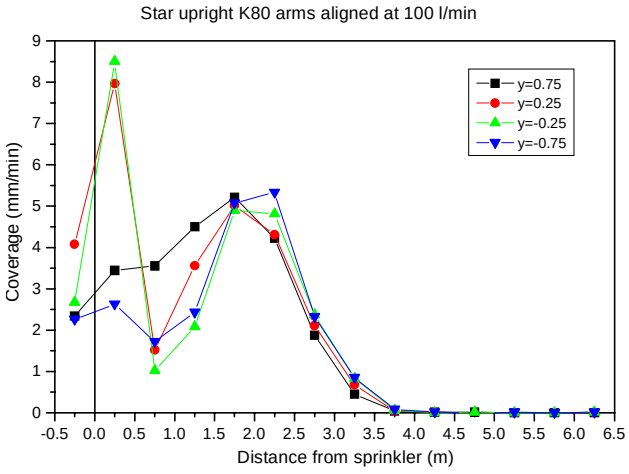

Figure 35 - Star LD2 K80 upright sprinkler arms in-line with pipe

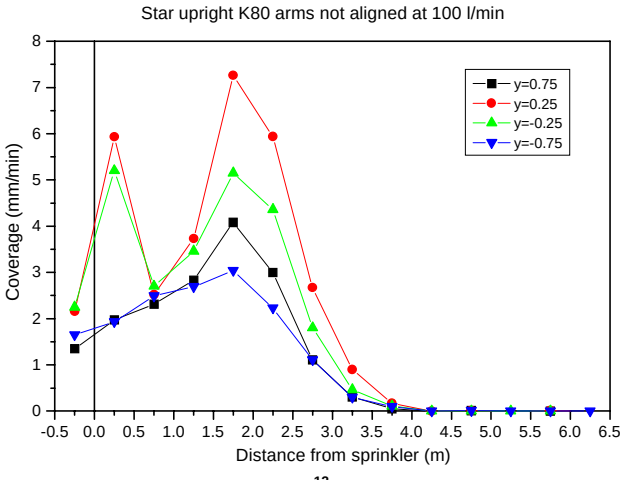

Figure 36 – Star LD2 K80 upright sprinkler arms at 90° to pipe

7. Discussion

7.1. Comparison of FM crib test results and ADD data

The pass/fail criteria for the Factory Mutual Research crib test is based on two variables:

- The crib weight loss must not exceed 20% of the dry weight before the fire test;
- The ceiling temperatures must not exceed 275 °C after five minutes from the commencement of water application and shall not exceed 275 °C for any period longer than 3 minutes.

The measured variables such as, percentage crib weight loss, ADD water densities and ceiling temperatures provide indications of performance and provide a method of performance ranking. The ADD Hopper and gap measurement gives the best correlation with the crib fire test. These ADD and crib fire test results are compared Table 19 with the ranking orders for each test method. The ADD hopper and gap densities (mm/min) and the crib fire test weight losses (%) are plotted in Figure 37, *indicating ranking correlation and the relationship between the crib test results and the ADD (hot) hopper and gap measured densities. Perfect correlation between the data sets would result in identical rankings and the plot would probably result in an exponential curve.*

Although there are differences between the ranking order achieved in the crib fire test and the ADD test result analysis, these differences are only significant with respect to one sprinkler, the GW DD1 Pendent spray sprinkler.

Supplier	Model	Orientation	Crib test Average flow rate (L/min)	Crib weight loss (%)	Crib test (Ranking order)	ADD Average water flow (L/min)	ADD 4 sprinkler array *Hoppers & Gap* (m/min)	ADD 4 sprinkler array *Hoppers & Gap* (Ranking order)
Star	SG	Pendent	393	4.6	1	404	11.8	1
Viking	M	Pendent	416	5.1	2	399	9.7	3
Star	SG	Upright	416	7.6	3	401	11.6	2
GW	DD1	Upright	416	8.4	4	401	8.3	5
Viking	M	Upright	416	10.0	5	402	9.0	4
Wormald	A	Pendent	416	11.7	6	405	7.8	7
GW	DD1	Pendent	416	22.7 (1)	7	403	8.3	6
Wormald	A	Upright	416	26.2 (1)(2)	8	405	5.1	8

Notes

(1) Exceeded the dry crib weight loss limit of 20%.

(2) Test terminated at 8 minutes due to excessively high ceiling temperatures – normal test duration 30 minutes.

Table 19 – Analysis of crib and ADD fire test results for k115 sprinklers

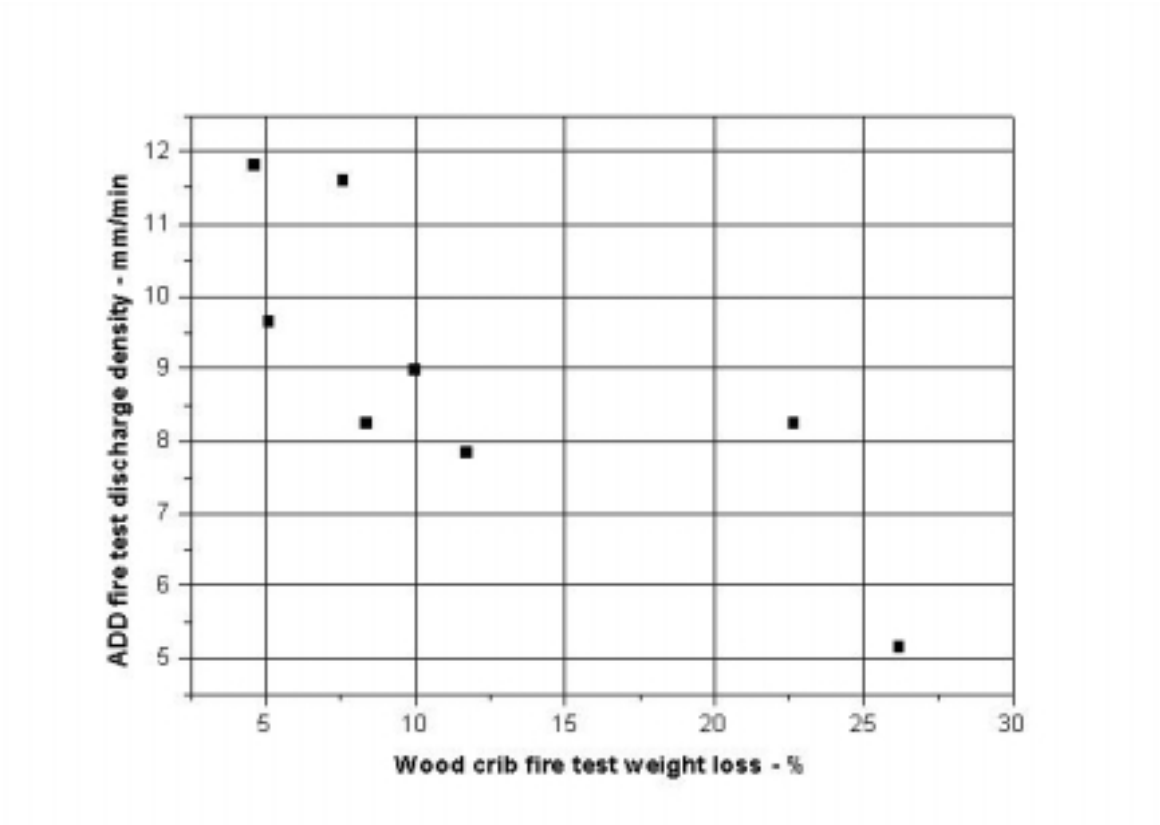

Figure 37 - Plot of ADD (Hopper & Gap) against crib fire test weight loss results

Supplier	Model	Orientation	ADD Average water flow (L/min)	ADD 4 sprinkler array *Hoppers & Gap* (m/min)
Star	SG	Pendent	398.6	11.9
Star	SG	Upright	397.5	10.8

Table 20 – Analysis of the ADD fire test results for k80 sprinklers

Examination of the video recording of the GW DD1 pendent sprinkler crib test indicated that the sprayed heptane ignition was delayed and consequently the wood crib was prewetted with unburned heptane prior to ignition. As result of this event, the ignition and early stages of the GW DD1 pendent sprinkler crib test were significantly different to the other sprinkler crib tests. It is not possible to determine what differences this may have made to the outcome of the tests. Additionally, any variations in the crib test heptane flow rate could not be evaluated as there is no requirement in the ISO specification for their measurement and consequently they were not reported.

The ADD tests resulted in significantly higher temperatures at the ceiling for the duration of the tests, than did the crib test. In both tests the ceiling temperatures

stabilised after about the first three minutes and remained fairly constant thereafter. The mean ceiling temperatures for the crib tests were within the range of 70 °C to 230 °C for sprinklers which achieved an acceptable level of crib weight loss over the duration of the test. The ceiling temperatures for two sprinklers that exceeded the specified crib weight loss achieved stabilised temperatures of 90 °C and 590 °C. There is no apparent correlation between crib weight loss and measured ceiling temperatures. Some of the lower ceiling temperatures measured may be explained by direct impingement of water on the thermocouples. During the ADD tests, the thermocouple array at the centre of the ceiling measured stabilised temperatures in the range 360°C to 470 °C for the duration of the tests. The thermocouples at the ceiling edge (3 m from the fire plume centre) measured temperatures within the range 75 °C to 200 °C. There was no apparent correlation between the ceiling temperatures and the water densities measured in the ADD collection area.

The influence of the variations in water flow rates has been considered over the test programme. The average flow rate for the crib fires tests was 413 L/min with a Standard Deviation of 8.1 L/min. The Average flow rate for the ADD fire tests was 402 L/min with a Standard Deviation of 2.1 L/min. Variations in water flow rate are not considered significant in either the crib or ADD test results.

7.2. K 80 sprinklers

Two k80 sprinklers were tested to establish the suitability of the ADD test method for sprinklers with smaller orifice sizes. Table 20 details the ADD performance of the k 80 sprinklers using the same criteria used in Table 19 for the k115 sprinklers. Both k 80 sprinklers gave a satisfactory result.

Supplier	Model	Orientation	ADD Average water flow .	ADD 4 sprinkler array *Hoppers & Gap* (m/min)
Star	SG	Pendent	398.6	11.9
Star	SG	Upright	397.5	10.8

Table 20 – Analysis of the ADD fire test results for k80 sprinklers

7.3. Influence of fire plume on delivered density

The Actual Delivered Density (hot) tests results identified substantial performance variations between sprinkler models. Comparison between the cold tests and the ADD fire tests also indicated substantial differences in efficiency (H/C) between sprinklers, see Tables 21, 22 and 23. The ratio H/C tended to decrease with decreasing numbers of sprinklers operating.

Sprinkler model	k factor	Orientation	ADD Cold *Hoppers & gap* mm/min	ADD Hot *Hoppers & gap* mm/min	ADD Hot: ADD Cold (H/C)
GW	115	Pendent	11.59	8.25	0.71
Star	115	Pendent	13.45	11.81	0.88
Viking	115	Pendent	11.79	9.65	0.82
Wormald	115	Pendent	9.67	7.83	0.81
Star	80	Pendent	13.34	11.99	0.90
GW	115	Upright	9.39	8.25	0.88
Star	115	Upright	13.45	11.6	0.86
Viking	115	Upright	11.14	8.97	0.81
Wormald	115	Upright	9.75	5.14	0.53
Star	80	Upright	13.85	10.97	0.79

Table 21 - Analysis of 4 sprinkler array ADD hot and cold tests (H/C) (nominal discharge density 10 mm/min)

Sprinkler model	k factor	Orientation	ADD Cold Hoppers & gap mm/min	ADD Hot Hoppers & gap mm/min	Hot/Cold
GW	115	Pendent	5.86	3.32	0.57
Star	115	Pendent	7.93	4.99	0.63
Viking	115	Pendent	7.09	4.6	0.65
Wormald	115	Pendent	6.03	4.36	0.72
Star	80	Pendent	11.1	7.39	0.67
GW	115	Upright	5.01	3.74	0.75
Star	115	Upright	9.41	6.89	0.73
Viking	115	Upright	7.95	5.72	0.72
Wormald	115	Upright	8.1	3.93	0.49
Star	80	Upright	7.7	7.51	0.98

Table 22 - Analysis of 2 sprinkler array ADD cold and hot tests (nominal discharge density 10 mm/min)

Sprinkler model	k factor	Orientation	ADD Cold *Hoppers & gap* mm/min	ADD Hot *Hoppers & gap* mm/min	Hot/Cold
GW	115	Pendent	1.52	0.86	0.57
Star	115	Pendent	2.05	0.88	0.43
Viking	115	Pendent	2.86	1.26	0.44
Wormald	115	Pendent	3.3	1.46	0.44
Star	80	Pendent	5.11	2.03	0.40
GW	115	Upright	6.59	3.6	0.55
Star	115	Upright	9.26	3.8	0.41
Viking	115	Upright	13.08	5.72	0.44
Wormald	115	Upright	14.3	6.31	0.44
Star	80	Upright	3.19	2.2	0.69

Table 23 - Analysis of single sprinkler ADD cold and hot tests (nominal discharge density 10 mm/min)

7.4. Influence of position of plume to sprinkler array geometry

The ADD test programme examined three fire plume to sprinkler array geometry's;

- Fire plume at centre of an array of four sprinklers;
- Fire plume at centre of an array two sprinklers;
- Fire plume directly below one sprinkler

The ADD test results showed major differences in performance between the different arrangements tested. The discharge density directly below and adjacent to the sprinkler axis was lower than anticipated under cold conditions for all the sprinklers tested and resulted in ADD (hot) Hopper and gap densities of between 0.86 mm/min to 2.66 mm/min. The sprinklers that perform well in the crib test tend to perform poorly as single sprinklers

7.5. Influence of sprinkler k factor

Insufficient k 80 sprinklers were examined to establish whether there were any significant differences between the two sizes of k factor. The tests conducted on the k 80 sprinklers gave similar results to k 115 sprinklers.

7.6. Influence of ADD ceiling height

A ceiling height of 2.6 m (measured from the top of the collecting pans to the underside of the ceiling) was used during the ADD experiments. This clearance was considered to be analogous to the clearance used during the crib test (2.3 m measured from the sprinkler to the top of the wood crib). Visual observation of the two tests indicates that the flame plumes developed by the ADD apparatus are taller than those developed by the wood crib test. The wood crib plume height is not constant, it reduces in height if the sprinkler spray influences the burning rate. The ADD fire plume remains constant throughout whilst testing sprinklers with a 'k' factor of 115. During the ADD tests a

significant proportion of the flame plume burns above spray sprinkler water spray envelope, which results in the higher ceiling temperatures reported in paragraph 7.1.

Consideration should be given to undertaking the ADD tests at two ceiling heights of 2.6 m and 4.0 m for arrays of four sprinklers. The higher ceiling height should give a more appropriate assessment of the ceiling temperatures for sprinklers operating under fire conditions. Testing at two ceiling heights would also provide useful additional data about sprinkler operations and efficacy of sprinkler water sprays.

7.7. Repeatability

The ADD tests have been shown to be repeatable. Typical repeat ADD test results are given in detail in Annex G. No repeat tests of the wood crib procedure were carried-out for this research project. It can be anticipated that there will be variations in wood crib burning characteristics due to wood density variations, moisture and natural resins content. Changes in these factors may influence the outcome of a sprinkler test, where the sprinkler performance is close to the pass/fail criteria. The fuel load for the ADD test is closely controlled, measured and recorded and variations between tests will therefore be both small and known.

7.8. Cost considerations

Although the cost of the ADD apparatus is higher than that required for the wood crib test, both require a similar sprinkler ceiling, water supplies and other facilities. The ADD test procedure is considerably lower cost on a test by test basis, since no pre and post conditioning of fire load is required. The time taken to complete tests and the number of tests that can be carried out in one day also favours the ADD procedure compared to the crib test method. Each ADD test is completed at the end of a test run and nine tests have been carried-out in one day. Each crib test takes several weeks (allowing for reconditioning, weighing and calculation of results) and no more than four tests could be carried in one day.

8. Conclusions

The ADD apparatus has proved to be an efficient and effective tool for measuring the performance of sprinklers under simulated fire conditions. Achievement of high Actual Delivered Densities values in the ADD test has been indicative of good performance in the wood crib fire test. Conversely, a low Actual Delivered Densities value has been indicative of poor performance in the wood crib fire test.

The consistently poor performance of all single sprinklers evaluated in both cold tests and Actual Delivered Density tests indicates the importance undertaking fire tests in the three configurations as arrays of four and two sprinklers and as a single sprinkler.

The ISO specification for automatic sprinklers does not require the heptane flow rates or heptane fuel consumed during the crib test to be measured, recorded or reported which is an unsatisfactory and significant omission.

The results of the research project indicate that the ADD apparatus can be used to emulate the crib testing procedure. There may be minor variations in outcome for sprinklers with a

marginal performance, but it is possible that these variations are a result of the crib test procedure.

9. Derivation of appraisal parameters and values

9.1. Test conditions for standard sprinklers

The following conditions are recommended for ADD testing K80 and K115 upright and pendent sprinklers:

- Four sprinkler array - (open heads)

  Test conditions:

  - Ceiling clearance 2.6 and 4.7 m;
  - Heat output 0 (cold) and 1.3 MW;
  - Sprinkler spacing (3m x 3m) or (3m x 4m) or (4m x 4m) as appropriate;
  - Water flow rate 100 L/min per sprinkler.

- One Sprinkler – (open head)

  Test conditions

  - Ceiling clearance 2.6 m
  - Heat output 0 (cold) and 1.3 MW;
  - One sprinkler centrally mounted;
  - Water flow rate 100 L/min.

- Four sprinkler array - (sealed heads)

  Test conditions:

  - Ceiling clearance 2.6m;
  - Heat output 1.3 MW;
  - Sprinkler spacing (3m x 3m) or (3m x 4m) or (4m x 4m) as appropriate;
  - Water flow rate 100 L/min per sprinkler.

9.2. ADD requirements for standard sprinklers

The following pass/fail criteria for 4 sprinkler array at 2.6 m ceiling clearance for heat outputs of 0 MW and 1.3 MW at a flow rate per sprinkler of 100 L/min should be:

- An average discharge density of 7.5 mm/min for all hoppers and gap hoppers;
- No single inner hopper less than 5.5 mm/min;
- No single middle hopper less than 5.5 mm/min;

- No single outer hopper less than 6.5 mm/min;

9.3. Additional test data and analysis

The results for single sprinkler tests and the test on an array of four sprinklers at a ceiling height of 4.7 m should be considered to be informative, for an interim period.

9.4. Presentation of results

Detailed results and analysis should be provided to the sprinkler supplier in the following form:

- Results sheet – ADD cold test;
- Results sheet – ADD hot test;
- Hot/Cold % (Hoppers & gap)
- A statement indicating whether the sprinklers satisfy the requirements

Appendix F details the specification for ADD requirements and test methods.

10. References

10.1. ISO DIS 6182 Fire protection – Automatic Sprinkler Systems – Part 7 Requirements and test methods for Early Suppression Fast Response (ESFR) sprinklers

10.2. ISO 6182 Fire protection – Automatic Sprinkler Systems – Part 1 Requirements and test methods for sprinklers

10.3. LPC project proposal No 12192 – Establishing criteria for evaluating the performance of sprinklers using thrust measurement and fire plume generators

10.4. Contract examination of crib fire tests - Factory Mutual Research Corporation (0D2Q6.AH)

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Appendix A

4 head array test results for 3 x 3 metre spacings of Upright and Pendent sprinklers

A.1. Nomenclature

Datasheet identification system i.e GU226Hb GW head in the upright position in an array of 2, , ceiling 2.6 metres above the ADD apparatus with a 1.3 MW fire – 2nd test		
Sprinkler name	**G** **S** **V** **W**	GW DD1 (SSU/P) Star SG (SSU/P) Viking M (SSU/P) Wormald A (C/UP)
Orientation	**P** **U**	Pendent Upright
No. of heads	**4** **2** **1**	Array of 4 on 3 x 3 metre spacing Array of 2 on 3 x 3 metre spacing Single sprinkler
Ceiling height	**26**	2.6 metres above collection pans
Condition	**H** **C**	Hot – with 1.3 MW sprayed heptane fire Cold – no fire
Test no.	**a, b, c, d, e, f**	Optional – where more than one test performed
Sprinkler k factor	**(no suffix)** **80**	Denotes sprinkler with a k factor of 115 Denotes use of a sprinkler with a k factor of 80

A.2. Typical ADD results sheets for Cold and Hot tests for an array of four sprinklers

Run number **GP426Cb**

Test duration	902	seconds
Mean water flowrate (HIGH)	2.13	l/min
Mean water flowrate (LOW)	402.22	l/min
Mean heptane flowrate	0.00042	l/min
Mean pump pressure	1.2	bar
Mean nozzle pressure	0.93	bar

Total water output (HIGH)	32.021	litres	
Total water output (LOW)	6046.707	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	799.594	2497.09	13.22
Total water collect (Hoppers)	684.636	2138.08	11.32
Total water collected (Gap)	114.958	359.01	1.90
Total water collected (Hoppers + non aligned gap)	753.650	2353.61	12.46
Total water collected (Aligned gap)	45.944	143.48	0.76

34.477	62.986	32.871	43.704	35.802
31.038	42.770		39.834	34.826
20.465			25.479	
30.272	48.511	36.143	63.895	31.660
34.566	73.912		42.965	33.418

KG

9.173	16.759	14.890	11.629	9.526
8.258	11.380		10.599	9.266
9.271			11.542	
8.055	12.908	16.373	17.001	8.424
9.197	19.666		11.432	8.892

mm/min

	mm/min
Mean coverage (Hoppers + gap)	11.593
Mean coverage (Hoppers)	11.385
Mean coverge (Gap)	13.019
Mean coverage (Hoppers + non aligned gap)	11.675
Mean coverage (Aligned gap)	10.406
Mean coverage (Inner hoppers)	12.972
Mean coverage (Middle hoppers)	11.686
Mean coverage (Outer hoppers)	9.197

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Run number **GP426Hb**

Test duration	603	seconds
Mean water flowrate (HIGH)	2.06	l/min
Mean water flowrate (LOW)	403.52	l/min
Mean heptane flowrate	0.62	l/min
Mean pump pressure	1.23	bar
Mean nozzle pressure	0.87	bar

Total water output (HIGH)	20.703	litres	
Total water output (LOW)	4055.376	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	380.410	1837.46	9.38
Total water collect (Hoppers)	336.266	1624.24	8.29
Total water collected (Gap)	44.144	213.23	1.09
Total water collected (Hoppers + non aligned gap)	363.178	1754.23	8.96
Total water collected (Aligned gap)	17.232	83.23	0.42

24.356	36.749	11.673	15.945	16.406
16.354	15.252		12.702	14.795
7.802			9.430	
16.180	16.106	15.239	28.262	14.552
22.887	35.646		24.709	25.365

KG

9.694	14.626	7.910	6.346	6.530
6.509	6.070		5.056	5.889
5.287			6.390	
6.440	6.410	10.326	11.249	5.792
9.109	14.187		9.834	10.096

mm/min

	mm/min
Mean coverage (Hoppers + gap)	8.250
Mean coverage (Hoppers)	8.365
Mean coverge (Gap)	7.478
Mean coverage (Hoppers + non aligned gap)	8.416
Mean coverage (Aligned gap)	5.838
Mean coverage (Inner hoppers)	7.196
Mean coverage (Middle hoppers)	8.703
Mean coverage (Outer hoppers)	8.857

A.3. ADD four sprinkler array data sets

The ADD results sheets are given on CD-ROM ‘TE 91014-19 ADD rig development and sprinkler test methodology data’.

Appendix B

2 head array test results for 3 x 3 metre spacings of Upright and Pendent sprinklers

B.1. Nomenclature

Datasheet identification system i.e GU226Hb GW head in the upright position in an array of 2, , ceiling 2.6 metres above the ADD apparatus with a 1.3 MW – 2nd test		
Sprinkler name	**G** **S** **V** **W**	GW DD1 (SSU/P) k115 Star SG (SSU/P) k115 Viking M (SSU/P) k115 Wormald A (C/UP) K115
Orientation	**P** **U**	Pendent Upright
No. of heads	**4** **2** **1**	Array of 4 on 3 x 3 metre spacing Array of 2 on 3 x 3 metre spacing Single sprinkler
Ceiling height	**26**	2.6 metres above collection pans
Condition	**H** **C**	Hot – with 1.3 MW sprayed heptane fire Cold – no fire
Test no.	**a, b, c, d, e, f**	Optional – where more than one test performed
Sprinkler k factor	**(no suffix)** **80**	Denotes sprinkler with a k factor of 115 Denotes use of a sprinkler with a k factor of 80

B.2. Typical ADD results sheets for Cold and Hot tests for an array of two sprinklers

Run number **GP226C**

Test duration	900	seconds
Mean water flowrate (HIGH)	2.09	l/min
Mean water flowrate (LOW)	205.96	l/min
Mean heptane flowrate	0	l/min
Mean pump pressure	0.91	bar
Mean nozzle pressure	0.92	bar

Total water output (HIGH)	31.350	litres
Total water output (LOW)	3089.400	litres

	litres	% collected HIGH	% collected LOW
Total water collected (Hoppers + gap)	403.106	1285.82	13.05
Total water collect (Hoppers)	345.988	1103.63	11.20
Total water collected (Gap)	57.118	182.19	1.85
Total water collected (Hoppers + non aligned gap)	378.091	1206.03	12.24
Total water collected (Aligned gap)	25.015	79.79	0.81

23.989	21.423	17.192	21.765	16.072
21.635	24.626		21.045	16.936
13.497			11.518	
20.475	26.936	14.911	22.441	18.968
24.582	22.632		20.061	22.402

KG

6.397	5.713	7.805	5.804	4.286
5.769	6.567		5.612	4.516
6.128			5.229	
5.460	7.183	6.770	5.984	5.058
6.555	6.035		5.350	5.974

mm/min

	mm/min
Mean coverage (Hoppers + gap)	5.857
Mean coverage (Hoppers)	5.766
Mean coverge (Gap)	6.483
Mean coverage (Hoppers + non aligned gap)	5.870
Mean coverage (Aligned gap)	5.678
Mean coverage (Inner hoppers)	6.337
Mean coverage (Middle hoppers)	5.463
Mean coverage (Outer hoppers)	5.803

Run number **GP226H**

Test duration	601	seconds
Mean water flowrate (HIGH)	2.1	l/min
Mean water flowrate (LOW)	204.01	l/min
Mean heptane flowrate	2.48	l/min
Mean pump pressure	0.89	bar
Mean nozzle pressure	0.65	bar

Total water output (HIGH)	21.035	litres	
Total water output (LOW)	2043.500	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	152.365	724.34	7.46
Total water collect (Hoppers)	131.701	626.10	6.44
Total water collected (Gap)	20.664	98.24	1.01
Total water collected (Hoppers + non aligned gap)	143.082	680.21	7.00
Total water collected (Aligned gap)	9.283	44.13	0.45

9.888	8.275	6.308	7.895	6.101
9.333	7.563		6.775	7.686
4.974			4.309	
8.527	9.276	5.073	6.683	8.370
8.424	10.159		7.094	9.652

KG

3.949	3.304	4.289	3.153	2.436
3.727	3.020		2.705	3.069
3.382			2.930	
3.405	3.704	3.449	2.669	3.342
3.364	4.057		2.833	3.854

mm/min

	mm/min
Mean coverage (Hoppers + gap)	3.315
Mean coverage (Hoppers)	3.287
Mean coverge (Gap)	3.512
Mean coverage (Hoppers + non aligned gap)	3.327
Mean coverage (Aligned gap)	3.156
Mean coverage (Inner hoppers)	3.025
Mean coverage (Middle hoppers)	3.361
Mean coverage (Outer hoppers)	3.401

B.3 ADD two sprinkler array data sets

The ADD results sheets are given on CD-ROM ‘TE 91014-19 ADD rig development and sprinkler test methodology data’.

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Appendix C

Single sprinkler results for Upright and Pendent sprinklers

C.1. Nomenclature

Datasheet identification system i.e GU226Hb GW head in the upright position in an array of 2, , ceiling 2.6 metres above the ADD apparatus with a 1.3 MW fire – 2nd test		
Sprinkler name	**G** **S** **V** **W**	GW DD1 (SSU/P) k115 Star SG (SSU/P) k115 Viking M (SSU/P) k115 Wormald A (C/UP) K115
Orientation	**P** **U**	Pendent Upright
No. of heads	**4** **2** **1**	Array of 4 on 3 x 3 metre spacing Array of 2 on 3 x 3 metre spacing Single sprinkler
Ceiling height	**26**	2.6 metres above collection pans
Condition	**H** **C**	Hot – with 1.3 MW sprayed heptane fire Cold – no fire
Test no.	**a, b, c, d, e, f**	Optional – where more than one test performed
Sprinkler k factor	**(no suffix)** **80**	Denotes sprinkler with a k factor of 115 Denotes use of a sprinkler with a k factor of 80

C.2. Typical ADD results sheets for Cold and Hot tests for a single sprinkler

Run number **GP126Cb**

Test duration	900	seconds
Mean water flowrate (HIGH)	1.99	l/min
Mean water flowrate (LOW)	106.04	l/min
Mean heptane flowrate	0.01	l/min
Mean pump pressure	0.74	bar
Mean nozzle pressure	0.84	bar

Total water output (HIGH)	29.850	litres	
Total water output (LOW)	1590.600	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	104.757	350.94	6.59
Total water collect (Hoppers)	87.034	291.57	5.47
Total water collected (Gap)	17.723	59.37	1.11
Total water collected (Hoppers + non aligned gap)	97.140	325.43	6.11
Total water collected (Aligned gap)	7.617	25.52	0.48

4.492	7.352	4.782	7.594	4.699
4.321	3.749		4.283	5.372
3.847			3.770	
6.574	3.787	5.324	3.747	4.715
6.148	7.610		7.819	4.772

KG

1.198	1.961	2.171	2.025	1.253
1.152	1.000		1.142	1.433
1.747			1.712	
1.753	1.010	2.417	0.999	1.257
1.639	2.029		2.085	1.273

mm/min

	mm/min
Mean coverage (Hoppers + gap)	1.522
Mean coverage (Hoppers)	1.451
Mean coverge (Gap)	2.012
Mean coverage (Hoppers + non aligned gap)	1.508
Mean coverage (Aligned gap)	1.729
Mean coverage (Inner hoppers)	1.038
Mean coverage (Middle hoppers)	1.712
Mean coverage (Outer hoppers)	1.341

Run number **GP126Hb**

Test duration	603	seconds
Mean water flowrate (HIGH)	2.09	l/min
Mean water flowrate (LOW)	110.06	l/min
Mean heptane flowrate	2.5	l/min
Mean pump pressure	0.78	bar
Mean nozzle pressure	0.74	bar

Total water output (HIGH)	21.005	litres	
Total water output (LOW)	1106.103	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	39.826	189.61	3.60
Total water collect (Hoppers)	31.773	151.27	2.87
Total water collected (Gap)	8.053	38.34	0.73
Total water collected (Hoppers + non aligned gap)	35.300	168.06	3.19
Total water collected (Aligned gap)	4.526	21.55	0.41

1.569	3.686	1.628	2.949	1.453
0.954	0.782		1.141	2.333
1.924			2.602	
2.272	0.584	1.899	1.015	2.246
1.852	2.976		4.006	1.955

KG

0.624	1.467	1.103	1.174	0.578
0.380	0.311		0.454	0.929
1.304			1.763	
0.904	0.232	1.287	0.404	0.894
0.737	1.184		1.594	0.778

mm/min

	mm/min
Mean coverage (Hoppers + gap)	0.864
Mean coverage (Hoppers)	0.790
Mean coverge (Gap)	1.364
Mean coverage (Hoppers + non aligned gap)	0.818
Mean coverage (Aligned gap)	1.533
Mean coverage (Inner hoppers)	0.350
Mean coverage (Middle hoppers)	1.066
Mean coverage (Outer hoppers)	0.680

C.3. ADD results sheets

ADD results sheets are given on CD-ROM ‘TE 91014-19 ADD rig development and sprinkler test methodology data’.

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Appendix D

Summary sheets for ADD sprinkler tests

D.1 Nomenclature

Datasheet identification system i.e GP162 Cb GW head in the pendent position tested as a single sprinkler, ceiling 2.6 metres above the ADD apparatus with a 1.3 MW fire – K80 head, 2nd Test		
Sprinkler name	**G** **S** **V** **W**	GW DD1 (SSU/P) k115 Star SG (SSU/P) k115 Viking M (SSU/P) k115 Wormald A (C/UP) K115
Orientation	**P** **U**	Pendent Upright
No. of heads	**4** **2** **1**	Array of 4 on 3 x 3 metre spacing Array of 2 on 3 x 3 metre spacing Single sprinkler
Ceiling height	**26**	2.6 metres above collection pans
Condition	**H** **C**	Hot – with 1.3 MW sprayed heptane fire Cold – no fire
Sprinkler k factor	**(no suffix)** **80**	Denotes sprinkler with a k factor of 115 Denotes use of a sprinkler with a k factor of 80

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D.2. Typical ADD summary sheet

Summary of GP126Cb and GP126Hb

COLLECTION

	Cold	Hot	Difference
LOW	(%)	(%)	(%)
Total water collected (Hoppers + gap)	6.59	3.60	54.67
Total water collect (Hoppers)	5.47	2.87	52.50
Total water collected (Gap)	1.11	0.73	65.34
Total water collected (Hoppers + non aligned gap)	6.11	3.19	52.26
Total water collected (Aligned gap)	0.48	0.41	85.45
HIGH			
Total water collected (Hoppers + gap)	350.94	189.61	54.03
Total water collect (Hoppers)	291.57	151.27	51.88
Total water collected (Gap)	59.37	38.34	64.57
Total water collected (Hoppers + non aligned gap)	325.43	168.06	51.64
Total water collected (Aligned gap)	25.52	21.55	84.44

COVERAGE

	Cold	Hot	Difference
	(mm/min)	(mm/min)	(%)
Mean coverage (Hoppers + gap)	1.522	0.864	56.743
Mean coverage (Hoppers)	1.451	0.790	54.487
Mean coverge (Gap)	2.012	1.364	67.818
Mean coverage (Hoppers + non aligned gap)	1.508	0.818	54.238
Mean coverage (Aligned gap)	1.729	1.533	88.686
Mean coverage (Inner hoppers)	1.038	0.350	33.771
Mean coverage (Middle hoppers)	1.712	1.066	62.257
Mean coverage (Outer hoppers)	1.341	0.680	50.681

D.3. ADD summary data

Summary data sheets are given on CD-ROM ‘TE 91014-19 ADD rig development and sprinkler test methodology data’.

Appendix E

'Long Profile' distribution data

E.1. Typical long profile distribution data

X	Y = 0.75 m	Y= 0.25 m	Y= -0.25 m	Y= -0.75 m
M	mm/min			
-0.25	1.81	1.17	0.99	1.08
0.25	1.43	0.99	0.89	1.21
0.75	1.24	1.68	2.14	1.14
1.25	1.84	2.66	3.23	1.85
1.75	2.18	2.79	3.13	2.55
2.25	3.14	2.95	3.11	3.1
2.75	3.63	3.32	2.86	3.45
3.25	2.08	2.03	1.95	1.81
3.75	0.41	0.17	0.41	0.25
4.25	0	0.02	0	0.01
4.75	0	0	0	0
5.25	0.01	0.01	0.01	0.01
5.75	0	0	0	0
6.25	0.01	0.01	0.01	0

Table E.1 - GW DD1 k 115 pendent sprinkler with frame aligned with pipework flow rate 100 l/min

X	Y = 0.75 m	Y= 0.25 m	Y= -0.25 m	Y= -0.75 m
m	mm/min			
-0.25	1.23	3.06	4.01	1.09
0.25	1.8	6.49	6.37	1.97
0.75	1.19	0.93	0.77	0.92
1.25	1.46	1.11	1.06	1.09
1.75	2.32	1.85	2.06	2.03
2.25	4.13	4.16	4.02	4.05
2.75	2.23	2.9	3.48	2.97
3.25	1.32	1.33	1.55	1.41
3.75	1.25	1.11	1.35	1.01
4.25	0.82	0.8	1.14	0.6
4.75	0.35	0.39	0.64	0.24
5.25	0.03	0.05	0.1	0.01
5.75	-0.02	0	0	0
6.25	-0.01	-0.01	0.01	0

Table E.2 - GW DD1 k 115 upright sprinkler with frame aligned with pipework flow rate 100 l/min

E.2. Long profile distribution data sets

The long profile distribution data are contained on CD-ROM 'TE 91014-19 ADD rig development and sprinkler test methodology data'.

Appendix F
ADD requirements and test methods

F.1. Actual Delivered Density

When tested in accordance with F.2, using the parameters specified in Table F.1, columns 1 to 5, sprinklers shall satisfy the requirements of columns 6 to 8.

At least one test shall be undertaken with sealed sprinklers (with heat sensitive elements and valves), in accordance with Table F.1, test 3. Sealed sprinkler tests shall be conducted for each sprinkler model and thermal sensitivity rating. All four sprinklers in the array shall open within 5 minutes of the first sprinkler operating.

1 Test No	2 Number of sprinklers under test	3 Ceiling clearance	4 Convective heat release rate	5 Flow rate per sprinkler	6 Hopper & Gap (20 pans) Average ADD (4)	7 Inner and middle hopper Minimum ADD (4)	8 Outer hoppers Minimum ADD (4)
		m	(MW)	(L/min)	(mm/min)	(mm/min)	(mm/min)
1	$1_{(1)}$	2.6	0	100	nr	nr	nr
2	$1_{(1)}$	2.6	1.3	100	nr	nr	nr
3	$4_{(2)(3)}$	2.6	1.3	100	nr	nr	nr
4	$4_{(1)}$	2.6	1.3	100	7.5	5.0	6.5
5	$4_{(1)}$	2.6	0	100	7.5	5.0	6.5
6	$4_{(1)}$	4.7	1.3	100	nr	nr	nr

NOTE

(1) Test may be undertaken with open sprinkler heads (with the heat sensitive elements and valves removed)

(2) Test shall be undertaken with sealed sprinklers.

(3) Test each thermal sensitivity rating.

(4) nr = no requirement.

Table F.1 – ADD test details and requirements

F.2. Actual Delivered Density (ADD) Test

Actual Delivered Density measurements shall be undertaken using a test apparatus shown in figure F1. Commercial grade heptane shall be used as the sprayed fuel. The ADD apparatus shall be located beneath a flat horizontal ceiling at least 6m x 6m plan area and positioned in accordance with the requirements, either 2.6m or 4.7 m above the collection containers. The test apparatus shall be located in a draft free enclosure of sufficient volume to minimize enclosure effects on the water spray.

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The sprinklers shall be installed on pipework of 50 mm DN minimum. Concealed recessed or flush sprinklers shall be installed in accordance with the supplier's instructions. All other sprinklers shall be located at or below the ceiling in accordance with one of arrangements shown in Figures F.1, F.2 or F.3, as appropriate. Where sprinklers may be fitted directly onto range pipes (below a ceiling or roof) or used as a ceiling flush sprinkler, they shall be tested in the configurations shown in figures F.2 and F.3.

Where arrays of four sprinklers are being tested, except concealed and recessed sprinklers, the sprinklers shall be spaced 3 m x 3 m apart (i.e. 9 m^2). Concealed or recessed sprinklers shall be spaced 3 m x 4 m apart (i.e. 12 m^2). Pairs of sprinklers shall be spaced 3 m apart.

Upright sprinklers mounted on pipework beneath the ceiling shall have the frame arms parallel to the pipework.

The heptane sprays shall be ignited and the flow stabilised to achieve the convective heat release rate required.

When open sprinklers are to be tested, commence the water discharge once the fuel flow rate has been stabilised at the specified flow rate.

The test shall be run for a minimum of ten minutes or until a minimum of 10 kg of water has been collected in each measuring container.

When sealed sprinkler heads are to be tested, install four open sprinklers with an identical k factor to those under test (with the frame and deflectors removed) in the connections at the end of the flow diversion pipework. Open the four solenoid valves on the flow diversion pipework and commence water flow through the diversion pipework at the flow rate specified for the test. When the water flow has stabilised, commence the heptane flow to the burners. Ignite the sprayed fuel. Immediately a sprinkler opens, close one solenoid valve, to reduce the diverted water flow. If necessary, adjust the water flow until the correct value is achieved. Immediately after the last sprinkler has opened and the water flow through the flow diversion system has ceased, check that the water flow rate through the sprinklers.

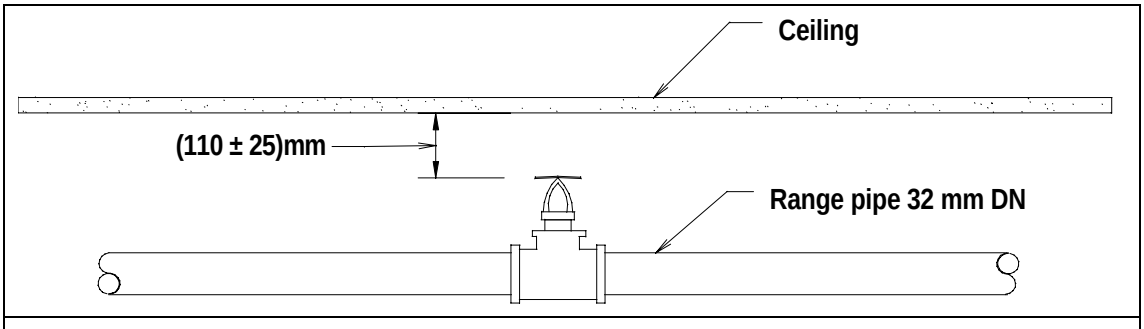

Figure F.1 - Upright sprinkler arrangement

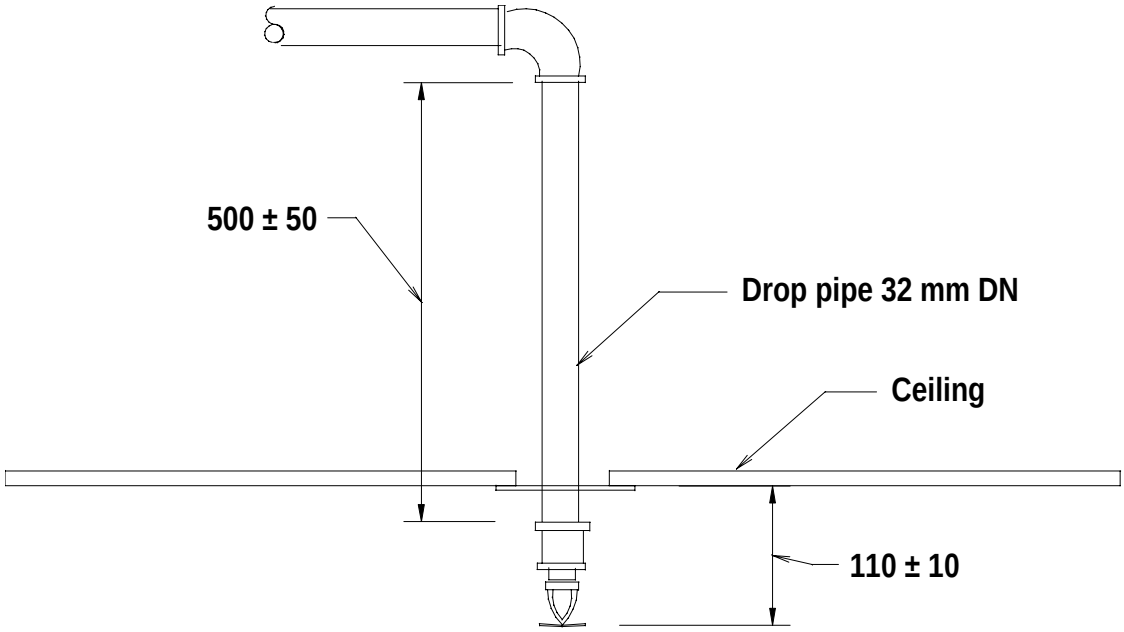

Figure F.2 - Pendent sprinkler arrangement

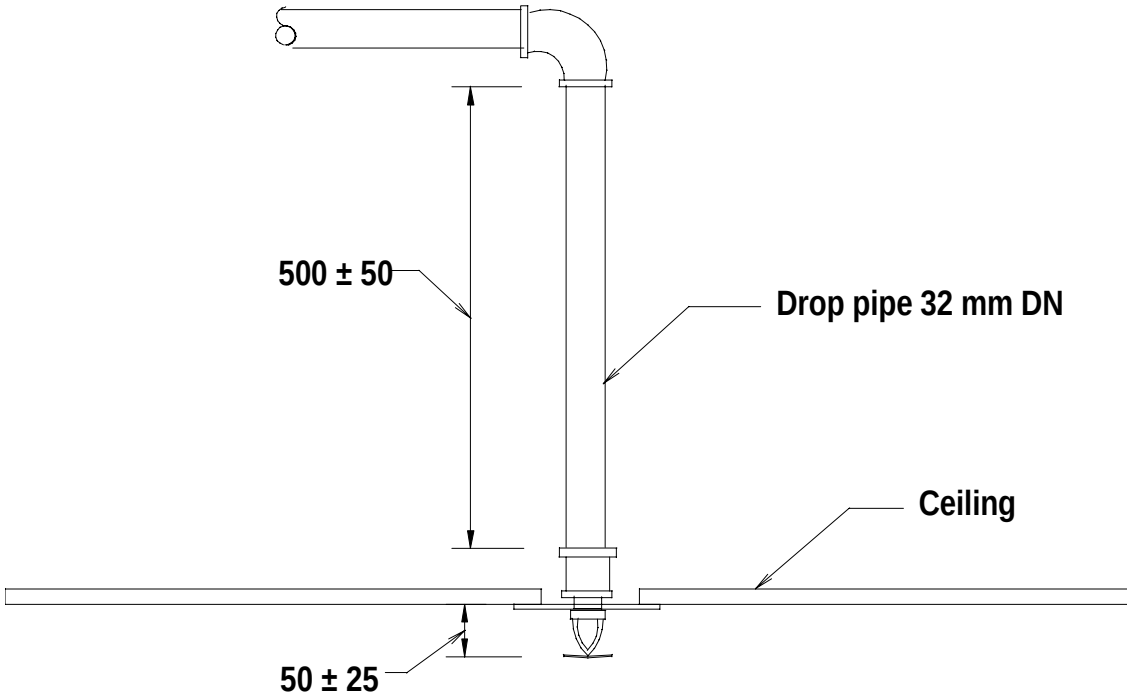

Figure F.3 - Installation detail for ceiling sprinklers

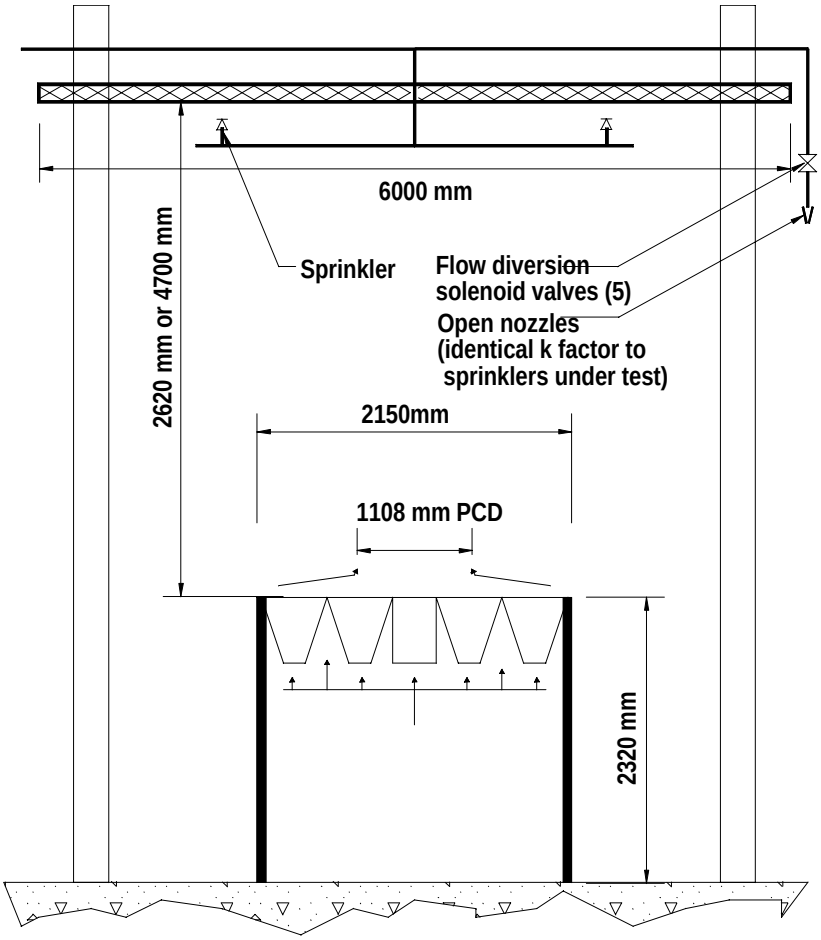

Figure F.4 ADD test rig – side elevation

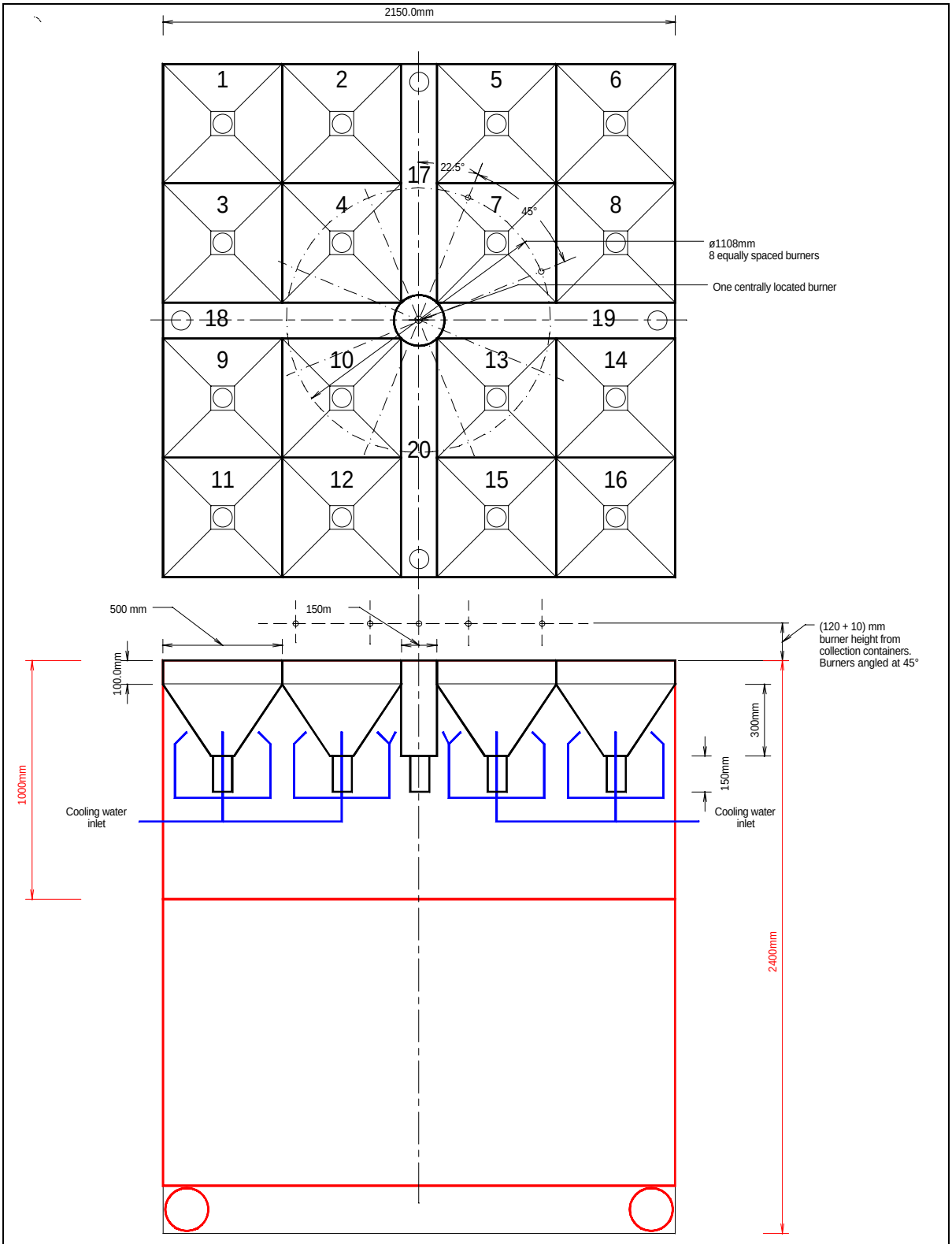

Figure F.5 ADD test rig – collection area and burner locations

Appendix G

Test method repeatability

G.1 Nomenclature

Datasheet identification system i.e GP162 Cb GW head in the pendent position tested as a single sprinkler, ceiling 2.6 metres above the ADD apparatus with a 1.3 MW fire – K80 head, 2nd Test		
Sprinkler name	**G** **S** **V** **W**	GW DD1 (SSU/P) k115 Star SG (SSU/P) k115 Viking M (SSU/P) k115 Wormald A (C/UP) K115
Orientation	**P** **U**	Pendent Upright
No. of heads	**4** **2** **1**	Array of 4 on 3 x 3 metre spacing Array of 2 on 3 x 3 metre spacing Single sprinkler
Ceiling height	**26**	2.6 metres above collection pans
Condition	**H** **C**	Hot – with 1.3 MW sprayed heptane fire Cold – no fire
Test no.	**r** **s**	First repeatability test Second repeatability test
Sprinkler k factor	**(no suffix)** **80**	Denotes sprinkler with a k factor of 115 Denotes use of a sprinkler with a k factor of 80

G.1 Repeatability tests results

Run number **VP426Cr**

Test duration	901	seconds
Mean water flowrate (HIGH)	2.07	l/min
Mean water flowrate (LOW)	401.83	l/min
Mean heptane flowrate	0.0001	l/min
Mean pump pressure	14.31	bar
Mean nozzle pressure	0.62	bar

Total water output (HIGH)	31.085	litres	
Total water output (LOW)	6034.147	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	860.696	2768.89	14.26
Total water collect (Hoppers)	743.916	2393.21	12.33
Total water collected (Gap)	116.780	375.69	1.94
Total water collected (Hoppers + non aligned gap)	806.280	2593.83	13.36
Total water collected (Aligned gap)	54.416	175.06	0.90

32.586	31.358	28.339	46.970	46.370
34.917	47.289		51.548	44.332
27.147			27.269	
37.223	54.623	34.025	57.692	49.779
37.200	44.046		67.340	60.643

KG

8.680	8.353	12.852	12.511	12.352
9.301	12.596		13.731	11.809
12.311			12.366	
9.915	14.550	15.430	15.367	13.260
9.909	11.733		17.937	16.154

mm/min

	mm/min
Mean coverage (Hoppers + gap)	12.493
Mean coverage (Hoppers)	12.385
Mean coverge (Gap)	13.240
Mean coverage (Hoppers + non aligned gap)	12.504
Mean coverage (Aligned gap)	12.339
Mean coverage (Inner hoppers)	14.061
Mean coverage (Middle hoppers)	11.852
Mean coverage (Outer hoppers)	11.774

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Run number **VP426Cs**

Test duration	300	seconds
Mean water flowrate (HIGH)	1.95	l/min
Mean water flowrate (LOW)	403.48	l/min
Mean heptane flowrate	1E-04	l/min
Mean pump pressure	14.36	bar
Mean nozzle pressure	0.62	bar

Total water output (HIGH)	9.750	litres	
Total water output (LOW)	2017.400	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	295.049	3026.14	14.63
Total water collect (Hoppers)	254.396	2609.19	12.61
Total water collected (Gap)	40.653	416.95	2.02
Total water collected (Hoppers + non aligned gap)	275.670	2827.38	13.66
Total water collected (Aligned gap)	19.379	198.76	0.96

11.071	10.852	9.814	16.353	15.429
12.456	16.294		17.521	14.788
9.549			9.830	
12.854	18.738	11.460	20.379	16.290
12.556	14.563		21.698	22.554

KG

8.857	8.682	13.367	13.082	12.343
9.965	13.035		14.017	11.830
13.006			13.388	
10.283	14.990	15.609	16.303	13.032
10.045	11.650		17.358	18.043

mm/min

	mm/min
Mean coverage (Hoppers + gap)	12.862
Mean coverage (Hoppers)	12.720
Mean coverge (Gap)	13.842
Mean coverage (Hoppers + non aligned gap)	12.840
Mean coverage (Aligned gap)	13.197
Mean coverage (Inner hoppers)	14.586
Mean coverage (Middle hoppers)	11.985
Mean coverage (Outer hoppers)	12.322

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Run number **VP426Hr**

Test duration	362	seconds
Mean water flowrate (HIGH)	4.12	l/min
Mean water flowrate (LOW)	406.4	l/min
Mean heptane flowrate	2.49	l/min
Mean pump pressure	14.27	bar
Mean nozzle pressure	0.6	bar

Total water output (HIGH)	24.857	litres	
Total water output (LOW)	2451.947	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	284.662	1145.18	11.61
Total water collect (Hoppers)	249.748	1004.73	10.19
Total water collected (Gap)	34.914	140.46	1.42
Total water collected (Hoppers + non aligned gap)	267.630	1076.66	10.92
Total water collected (Aligned gap)	17.032	68.52	0.69

12.412	13.583	8.077	16.993	17.743
14.991	11.242		12.122	14.506
9.150			7.882	
16.786	14.553	9.805	14.833	16.087
14.383	16.080		21.216	22.218

KG

8.229	9.005	9.117	11.266	11.763
9.939	7.453		8.037	9.617
10.328			8.897	
11.129	9.648	11.067	9.834	10.665
9.536	10.661		14.066	14.730

mm/min

	mm/min
Mean coverage (Hoppers + gap)	10.284
Mean coverage (Hoppers)	10.349
Mean coverge (Gap)	9.852
Mean coverage (Hoppers + non aligned gap)	10.330
Mean coverage (Aligned gap)	9.612
Mean coverage (Inner hoppers)	8.743
Mean coverage (Middle hoppers)	10.794
Mean coverage (Outer hoppers)	11.065

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Run number **VP426Hs**

Test duration	362	seconds
Mean water flowrate (HIGH)	3.99	l/min
Mean water flowrate (LOW)	399.64	l/min
Mean heptane flowrate	2.53	l/min
Mean pump pressure	14.22	bar
Mean nozzle pressure	0.54	bar

Total water output (HIGH)	24.073	litres	
Total water output (LOW)	2411.161	litres	
		% collected	
	litres	**HIGH**	**LOW**
Total water collected (Hoppers + gap)	281.206	1168.14	11.66
Total water collect (Hoppers)	246.881	1025.55	10.24
Total water collected (Gap)	34.325	142.59	1.42
Total water collected (Hoppers + non aligned gap)	263.998	1096.66	10.95
Total water collected (Aligned gap)	17.208	71.48	0.71

12.209	12.891	7.763	16.469	17.351
14.882	11.592		12.211	14.064
9.808			7.400	
17.016	14.258	9.354	14.412	15.656
13.926	16.182		21.113	22.649

KG

8.094	8.547	8.762	10.919	11.503
9.867	7.685		8.096	9.324
11.071			8.353	
11.281	9.453	10.558	9.555	10.380
9.233	10.728		13.998	15.016

mm/min

	mm/min
Mean coverage (Hoppers + gap)	10.159
Mean coverage (Hoppers)	10.230
Mean coverge (Gap)	9.686
Mean coverage (Hoppers + non aligned gap)	10.190
Mean coverage (Aligned gap)	9.712
Mean coverage (Inner hoppers)	8.697
Mean coverage (Middle hoppers)	10.630
Mean coverage (Outer hoppers)	10.962

G.3 Repeatability test analysis

The differences between the repeatability tests, expressed as percentage differences are shown in Table G1 and G2.

-1.59	-3.39	-3.45	-3.96	0.49
-6.27	-2.96		-1.63	0.24
-4.95			-7.25	
-3.18	-2.53	-0.73	-5.35	2.17
-0.94	1.13		3.77	-10.10

Table G.1 – Percentage Difference between cold ADD test results VP426Cr and VP426Cs

-0.02	3.61	2.32	1.46	0.56
-0.95	-4.63		-2.38	1.43
-8.26			4.74	
-2.99	0.37	3.08	1.21	1.04
1.56	-2.28		-1.19	-3.54

Table G.1 – Percentage Difference between hot ADD test results VP426Hr and VP426Hs

G.4 Discussion of repeatability test results

The cold and hot ADD test results indicate that an acceptable level of repeatability can be achieved. However, examination of all cold ADD test results indicates that distribution symmetry is not always achieved. Examination of batches new sprinklers of the types used in the experiments has indicated variations in sprinkler manufacture and condition, for example distorted deflectors, asymmetric sprinkler frame machining, and partially machined nozzles. Any one of these defects could result in distribution variations from sprinkler to sprinkler. Variations in ADD test results could also occur if the sprinklers or range pipes are incorrectly aligned or orientated. Further modifications are anticipated to the sprinkler ceiling, ranges and sprinkler fittings to make the ADD rig suitable as a routine test apparatus.

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