



Water distribution tests using Extended Coverage sprinklers for the Muskö Tunnel

Magnus Arvidson

Lotta Vylund

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Abstract

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The objective of the tests was to determine the water distribution characteristics using different water pressures and sprinkler spacing of two selected Extended Coverage sprinklers. The sprinklers may be used for the protection of the Muskö tunnel and the test set-up simulated a freight truck trailer positioned inside the tunnel.

Adequate sprinkler coverage would require that sprinklers are positioned close to the peak of the ceiling. A relatively short vertical distance from the sprinklers and the ceiling is also essential for proper thermal activation. These requirements are best met by the use of upright sprinklers. Two extended coverage upright sprinklers with a K-factor of 363 (metric) and 202 was selected for the tests.

For the extended coverage upright K363 sprinkler (Tyco model EC-25), a sprinkler spacing of 4.0 m is recommended, in order to account for the fact that full coverage of the freight truck trailer was not achieved at the tested 4.2 m spacing. A density of 10 mm/min requires an operating pressure of around 0.7 bar at this particular spacing.

The tested extended coverage upright K202 sprinkler (Tyco model EC-14) provided a wider water discharge pattern, with a proper water distribution on the top of a freight truck trailer positioned offset in the tunnel at sprinkler spacing up to 5.0 m. For an actual installation, a K202 sprinkler designed for a density of 10 mm/min require an operating pressure of around 3.6 bar at this particular spacing.

Key words: Tunnel fire, automatic sprinklers, extended coverage sprinklers, water distribution.

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Preface

The research work was initiated by the Swedish Road Administration (STA). Thanks to Ulf Lundström, Anna Niva and Audey Pules, who contributed to in the discussions and preparation for this work.

The research work presented in this report has been sponsored by TUSC Tunnel Underground Safety Center and the Swedish Transport Administration (STA). The financiers of TUSC are the Swedish Transport Administration, the Swedish Fortifications Agency, the Swedish Nuclear Fuel and Waste Management Company (SKB) and RISE Research Institutes of Sweden. Additional funding was obtained from STA in order to broaden the scope of the original project plan, which is gratefully acknowledged.

Summary

The objective of the tests was to determine the water distribution characteristics using different water pressures and sprinkler spacing with two selected Extended Coverage upright sprinklers. The sprinklers may be used for the protection of the Muskö tunnel and the test set-up simulated a freight truck trailer positioned inside the tunnel. The long-term objective is to investigate whether an automatic sprinkler system is feasible in the Muskö tunnel. This would require additional intermediate- or large-scale fire sprinkler tests.

The test set-up was designed to simulate a freight truck trailer positioned close to a sidewalk in the tunnel. The rationale is that a freight truck on fire would be parked as far as possible to the side of the road by an alert driver. A platform with a horizontal plane that measured 5000 mm (L) by 2600 mm (W) was constructed to simulate the top of a trailer.

The water discharge densities were measured at the top of the platform and at floor level, with a total of 22 water collector trays. Each tray measured 500 mm by 500 mm and had a rim height of 100 mm. At the top of the platform, 4 by 4 trays were abutted together and at the floor, 2 by 3 trays were used. The individual discharge tests were conducted for two minutes and the amount of water in each tray was determined by the measurement of the water level at four different positions in each tray. The result is presented as the mean level (water density) of the four measurement points.

Prior the tests, a review of commercially available extended coverage sprinklers were undertaken by RISE. Two upright sprinklers with a K-factor of 363 (metric) and 202 was selected for the tests; Tyco model EC-25 and Tyco model EC-14.

The tests showed that the Tyco model EC-25 sprinkler may be installed at a spacing of 4.2 m. For a design density of 10 mm/min, the operating pressure would be around 0.8 bar. A reduction of the spacing to 4.0 m would reduce the required pressure to around 0.7 bar, which would meet the minimum pressure requirement of 0.5 bar and would improve the coverage over a freight truck trailer.

The Tyco model EC-14 sprinkler may be installed at a spacing of 5.0 m. For a design density of 10 mm/min, the operating pressure would be around 3.6 bar. A reduction of the spacing to 4.2 bar would reduce the required pressure to around 2.6 bar.

An attempt was made to increase the area of coverage of the Tyco model EC-25 sprinkler by a modification of the deflector. A sprinkler spacing of 4.2 m was required to distribute water on the top of the simulated freight truck trailer. Compared to the non-modified sprinkler, the discharge density on the top increased with approximately a factor of 2, but less water was collected in the trays at the floor. To some extent, it is likely that the wider spray pattern would affect the downward momentum and water uniformity directly under the sprinkler.

The last tests combined the model EC-14 and the EC-25 sprinklers, which improved water coverage on the top of the platform as compared to only using Tyco model EC-25 sprinklers.

1 Introduction

Fire Research as RISE Research Institutes of Sweden has on request by the STA, the Swedish Transport Administration (Trafikverket) conducted water distribution tests with selected large K-factor, extended coverage sprinklers. The objective of the tests was to determine the water distribution characteristics using different water pressures and sprinkler spacing. The sprinklers may be used for the protection of the Muskö tunnel and the test set-up simulated a freight truck trailer positioned inside the tunnel. Furthermore, the test set-up mimicked the actual horizontal distance from one line of sprinklers installed along the centerline of the tunnel ceiling as well the actual vertical distance from the deflector of the sprinklers to the top of the freight truck trailer. The centerline position has been found to be the most optimal position in relation to activation time [1].

The tests were conducted inside the large fire test hall of RISE in Borås, during June 2017.

The long-term objective is to investigate whether an automatic sprinkler system is feasible in the Muskö tunnel. This would require additional intermediate- or large-scale fire sprinkler tests.

2 Muskö tunnel

The Muskö tunnel is part of the connection between Muskö and the shore and was opened for traffic on March 15, 1964. Today, approximately 1 300 vehicles pass the tunnel daily (daily average traffic). The tunnel is 2 912 meter and stretches about 60 meters below the seabed¹. Initially, the free height was assumed to be 4.5 m, but measurements² conducted in 1988 showed that some parts were less high and the free height was reduced to 4.2 m.

Prior the water distribution tests, an analysis were undertaken by RISE of recent laser scan data. The analysis indicates that the mean width of the tunnel is approximately 7.7 m and the mean height approximately 5.2 m. On both sides of the tunnel, there are sidewalks, approximately 850 mm in width. These figures were used to create an schematic cross-sectional illustration of the tunnel, with the potential position of a sprinkler distribution pipe along the length of the tunnel, refer to Appendix 1. In an ideal case, a single line of sprinklers intended to protect the full width of the tunnel should be positioned as high as possible, in order to maximize the coverage area and to minimize the influence of any obstructions (lights fixtures, cable trays, etc.) positioned entirely below sprinklers. However, in practice it is likely that sprinklers need to be positioned at a somewhat lesser distance below the peak of the ceiling and that the water distribution pipe needs to be installed offset the centerline. At a more probable vertical distance of 300 mm below the ceiling, the vertical distance from the

¹ "Väg 539, Muskötunneln", <http://www.trafikverket.se/nara-dig/stockholm/projekt-i-stockholms-lan/vag-539-muskotunneln/>, Senast uppdaterad/granskad: 2016-08-31.

² <http://www.musko.nu/muskotunneln/>, 2017-08-21.

deflector of the sprinkler to the top of a freight truck trailer would be 900 mm, as illustrated in Appendix 1.

3 Potential sprinklers to be used in the Muskö tunnel

Prior the tests, a review of commercially available extended coverage sprinklers were undertaken by RISE. The review is summarized in Tables 1 and 2, indicating the make, the K-factor, the Sprinkler Identification Number (SIN), the type of thermal element on the sprinkler and the available temperature ratings.

Table 1 Commercially available **upright** extended coverage sprinklers.

Make	K-factor [metric]	SIN	Thermal element	Available temp. ratings [°C]
Tyco	363	TY9128	Fast response link	74 and 100
Viking	363	VK592	Fast response link	74 and 100
Tyco	202	TY6137	3 mm glass bulb	57, 68, 79, 93, 141
Viking	202	VK570	3 mm glass bulb	57, 68, 79, 93, 141
RASCO	202	R6553	Fast response link	74 and 100
Victaulic	202	V3425	3 mm glass bulb	57, 68, 79, 93

Table 2 Commercially available **pendent** extended coverage sprinklers.

Make	K-factor [metric]	SIN	Thermal element	Available temp. ratings [°C]
RASCO	363	RA0842	Fast response link	74 and 100
Tyco	202	TY6237	3 mm glass bulb	57, 68, 79, 93, 141
Viking	202	VK572	3 mm glass bulb	57, 68, 79, 93, 141
RASCO	202	R6043	Fast response link	74 and 100
Victaulic	202	V3421	3 mm glass bulb	57, 68, 79, 93

The review shows that there are two commercially available upright extended coverage sprinklers having a K-factor of 363 and four sprinklers with a K-factor of 202. There is one commercially available pendent extended coverage sprinkler having a K-factor of 363 and four sprinklers with a K-factor of 202.

Preferably, sprinklers used for the Muskö tunnel should have a large K-factor, in order to reduce the operating pressure. It is also preferable that the sprinklers are upright orientated sprinklers, in order to be positioned closer to the ceiling than would pendent sprinklers. Therefore, the water distribution tests focused on upright sprinklers.

The upright K363 sprinklers in the list are intended for warehouse protection. These sprinklers offer a maximum coverage area of 196 ft² (18.2 m²), which is almost double the area offered by standard coverage sprinklers used for similar applications. The maximum coverage area corresponds to a maximum sprinkler spacing of 4.3 m.

The upright K202 sprinklers in the list are intended for light- or ordinary hazard applications. These sprinklers are intended for use in accordance with NFPA 13 for a maximum coverage area of 400 ft² (37.2 m²), as compared to the maximum coverage

area of 130 ft² (12.1 m²) for standard coverage sprinklers used in ordinary hazard occupancies or 225 ft² (20.6 m²) for standard coverage sprinklers used in light hazard occupancies. The maximum allowed coverage area corresponds to a maximum sprinkler spacing of 6.1 m.

4 Water flow rate and operating pressure requirements

Given that the mean width of the tunnel is approximately 7.7 m, the area of coverage, the corresponding water flow rate and the corresponding operating pressure was calculated given a sprinkler spacing of 4.2 m, 4.6 m and 5.0 m, respectively and for three different design densities; 5 mm/min, 7.5 mm/min and 10 mm/min, respectively.

Table 3 shows the results for K363 sprinklers.

Table 3 The area of coverage, the water flow rate and the operating pressure for K363 sprinklers if used in the Muskö tunnel.

K-factor [metric]	Tunnel width [m]	Sprinkler spacing [m]	Area of coverage [m²]	Design density [mm/min]	Corresponding water flow rate [liter/min]	Corresponding operating pressure [bar]
363	7.7	4.2	32.3	5	162	0.20
363	7.7	4.6	35.4	5	177	0.24
363	7.7	5.0	38.5	5	193	0.28
363	7.7	4.2	32.3	7.5	243	0.45
363	7.7	4.6	35.4	7.5	266	0.54
363	7.7	5.0	38.5	7.5	289	0.63
363	7.7	4.2	32.3	10	323	0.79
363	7.7	4.6	35.4	10	354	0.95
363	7.7	5.0	38.5	10	385	1.12

For a K363 sprinkler the area of coverage is significantly larger than the maximum allowed, although it is regarded that the smallest spacing match the minimum required spacing of 4.3 m well. The calculation shows that the required operating pressure is reasonably low even at a design density of 10 mm/min. It also is noted that the minimum required operating pressure of 0.5 bar is undershot at a design density of 5 mm/min and at a design density of 7.5 mm/min for the 4.2 m spacing.

Table 4 shows the results for K202 sprinklers.

Table 4 The area of coverage, the water flow rate and the operating pressure for K202 sprinklers if used in the Muskö tunnel.

K-factor [metric]	Tunnel width [m]	Sprinkler spacing [m]	Area of coverage [m²]	Design density [mm/min]	Corresponding water flow rate [liter/min]	Corresponding operating pressure [bar]
202	7.7	4.2	32.3	5	162	0.64
202	7.7	4.6	35.4	5	177	0.77
202	7.7	5.0	38.5	5	193	0.91
202	7.7	4.2	32.3	7.5	243	1.44
202	7.7	4.6	35.4	7.5	266	1.73
202	7.7	5.0	38.5	7.5	289	2.04
202	7.7	4.2	32.3	10	323	2.56
202	7.7	4.6	35.4	10	354	3.07
202	7.7	5.0	38.5	10	385	3.63

For a K202 sprinkler the area of coverage is below or slightly larger than the maximum allowed, which from that perspective make the sprinkler an interesting option. The calculations shows that the minimum operating pressure is not undershot at any of the design options. However, for a design density of 10 mm/min the required operating pressures are from a practical perspective high, but probably not critically high.

5 The test set-up

The test set-up was designed to simulate a freight truck trailer positioned close to a sidewalk in the tunnel, as shown in Appendix 2. The rationale is that a freight truck fire would be parked as far as possible to the side of the road by an alert driver. A platform with a horizontal plane that measured 5000 mm (L) by 2600 mm (W) was constructed. However, for practical reasons the width of the platform was extended 400 mm in to the “sidewalk”. The top edge of the trays at the top of the platform was positioned 4000 mm above floor level. The width and height represents the maximum allowed geometry of a freight truck trailer in Sweden.

The water discharge densities were measured at the top of the platform and at floor level, with a total of 22 water collector trays. Each tray measured 500 mm by 500 mm and had a rim height of 100 mm. At the top of the platform, 4 by 4 trays were abutted together and at the floor, 2 by 3 trays were used.

The individual discharge tests were conducted for two minutes and the amount of water in each tray was determined by measuring the water level at four different positions in each tray. The result is presented as the mean level (water density) of the four measurement points.

A piping arrangement was fabricated consisting of one DN50 (2") pipe with connections for sprinklers at an optional spacing of 4.2 m, 4.6 m and 5.0 m, respectively, i.e. a coverage area of between 32.3 m² and 38.5 m², based on the assumed width of the tunnel. The pipe was secured in two parallel grid beams and

water was fed from two directions using a fire hose with a diameter of 76 mm, connected to the public main via a pump. The system was fitted with a pressure transducer installed in the pipe between the two sprinklers and a flow meter was installed directly after the pump. The test set-up is shown in Figure 1.



Figure 1 The test set-up, with the platform that simulated the freight truck trailer and the sprinkler pipe positioned at the centerline of an imaginary tunnel. The water distribution was measured with trays positioned at the top of the platform as well as on the floor. Imaginary sidewalks and the outer boundary of the tunnel are drawn on the floor.

For each of the sprinkler test set-ups, a maximum water flow rate test was conducted, at the maximum possible pressure obtained with the pump. This test was conducted to visually verify that the water spray pattern remained unaffected and did not 'collapse' due to a high pressure. For these tests, the water distribution was not measured.

6 The sprinklers used in the tests

Two commercially available sprinklers were tested:

- Tyco model EC-25 (SIN TY9128) with a K-factor of 363. The sprinkler is an upright extended coverage sprinkler for warehouse protection and is available with a temperature rating of 74°C and 100°C. The sprinkler is fitted with a solder link that was removed prior the tests.
- Tyco model EC-14 (SIN TY6137) with a K-factor of 202. The sprinkler is an upright extended coverage sprinkler for use in light or ordinary hazard occupancies and is available with a temperature rating of either 57°C, 68°C, 79°C, 93°C or 141°C. The sprinkler is fitted with a glass bulb that was removed prior the tests.

The sprinklers are shown in Figure 2.



Figure 2 The Tyco model EC-25 (left) and Tyco model EC-14 extended coverage sprinklers used in parts of the tests.

During the test series, it was concluded that a wider water distribution pattern was desired. Therefore, the deflector of the Tyco model EC-25 sprinkler was modified by pressing the deflector between a piece of steel pipe and a steel plate. The intent was to provide a more flat profile of the deflector, see figure 3.



Figure 3 The modification of the deflector of the Tyco model EC-25 sprinkler (left) and the result (right). The modified sprinkler is shown to the left.

7 Results

The results are summarized below. All measurement data is given in Appendix 3.

7.1 Tyco model EC-25 sprinklers

The first series of tests was conducted using the Tyco model EC-25 sprinkler, refer to Table 5.

Table 5 A summary of the test results using the Tyco model EC-25 sprinkler.

Test	Sprinkler K-factor [metric]	Water pressure [bar]	Water flow rate per spr [l/min]	Spacing [m]	Nominal density [mm/min]	Mean density in the trays at the top of the platform [mm/min]	Mean density in the trays on the floor [mm/min]	Comments regarding the water distribution on and over the simulated trailer
1.1	363	0.56	266	4.6	7.5	1.4	9.2	Very little water in the trays, due to the narrow discharge pattern of the sprinkler.
1.2	363	0.56	266	4.2	8.2	3.1	9.5	Only water in the two rows of tray closest to the sprinklers. Mean for row 1 and 2: 6.3 mm/min
1.3	363	0.95	354	4.2	10.9	4.5	8.6	Only water in the two rows of tray closest to the sprinklers. Mean for row 1 and 2: 8.8 mm/min
1.4	363	4.3	760	4.2	23.5	-	-	The spray pattern remained unaffected by the higher pressure. It was observed that water did not reach beyond the simulated roof.

At a horizontal spacing of 4.6 m, very little water was collected in the trays at the top of the platform. When the spacing was reduced to 4.2 m, water was collected in the two rows of trays closest to the sprinklers, but no water reached the two furthest rows of trays. The mean density in the two rows of trays closest to the sprinklers was 6.3 mm/min, as compared to a nominal density of 8.2 mm/min. When the water pressure was increased from 0.56 bar to 0.95 bar, the mean density in these trays increased to 8.8 mm/min, as compared to a nominal density of 10.9 mm/min, refer to figures 4 and 5, respectively.



Figure 4 *Test 1.2:* The water spray pattern of the Tyco model EC-25 sprinkler at a pressure of 0.56 bar and a spacing of 4.2 m. The water flow rate per sprinkler was 266 liter/min.

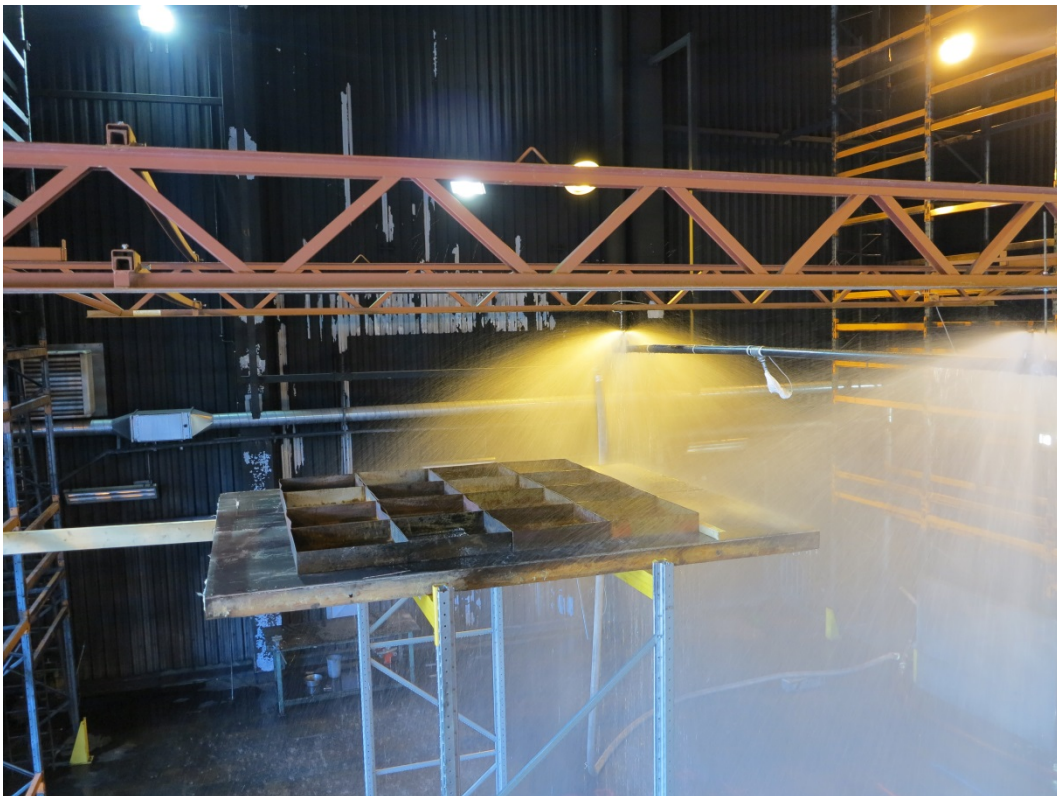


Figure 5 *Test 1.3:* The water spray pattern of the Tyco model EC-25 sprinkler at a pressure of 0.95 bar and a spacing of 4.2 m. The water flow rate per sprinkler was 354 liter/min.

For all three tests, the measured discharge density on the floor was reasonably similar to the nominal density.

When the water pressure was increased to the maximum limit of the pump it was visually verified that the spray pattern remained unaffected, refer to figure 6.



Figure 6 **Test 1.4:** The water spray pattern of the Tyco model EC-25 sprinkler at the maximum pressure of 4.2 bar obtained with the pump. The water flow rate per sprinkler was 760 liter/min.

7.2 Tyco model EC-14 sprinklers

The second series of tests was conducted using the Tyco model EC-14 sprinkler, refer to Table 6.

Table 6 A summary of the test results using the Tyco model EC-14 sprinkler.

Test	Sprinkler K-factor [metric]	Water pressure [bar]	Water flow rate per spr [l/min]	Spacing [m]	Nominal density [mm/min]	Mean density in the trays at the top of the platform [mm/min]	Mean density in the trays on the floor [mm/min]	Comments regarding the water distribution on and over the simulated trailer
2.1	202	6.8	522	4.2	16.1	-	-	The spray pattern remained unaffected by the higher pressure.
2.2	202	0.7	162	4.2	5.0	6.6	4.7	Water concentrated in the middle.
2.3	202	1.8	266	4.2	8.2	10.4	7.8	Relatively uniform distribution of water.
2.4	202	3.2	354	4.2	10.9	14.0	13.1	Uniform distribution of water.
2.5	202	0.7	162	5.0	4.2	5.5	4.6	Relatively uniform distribution of water.
2.6	202	3.2	354	5.0	9.2	13.2	12.8	Uniform distribution of water.

The design of this sprinkler results in a larger coverage area, which was verified by improved water distribution on the top of the platform. The mean desired density of 10 mm/min was recorded or exceeded at a pressure of 3.2 bar when the spacing was 4.2 m and at a pressure of 3.2 bar when the spacing was 5.0 m. Figures 7 and 8, respectively, shows the water distribution at the spacing of 5.0 m.



Figure 7 **Test 2.5:** The water spray pattern of the Tyco model EC-14 sprinkler at a pressure of 0.7 bar and a spacing of 5.0 m. The water flow rate per sprinkler was 162 liter/min.



Figure 8 **Test 2.6:** The water spray pattern of the Tyco model EC-14 sprinkler at a pressure of 3.2 bar and a spacing of 5.0 m. The water flow rate per sprinkler was 354 liter/min.

When the water pressure was increased to the maximum limit of the pump it was visually verified that the spray pattern remained unaffected, see figure 9.



Figure 9 Test 2.1: The water spray pattern of the Tyco model EC-14 sprinkler at the maximum pressure of 6.8 bar obtained with the pump. The water flow rate per sprinkler was 520 liter/min.

7.3 Modified Tyco model EC-25 sprinklers

The third series of tests was conducted using the modified Tyco EC-25 sprinkler, refer to Table 7.

Table 7 A summary of the test results using the modified Tyco model EC-25 sprinkler.

Test	Sprinkler K-factor [metric]	Water pressure [bar]	Water flow rate per spr [l/min]	Spacing [m]	Nominal density [mm/min]	Mean density in the trays at the top of the platform [mm/min]	Mean density in the trays on the floor [mm/min]	Comments regarding the water distribution on and over the simulated trailer
2.7	363	0.95	354	5.0	9.2	4.8	6.5	Only the first row had a good coverage of water.
2.8	363	0.95	354	4.2	10.9	9.0	5.7	Non-uniform distribution and water concentrated to rows 1 and 2.
2.9	363	0.56	266	4.2	8.2	5.9	4.9	Almost no water in rows 3 and 4. Mean for row 1 and 2: 10.8 mm/min
2.10	363	5.7	835	4.2	25.8	-	-	The spray pattern remained unaffected by the higher pressure.
2.11	363	5.2	485	4.2	15.0	11.6	7.3	Non-uniform distribution.

The first test was conducted using 5.0 m spacing, however, water did only reach to the first row of trays on the top. For the second test, the spacing was reduced to 4.2 m,

maintaining the water flow rate, but the water distribution was non-uniform and concentrated to rows 1 and 2.

For the third test, the 4.2 m spacing was kept and the water flow rate reduced. This did not increase the coverage area, but reduced the water density accordingly.

When the water pressure was increased to the maximum limit of the pump it was visually verified that the spray pattern remained unaffected. For the last test, the water density at a high pressure was measured, see figure 10.



Figure 10 *Test 2.8:* The water spray pattern of the modified Tyco model EC-25 sprinkler at a pressure of 0.95 bar and a spacing of 4.2 m. The water flow rate per sprinkler was 354 liter/min. The modification of the sprinkler deflector provided improved coverage on the top of the platform but a reduced discharge density on the floor.

7.4 Combined Tyco model EC-25 and EC-14 sprinklers

In the fourth series of tests, the model EC-14 and the EC-25 sprinklers were combined, refer to Table 8.

Table 8 A summary of the test results when combining the EC-14 and EC-25 sprinklers.

Test	Sprinkler K-factor [metric]	Water pressure [bar]	Total water flow rate [l/min]	Spacing [m]	Nominal density [mm/min]	Mean density in the trays at the top of the platform [mm/min]	Mean density in the trays on the floor [mm/min]	Comments regarding the water distribution on and over the simulated trailer
2.12	202+363 (modified)	1.7	708	4.2	10.9	10.4	6.2	A bit more water to the right.
2.13	202+363	1.7	708	4.2	10.9	8.4	8.6	Less water in row 4.

It should be noted that the total water flow rate is given in the table. The flow rate of the model EC-14 sprinkler was approximately 250 liter/min and flow rate of the model EC-25 sprinkler approximately 460 liter/min.

In the first test, the EC-14 sprinkler and the modified EC-25 sprinkler was combined which resulted in a mean density of 10.4 mm/min in the top trays. The combination of the EC-14 sprinkler and the non-modified EC-25 sprinkler resulted in less water in the top trays but more water in the trays at floor level. Figure 11 shows the combination of the EC-14 sprinkler and the non-modified EC-25 sprinkler.



Figure 11 **Test 2.13:** The water spray pattern of the combined non-modified Tyco model EC-25 (the furthest sprinkler) and Tyco model EC-14 sprinkler at a pressure of 1.7 bar and a spacing of 4.2 m. The total water flow rate was 708 liter/min.

8 Discussion

It should be understood that the tested extended coverage sprinklers represents sprinkler technology for other type of fire hazards than expected in the Muskö tunnel. The Tyco model EC-25, which is intended for warehouse protection, incorporates a larger K-factor that delivers large, high-momentum water droplets to penetrate the fire plume. The Tyco model EC-14 sprinkler is designed for light- or ordinary hazard applications, which allows for a larger coverage area and a lighter discharge directly under the sprinkler. The smaller K-factor and higher operating pressure of this sprinkler would results in relatively smaller water droplets.

The visual difference of the spray patterns of these sprinklers are well illustrated by the photos in the report.

8.1 Tyco model EC-25 sprinklers

The Tyco model EC-25 sprinkler is an upright extended coverage sprinkler for warehouse protection, with a maximum coverage area of 196 ft.² (18.2 m²). The sprinkler was tested at a spacing of 4.6 m and 4.2 m, respectively. At the larger spacing, very little water was collected in the trays at the top of the platform. When the spacing was reduced to 4.2 m, water was collected in the two rows of trays closest to the sprinklers, but relatively little water reached to the two rows of trays positioned further away on top of the simulated freight truck trailer.

For the Muskö tunnel, the sprinkler may be installed at a spacing of 4.2 m. For a design density of 10 mm/min, the operating pressure would be around 0.8 bar. A

reduction of the spacing to 4.0 m would reduce the required pressure to around 0.7 bar, which would meet the minimum pressure requirement of 0.5 bar. This reduction in spacing would to some degree improve the water coverage on the top of a freight truck trailer.

8.2 Tyco model EC-14 sprinklers

The Tyco model EC-14 sprinkler is intended for light- or ordinary hazard applications at a maximum coverage area of 400 ft² (37.2 m²). The sprinkler provided a uniform spray pattern where the mean density measured in trays at the top of the simulated freight truck trailer was reasonably similar to the mean density measured in the trays at the floor. It should, however, be noted that the discharge (not measured) directly under the sprinkler is less. The measured densities were comparable to the nominal density, i.e. the calculated density based on the water flow rate and area of coverage of the sprinkler. The results are in line with the wider spray pattern of this particular sprinkler.

For the Muskö tunnel, the sprinkler may be installed at a spacing of 5.0 m. For a design density of 10 mm/min, the operating pressure would be around 3.6 bar. A reduction of the spacing to 4.2 m would reduce the required pressure to around 2.6 bar.

8.3 Modified Tyco model EC-25 sprinklers

An attempt was made to increase the area of the coverage of the Tyco model EC-25 sprinkler by a modification of the deflector. A sprinkler spacing of 4.2 m was required to distribute water on the top of the simulated freight truck trailer. Compared to the non-modified sprinkler, the discharge density on the top increased with approximately a factor of 2, but less water was collected in the trays at the floor. To some extent, it is likely that the wider spray pattern would affect the downward momentum and water uniformity directly under the sprinkler.

8.4 Combined Tyco model EC-25 and EC-14 sprinklers

When combining the model EC-14 and the EC-25 sprinklers, improved water coverage on the top of the platform was achieved as compared to only using the Tyco model EC-25 sprinkler.

9 Conclusion

An investigation of suitable commercially available extended coverage sprinklers for use in the Muskö tunnel has been made. The objective is to install a single line of automatic sprinklers at the centerline of the ceiling. An adequate sprinkler coverage would require that sprinklers are positioned close to the peak of the ceiling. A short vertical distance from the sprinklers and the ceiling is also essential for proper thermal activation. These requirements are best met by the use of upright sprinklers.

A market study shows that K363 and K202 upright sprinklers are available from several sprinkler manufacturers and two sprinklers manufactured by Tyco Fire Protection Products were selected for water distribution tests. The mean width and

height of the Muskö tunnel was determined based on a laser scan of the tunnel and a generic cross-sectional drawing was established. Based on this generic drawing, a water distribution test set-up was designed to simulate a freight truck trailer positioned close to a sidewalk in the tunnel.

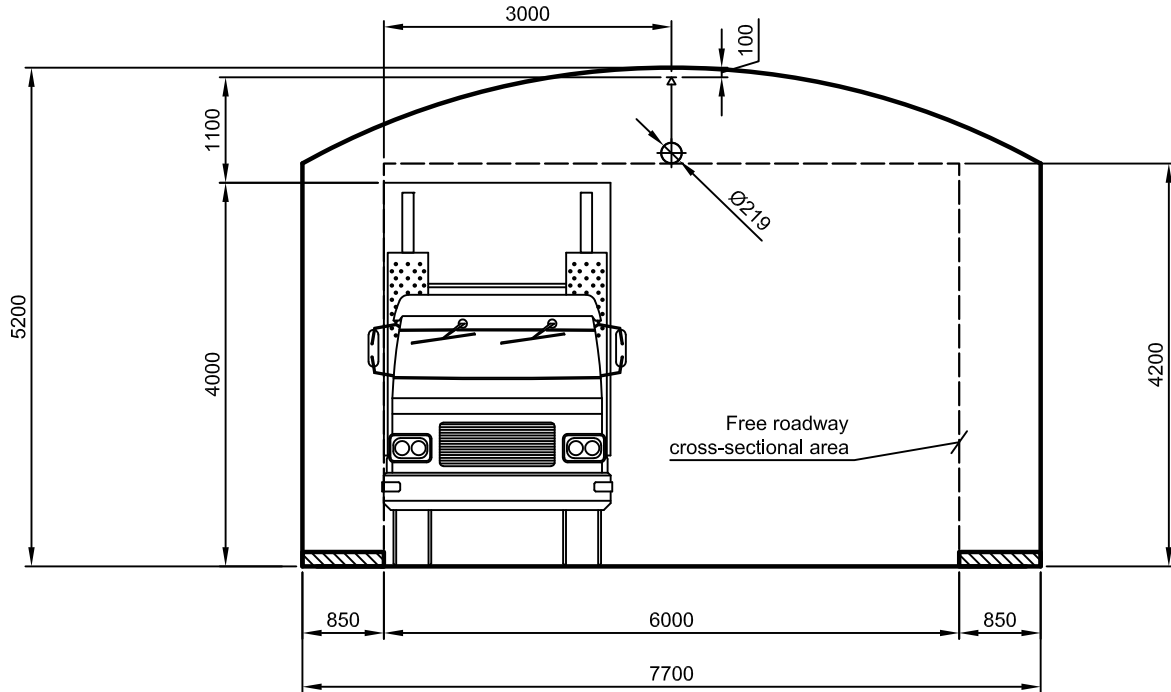
The tests show the tested K363 extended coverage upright sprinkler (Tyco model EC-25) require a sprinkler spacing of equal or less than 4.2 m in order to obtain some degree of water distribution on the top of a freight truck trailer positioned offset in the tunnel. For an actual installation, a sprinkler spacing of 4.0 m is recommended to account for the fact that full coverage of the freight truck trailer was not achieved at the tested 4.2 m spacing. A density of 10 mm/min requires an operating pressure of around 0.7 bar at this particular spacing.

The tested K202 extended coverage upright sprinkler (Tyco model EC-14) provided a wider water discharge pattern, with a proper water distribution on the top of a freight truck trailer positioned offset in the tunnel at a sprinkler spacing up to 5.0 m. For an actual installation, a K202 sprinkler designed for a density of 10 mm/min require an operating pressure of around 3.6 bar at this particular spacing.

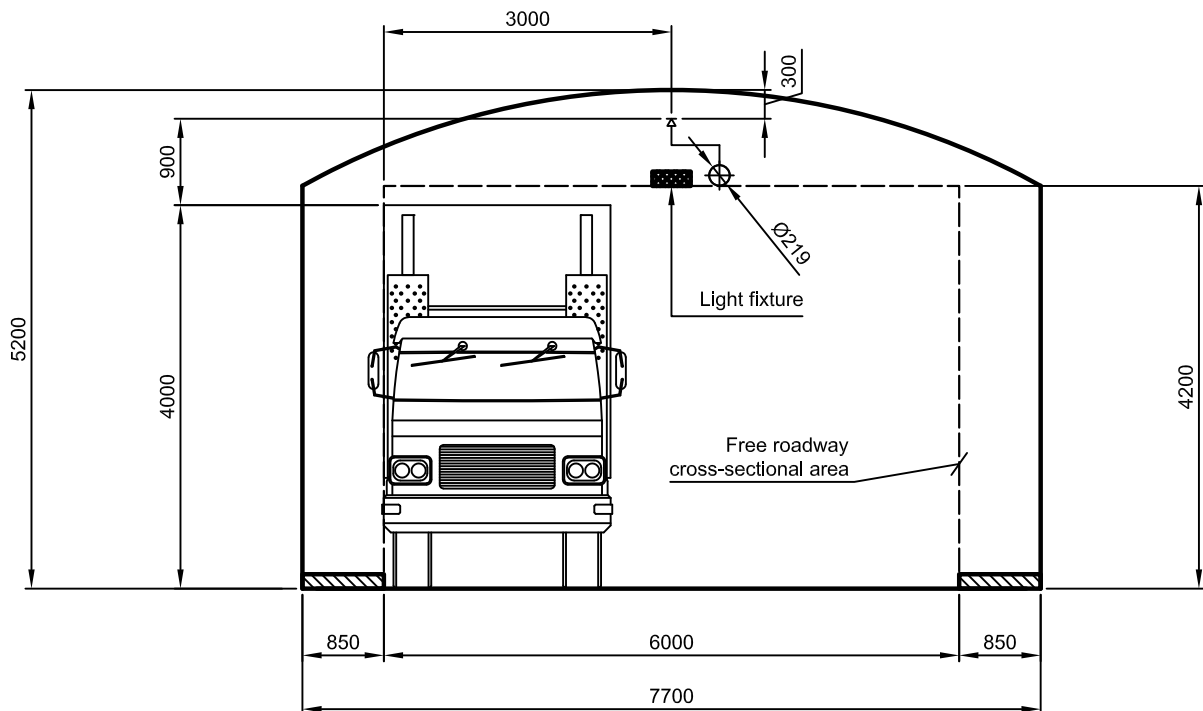
Additional tests indicate that a modification of the deflector of a K363 extended coverage upright sprinkler may provide a wider water discharge pattern, but the downward momentum and water uniformity directly under the sprinkler is affected.

10 References

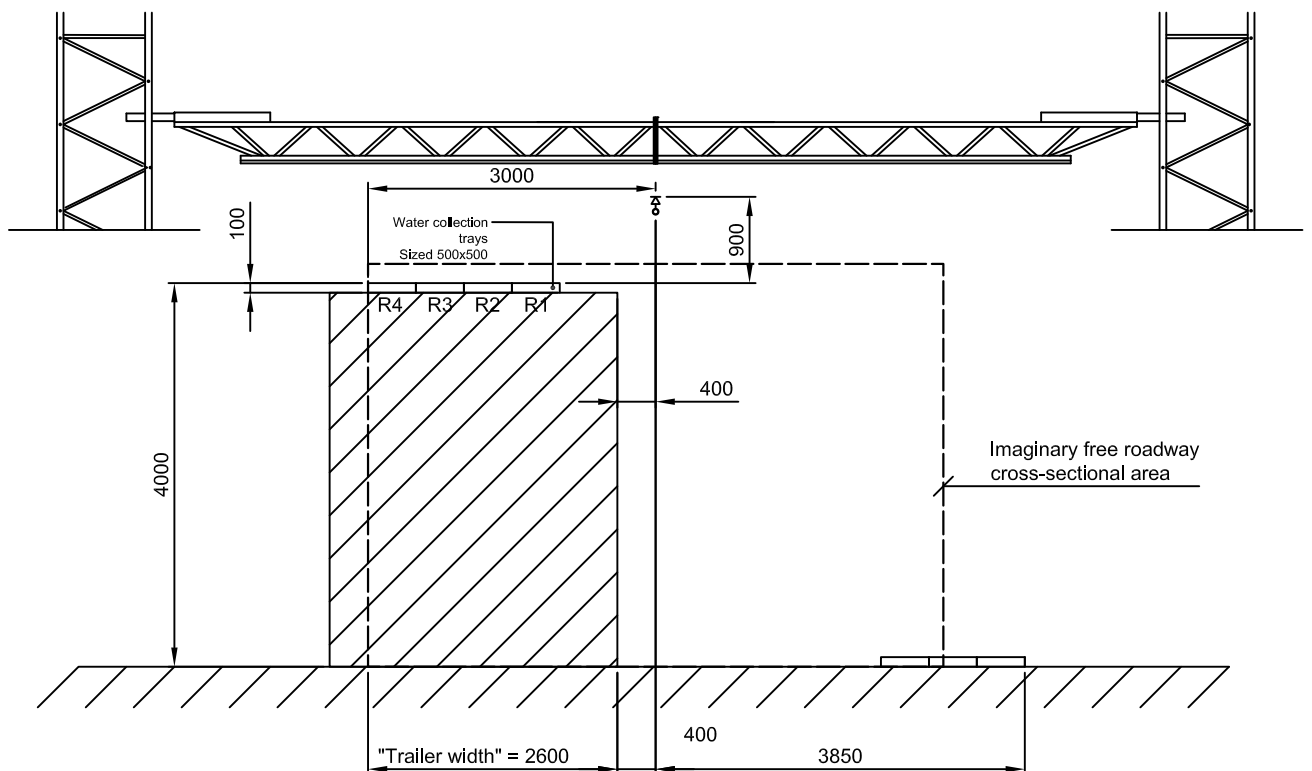
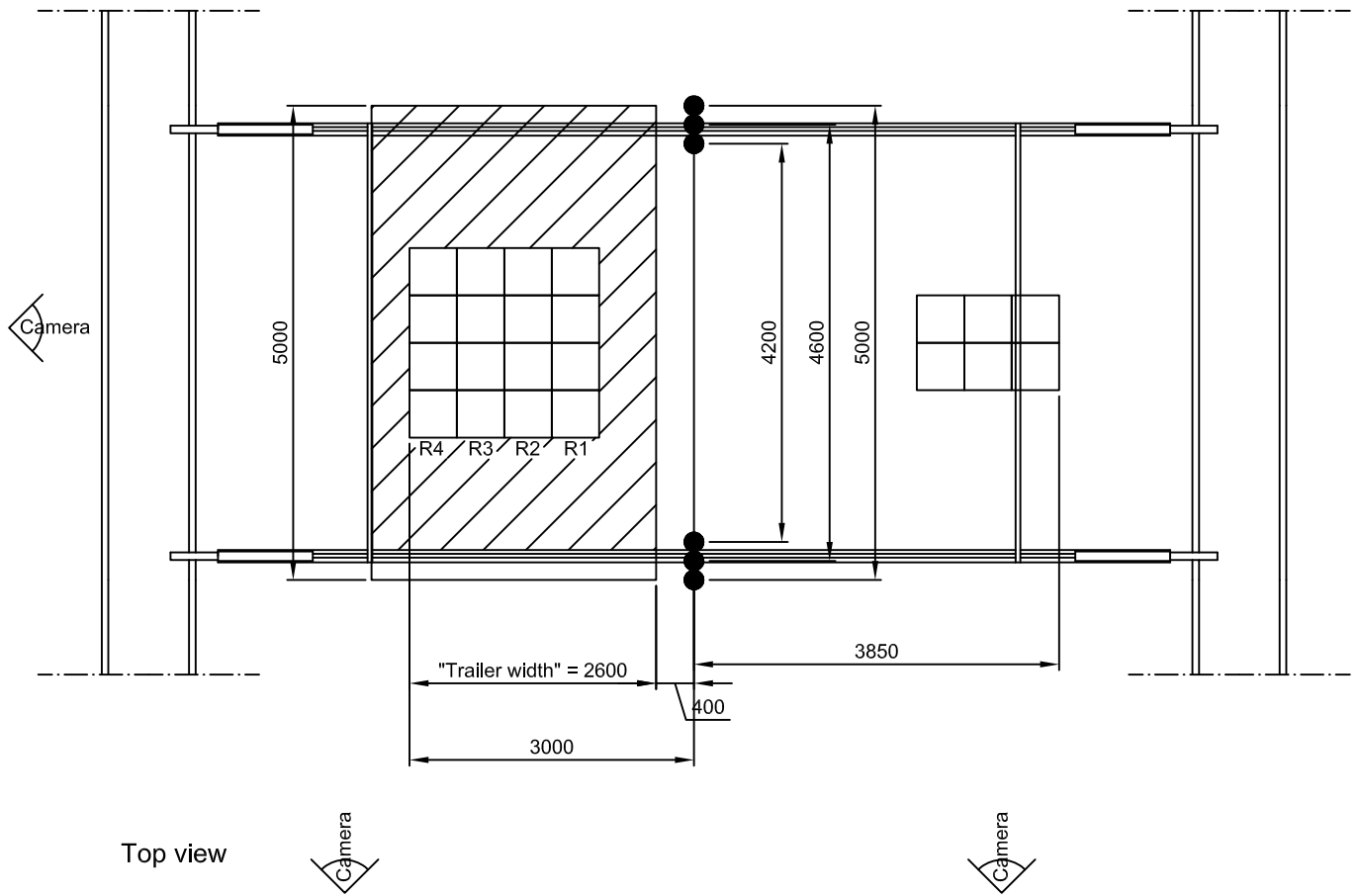
1. Li, Y.Z. and Ingason, H. "Analysis of Muskö tunnel fire flows with automatic sprinkler activation", RISE Report 2017:51, RISE Research Institute of Sweden, 2017



Ideal case. Sprinkler very close to the ceiling and sprinkler piping along the centreline of the tunnel.



Realistic case. Sprinkler further from the ceiling and sprinkler piping offset the centreline of the tunnel. Light fixture (obstruction) positioned along the centreline.



Appendix 3: Water distribution measurement data

Color pattern:

<2,4 mm/min
2,5 - 4,9 mm/min
5,0 - 9,9 mm/min
>10,0 mm/min

Tyco model EC-25 sprinklers

The first series of tests was conducted using the Tyco model EC-25 sprinkler.

Test 1:1 flow 266 l/min, spacing 4,6 m

Platform mm/min

0,0	0,0	0,0	0,0
0,0	0,0	0,0	0,0
1,9	0,2	0,3	1,0
9,3	0,5	1,4	8,4

Mean 1,4

Median 0,1

Floor mm/min

9,2	9,2
7,4	6,0
7,4	5,4

Mean 7,4

Median 7,4

Test 1:2 flow 266 l/min, spacing 4,2 m

Platform mm/min

0,0	0,0	0,0	0,0
0,0	0,0	0,0	0,0
3,4	2,5	1,9	4,0
15,8	2,9	2,8	16,9

Mean 3,1

Median 0,9

Floor mm/min

9,9	9,2
8,6	8,6
8,9	11,9

Mean 9,5

Median 9,1

Test 1:3 flow 354 l/min, spacing 4,2 m

Platform mm/min

0,0	0,0	0,0	0,0
0,1	0,3	0,5	0,5
5,4	7,1	6,6	6,4
18,3	4,3	3,4	19,4
Mean	4,5		
Median	2,0		

Floor mm/min

9,3	8,5
7,4	8,0
7,9	10,7
Medel	8,6
Median	8,3

Tyco model EC-14 sprinklers

The second series of tests was conducted using the Tyco model EC-14 sprinkler.

Test 2:2 flow 162 l/min, spacing 4,2 m

Platform mm/min

0,9	4,3	2,1	2,9
5,4	9,3	9,0	4,5
8,3	12,4	10,4	5,8
8,5	3,5	5,5	12,8
Medel:	6,6		
Median	5,6		

Floor mm/min

5,3	4,6
5,0	4,2
5,3	3,7
Medel	4,7
Median	4,8

Test 2:3 flow 266 l/min, spacing 4,2 m

Platform mm/min

6,4	9,9	8,3	8,6
11,1	14,6	14,1	11,1
10,5	15,1	13,6	8,1
10,1	3,8	6,4	14,0
Medel:	10,4		
Median	10,3		

Floor mm/min

7,0	8,3
7,8	8,1
8,5	6,9
Medel	7,8
Median	8,0

Test 2:4 flow 354 l/min, spacing 4,2 m

Platform mm/min

9,0	13,8	13,1	12,1
11,0	21,6	22,5	12,6
13,6	19,5	19,3	12,6
12,0	5,1	8,9	17,5

Medel: 14,0

Median 12,9

Floor mm/min

9,9	12,5
13,9	13,8
16,5	12,3

Medel 13,1

Median 13,1

Test 2:5 flow 162 l/min, spacing 5,0 m

Platform mm/min

4,3	2,1	3,0	2,1
7,1	8,4	6,6	4,5
7,4	6,4	7,3	7,0
4,3	4,0	7,3	6,5

Medel: 5,5

Median 6,4

Floor mm/min

4,5	4,5
4,6	4,3
6,1	3,4

Medel 4,6

Median 4,5

Test 2:6 flow 354 l/min, spacing 5,0 m

Platform mm/min

11,0	18,9	14,8	4,4
17,4	23,3	16,9	9,1
11,9	9,8	13,9	18,6
11,5	10,3	9,6	9,6

Medel: 13,2

Median 11,7

Floor mm/min

10,9	13,1
12,8	13,4
15,4	11,4

Medel 12,8

Median 12,9

Modified Tyco model EC-25 sprinklers

The third series of tests was conducted using the modified Tyco EC-25 sprinkler.

Test 2:7 flow 354 l/min, spacing 5,0 m

Platform mm/min

0,1	0,0	0,1	1,1
1,1	0,5	1,0	2,1
10,0	1,8	5,6	11,4
12,3	9,6	7,3	12,1

Medel: 4,8

Median 1,9

Floor mm/min

8,3	7,2
6,5	6,0
5,8	5,4

Medel 6,5

Median 6,3

Test 2:8 flow 354 l/min, spacing 4,2 m

Platform mm/min

0,1	0,0	2,4	9,1
3,4	3,9	2,6	12,9
8,1	27,1	12,5	5,1
17,0	9,0	18,8	11,8

Medel: 9,0

Median 8,6

Floor mm/min

6,3	5,5
5,8	5,0
5,9	5,6

Medel 5,7

Median 5,7

Test 2:9 flow 266 l/min, spacing 4,2 m

Platform mm/min

0,0	0,0	0,0	1,3
0,4	0,3	0,4	5,8
8,5	7,8	9,1	11,3
16,8	7,9	14,3	10,9

Medel: 5,9

Median 6,8

Floor mm/min

5,3	5,0
5,0	4,5
5,0	4,9

Medel 4,9

Median 5,0

Test 2:11 flow 485 l/min, spacing 4,2 m

Platform mm/min

0,6	0,0	5,6	13,8
4,3	13,9	3,5	15,9
12,0	39,5	16,0	5,9
21,6	11,3	5,9	15,4

Medel: 11,6

Median 11,6

Floor mm/min

7,6	7,0
7,8	6,0
7,3	8,0

Medel 7,3

Median 7,4

Combined Tyco model EC-25 and EC-14 sprinklers

In the fourth series of tests, the model EC-14 and the EC-25 sprinklers were combined.

Test 2:12 flow 354 l/min, spacing 4,2 m

Platform mm/min

2,1	2,4	5,5	10,3
5,0	11,6	9,5	14,3
6,9	16,8	20,6	9,4
14,6	9,1	10,5	17,6

Medel: 10,4

Median 9,9

Floor mm/min

8,4	6,3
6,3	5,8
4,9	6,0

Medel 6,2

Median 6,1

Test 2:13 flow 354 l/min, spacing 4,2 m

Platform mm/min

1,9	2,3	4,4	1,0
4,4	7,9	7,1	7,8
7,4	10,9	13,8	11,0
13,0	6,5	9,6	25,0

Medel: 8,4

Median 7,6

Floor mm/min

10,3	10,0
8,3	8,3
5,9	9,1

Medel 8,6

Median 8,7

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Telefon: 010-516 50 00
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