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# Deliverable D10.1

# Description of the development of automatic first response fire protection systems for ro-ro spaces on vehicle carriers

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# Abstract

Ro-ro spaces on vehicle carriers are typically protected by a total-flooding Carbon Dioxide system. Due to its toxicity, there could be a considerable time delay from the start of a fire until the Carbon Dioxide system is discharged, which can cause fire damage and jeopardize the performance of the system. This report summarises the development, theoretical evaluation, and preliminary assessment of supplementary water-based **Automatic first response fire protection systems.** The system should automatically activate at an early stage of the fire and limit the size of a vehicle fire to allow more time to fight the fire safely manually or to safely evacuate the space prior to discharging the Carbon Dioxide system.

The starting point for the work was a comprehensive literature review, identifying relevant standards and information in those standards that are applicable to the design of an automatic fire sprinkler and Compressed Air Foam System (CAFS). The literature review did also summarize fire tests and field experience with automatic sprinkler and water spray systems.

Three primary systems were studied in detail, a dry-pipe sprinkler system utilizing automatic sprinklers, an automatic deluge water spray system and a deluge CAFS using rotating nozzles. For the first system, individual sprinklers are activated by the heat from the fire, the latter systems require a fire detection system for activation. The system development work included small- and intermediate-scale tests. Small-scale CAFS tests were conducted to establish the most efficient foam agent, the admixture concentration, and foam expansion ratio. Intermediate-scale fire tests were conducted with a water spray system and a prototype CAFS to determine the fire suppression performance. Large-scale system validation fire tests were conducted. The results proved that suggested system solutions provided the intended fire control of vehicles in a simulated ro-ro vehicle space.

The work has resulted in detailed design and installation guidelines (as given in the Annex of the report), where additional systems are recognized. These guidelines may be part of regulatory requirements or be adopted on a voluntary basis.

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# Involved partners

| No. | Short name | Full name of Partner | Name and contact info of persons involved |
|---|---|---|---|
| 1 | RISE | RISE Research Institutes of Sweden AB | Magnus Arvidson (magnus.arvidson@ri.se) |
| 5 | MAR | Marioff Corporation Oy | Antti Virkajärvi (antti.virkajarvi@carrier.com), Maarit Tuomisaari (maarit.tuomisaari@carrier.com) |
| 6 | UNF | Unifire AB | Mattias Eggert (mattias@unifire.se), Roger James (roger@unifire.com) |
| 25 | F4M | FiFi4Marine BV | Cor Meedendorp (c.meedendorp@fifi4marine.com), Martijn Teela (m.teela@fifi4marine.com) |

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# Content

# 1 Executive summary

This report summarises the development, theoretical evaluation, and preliminary assessment of water-based, local-application fire-extinguishing system solutions for ro-ro spaces on vehicle carriers. LASH FIRE adopted the terminology **Automatic first response fire protection systems** as a proper term to describe the systems that were developed.

## Problem definition

Ro-ro spaces on vehicle carriers are typically protected by a total-flooding Carbon Dioxide system. Such systems have many benefits. However, due to its toxicity, there could be a considerable time delay from the start of a fire until the Carbon Dioxide system is discharged, to confirm that no crew members are present in the protected spaces. This delay time can cause considerably fire damage and jeopardize the performance of the system.

The objective under Action 10-A is to develop and demonstrate a low-cost, low-weight and high-efficiency automatic water-based fire protection system alternatives for closed ro-ro spaces on vehicle carriers. The systems should be regarded as supplementary to the Carbon Dioxide system and should automatically activate at an early stage of the fire and limit the size of a vehicle fire. This would allow more time to fight the fire safely manually or to safely evacuate the space and discharge the Carbon Dioxide system.

## Technical approach

The development work was partly based on a comprehensive literature review. This review aimed at identifying relevant standards and information in those standards that are applicable to the design of an automatic fire sprinkler and Compressed Air Foam Systems (CAFS) for the fire hazards found in ro-ro spaces on vehicle carriers. The literature review also summarized fire tests and field experience with automatic sprinkler and water spray systems. The information provides an indication on the design of such systems that complements the information that was found in relevant standards.

Three primary systems were studied in detail, a dry-pipe sprinkler system utilizing automatic sprinklers, a deluge water spray system and a deluge system using rotating CAFS nozzles. For the first system, individual sprinklers are activated by the heat from the fire, the latter systems require a fire detection system for activation. The development included small and intermediate-scale tests. Small-scale CAFS tests were conducted to establish the most efficient foam agent, the admixture concentration, and foam expansion ratio. Intermediate-scale fire tests were conducted with a water spray system and a prototype CAFS to determine the fire suppression performance. Large-scale system validation fire tests were conducted.

An installation cost assessment and an assessment of the annual cost for the inspections, testing and maintenance of the systems were made, assuming an installation on the generic vehicle carrier of the project, MS Torrens.

## Results and achievements

Automatic fire sprinkler systems are used for fire hazards that are similar to those found on vehicle carriers, as car parking garages and facilities for manufacturing and assembly of boats, highway trailers and trucks, boxcars, mobile homes, or similar metal vehicles with combustible interiors. A fire in such facilities is characterised by a moderate to substantial amounts of flammable or combustible material and liquids where shielding of combustibles is extensive. Fire test data and field experience with sprinklers in parking garages and from fires within ro-ro spaces on ro-pax vessels, vehicle carriers and general ro-ro cargo vessels was found. This information provides a good understanding of how to design and install sprinkler and water spray systems. Much less information was found for CAFS, simply because these systems have not been used for similar fire hazards.

These cost assessments indicate that an automatic dry-pipe sprinkler system is the least expensive to install and operate. This system is also the system with the least overall system weight. The CAFS is the most expensive system to install and maintain serviceable, it is also the system with the highest total weight. Two system solutions were selected for the large-scale validation tests. These tests proved that the system solutions provided the intended fire control of vehicle fires in a simulated ro-ro vehicle space.

The work has resulted in design and installation guidelines, where additional systems are recognized.

## Contribution to LASH FIRE objectives

The overall objective of WP10 is to provide for efficient, effective, and safe fire extinguishment in ro-ro spaces, regardless of the type or size space and with less crew dependence. The objective of Action 10-A is to develop and demonstrate feasible (cost and weight) high-efficient water-based local application fire-extinguishing system solutions for closed ro-ro spaces.

The objective was met in that several alternative system solutions were developed for the protection of ro-ro spaces on vehicle carriers and these solutions were studied in detail regarding performance, weight, electrical power requirements, water demand, installation cost and the cost to maintain serviceable.

## Exploitation and implementation

Three specific system solutions were studied in detail; however, the design and installation guidelines that were written provide additional fire protection system options. As an example, a pre-action system will prevent the probability for unintentional system activations, to meet the concern among ship operators related to unintentional activations (no fire) or water leakage with potential damage to the cargo.

Regulatory and standardisation bodies or classification societies may include the design and installation guidelines in their regulatory framework, to be used either on a voluntary basis or as a requirement.

# 2 List of symbols and abbreviations

| | |
|---|---|
| CAF | Compressed Air Foam |
| CAFS | Compressed Air Foam Systems |
| CEA | The European Insurance and Reinsurance Federation |
| CEU | Car Equivalent Unit, a unit of measurement indicating the car carrying capacity of a vessel |
| CPVC | Chlorinated Polyvinyl Chloride |
| EUR | Marking on load pallets as specified by the European Pallet Association |
| FSS | International Code for Fire Safety Systems |
| F4M | FiFi4Marine B.V. (partner of WP10) |
| IMO | International Maritime Organization |
| ISO | International Organization for Standardization |
| NFPA | National Fire Protection Association |
| MAR | Marioff Corporation OY (partner of WP10) |
| MIC | Microbiologically Influenced Corrosion |
| PEX | Cross-linked polyethylene |
| RISE | RISE Research Institutes of Sweden |
| RTI | Response Time Index |
| UNF | Unifire AB (partner of WP10) |
| VdS | VdS Schadenverhütung GmbH, a subsidiary of the German Insurance Association |

# 3 Introduction

Main author of the chapter: Magnus Arvidson, RISE.

## 3.1 Fixed-installed fire-fighting systems on vehicle carriers

Ro-ro spaces on vehicle carriers are typically protected by a total-flooding Carbon Dioxide system. Such systems have many benefits. If properly designed, it acts as an effective fire suppressant, Carbon Dioxide is also colourless, odourless, electrically non-conductive, and leaves no residue. But there is one important drawback. If exposed to humans, it does not only cause asphyxiation by hypoxia but also acts as a toxicant. At the (high) concentrations required for fire extinguishment, Carbon Dioxide is acute lethal. Due to its toxicity, there could be a considerable time delay from the start of a fire until the Carbon Dioxide system is discharged, as it needs to be confirmed that there are no crew members inside the protected space. This delay time can cause considerably fire damage and jeopardize the performance of the system.

## 3.2 Experience from fires on vehicle carriers

This section contains a short review of three actual fires, compiled from accident investigation reports, where the total-flooding Carbon Dioxide system was activated under fire conditions.

### 3.2.1 The fire onboard Courage in 2015

A fire started on June 2, 2015, in the cargo hold of the ro-ro vehicle carrier Courage (built in 1991) when on route from Bremerhaven, Germany, to Southampton, United Kingdom [1]. The likely cause of the fire was electrical arcing in the automatic braking system module of a 2002 Ford Escape sport utility vehicle (SUV). It was found that this particular make and model was the subject of recalls in 2007 and 2010 due to non-crash-related fires or thermal events in the vehicles' engine compartment. The owner had been overseas for a number of years and was not aware of the recalls. The fire was extinguished by the operation of the fixed-installed Carbon Dioxide system. No persons were injured but based on the extent of fire damage, the owner of the ship decided to scrap it.

**Comments:** The extensive fire damage illustrates how fast a fire that starts small (electrical arcing) could spread to an extent that results in severe damage, despite the activation of the fixed-installed Carbon Dioxide system.

### 3.2.2 The fire onboard Honor in 2017

On February 24, 2017, a fire started in the upper vehicle deck on the ro-ro vehicle carrier Honor (built in 1996) when on route from Southampton, England, to Baltimore, USA [2]. The fire was extinguished by the operation of the fixed Carbon Dioxide system. One crew member was injured during the fire-fighting efforts and the fire damage was extensive to the cargo hold and the cargo of about 5,000 vehicles.

However, it was concluded that the crew's appropriate and effective use of the Carbon Dioxide system, along with boundary cooling, likely prevented the spread of the fire and reduced the damage. The likely cause of the fire was a fault in the starter motor solenoid in one of the personally owned vehicles in shipment. Preliminary testing of this scenario confirmed that a fault within the solenoid could cause ignition of the insulation and covering on the adjacent wiring.

**Comments:** Another example of an electrical cause of fire and extensive fire damage on a vehicle carrier, despite the activation of the fixed-installed Carbon Dioxide system.

### 3.2.3 The fire onboard Höegh Xiamen in 2020

The vehicle carrier Höegh Xiamen was built in 2010, designed for unrestricted oceangoing worldwide service with a capacity of 4,900 vehicles. The ship caught fire at about 15:30 on June 4, 2020, while in Jacksonville, Florida, USA during loading operations [3]. The fire was discovered by crew members on deck 8, which had been loaded with used vehicles. It was also observed that flaming material was dripping to deck 7 through holes used for lashing on deck 8, i.e., the fire was spreading from the deck with the initial fire to the deck below.

The crew members tried to fight the fire but had to retreat due to heavy smoke. Shoreside fire department teams from the Jacksonville Fire and Rescue Department arrived at the scene at 16:03. The captain, after consulting with the fire department, decided to discharge the Carbon Dioxide system into decks 7 and 8. These two decks covered one (Zone 3) of the five fire zones. Thereafter the crew evacuated from the ship. The fire-fighters monitored the fire using a thermal imaging camera and judged that the fire was continuing to spread despite the discharge of Carbon Dioxide. Therefore, they decided to enter decks 7 and 8 from the port aft stairwell. Nine fire-fighters were subsequently injured, five of them seriously, in an explosion. The “explosion” occurred about the same time that the fire-fighters opened an exhaust in the aft ventilation trunks located near the port aft stairwell. Deck 9 likely contained a rich atmosphere of heated flammable vapours (thick, black smoke had been observed), which rapidly combusted when fresh air was introduced via the opening of the ventilation trunks for decks 9 and 10/11. The fire-fighters who were in the stairwell and on deck 5 near the stairwell during the over-pressurization event described a violent rush of extremely hot air. Consequently, a defensive strategy was adopted, cooling external exposed surfaces of the ship with fire monitors and fire hoses.

The investigation showed that the fire detection was delayed as there were no procedures to reduce the time that the fire detection system remained deactivated after loading. The shoreside fire department’s response was also delayed because the master of the ship did not have immediately available contact information.

The fire burned for over a week and resulted in a total loss of the vessel and its cargo of 2,420 used vehicles. Total damages are estimated at $40 million. After salvage operations were completed, the vessel was towed to Turkey to be recycled. The investigation after the fire concluded that many of the vehicles had batteries that were not disconnected and secured in accordance with established procedures. It is likely that the fire was caused by an electrical arc or component fault in one of the used vehicles.

**Comments:** Another example of an electrical cause of fire and extensive fire damage on a vehicle carrier. The fire was not fully extinguished by the discharge of Carbon Dioxide and an “explosion” occurred during manual fire-fighting operations that injured nine firefighters, five of them seriously. This is yet an illustration that shows that time is crucial and that manual fire-fighting operations are hazardous.

## 3.3 The objective of Action 10-A in the LASH FIRE project

The objective under Action 10-A is to develop and demonstrate low-cost, low-weight and high-efficiency (automatic) water-based local application fire-extinguishing solutions for closed ro-ro spaces on vehicle carriers. Development testing and validation testing of at least two technologies are required. Additionally, an installation cost assessment of the system solutions shall be made.

The water-based fire protection systems should be regarded as supplementary to the total-flooding Carbon Dioxide system. The system should activate automatically at an early stage of the fire and limit the size of a vehicle fire. This would allow more time to manually fight the fire or to safely evacuate the space and discharge the Carbon Dioxide system.

The term “fire-extinguishing” is adopted from IMO and is misleading because full fire extinguishment cannot be expected. The term “local application” is also misleading because the fire hazards on closed ro-ro spaces are not within a specific area of the space, in contrary to for example machinery spaces where areas of higher fire risk can be identified. However, it is envisaged that water is applied over the area with the fire. It is suggested that the following terminology be used to describe what is intended to be developed: **Automatic first response fire protection systems.**

Three water-based system alternatives were studied in detail:

- A dry-pipe system using automatic sprinklers.
- An automatic deluge water spray system.
- An automatic deluge CAFS.

A dry-pipe sprinkler system uses automatic sprinklers that are attached to a piping system containing air or nitrogen under pressure. When one or more sprinklers operate by the heat from the fire, the pressure drop opens a dry-pipe valve, and the water flows into the piping system and out of the opened sprinklers. There is typically a maximum delay time in the order of 45 s to 60 s from the activation of the first sprinklers to the discharge of water.

A deluge water spray system has a fixed pipe system connected to a water supply and is equipped with open water spray nozzles designed to provide a specific water discharge and distribution over the protected surfaces or area. Automatic activation requires a separate fire detection system that is installed in the deluge section protection areas. Manual activation is made by physical operation of the deluge valve but may be electronically remote controlled from another location. There is a time delay from the operation of the deluge valve until water is discharged from the water spray nozzles. From an installation aspect, there is a balance/conflict between the number of deluge valves and the size of the deluge zones.

A Compressed Air Foam System (CAFS) is designed similar to a foam-water deluge system, i.e., a system employing open discharge devices, which are attached to a piping system that is connected to a water supply through a valve that is opened by the operation of a detection system installed in the same areas as the discharge devices. The difference as compared to a traditional foam system is, however, that the foam is generated by the combination of compressed air, water and foam concentrate in the right proportions and finished foam (rather than a mixture of water and foam concentrate) is delivered through the fixed piping system to the discharge devices.

These three systems were studied in detail and are discussed in terms of choice of sprinklers or nozzles, nozzle coverage areas, system flow rates, power demand, type of foam, etc., but other system alternatives are also discussed, such as pre-action systems and systems with electronically activated sprinklers.

Water mist fire protection systems may be used as an alternative to traditional deluge water spray systems (commonly denoted ‘Drencher systems’) on ro-pax vessels. Water mist technology was not included as none of the approached manufacturers were willing to participate in the project to develop a water mist system for evaluation as an Automatic first response fire protection system.

# 4 Identification of relevant standards for fixed-installed sprinkler systems and CAFS

Main author: Magnus Arvidson, RISE.

## 4.1 General

This section summarises a literature review aimed at identifying relevant standards and information in those standards that are applicable to the design of a sprinkler system and CAFS in closed ro-ro spaces on vehicle carriers. The applicable information of these standards is used elsewhere in the report.

## 4.2 Automatic sprinkler systems

Previous design and installation recommendations in IMO Resolution A.123(V) published in 1967 [4] did only permit the use of manually activated deluge water spray systems. With the introduction of MSC.1/Circ. 1272 [5] in 2008, alternative (to systems designed in accordance with IMO Resolution A.123(V)) systems were allowed to be automatically activated. The use of automatic sprinklers and deluge water spray systems is recognized in the design and installation recommendations in MSC.1/Circ. 1430 [6] as amended in [7]. The recommendations in MSC.1/Circ. 1430 were used as the starting point for the work described in this report. The recommendations cover aspects as the system type, positioning of sprinklers, design densities and operating areas.

The 2019 edition of NFPA 13 [8] and EN 12845:2015+A1:2019 [9] provide the minimum requirements for the design and installation of automatic sprinkler systems. They offer a range of sprinkler system approaches, design development alternatives and component options. These standards were consulted and all information applicable for the protection of closed ro-ro spaces was considered.

The 2019 edition of FM DS 3-26 [10] by FM Global provide recommendations for fire protection using automatic sprinkler systems in non-storage occupancies, i.e., an area or building consisting of equipment, processes, and/or materials that are not maintained in a storage arrangement. Three different hazard categories are used in the document, HC-1, HC-2 and HC-3. Several of the occupancies listed in Appendix C of the document are relevant for the fire hazards found in closed ro-ro spaces on vehicle carriers.

The 2018 edition of FM DS 2-0 [11] by FM Global contains recommendations for the installation of automatic sprinkler systems. For example, the document provides guidance on components used as part of a system, the response time of sprinklers to a fire and the distribution of sprinkler discharge to a fire area. This document does not provide guidance on the designs for sprinkler systems, system maintenance requirements and fire detection systems. This is information is given in other data sheets by FM Global.

Protection of sprinkler system piping from internal corrosion is essential to maintain a long service life of a system. The 2018 edition of FM DS 2-1 [12] by FM Global contains recommendations that are intended to address the prevention and control of corrosion in automatic sprinkler system piping.

## 4.3 Deluge water spray systems

For deluge water spray systems, the recommendations of the 2017 edition of NFPA 15 [13] was considered. This standard provides the minimum requirements for the design, installation, and system acceptance testing of fixed water spray systems. The standard does not list or describe hazards or applications that are directly applicable for the fire hazards on closed ro-ro spaces on vehicle carriers. However, the standard contains installation recommendations that are useful.

## 4.4 Compressed Air Foam Systems (CAFS)

The 2016 edition of NFPA 11 [14] covers the design, installation, operation, testing, and maintenance of low-, medium-, and high-expansion and compressed air foam systems (CAFS) for fire protection. It is not the intent of the standard to specify where foam protection is required.

# 5 Relevant fire tests and field experience with automatic sprinkler and water spray systems

Main author: Magnus Arvidson, RISE.

## 5.1 General

This section summarises fire tests and field experience with automatic sprinkler and water spray systems. The information provides an indication on the design of such systems that complements the information that is found in relevant standards.

## 5.2 Parking garage fire tests at RISE

VdS Schadenverhütung has published several fire test methods for water mist fire protection systems. One of these is a fire test method for parking garages [15]. The method simulates real conditions in a parking garage. The cars used in the tests are scrapped cars but must be intact with entire windscreens, etc. The cars' fuel tanks must be emptied of fuel. Three cars are parked side by side at a horizontal distance of 60 cm, under a suspended ceiling. The ceiling height should be in accordance with the manufacturers design and installation instructions and should reflect the maximum height at which approval is sought. The fire is started with two trays of heptane that are placed under the middle car and ignited. The tested water mist system shall be proven to have an efficiency comparable to traditional sprinklers. Therefore, reference fire tests are first performed with traditional sprinklers where the temperature at the ceiling above the fire is measured with thermocouples. The temperature is also measured with Plate Thermometers positioned in front of and behind the parked cars, which along with a visual assessment gives an indication of the risk of fire spreading. In fire tests carried out at RISE, the surface temperatures of the bodies on the cars on both sides of the middle car are measured. The middle car is placed so that it is either directly under a sprinkler or between four sprinklers. The fire test set-up that gives the worst results of these set-ups must be repeated.

The traditional sprinkler system, which thus constitutes the reference system, is installed with automatic sprinklers on horizontal spacing of 3,5 m by 3,5 m. The sprinklers should be standard-orifice, 68 °C, special-response sprinklers, i.e., a sprinkler having a 4 mm glass bulb. The system is designed for a water discharge density of 6,5 mm/min, which corresponds to 80 l/min per sprinkler.

The test results from assignment tests at RISE are usually proprietary, but some test results have been published with permission from the client [16]. For these tests, the ceiling height was 3,0 m and the cars were manufactured in the late 1990s. The reference tests with the traditional sprinklers showed good effectiveness. Since the fire is in principle completely hidden for direct water application of the body of the car, the primary effect is in preventing the spread of fire and to reduce the gas temperature at the ceiling. Figure 1 shows one of the fire tests, just prior the activation of the first sprinkler and about five minutes later.


*Figure 1 Automatic sprinkler tests at RISE simulating a passenger car fire in an underground parking garage.*

Sheathed thermocouples (Ø=1 mm) were used to measure ceiling gas temperatures above the centremost of the cars, in order to determine the thermal exposure of the fire on the ceiling. One thermocouple was positioned directly above the centre point of the car and four additional thermocouples at a 1,2 m radius. The thermocouples were installed 75 mm below the ceiling. The average gas temperature at the ceiling was at most around 150 °C. Figure 2 shows the data.

The surface temperatures on the part of the body facing the centremost car on both target cars were measured with four thermocouples welded to the steel body. A small area of the lacquer of the body was sanded before the thermocouple was welded to the steel and the area was painted black afterwards. One thermocouple was installed at the front and back fender respectively, directly above the centre point of the wheel. One thermocouple was installed on the front and one on the back door. The horizontal distance between the thermocouples on the front fender and front door was 750 mm. The horizontal distance between the thermocouples on the back fender and the back door was 750 mm. All thermocouples were installed at a vertical distance of 750 mm above the floor. The average surface temperature at the bodies of the adjacent cars peaked at around 100 °C. Figure 2 shows the data.

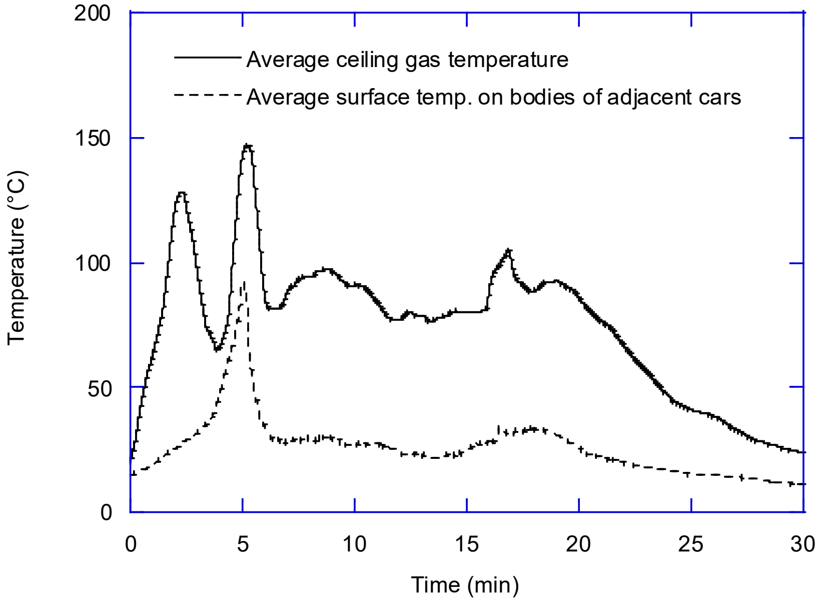



*Figure 2 The average ceiling gas and ceiling surface temperature at the bodies of the adjacent cars during an automatic sprinkler tests at RISE simulating a passenger car fire in a parking garage.*

## 5.3 Parking garage fire tests at BRE

In 2007 and 2008, BRE in United Kingdom conducted several multi-vehicle, full car fire tests in a parking garage mock-up having a floor area of 12 m by 6 m and ceiling height of 2,9 m [17]. All of the cars were used and were selected on the basis of age, size and availability and were either less than five years old, or, if older, of a current model. Gas struts, air bags and other pressurised or pyrotechnic components were left in place, but their air conditioning gas was removed. For each of cars, the fuel tank contained 20 l of fuel. Test 2 of the test programme that included four tests that involved car park enclosure tests was conducted with automatic sprinklers. This test included a 2000 Renault Grand Espace, a 2002 Seat Ibiza S and a 2002 Land Rover Freelander. The test set-up allowed collection of combustion gases and the measurement of the heat release rate.

The sprinkler system was designed and installed as representative of a system in place in a typical multi-storey or underground car park accordance with OH2 of BS EN 12845:2004 [18], i.e., a design density of 5 mm/min and a sprinkler coverage of 12 m$^2$ per sprinkler. The sprinkler spacing along the branch lines (parallel with the cars) was 3,0 m and the spacing perpendicular to the cars 4,0 m. BS EN 12845 provides the minimum requirements for the design, installation, and maintenance of fixed fire sprinklers in buildings and industrial plants.

The first sprinkler activated after 4 minutes, but the fire continued to grow, and eventually (after 55 minutes) broke out and reached a peak of around 7 MW. All six installed sprinklers operated. The fire did not spread to the adjacent cars. The gas temperature at the ceiling peaked at almost 800 °C.

The actual discharge density was higher than the design density. Table 1 shows the activation times of the sprinklers, the measured flow rates, and the corresponding calculated discharge densities.

*Table 1 The activation times of the sprinklers, the measured flow rates and the corresponding calculated discharge densities in the parking garage fire test conducted by BRE Global [17].*

| Number of activated sprinklers | Activation time (min:s) | Measured water flow rate (l/min) | Sprinkler coverage area (m$^2$) | Calculated discharge density (mm/min) |
|---|---|---|---|---|
| 1 | 04:02 | 115 | 12 | 9,6 |
| 2 | 04:10 | 223 | 24 | 9,3 |
| 3 and 4 | 42:20 and 42:42 | 395 | 48 | 8,3 |
| 5 and 6 | 45:02 and 45:26 | 510 | 72 | 7,1 |

The report concludes that the effectiveness of sprinklers in limiting a fire to a single car was demonstrated, which supports findings reported verbally by the fire and rescue service. Sprinklers clearly assist in reducing structural damage, but their limitations with regards to the influence on the severity of the fire in a car was also shown.

In 2009, BRE did also conduct a single automatic sprinkler test using two-car stacker configuration [19]. Automatic sprinklers were positioned both at the ceiling above the stacker and above the car at the lower position. The lower car was a 1992 Landrover Discover with a diesel engine and the upper car a Ford Mondeo hatchback with a petrol engine. The fuel tanks of the cars were filled with 20 l of fuel. Four automatic sprinklers were installed at each ‘corner’ above the cars. The fire was ignited on the seat of the car at the lower position, with the driver’s window open. After 13:06 [min:s], a sprinkler at the ceiling activated, followed by a second sprinkler at 14:41 [min:s]. At 22:47 [min:s] a third (and final) sprinkler at the low level activated. The water flow to the system was shut-off after one hour. It was concluded that automatic sprinklers at the ceiling contained the fire to the lower car, allowed some spread to the above vehicle, but prevented it from becoming fully involved.

## 5.4 Field experience with automatic sprinklers

A total of 3 096 fires in car were reported United Kingdom during the years 1994-2005 [17]. 1 592 (51,4 %) of the fires started in a vehicle. In 162 of these fires, an automatic sprinkler system was present resulting in the following:

- In 16 of the fires (9,9 %), the sprinkler system activated and extinguished the fire.
- In 84 fires (51,9 %), the sprinkler system activated and contained/controlled the fire.
- In one fire (0,6 %), the sprinkler system activated but the fire was not contained/controlled.
- In 61 fires (37,6 %), the sprinkler system did not activate, probably as the fire was too small or that the fire was extinguished by fire department actions.

In the 101 fires (162 – 61 = 101) where the sprinkler system activated, it can be concluded that it extinguished or contained the fire in 100 cases (16 + 84 = 100).

An electric vehicle fire in a car park in the Netherlands was started deliberately on September 1, 2020. The sprinkler system controlled the fire, which did not spread to the battery pack. The car park and other vehicles were undamaged [20, 21].

Shortly after 03:00 on November 21, 2021, there was a fire in the underground car park Marienplatzgarage in Ravensburg, Germany [22]. According to initial information, an electric vehicle parked on the first parking level and connected to a charging station was probably the cause of the fire. “The sprinkler systems and other fire protection devices worked extremely well”, according to the press spokesman for the Ravensburg fire brigade. The fire started in an electric vehicle. Three other vehicles were damaged by the heat. In addition to the cars, two charging stations for electric cars, several lights and cables and the concrete ceiling were damaged. As early as 2014, there was a serious fire in the underground car park, which resulted in closure for six years and a restoration for several million euros. The garage was reopened in 2020 with the latest technology.

Overall, the property damage is estimated to €370,000 [23]. In addition to the Volkswagen ID.4, which costs around €50,000, three other vehicles were also affected. With them, the damage would amount to a total of €120,000. The repair of the underground car park should cost at least €200,000, according to the police.

It is likely (although not confirmed) that the sprinkler system was a dry-pipe system designed and installed in accordance with VdS CEA 4001, i.e., with a discharge density of 5 mm/min over 180 m². If it was a wet-pipe system, the design area is 144 m².

## 5.5 Deluge water spray fire tests in the IMPRO project

RISE (then SP) conducted intermediate-scale fire suppression tests in the IMPRO project in 2009. A freight truck trailer mock-up with authentic geometry was used as the fire test source [24]. The tests were designed to vary the following parameters: the system technology, i.e., a traditional water spray system or high-pressure water mist system, the water discharge density, the water pressure (water spray system only) maintaining the water discharge density, thereby varying the droplet size and the momentum of the water spray and finally the exposure of the fire by using and not using a roof on the trailer mock-up. The application of water was manually started when the measured heat release rate was 5 MW. This would be representative of a manual activation approach on a ship but is not in any way unrepresentative of automatic activation. However, as a conservative approach, the water application was started when the fire was twice as large in one of the tests.

Table 2 summarizes the water spray and high-pressure water mist nozzles used in the tests, their K-factor, nominal water discharge density, system operating pressure and estimated media droplet size.

*Table 2 The water spray and high-pressure water mist nozzles used in the tests, their K-factor, nominal water discharge density, system operating pressure and estimated media droplet size [12].*

| System | Nominal discharge density (mm/min) | Nozzle K-factor (metric) | Minimum orifice diameter (mm) | System operating pressure (bar) | Water flow rate per nozzle (l/min) | Estimated median droplet size (µm) |
|---|---|---|---|---|---|---|
| Water spray | 5 | 43,2 | 8,3 | 1,2 | 48 | 889 |
| Water spray | 10 | 80,6 | 11,1 | 1,4 | 96 | 1028 |
| Water spray | 10 | 43,2 | 8,3 | 4,9 | 96 | 559 |
| Water spray | 15 | 103,7 | 12,7 | 1,9 | 144 | 1014 |
| Water mist | 3,75 | 3,6 | - | 100 | 36 | ~150 |
| Water mist | 4,6 | 4,4 | - | 100 | 45 | ~150 |
| Water mist | 5,8 | 6,1 | - | 84 | 56 | ~150 |

The tests where the fire was fully exposed (no roof on the trailer used) to the water spray showed a strong relationship between the level of performance and the water application rate. A discharge density of 15 mm/min provided immediate fire suppression, 10 mm/min fire suppression, and 5 mm/min fire control. The high-pressure water mist system provided fire control at a discharge density of 5,8 mm/min. However, the tests at 3,75 and 4,6 mm/min, respectively, went out of control and were manually terminated. In a final test, the activation of the water spray system (10 mm/min at 4,9 bar) was intentionally delayed until the fire size was twice as large (10 MW instead of 5 MW) as in the other tests. Despite this, the fire was almost immediately suppressed.

When the fire was shielded (using a roof on the trailer) from direct water application, the tested systems had a limited effect on the total heat release rate, and almost all combustible material was consumed. The most efficient reduction of the convective heat release rate of the water spray systems was demonstrated with 10 mm/min at the higher system operating pressure of 4,9 bar, likely because of the small water droplets. The high-pressure water mist system reduced the total convective energy to a level that was less than all water spray system tests which underlines the improved cooling efficiency of the even smaller water droplets.

## 5.6 Deluge water spray fire tests in the FIRESAFE II project

In 2018, RISE conducted intermediate-scale tests with a foam-water spray system and a CAFS under the FIRESAFE II project [25]. The fire suppression performance of the two systems was compared to the performance of a deluge water spray systems designed in accordance with Resolution A.123(V) as well as a system designed in accordance with MSC.1/Circ. 1430. A mock-up was constructed to geometrically replicate a typical freight truck trailer, except that the overall length was shorter. The fire scenario used in the tests simulated a fire that was partly shielded to the water spray by a roof on a freight truck trailer. Steel sheet (nominally 0,8 mm thick) screens were positioned parallel with the long sides of the trailer mock-up to simulate adjacent vehicles. The surface temperatures of the steel sheet screens were measured using several thermocouples positioned evenly across the surface area of the screens.

The systems were manually activated at a heat release rate of approximately 5 MW. The heat release rate upon activation was selected to simulate a manually activated system and to allow the fire to be well established before activation, to mimic manual activation. It was observed that the initial fire growth rate, up until the manual activation of the systems, was very similar for all fire tests indicating a good test-to-test repeatability. Figure 3 shows the results.

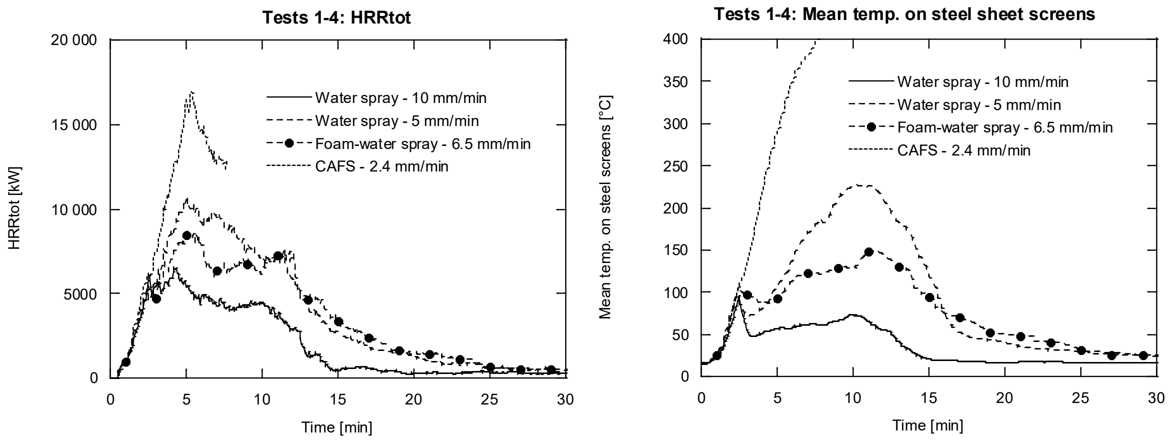



*Figure 3* *Tests 1-4: Total heat release rate histories (left) and the mean temperature on the steel sheet screens. The CAFS test was manually terminated at the time the dotted line is cut.*

It can be concluded that the water spray system discharging 10 mm/min reduced the heat release rate immediately after activation. The fire re-developed slightly but the fire size did barely exceed this level after at the activation. Thereafter, the fire size was gradually reduced, and the fire size was promptly reduced after a 10-minute discharge. The activation of the water spray system discharging 5 mm/min had a minor initial effect on the fire and the fire continued to grow to about 10,5 MW before it started to decrease. A similar observation is made for the foam-water spray system discharging 6,5 mm/min. However, the peak heat release rate was less, around 8,5 MW. The fire dropped faster in this test, however, fire re-growth is observed about 7 minutes after the start of the test. The activation of CAFS had a limited effect on the heat release rate and the fire grew to a level that required termination of the test.

The trends of the mean temperature on the steel sheet screens follows the trends of the heat release rate measurements and directly correlates to the water discharge densities of the systems.

## 5.7 Field experience with deluge water spray systems in ro-ro spaces

DNV GL AS has analysed fires within ro-ro spaces on ro-pax vessels, vehicle carriers and general ro-ro cargo vessels. The first report [26] covers eighteen fire incidents world-wide between 1990 to 2003. There were no fatalities, but six fires resulted in two total losses and four cases with major damage to the cargo and the ship. Both the total losses occurred when the ships were in port.

There were at least five incidents where the deluge water spray system was manually activated. The times to activation were:

a) Within 10 minutes (one incident).
b) 10 minutes (one incident).
c) Not stated (three incidents).

Based on the post-fire damage observations, it was concluded that the time to activation probably was short for at least one of the incidents where the activation time was not recorded. Only one of the five incidents caused major damages to the ship and the cargo.

The second report [27] identifies 35 fires between 2005 and 2016. Eighteen of the incidents occurred on ro-pax vessels, nine fires on pure car and pure car and truck carriers and eight fires occurred on cargo ro-ro vessels.

If installed, it is of great importance that the deluge water spray system is manually activated early and that it operates as intended. Reliable data was available for nine cases, where the estimated time from fire ignition to the manual activation of the system and the extent of damage could be identified. Table 3 summarises the data.

*Table 3 Fires on ro-pax and cargo ro-ro vessels where the estimated time from fire ignition to the manual activation of the deluge water spray system and the extent of damage could be identified [27].*

| Vessel | Time to release | Damages, other findings |
|---|---|---|
| **RoPax vessels** | | |
| Victoria Seaways | 3 minutes | Limited damages |
| 2009.R1 | "immediately" | Damages to some lorries |
| 2015.R1 | 8 minutes | Limited to one car |
| Mecklenburg-Vorpommern | 8 minutes | One trailer damaged as well as some steel structures above this one. Deluge valve hard to operate (release delayed 3 to 5 minutes as a result) |
| Commodore | 25 minutes | Several lorries and some structures damaged |
| Pearl of Scandinavia | 35 minutes | Incorrect section released after 17 minutes, but corrected after 35 minutes. Car burnt out, and some damages to the adjacent trailer plus some structures (a few days off-hire) |
| Lisco Gloria | Did not operate | Total loss of vessel |
| Norman Atlantic | Did not operate | Total loss of vessel |
| **Cargo Ro-Ro vessels** | | |
| UND Adriyatik | Did not operate | Total loss of vessel |

There were three cases where the water from the deluge system was not applied to the area on fire. All three cases were in open ro-ro spaces and all fire resulted in total losses. The failures include a combination of incorrect operation, the pump starter being in local mode and loss of main power.

DNV GL AS concludes that comprehensive crew training and well-defined procedures for responding to fire incidents are necessary to ensure that the crew can operate the fixed fire-extinguishing system as swiftly as possible. Three minutes for water deluge systems and 15 minutes for Carbon Dioxide systems is suggested.

For all incidents discussed above it is likely that the deluge water spray system was designed and installed in accordance with the requirements in IMO Resolution A.123 (V), that was published in 1967 [4]. Some requirements in this document that can be mentioned are that:

- The system shall be designed for a water discharge density of at least 3,5 mm/min for decks with a maximum height of 2,5 m height and at least 5 mm/min for decks with higher height.
- The system can be divided into sections where each section should cover the entire width of the ship. Exemptions from this requirement may be allowed if the deck is separated longitudinally by 'A' class divisions.
- Each section must be at least 20 m long, and the system's pumps must have a capacity sufficient for either the entire deck or at least two sections.
- Section valves must be located outside the protected space.

# 6 Performance objectives

Main author of the chapter: Magnus Arvidson, RISE.

## 6.1 General system requirements

As indicated by the terminology, the system should activate automatically, without any human intervention. This may be achieved by automatic sprinklers having a thermal element for activation by heat from the fire or by a separate fire detection system that operates a deluge zone with nozzles. The system should cover the full area of a ro-ro space unless the space is subdivided by permanent bulkheads with sufficient fire rating.

The system should control a fire during an extended period of time, either to allow manual fire-fighting, the activation of the (required) Carbon Dioxide system or fire burn out under controlled conditions (cooling by the water spray).

## 6.2 System performance objectives

The terminology "fire-extinguishing" system is often used by IMO and is misleading as full fire extinguishment cannot be expected from a water-based fire protection system. Fact is that "fire suppression" would also be difficult to achieve for the expected fire hazards. The seat of a fire could be severely shielded from direct application of water from overhead sprinklers or nozzles by the body of a vehicle.

Fire control would be a more realistic expectation from a system and a suggested definition is as follows: "Fire control is limiting fire spread while reducing heat radiation and cooling of combustion gases to avoid structural damage".

The understanding of this definition, that is partly adopted from NFPA 13, is that fire spread from a vehicle under fire to adjacent vehicles and spaces should be limited and structural damage to the ship should be avoided. Figure 4 exemplifies the performance of an automatic fire sprinkler system in a scenario mimicking an underground car parking garage, per the fire test procedure by VdS discussed above. These tests [28] were conducted at RISE, but not within the LASH FIRE project. The fire was started with a pool fire tray positioned underneath the centremost car.

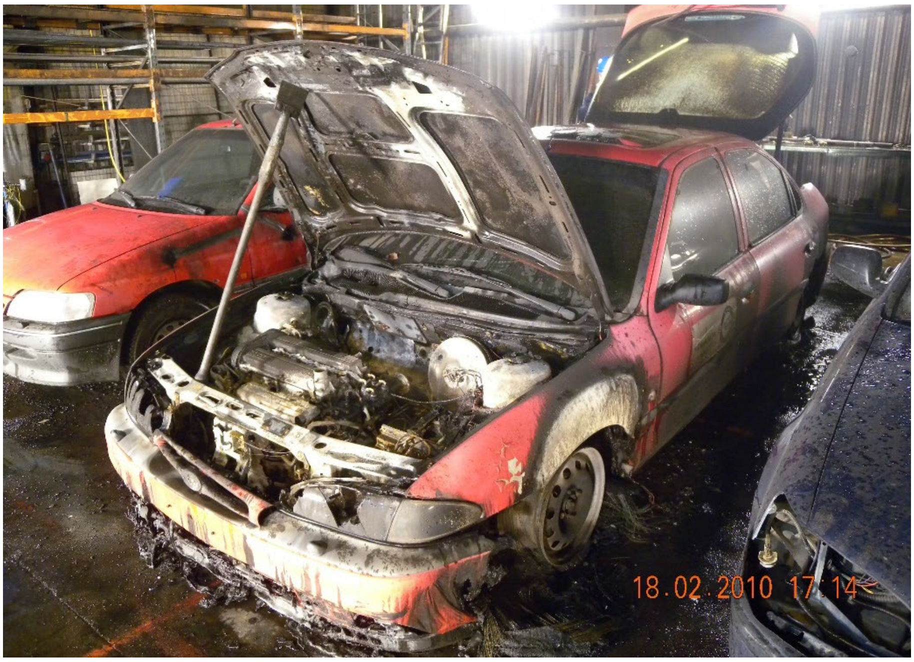



*Figure 4 Fire testing of an automatic sprinkler system in a scenario mimicking an underground car parking garage. The fire was controlled by the operation of two sprinklers and the fire damage was concentrated to the centremost car. It can be observed that the application of water prevented breakage of the windows of the car and thereby any significant involvement of its interior.*

For this particular test, the activation of two sprinklers prevented the fire in the centremost car from spreading to the adjacent cars.

The definition of fire control suggested above was implemented in the design and installation guidelines that were written (refer to the Annex). For the large-scale fire validation tests (presented later in the report), the fire control performance was measured by ceiling gas temperature measurements, measurements of the surface temperature of adjacent cars and by visual damage recordings.

Typically, a fire sprinkler system for hazards similar to those found in ro-ro spaces on vehicle carriers should have an operating time of at least 60 minutes. As the water-based systems developed in the project should be supplemental to the total-flooding Carbon Dioxide system, a minimum 30-minute operating time is suggested. This would allow the system to be connected to the freshwater tank(s) of a ship with no seawater connection, which would reduce the installation cost. For actual ships, it is likely that the capacity of the freshwater tanks would allow an even longer operating time than this minimum requirement.

## 6.3 Natural environmental and health effects

A fire is itself an acute and long-term threat to both the natural environment and the life and health of humans. It is essential that any additive to the water of the system, whether it being a fire suppression enhancing additive and/or an antifreeze agent does not increase these effects.

Any additives should be approved for fire protection service by an independent authority. The approval should consider possible adverse environmental effects and health effects to exposed personnel, including inhalation toxicity.

# 7 Electronically activated sprinklers

Main author: Magnus Arvidson, RISE.

During the work, a relatively new sprinkler concept was identified, electronically (also referred to as electrically) activated sprinklers. The concept is commercially available from at least two sprinkler manufacturers. The technology is described in this section and the possible use in ro-ro spaces is discussed.

## 7.1 General system concept

The fundamental difference as compared to standard automatic sprinklers, that activates individually by the heat from a fire is that individual sprinklers are possible to be electrically activated, either manually or (most commonly) by a fire detection system. Fire detection will typically be by means of heat, smoke, or flame detection - or combinations of these. Electrical activation of sprinklers speeds up the time to discharge compared to the traditional automatic sprinklers. Therefore, a single, or several sprinklers in the area of detection can be activated at an early stage of a fire, providing possibilities for fast fire containment or suppression.

One of the main changes compared to the previous editions of ISO 6182-1 [29] is that the 2021 edition includes new requirements for electronically activated sprinklers. As a minimum, it is suggested that electronically activated sprinklers used in ro-ro spaces meet the requirements of this standard.

## 7.2 Concept using standard automatic sprinklers

This concept allows an individual sprinkler to be operated both as a traditional heat-activated automatic sprinkler and as a remotely controlled sprinkler activated by an electrical signal, thus offering a robust operation and system performance. The sprinkler incorporates both a frangible glass bulb and an electrical actuator, refer to Figure 5. An electrical signal from the fire detection system ignites a small quantity of explosive that forces a piston to extend into and break the glass bulb. This activates the sprinkler within milliseconds. Should this function not work, the glass bulb will activate from the heat of the fire as a back-up.

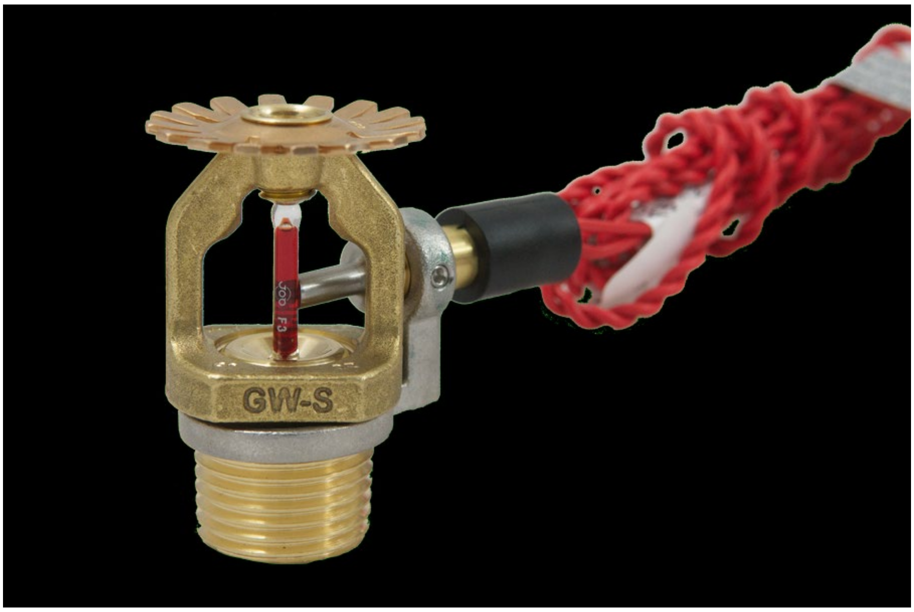



*Figure 5 An electrically activated standard automatic sprinkler that incorporates both a frangible glass bulb and an electrical actuator. Photo from GW Sprinkler A/S.*

## 7.3 Concept using storage sprinklers

There are also electronically activated performance-based sprinkler systems in the marketplace that are specifically engineered to address highly challenging storage fire hazards. The sprinkler system contains addressable heat detectors connected to an electronic control system that continuously analyses temperature information within the protected area.

The electronically activated sprinkler system and algorithm are designed to respond to a single fire originating from a single ignition location. In the event of a fire, the heat detectors provide information to the control unit. The software program in the control unit analyses information from multiple heat detectors and determines if the resulting information indicates a fire condition. As the fire continues to grow, the software confirms the fire’s signature and determines which sprinklers should be operated. The control unit then operates all the necessary sprinklers simultaneously. The hydraulic design should be based on a minimum of nine sprinklers in the design area. The first sprinkler that activates is immediately followed by the eight surrounding sprinklers.

For storage applications, the systems provide better protection with less water by locating fire origin and responding with only the appropriate sprinklers.

The sprinkler forming the concepts discussed above have no thermal heat-activated element, refer to Figure 6, and system activation relies on the function of the fire detection system.

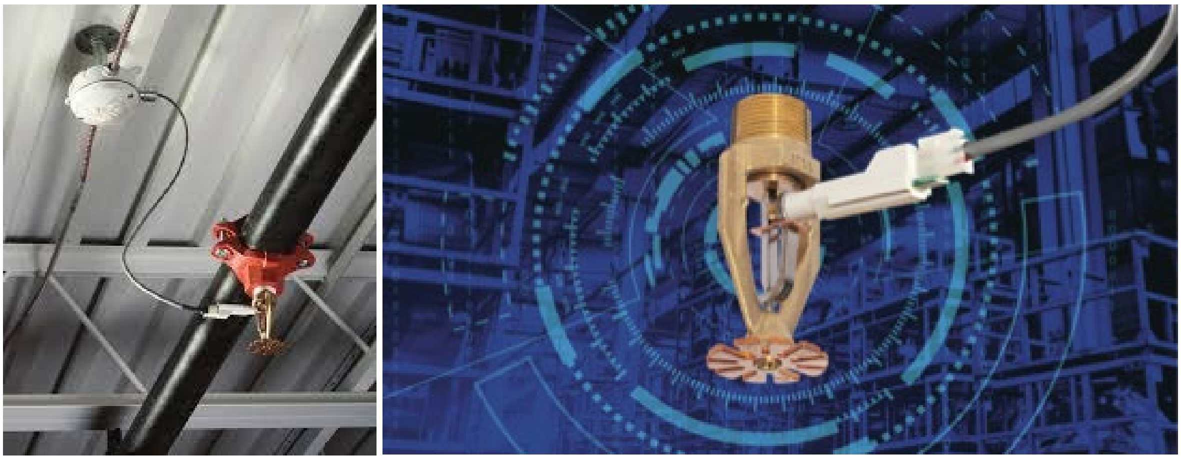


*Figure 6 An electrically activated storage sprinkler connected to a fire detector. This sprinkler does not that incorporate a heat-activated thermal element, only an electrical actuator. Photos from Johnson Controls.*

FM Global have tested electronically activated sprinklers in large-scale fire tests to determine if simultaneous activation of a minimum number of sprinklers around the fire location could control a fire of low-pile storage [30]. Two ignition fire scenarios were used, with four or five sprinklers activating simultaneously when one of the ceiling thermocouples reach a temperature of 57 °C. The testing involved uncartoned unexpanded plastics or cartoned unexpanded plastic commodity stored to either 1,5 m or 1,7 m, respectively. The ceiling height was either 9,1 m or 18,3 m and protection considered successful if the fire was controlled, with no fire spread to target arrays. The test results showed that a significant reduction in water flow rate as compared to traditional automatic sprinklers was possible. The sprinkler technology was also tested in a high bay rack storage using 12,2 meter high storage under a 13,7 m high ceiling. The sprinkler system was activated using a linear heat detector installed in the rack at half the height of the array. The results show that the electronically activated sprinklers could reduce the water significantly compared to traditional automatic sprinklers installed at the ceiling.

## 7.4 The possible use in ro-ro spaces

One of the problems of using automatic sprinklers in ro-ro spaces is the complex ceiling construction. The span length of the transversal beams is long and the weight load on the decks high, which results in deep structural members and beams on a short horizontal distance.

Another challenge is the short clearance between the vehicles that are transported and the underside of the beams. Sprinklers and sprinkler piping underneath these beams are not desired. Electrically activated sprinklers would offer an attractive solution to some of the problems, i.e.:

- The spot-type heat detector could be installed close to the underside of the ceiling surface, thereby reducing the time to fire detection.
- The associated (pendent) sprinkler could be installed with its deflector vertically aligned with the bottom edge of the members to provide an unobstructed discharge over the tops of the vehicles.
- The total flow rate would be significantly lower than that of a traditional deluge water spray system, but also lower than an automatic dry-pipe sprinkler system. This aspect is discussed in more detail below.

As a fire detection system is required in ro-ro spaces, this system could be combined with the fire detection system for the sprinklers. A combined heat and smoke spot-type detector could be used for the cases smoke detection is also required.

The concerns of using the concept are:

- The system needs to have empty piping due to risk for freezing in ro-ro spaces. Obviously, an antifreeze could be used, but water-filled piping results in a high weight load that should be avoided.
- Empty piping results in a delay time before water is distributed from the sprinklers and problems with stagnant water in the (pendent) sprinkler inlets after an activation.
- The storage sprinklers discussed above are “overkill” for ro-ro spaces transporting regular passenger cars. For higher spaces, where larger vehicles are carried, the high flow rates of these sprinklers are better suited.
- The system complexity increases, as every sprinkler needs a dedicated fire detector and a wire connection.
- The sprinklers are more expensive than traditional sprinklers, which with the additional components increases the overall cost of a system.

A design with nine sprinklers in the design area (i.e., nine sprinklers operating simultaneously) would be sufficient for low spaces transporting regular passenger cars. A fire in a single car and the surrounding cars would be well covered.

For higher ceiling spaces, able to transport larger vehicles, additional sprinklers need to be included in the design to provide full coverage of a single vehicle. A design using 12 sprinklers would cover an approximate area of 6 m in width by 12 m in length which would seem to be sufficient. The number of sprinklers in the design would still be less than that of a traditional automatic sprinkler system. The savings in total water flow rate would result in a smaller and less power demanding pump and less diameter sprinkler piping than that of a traditional automatic sprinkler system

A concept with sprinklers that both are heat-actuated and electrically activated offers a robust operation and improved system performance. Furthermore, to limit the number of sprinklers that may activate in a fire, the use of high-temperature rated sprinklers is suggested.

# 8 System development work

Main author: Magnus Arvidson, RISE.

## 8.1 General

This section describes the specific testing that was undertaken to develop and verify the performance of selected water spray system nozzles and a CAFS.

## 8.2 Intermediate-scale fire tests with water spray system nozzles

Intermediate-scale fire tests with water spray system nozzles were conducted in April 2020 at RISE in Borås, Sweden to supplement the information on system design that was found in the literature review.

### 8.2.1 General approach

Two test commodities were used:

- The EUR Std plastic commodity.
- Stacks of idle wood EUR pallets.

For each fire test, four stacks (2 by 2 stacks) of commodities were arranged such that a similar overall height was provided. The longitudinal and transversal flue space, respectively, between each stack of commodity was 150 mm. Each stack was supported by vertical 45 mm × 90 mm wood studs on each side to prevent a stack from collapsing at an early stage of the fire. The intent of this measure was to improve the test-to-test repeatability.

The set-up using the EUR Std plastic commodity pallet load arrangement totaled eight pallets loads. The four stacks of idle wood pallets totaled 64 pallets, i.e., 16 wood pallets in each stack. The overall height of the test set-ups was similar. The height represents a realistic height of the cargo on a freight truck trailer.

### 8.2.2 The EUR Std plastic commodity

The EUR Std Plastic commodity consists of empty Polystyrene (PS) cups without lids, placed upside down (i.e., open end down), in compartmented cartons, 120 cups per carton. The cartons measure 600 mm × 400 mm × 500 mm (L × W × H) and are made from single-wall, corrugated cardboard. Figure 7 shows a cardboard carton and the arrangement of the plastic cups inside. The total weight (excluding the pallet) of one 1200 mm × 800 mm pallet load of the commodity is approximately 40 kg of which approximately 65 % by weight was plastic, excluding the pallet. If the weight of the wooden pallet is included in this estimation, approximately 42 % by weight is plastic.

The similar Group A Std Plastic Commodity have been extensively used in the fire protection community as a representative "benchmark" commodity for warehouse fire hazards for the evaluation of fire sprinkler protection performance in large-scale fire tests since the 1970s.

*Figure 7 A cardboard carton for EUR Std plastic commodity showing the arrangement of the plastic cups inside.*

Two pallet loads were positioned on top of each other which equalled an overall height of nominally 2 290 mm. The overall test set-up included four stacks of two pallet loads, i.e., eight pallet loads of commodity. Figure 8 shows the test set-up.

*Figure 8 The test set-up using the EUR Std Plastic commodity depicted from two different positions.*

### 8.2.3 The idle wood pallets

The pallets had a nominal dimension of 1200 mm × 1000 mm × 145 mm (L × W × H) and 16 pallets were stacked on top of each other. The overall test set-up included four stacks of 16 pallets, i.e., 64 pallets. The overall height of one stack was 2 320 mm, which is just 30 mm higher than the overall height of the EUR Std Plastic commodity arrangement. Figure 9 shows the test set-up.

*Figure 9 The test set-up using the idle wood pallets depicted from two different positions.*

Stacks of idle wood pallets have become a common Class A fire test source for testing of sprinkler or water mist fire protection systems for road tunnels and is also used in the fire test procedures of IMO MSC/Circ. 1430 as the fire load for the fictive fire in a truck trailer and passenger car.

### 8.2.4 The open water spray nozzles

The nozzles used in the tests were open (non-automatic), pendent directional discharge water spray nozzles. The nozzles had an external deflector that discharged a uniformly filled cone of medium-velocity water droplets. The nozzles used in the tests had no nozzle strainer. The nozzles are available in a wide variety of orifice sizes and spray angles, however, the types listed in Table 4 were used during these tests.

*Table 4 The open, commercial water spray nozzles that were used.*

| Nozzle designation | K-factor (metric) | Spray angle (°) | Coverage area ($m^2$) | Nominal discharge density (mm/min) | Flow rate (l/min) per nozzle | Nominal water pressure (bar) | Total flow rate (l/min) |
|---|---|---|---|---|---|---|---|
| 32 | 80,6 | 180 | 9,3 | 10 | 93 | 1,3 | 372 |
| 34 | 103,7 | 180 | 9,3 | 12,5 | 116 | 1,3 | 465 |
| 34 | 103,7 | 180 | 9,3 | 15 | 139,5 | 1,5 | 558 |

The recommended discharge pressures range from 1,4 bar to 4,1 bar. Discharge pressures in excess of 4,1 bar will result in a decrease in coverage area since the spray pattern tends to draw inwards at higher pressures. The maximum recommended working pressure is 12,1 bar.

The nozzles were installed with their frame arms parallel with the short sides of the commodity set-ups and positioned vertically 500 mm above its top. The nozzles were positioned approximately 2,8 m above floor, as measured to the deflectors.

For the tests, four water spray nozzles were installed in a hydraulically balanced pipe-work, having a nozzle spacing of 3,05 m by 3,05 m (10 ft. by 10 ft.). Each of the nozzles covered an area of 9,3 $m^2$.

The pipe-work was constructed from DN50 (2") steel pipe. The pipe-work exposed to the fire was thermally insulated. A pressure transducer was installed at the end of one of the inner the branch lines. The distribution line of the pipe-work had a solenoid valve that was remotely operated.

Figure 10 shows one of the nozzles and the water discharge prior Test 3, discharging 12,5 mm/min.

*Figure 10 One of the open (non-automatic), pendent directional discharge water spray nozzles used in the tests and the water discharge prior Test 3, discharging 12,5 mm/min.*

The nozzles were provided by TYCO Fire Suppression & Building Products. However, it is recognized that similar nozzles in terms of spray angles and orifice sizes are available from several other sprinkler manufacturers.

### 8.2.5 Fire test procedures

The tests were conducted under the Industry Calorimeter, a large hood connected to an evacuation system capable of collecting all the combustion gases produced by the fire.

The water flow was manually initiated by the remote operation of the solenoid valve at the distribution line of the pipework. The convective heat release rate (HRRconv) at the operation of the valve was 1,5 MW, which equals a total heat release rate of approximately 2,2 MW. There was a time delay of approximately 3 s from the operation of the solenoid valve until water was flowing from the water spray nozzles.

The fire was allowed to burn for 30 min from the time of manual activation of the water spray system and any residual fire was extinguished by hose streams of water and a water lance that could penetrate the cardboard cartons.

Figure 11 illustrates the size of the fire shortly after the start of water discharge from Tests 3 and 4, respectively.

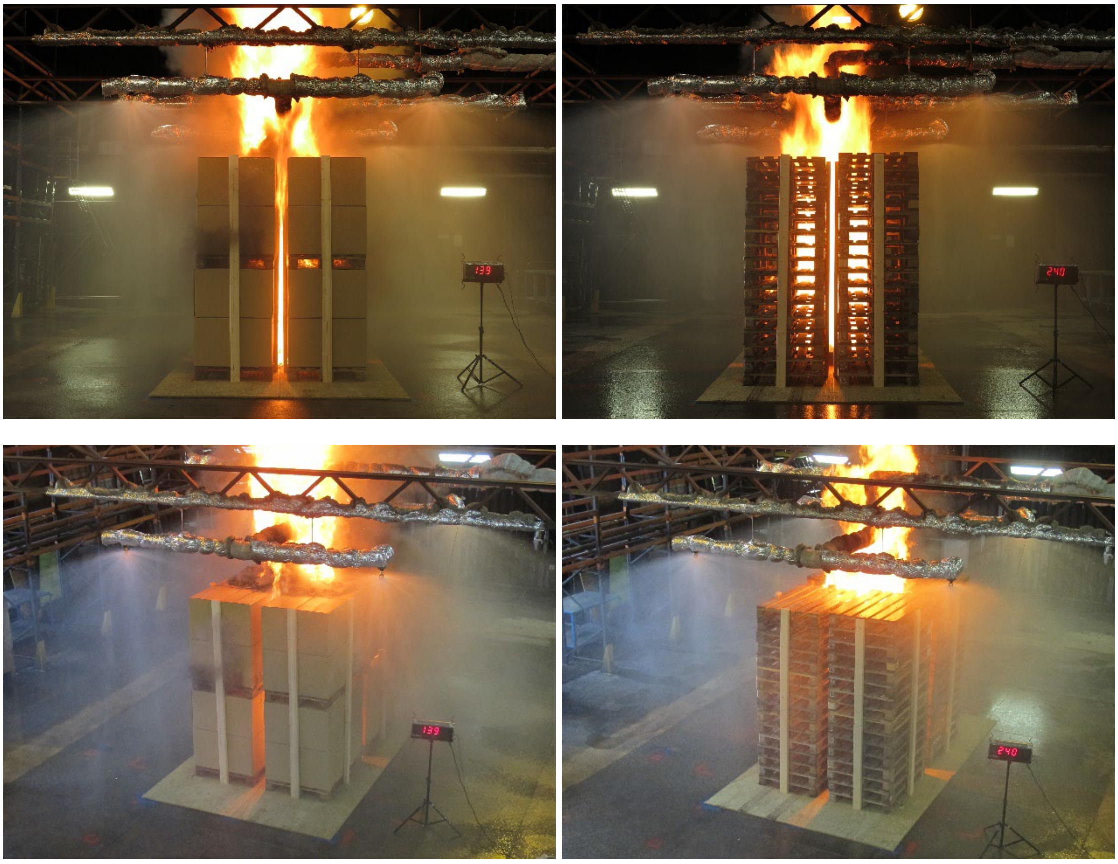


*Figure 11 An illustration from Tests 3 and 4, respectively, of the fire size shortly after the start of water discharge depicted from the two different camera positions.*

### 8.2.6 Fire tests results

Figure 12 shows the total heat release rate histories for all tests.

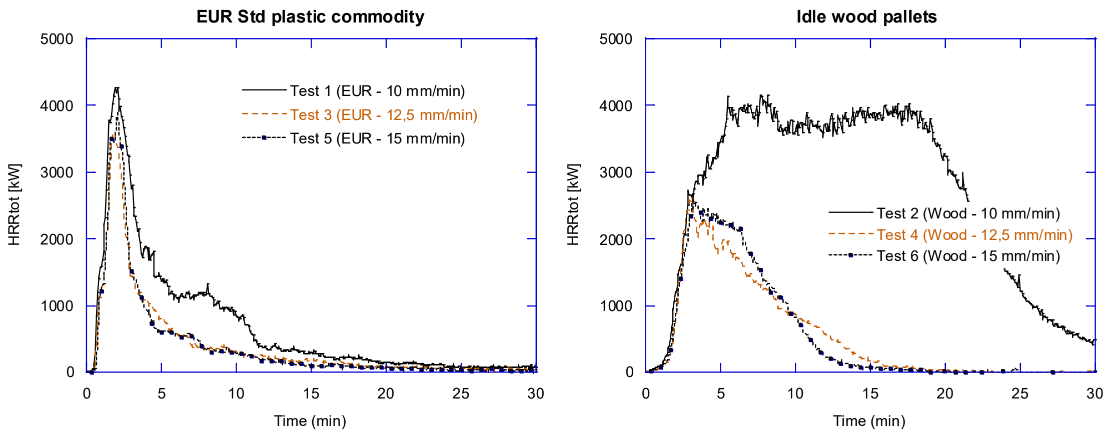



*Figure 12 The total heat release rate histories for the tests.*

The fire growth rate EUR Std plastic commodity was faster that the fire growth rate in the idle wood pallets. For commodities made entirely from plastics or containing plastics the threshold between 'fire control' and 'fire suppression' is often sharp as the plastics cannot be wetted (soaked) by the application of water. For the EUR Std plastic commodity tests, it seems that the critical water application rate for fire suppression is around 10 mm/min. An increase in water discharge density above this threshold does not result in a significant improvement in fire suppression performance. It can also be observed that the fire continues to grow after the start of the application of water, reaches a peak around 4 000 kW, and is then sharply suppressed.

The critical water application rate for fire suppression for the idle wood pallets is between 10 mm/min and 12,5 mm/min. At a water discharge density 10 mm/min, the fire is controlled and at 12,5 mm/min it is supressed. For Class A combustibles, the borderline between fire control and fire suppression is typically regarded as more gradual than for plastics. Looking closely at the data for the idle wood pallets, this trend is observed as a plateau in the heat release rate before the fire size is reduced. For the higher discharge densities of 12,5 mm/min and 15 mm/min it can also be observed that the fire barely continues to grow after the start of the application of water. The peak heat release is close to that when water was applied.

## 8.3 Compressed Air Foam Systems (CAFS)

CAFS stands for Compressed Air Foam System and is a system for the production of high-quality CAF (Compressed Air Foam), which is used to fight solid and liquid fires. For the generation of CAF, three components are required (water, foam concentrate and air) as in the generation of conventional fire-fighting foam. The crucial difference lies in the foam expansion of the water-foam compound mixture, which in the CAFS system does not take place through the injector principle at the nozzle, but in a mixing chamber in the system by means of compressed air. Due to this active foam expansion, the resulting CAF foam has a more homogeneous foam structure as well as a much higher cooling capacity in comparison with conventional fire-fighting foam.

During the mixing process, a single water drop is distributed across multiple foam bubbles, which results in a larger surface area for heat absorption. Furthermore, the CAF foam sticks to the flammable material thanks to its homogeneous structure, and this enables continuous heat absorption. As a result, a large part of the water bound in the CAF is able to evaporate, this provides a maximum cooling effect at the seat of the fire. The oxygen is displaced from the flammable material through evaporation of the water into steam. Additionally, a natural separating layer is created between the flammable material and the oxygen as a result of the CAF foam. With the CAF foam the oxygen supply to the seat of the fire is interrupted in the best possible way. Due to the high kinetic energy of the CAF foam and the reduction of surface tension through the added foam concentrate, water can penetrate deeper into the flammable material and thus soak in better.

Small systems generally have one or multiple air cylinders to provide air and have one tank which contains pre-mix of water and foam concentrate. Such systems are common for mobile devices and stand-alone units for lithium battery storage rooms or transformers, with a relatively small fire load.

Large-scale systems are built up from separate pumps and units or as a combined skid but all contain a water pump which takes water from the freshwater tank of the vessel or seawater if there is a shortage of fresh water. The foam concentrate is stored in a foam concentrate tank and is mixed with the water with a dosing pump and inline mixer. Figure 13 shows a stand-alone system, a back-pack device and large-scale CAFS unit.


*Figure 13 A stand-alone system, a backpack device and large-scale CAFS unit.*

This report summarises fire tests, field experience design guidelines found in relevant standards for automatic sprinkler and water spray systems. The information provides a good indication on the design of such systems.

## 8.4 CAFS development testing

During the spring and summer 2020, F4M conducted system development tests at their site in Medemblik in the Netherlands. The primary objectives of the tests were to develop appropriate CAFS nozzles, determine the best type of foam agents, foam admixture, and the influence of different system settings on the drainage time and expansion ratio of the foam.

Several nozzle alternatives were tested, both spiral type nozzles and rotating type nozzles having different spray angles and orifice sizes. The spiral nozzles were commercially available for fire protection purposes and the prototype rotating were developed by F4M. Figure 14 illustrates some of the nozzle discharge tests.

*Figure 14 The discharge of foam from a spiral type of nozzle (left) and a rotating type of nozzle (right) during CAFS development work.*

It was concluded that a nozzle pressure around 1 bar provided a foam quality and foam distribution pattern that was judged as appropriate. Higher nozzle pressure resulted in lower expansion ratios and lower pressures in less nozzle coverage areas.

Two types of foam agents were selected from the intermediate-scale fire tests, a wetting and foaming agent developed for forest and industrial fires (Bio4C) and a Class A additive (Enviro Class A) that also is suitable for smaller Class B fires. Both agents are fluorine-free and biodegradable.

## 8.5 Intermediate-scale fire tests with CAFS

In November 2020, a series of intermediate-scale fire tests similar to those conducted with the water spray system nozzles (see the description earlier in the report) were conducted at RISE in Borås, Sweden.

### 8.5.1 The system set-up

Four CAFS nozzles were installed in a hydraulically balanced pipe-work, having a nozzle spacing of 3,05 m by 3,05 m (10 ft. by 10 ft.). Each of the nozzles covered an area of 9,3 $m^2$. The pipe-work was constructed from DN50 (2") steel pipe. The pipe-work exposed to the fire was thermally insulated. A pressure transducer was installed at the end of one of the inner the branch lines.

The distribution line of the pipe-work had a solenoid valve that was remotely operated. A pressure transducer installed was upstream of the solenoid valve. Figure 15 shows the system set-up.

*Figure 15 The system set-up, with the system pipe-work, the solenoid valve with the pressure transducer, and the rotating type CAFS nozzle.*

The pipe-work was connected to the foam mixing chamber via a flexible DN65 (3") hose, as shown in Figure 16.

*Figure 16 The foam mixing chamber and the DN65 (3") hose that connected it to the system pipe-work. Water and the foam agent were pre-mixed in the cubical stainless steel tank shown in the right hand side photo.*

Water and the foam agent were pre-mixed in the cubical stainless steel tank and pumped to the two 1800 l pre-mix tanks inside the system container, refer to Figure 17.

*Figure 17 The two 1 800 l pre-mix tanks inside the system container and the compressed air cylinders.*

Four compressed air cylinders (maximum pressure of 300 bar) were connected, via pressure regulators, to the foam mixing chamber and the two pre-mix tanks. The pressurisation of the pre-mix tanks propelled the pre-mix to the mixing chamber and the finished foam through the hose and system piping to the nozzles. Another line of pressure-reduced (about 5 bar) air expanded the foam in the mixing chamber. From Test 2, two additional compressed air cylinders were connected to the system to reduce the rapid pressure drop in the pre-mix tanks.

The CAFS nozzles were positioned vertically about 500 mm above the top of the fire test sources. The nozzles were positioned approximately 2,8 m above floor.

### 8.5.2 The fire test sources

The same two fire test commodities as used for the water spray nozzle tests were used:

- The EUR Std plastic commodity.

- Stacks of idle wood EUR pallets.

Figure 18 shows the test set-ups.

*Figure 18 The fire test sources, stacks of idle wood EUR pallets (left) and the EUR Std plastic commodity (right).*

### 8.5.3 Foam distribution tests

Prior the first fire test, a foam distribution test was conducted with the larger of the two types of rotating nozzles that were available, refer to Figure 19. These nozzles had an orifice diameter of about 10 mm. A bucket with a diameter of 25,5 cm was placed at the floor, centred between the four nozzles in the test set-up. The approximate discharge density for the position of the bucket was calculated to 19,6 mm/min, based on the measurement of the weight of the foam (primarily water on a mass basis). Foam was collected and the expansion ratio and drainage time was measured. The expansion ratio was around 10 and the drainage time was long, although no specific time was possible to determine.

Visually, it was estimated that foam was distributed over a fairly circular area on the floor having a diameter of around 10 m (i.e., the free width of the fire test hall). This corresponds to a coverage area of around 80 m$^2$. With a nominal initial pre-mix flow rate 200 l/min of the system, the estimated mean discharge density is 2,5 mm/min.

*Figure 19 Distribution of foam over the floor of the fire test hall using the rotating nozzles. The free width of the fire test hall is about 10 m. Visually, and determined by collection of foam with a bucket, the distribution of foam was high between the four nozzles.*

The first fire test (Test 1) was conducted with this type of rotating nozzle.

After Test 1, foam distribution tests were conducted with the spiral nozzles (refer to Figure 20) and the 90° nozzles (refer to Figure 21). During these foam distribution tests, the idle wood pallet test set-up from Test 1 was left, to examine the distribution of foam over it.

The spray pattern of the spiral nozzle was non-uniform. All these nozzles were purposely aligned similar. It was observed that the opposite two corners of the test set-up were covered by foam, whilst the other two opposite corners had no foam. A similar foam distribution was observed at the floor. It was also observed that no foam was distributed directly underneath the nozzle. Thirdly, the foam expansion was less (wetter foam) compared to the rotating type of nozzle. This is likely due to mechanical impact of foam in the nozzle, that influence the bubbles of foam.

The 90° nozzles were orientated towards the centre point of the test set-up and foam distribution tests were conducted. Plenty of foam settled on the top of the set-up and filled the longitudinal and transversal flue spaces between the stacks of pallets. However, it was judged that the application of the nozzle position is difficult to translate to actual conditions and a sufficient system concept.

*Figure 20 Distribution of foam over the floor and the stacks of idle wood pallets from Test 1 using the spiral nozzles. Visually, it was observed that the opposite two corners of the test set up were covered by foam, whilst the other two opposite corners had no foam.*

*Figure 21 Distribution of foam over the floor and the stacks of idle wood pallets from Test 1 using the 90° nozzles. Plenty of foam settled on the top of the set up and filled the longitudinal and transversal flue spaces between the stacks of pallets.*

Based on the foam distribution test observations, it was determined that the remaining fire tests should focus on the rotating type of nozzle. Thereby, all fire tests were conducted using the same type of foam nozzle.

### 8.5.4 Fire test parameter variations

A total of five fire tests were conducted. The following parameters were intentionally varied:

- The type of commodity: Stacks of idle wood pallets (Tests 1, 2 and 4) or the EUR Std plastic commodity (Tests 3 and 5).
- The foam agent: Bio4C (Tests 1, 2 and 3) at an admixture concentration of 2,5 % or Enviro Class A (Tests 4 and 5) at an admixture concentration of 0,5 %.
- Test 1 was conducted using the six compressed air cylinders positioned inside the system equipment container. Two additional compressed air cylinders were connected to the system from Test 2, with the intent to maintain the pre-mix flow rate better than was documented in Test 1.

### 8.5.5 Fire tests observations

Tests 1 and 2 were conducted with the idle wood pallets and the Bio4C foam agent (2,5 %). For both tests, the fire was initially suppressed, but fire re-growth was faster in Test 2. The reason may be that the flow rate in Test 2 had a more noticeable initial drop before stabilizing at a significantly lower rate than the starting point, while the drop was constant and more linearly decreasing in Test 1. The result being that the actual total amount foam applied was higher in Test 1 during the first couple of minutes. The flow rate at the start of the application of foam was higher than indicated in the graph, as the first visual reading was moments later. The flow rate stabilised during the later stage of the fire in Test 2, however, still the fire continued to grow, as was also observed in Test 1.

Test 4 was conducted with the same type of commodity, i.e., the stacks of idle wood pallets, but the foam agent was changed to the Enviro Class A (0,5%). Under this configuration the fire re-growth rate was not as fast. Two main observation were made during the test. The flow rate followed the same pattern as in Test 2. However, the initial drop was less. The flow rate stabilized at a level of approximately 15 l/min higher and the foam expansion ratio was noticeably less (wetter foam). Compared to Tests 1 and 2, it was observed that the foam was more fluid and was flowing down the stacks and clearly soaked/reached the core of the test set-up and in-between the individual pallets. As the fire was kept under reasonable control, it was allowed to burn longer compared to Tests 1 and 2 before it was manually terminated. However, the fire size at termination was like that in Test 2.

Test 3 was conducted with the EUR Std plastic commodity and the Bio4C foam agent (2,5 %). The heat release rate continued to increase after the activation of the system before starting to decrease, followed by a gradual fire re-growth. At this point the foam build up on the top started to slide down the inner walls of the commodity. Unevenly distributed foam film was also forming on the outside surfaces of the commodity. This had to some extent the effect of “plugging the holes” as flames started to penetrate the side walls of the commodity cartons from inside. As this foam film was more and more consumed by the fire, fire re-growth was observed as the side walls of the upper stacks were fully penetrated by the flames. Partial collapse of cartons of the commodity at the later stage exposed the fire to the foam and the fire size decreased as combustible material was consumed. The flow rate followed the same pattern as in Test 2. However, the initial flow rate was noticeably higher (approximately 20 l/min higher), and it stabilized at the level of approx. 10 - 15 l/min higher.

The heat release rate histories for the tests discussed above is shown in Figure 22.

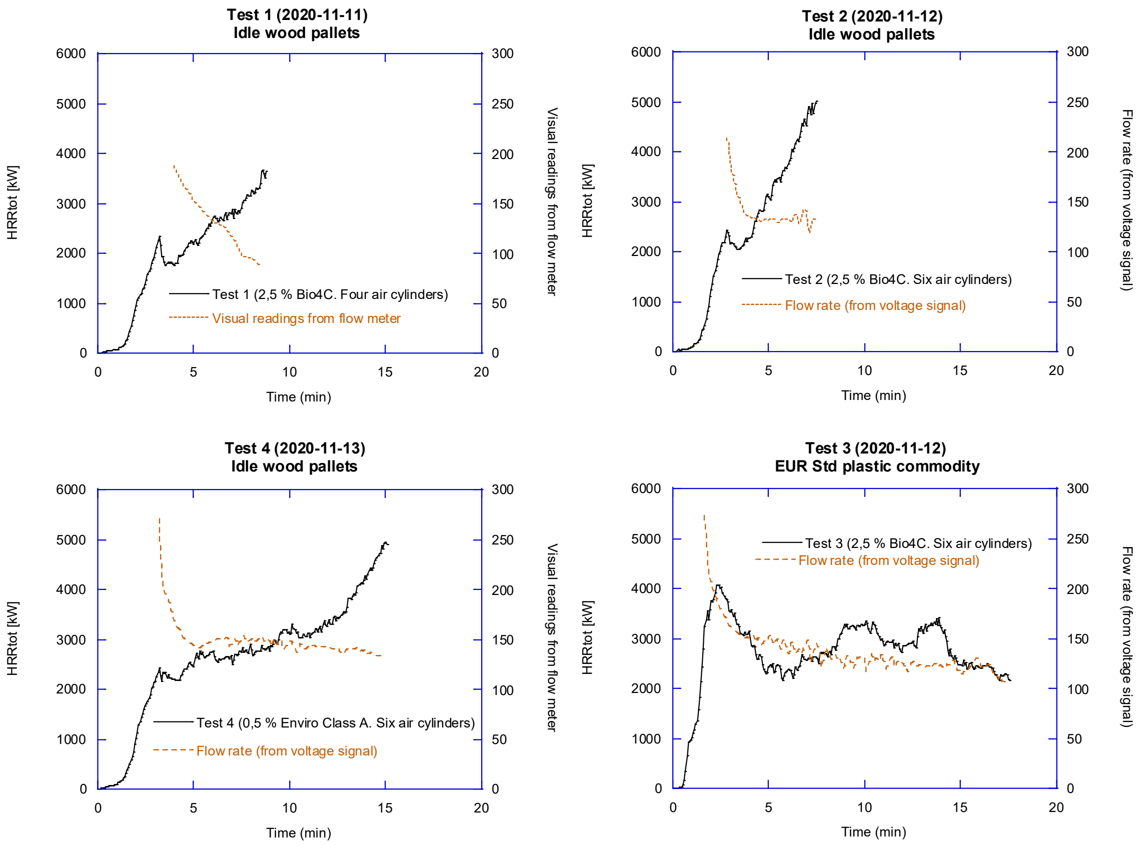



*Figure 22 The heat release and the flow rates in Tests 1, 2 and 4 (stacks of idle wood pallets) and Test 3 (EUR Std plastic commodity).*

Test 5 was conducted using Enviro Class A at 0,5 % admixture. Technical difficulties emerged with the measurement system during Test 5 and the heat release rate recordings was not available. The test was ultimately terminated, and no evaluation data could be extracted. However, although the test was not performed in accordance with the established protocol, it was continued to the point where the assessment was made that the CAFS could not control the growth of the fire. Considering the given circumstances, some visual observations could nonetheless be made during the test. To begin with, the CAFS was activated approximately one minute later than in Test 3, at 02:28 [min:s] after ignition as compared to 01:40 [min:s], i.e., the heat release rate was considerably higher. At this point, the whole top surface of the commodity was involved in the fire and the fire was also noticeably established in the wood pallets between the two levels of commodity. The flames on the outskirts of the top were suppressed. However, within 30 seconds the flames from underneath the top level of the commodity were spreading along the outer surfaces of the long side of commodity. The fire was progressively growing. Four minutes after activation of the CAFS, at 06:28 [min:s] after ignition, the entire upper level of the commodity was engulfed in flames. Manual extinguishing with water was initiated while keeping the CAFS activated. CAFS was shut off six minutes after activation (08:28 [min:s] after ignition) and manual extinguishing with water continued. The manual extinguishing continued for another six minutes before the last flames were completely out. The observed sequence of events in this test demonstrates the difficulties in final extinguishment of the fire, despite manual fire-fighting efforts.

### 8.5.6 The CAFS handling and performance experience

A general experience was that the pre-mix flow rate, which was measured directly upstream of the foam mixing chamber, decreased relatively rapidly during the tests as illustrated in Figure 23. In order to limit the decrease of the flow, two additional compressed air cylinders were connected to the system from Test 2. This did not fully re-solve the issue, but the decrease in flow rate was reduced. Test 1 stands out with a rapid, almost linear decrease in flow rate that did not stabilise as in the other tests.

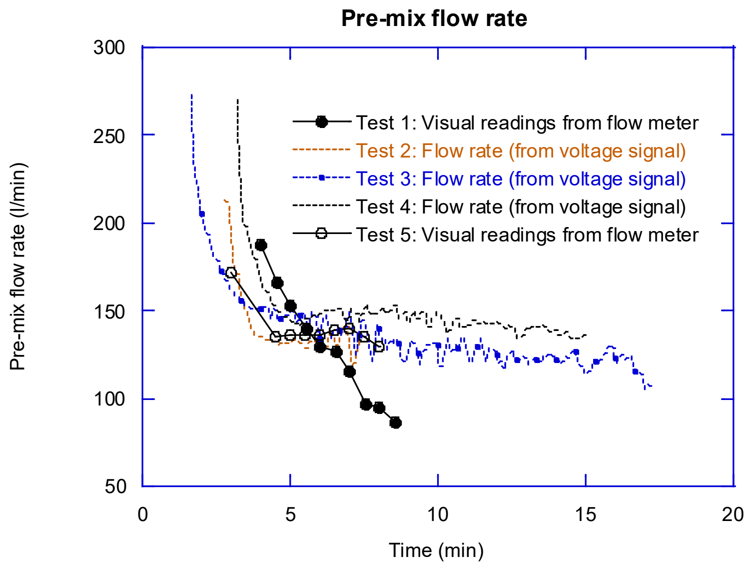



*Figure 23 The measured pre-mix flow rates during all CAFS tests.*

The test-to-test variation in flow rate limits the possibilities for a completely straightforward comparison of test results. It is likely that the flow rate is an important parameter, and a higher flow rate will correspond to improved system performance.

There was a significant pressure loss from the mixing chamber as well as from the solenoid valve to the nozzles. Table 5 summarises these pressure losses. The large pressure losses indicate that a large dimension system piping need to be used in practice.

*Table 5 Maximum nozzle pressures, pressure losses and pre-mix flow rates.*

| Test | Maximum flowing pressure at nozzle (bar) | Minimum flowing pressure at nozzle (bar) | Maximum pressure loss (at the highest pre-mix flow rate) between the system piping solenoid valve and nozzle (bar) | Maximum pressure loss (at the highest pre-mix flow rate) between the mixing chamber and nozzle (bar) | Maximum and minimum measured pre-mix flow rate (l/min) |
|---|---|---|---|---|---|
| 1 | 1,0 | 0,3 | 1,6 | 3,8 | 188* - 87* |
| 2 | 1,2 | 0,5 | 1,8 | 4,1 | 212 - 120 |
| 3 | 0,8 | 0,4 | 1,8 | 4,5 | 272 - 105 |
| 4 | 1,0 | 0,4 | 1,6 | 4,0 | 270 - 135 |
| 5 | N/A | N/A | N/A | N/A | 172* - 130* |

*) Visual readings on the flow meter during the test. The initial flow rate was slightly higher than recorded.
N/A = Not Available.

The delay time from the start of the system and the operation of the solenoid valve on the system piping was very short. Foam was distributed from the nozzles almost immediately. The pipe length from the solenoid valve to the nozzles was approximately 9 m.

### 8.5.7 Overall conclusions

The following is concluded from the CAFS tests:

- The foam distribution tests indicate that the rotating nozzle was the best choice for the fire tests. However, the following was observed; a) the coverage area of the four nozzles was very large, b) the distribution was relatively non-uniform, with little foam, directly below a nozzle.
- The stacks of idle wood pallets seem more difficult to suppress and control as compared to the EUR Std plastic commodity, based on a strict test-to-test comparison (Test 2 vs. Test 3). For these two tests, the same foam agent and similar pre-mix flow rates were used.
- The fire in the EUR Std plastic commodity was not visually controlled in Test 5, where the application of foam was initiated later than in Test 3. Manual fire extinguishment after the termination of the test was difficult and time consuming.
- The Enviro Class A foam was wetter, which is believed to improve distribution through the flame and fire plume. Improved fire control performance was documented in Test 4 vs. Tests 1 and 2.
- The pressure drops in the system piping and in the fire hose that connected the system piping with the mixing chamber of the CAFS was relatively high, highlighting that large diameter piping is essential in an actual system.

### 8.5.8 Measures to improve CAFS performance

It is likely that a pre-mix flow rate of around 250 l/min would be sufficient to suppress these fires, given that the flow rate remains constant during a test and that the foam reaches the fire. This flow rate is two-thirds of the water flow using water only to suppress the fires.

Improved foam distribution through the fire plume of the nozzles is desired. This could be achieved with a significantly narrower spray pattern. It is also essential that the distribution of foam directly under a nozzle improves, which would be the result of a reduced spray angle.

A wetter (lower expansion ratio) would improve the penetration. On the other hand, this will reduce the ability of the foam to stick to vertical surfaces, which is a feature that is important for shielded fires in vehicles, to obtain a barrier to heat radiation that prevent fire from spreading to adjacent vehicles.

# 9 The design and installation of automatic sprinkler or deluge water spray systems

Main author: Magnus Arvidson, RISE.

## 9.1 General

This section describes design and installation aspects of automatic sprinkler or automatic deluge systems for closed ro-ro spaces on vehicle carriers. The design and installation requirements that are discussed are based on information from the standards identified in the literature review, with the additional references provided in the text.

## 9.2 The essential installation requirements in ro-ro spaces

### 9.2.1 System types

Different sprinkler system types may be used in a ro-ro space. A list of different system types as defined MSC.1/Circ. 1430, NFPA 13 and in other sprinkler installation standards are given below, with some additional information concerning how each system operates:

**Wet-pipe systems** are designed for applications where the temperature is maintained above freezing and employ sprinklers attached to a piping system containing water under pressure. The water discharges immediately as one or more sprinklers are activated by the heat from a fire. An antifreeze may be used if the system is subject to low ambient temperature.

**Dry-pipe systems** employ automatic sprinklers attached to a piping system containing air or Nitrogen under pressure. The activation of one or more sprinkler permits the water pressure to open a valve, known as the dry-pipe valve. The water then flows into the pipe-work and out of the opened sprinklers. It is essential that the dry-pipe valve is installed in an area not subject to freezing. It is also important to prevent condensation inside the pipe-work, in order to avoid ice build-up or corrosion. This is made by a number of measures, including de-humidifying the compressed air from the air supply or by using pure Nitrogen. It is also essential that the system piping is pitched and that provisions are made to drain all parts of the system. For the reason of drainage, upright sprinklers should typically be used with dry-pipe systems.

**Pre-action systems** are similar to a dry-pipe systems; however, water is also held back by an electronically operated valve. Pre-action systems are commonly used for areas where there is a danger of serious water damage as a result of impact on automatic sprinklers or broken piping. There are three types of pre-action systems:

1) Single-interlock systems, which admit water to the sprinkler piping upon operation of the fire detection system. With a rapid fire detection, water may be discharged as quickly as the discharge from a wet-pipe system. Single-interlock systems are not as suitable as double-interlock systems in areas subject to freezing, see the discussion below.

2) Non-interlock systems, which admit water to the sprinkler piping upon operation of the fire detection system or the automatic sprinklers. For a non-interlock system containing a dry-pipe valve, pressure drop, or activation of the detection system would trip the valve. For a non-interlock system containing a deluge valve, a separate detection system would trip the valve, but loss of a low system monitoring pressure could also be used to trip the system.

3) For double-interlock systems, the pre-action valve is arranged to open only once both a sprinkler has operated, and a fire is detected in the area being protected. This type of system is therefore safer than single-interlock systems in areas subject to freezing, as the sprinkler

piping will not fill up due to a failure of the fire detection system. The time delay, from the activation of the system until full discharge at the sprinkler, typically requires that this specific type of pre-action system be designed with a 30 % increase in area of operation.

**Deluge systems** employ open sprinklers or spray nozzles attached to a piping system. The system is connected to a water supply through a deluge valve. This valve is opened manually and/or by the operation of a fire detection system installed in the protected area. When it opens, water flows into the piping system and discharges from all sprinklers or nozzles. A deluge system has a time delay between detection of a fire and the discharge of water due to the time required to operate the valve and to fill the piping network with water.

### 9.2.2 The choice of automatic sprinklers

#### *9.2.2.1 Installation orientation*

Either pendent or upright sprinklers are to be used. Upright sprinklers are installed with the deflector above the frame arms of the sprinkler so that water flows upward from the orifice opening, striking the deflector to create the spray pattern. Pendent sprinklers are installed with the deflector below the frame.

For dry-pipe or pre-action systems, only upright sprinklers, or dry pendent sprinklers (see below) should be used. A standard pendent sprinkler on dry-pipe systems would trap water in the sprinkler and fitting to which it is attached. The trapped water would have the potential to freeze and to cause mechanical damage to the sprinkler or prevent the sprinkler from operating during a fire. Upright sprinklers will place the sprinkler pipe-work lower, but the benefit is that it would protect the sprinklers from mechanical impact. The shielding effect of the pipe below an upright sprinkler can be minimized by aligning the frame arms so that they are in line with the pipe.

#### *9.2.2.2 Dry sprinklers*

A dry sprinkler is a sprinkler secured in an extension nipple that has a seal at the inlet to prevent water from entering the nipple until the sprinkler operates. The dry sprinkler type can be used in wet-pipe system where the sprinkler piping is installed in a heated area and the actual sprinklers are installed in an area subject to freezing. Dry pendent, upright, or horizontal sidewall sprinklers are available, as the protected, unheated area may be below, above or to the side of the heated area with the wet-pipe system [31].

*Figure 24 A typical of dry pendent sprinkler. Illustration from Reliable Automatic Sprinkler Co.*

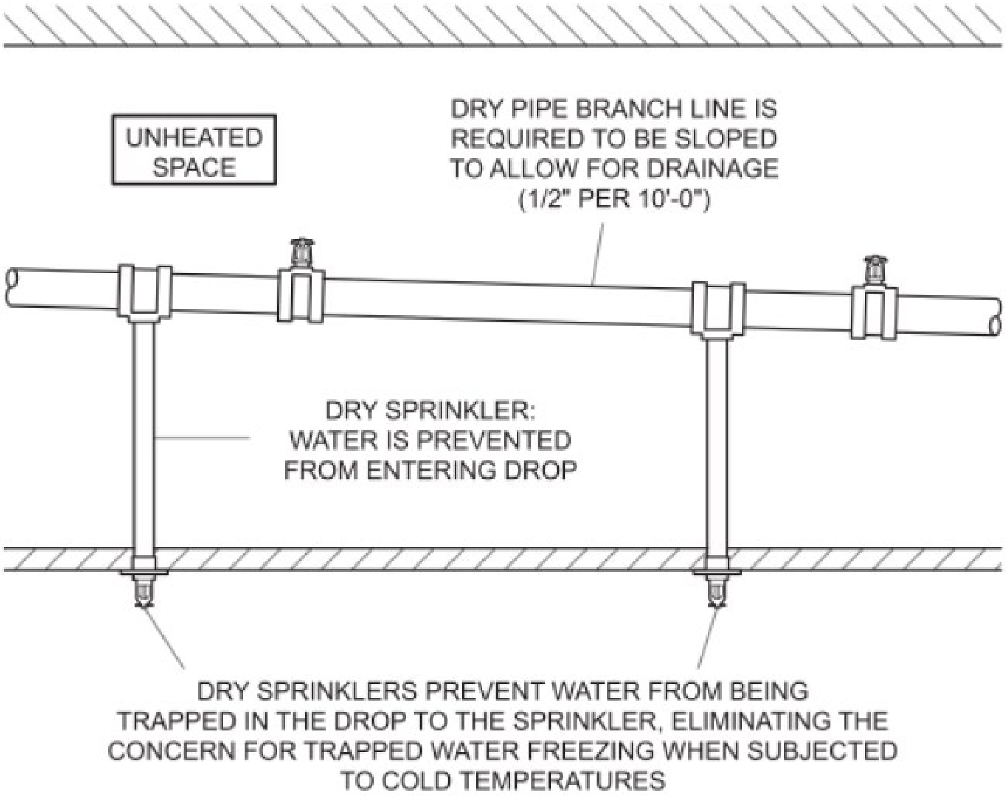



*Figure 25 A typical installation of dry pendent sprinklers on a dry-pipe system. The dry sprinklers prevent stagnant water in the drop to the sprinklers, remaining after sprinkler operation or testing [31].*

The benefit of using pendent sprinklers on a ro-ro space is that the sprinkler deflector could be vertically aligned or positioned slightly above the underside of the beams in order to minimize the influence from obstructions on the spray pattern.

A dry sprinkler is more complicated when compared to standard sprinklers. Based on failure reports in the late 1990s and studies performed by UL, the NFPA require that dry sprinklers that have been installed for 15 years shall be replaced or representative samples shall be tested and then retested at 10-year intervals instead of 50 years as with standard sprinklers [32].

Dry sprinklers are also typically more expensive that standard sprinklers. The list price of a standard coverage, K80 pendent standard-response or quick-response sprinkler made from brass is between around $200 to $400 all dependent on the nipple length. A standard-response, standard coverage, K80 upright or pendent sprinkler made from brass is around $40. All list prices are from Johnson Controls [33], but similar list prices are expected from other sprinkler manufacturers.

#### *9.2.2.3 The K-factor*

The K-factor is a mathematical constant that relates the water flow that is discharged from a sprinkler at a given pressure. The constant is primarily dependent on the orifice diameter. The larger the K-factor (orifice size) of a sprinkler or nozzles, the higher the flow rate at a given pressure.

Some installation standards, as NFPA 13 and FM DS 3-26 specify the appropriate K-factor, minimum operating pressure, and number of sprinklers (or design area) to be calculated for each applicable design criteria.

NFPA 13 specify that sprinklers shall have a minimum nominal K-factor of 80. For light hazard occupancies, smaller K-factors may permitted given certain restrictions. Sprinklers with nominal K-factors of 57 shall be permitted to be installed in dry-pipe and pre-action systems protection light hazard occupancies where piping is corrosion resistant or internally galvanized. For storage applications, NFPA 13 further specifies that standard-response K115 sprinklers must be used with a density greater than 8,2 mm/min to 13,9 mm/min. Standard-response K160 sprinklers or larger that are listed for storage applications shall be used for densities greater than 13,9 mm/min.

#### *9.2.2.4 Operating temperature*

Sprinklers activate individually when the predetermined operating temperature is reached. For the selection of the operating temperature, the maximum expected ceiling temperature need to be known to avoid inadvertent operation of sprinklers. In NFPA 13, the area of sprinkler operation can be reduced under certain conditions, without revising the water discharge density. Relevant for hazards like ro-ro spaces is that the area of operation can be reduced by 25 % when using high-temperature sprinklers for extra hazard occupancies. The area is, however, not allowed to be less than 186 $m^2$. High-temperature sprinklers are defined as sprinklers having a nominal activation temperature between 121 °C to 149 °C. With such sprinklers, the number of sprinklers that activate during a fire will be reduced, especially for fires where flammable or combustible liquids are present or where shielding of combustibles is extensive, as with fires in vehicles.

For dry-pipe sprinkler systems, FM DS 3-26 recommends the use of upright or dry-pendent sprinklers with a nominal 140 °C temperature rating. Nominal 70 °C sprinklers are acceptable for HC-1 and HC-2 occupancies.

#### 9.2.2.5 Thermal sensitivity

Thermal sensitivity is the measure of how fast the thermal element (glass bulb or fusible link) operates in a standardised test. Based on this time, the Response Time Index (RTI) can be calculated. The lower the RTI of a sprinkler, the faster it activates in a fire.

But a low RTI is not necessarily the best option. For dry-pipe sprinkler systems, FM DS 3-26 recommends the use of upright or dry-pendent sprinklers with standard-response characteristics. Standard-response sprinklers are, however, acceptable for HC-1 and HC-2 occupancies. The reason that standard-response sprinklers should be used with dry-pipe systems is to prevent too many sprinklers from opening before water fills the pipe-work.

#### 9.2.2.6 Glass bulb vs. solder link sprinklers

Glass bulbs are fragile. Any mechanical impact can lead to operation and very costly damage.

Solder links are more robust. On the negative side, for this application, is that links are more prone to salt-spray corrosion because droplets of water in the atmosphere can collect on the link and over time this will start to corrode the thin metal plates. From that aspect, sprinklers with frangible glass bulbs are preferable.

#### 9.2.2.7 Sprinkler finishes

Automatic sprinklers are available in a range of finishes (including decorative finishes) to match the demands of a wide range of aesthetical desires and environmental conditions. Finishes range from standard brass to high grade stainless steel and include other corrosion resistant coatings. The end user is responsible for determining the finish that is best suited to a specific environment.

Section 3.10 of MSC.1/Circ. 1430 states that: “The system and its components should be designed to withstand ambient temperatures, vibration, humidity, shock, impact, clogging and corrosion normally encountered. Piping, pipe fittings and related components except gaskets inside the protected spaces should be designed to withstand 925°C. Distribution piping should be constructed of galvanized steel, stainless steel, or equivalent. Sprinklers and nozzles should comply with paragraph 3.11.”.

Section 3.11 states that: “The system and its components should be designed and installed based on international standards acceptable to the Organization[2]. The nozzles should be manufactured and tested based on the relevant sections of appendix A to circular MSC/Circ.1165” [The Revised Guidelines for the approval of equivalent water-based fire-extinguishing systems for machinery spaces and cargo pump-rooms].

The footnote says that: “Pending the development of international standards acceptable to the Organization, national standards as prescribed by the Administration should be applied”.

### 9.2.3 Positioning of sprinklers relative to the ceiling construction

For automatic sprinklers or nozzles (i.e., sprinklers or nozzles that are activated by the heat from a fire), it is essential that the vertical distance from the underside of the deck to the thermal element is within certain limits to provide as fast activation as possible. Sprinklers or nozzles at the underside of ‘obstructed ceiling constructions’ need to also be positioned such that the ceiling construction in terms of beams, trusses, or other members do not affect the water distribution. On the other hand, a vertical distance too far from the deckhead will influence the activation time. Both NFPA 13 and FM DS 2-0 [34] provide recommendations of the minimum and maximum allowed vertical distances from the ceiling surface for obstructed ceiling constructions. For unobstructed ceiling constructions, the general recommendation in for example NFPA 13 is that the distance between the sprinkler deflector and the ceiling surface shall be a minimum of 25 mm and a maximum of 305 mm. For obstructed ceiling constructions, an extensive vertical distance of 550 mm is allowed.

The January 2018 edition of FM DS 2-0 defines an "Unobstructed Ceiling Construction" as a "A ceiling structural assembly that allows the flow of hot gases to spread out under the ceiling uniformly from the point of fire origin to the nearest four sprinklers in a timely fashion". Ceiling structural assemblies that meet this definition include:

- Ceiling systems that have construction materials that do not protrude downward from the ceiling more than 100 mm, or,
- Ceiling systems that have construction materials that protrude downward from the ceiling more than 100 mm, but their cross-sectional area is 70 % or more open, or,
- Ceiling systems that have construction materials that protrude downward from the ceiling more than 100 mm and are less than 70 % open in their cross-sectional area, but the volume created by the ceiling structural assembly does not exceed 2,8 $m^3$, or
- The horizontal distance between the construction material protrusions exceeds the maximum allowable spacing for the sprinkler being installed.

FM DS 2-0 defines an "Obstructed Ceiling Construction" as a "A ceiling structural assembly that prevents the flow of hot gases from spreading out under the ceiling uniformly from the point of fire origin to the nearest four sprinklers. This would apply to ceiling structural assemblies that do not meet the definition of unobstructed ceiling construction.".

As mentioned, sprinklers need also to be installed to ensure that the water discharged from sprinklers is not significantly obstructed. Such guidance is given in NFPA 13 and FM DS 2-0 for sprinklers on standard spacing and extended coverage sprinklers. Figure 25 is adopted from FM DS 2-0 and shows the position of a standard coverage sprinkler to avoid the umbrella pattern being obstructed by an object located at or near the ceiling level. As a baseline, it is required that objects located less than 300 mm horizontally from the sprinkler are above the horizontal plane of the sprinkler's deflector.

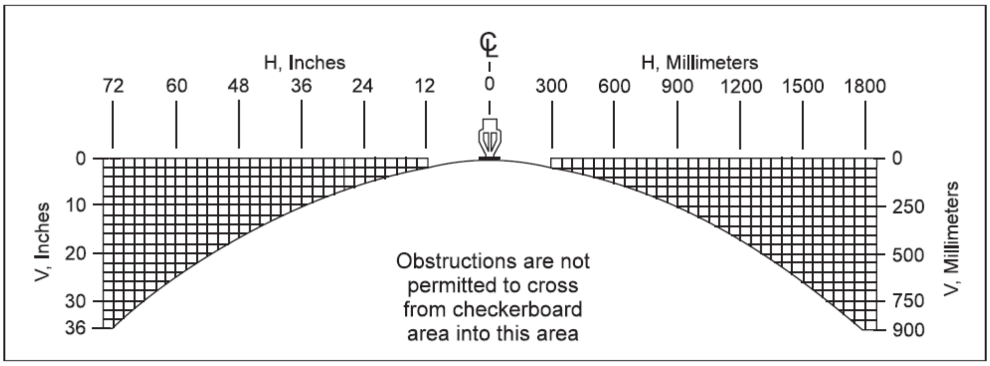



*Fig. 8. Obstruction area to umbrella pattern of pendent and upright Nonstorage sprinklers (excluding Extended-Coverage)*

*Figure 26 Guidance adopted from FM DS 2-0 that shows the position of a standard coverage sprinkler to avoid the umbrella pattern being obstructed by an object located at or near the ceiling level.*

The recommendations by NFPA 13 and FM Global were consulted, but recent research [35] made by FM Global proved to be valuable for the project. For ceiling constructions with beams, 'channels' are formed. The distance between the beams may be so short that no more than one sprinkler branch line can be installed in each channel. Therefore, the hot gases produced during a fire cannot reach the nearest four ceiling-level sprinklers anywhere within a single channel. When sprinklers are not installed within every channel, questions have arisen whether they will operate sufficiently fast to provide fire control. The impact of obstructed ceiling constructions on sprinkler protection under non-sloped ceilings was studied using numerical simulations and supporting large-scale fire testing. Some of the ceiling constructions that were studied mimics those found on ro-ro spaces well.

Numerical simulations indicated that the flow channelling effect is greater for slower growing fires as compared to the faster fire growing fires. This is because the weak plume from the fire results in a thin ceiling jet, which tends to remain confined in the channels formed by the beams. This is an important observation as a fire in a ro-ro space can be regarded as developing slower than fire scenarios used by FM Global, that involved plastic commodities. A possible solution for stopping the hot gases going in one direction only would be to close the beam channels. The closing of the beam channels forces the gas flow to go in the direction perpendicular to the beams. The effect of the closed channels was proven greater for beams having depths larger than 300 mm. For deeper beams, another helpful action for achieving near symmetric activation patterns, as lowering the sprinklers, and vertically aligning them with the bottom edge of the beams did not have a significant effect for weak-plume-driven ceiling jets.

It was concluded that beams less than or equal to 300 mm in depth do not negatively affect the activation times of the central sprinklers in a fast fire growing fire scenario. Additionally, no significantly biased sprinkler activation patterns due to flow confinement in the beam channels was observed. Ceiling with beams less than or equal to 300 mm in depth can therefore be considered as an unobstructed ceiling according to the research.

For beams deeper than 430 mm (using quick-response sprinklers having ordinary temperature rating) and beams deeper than 330 mm (using standard-response sprinklers having high temperature rating) the thermal element can be placed on a plane at a maximum distance of 150 mm below the bottom edge beams. This recommendation is valid for a maximum beam depth of 610 mm.

Due to the strong channelling effect for beams having depths less than or equal to 460 mm, the recommendation from the study is that vertical barriers are installed to close the channels in order to reduce biased sprinkler activation patterns. Based on modelling results, a maximum closed beam channel length of 7,6 m is recommended. For beam depths less than or equal to 610 mm, sprinklers need not be installed in every channel formed by the beams, if having these vertical barriers.

### 9.2.4 Design densities and areas of operation

The recommended design densities and areas of operation in MSC.1/Circ. 1430, NFPA 13, EN 12845:2015+A1:2019 and FM DS 3-26 are summarised below.

### 9.2.4.1 MSC.1/Circ. 1430 (2012)

Table 6 shows the minimum required water discharge density and minimum area of operation given in MSC.1/Circ. 1430.

*Table 6 The minimum required water discharge density and minimum area of operation given in MSC.1/Circ. 1430.*

| Ceiling height (m) | Type of system | Minimum water discharge density (mm/min) | Minimum area of operation |
|---|---|---|---|
| ≤ 2,5 | Wet-pipe | 6,5 | 280 $m^2$ |
| | Dry-pipe or pre-action | 6,5 | 280 $m^2$ |
| | Deluge | 5 | 2 × 20 m x B |
| > 2,5 - ≤ 6,5 | Wet-pipe | 15 | 280 $m^2$ |
| | Dry-pipe or pre-action | 15 | 365 $m^2$ |
| | Deluge | 10 | 2 × 20 m x B |
| > 6,5 - ≤ 9 | Wet-pipe | 20 | 280 $m^2$ |
| | Dry-pipe or pre-action | 20 | 365 $m^2$ |
| | Deluge | 15 | 2 × 20 m x B |

B = breadth of the protected space.

Automatic sprinklers intended for spaces with a free height equal to or less than 2,5 m should have a nominal operating temperature range between 57 °C and 79 °C and standard-response characteristics. Automatic sprinklers or nozzles intended for spaces with a free height in excess of 2,5 m should have a nominal operating temperature range between 121 °C and 149 °C and standard-response characteristics.

Deluge systems should be designed for the simultaneous activation of the two adjacent deluge sections with the greatest hydraulic demand at the minimum water discharge density given in Table 6.

Automatic sprinklers or nozzles should be positioned and located so as to provide satisfactory performance with respect to both activation time and water distribution. The maximum horizontal spacing between nozzles or sprinklers should not exceed 3,2 m. This corresponds to a sprinkler coverage area of 10,24 $m^2$.

### 9.2.4.2 NFPA 13 (2019)

For the design of a system, the following classification of occupancies is used in NFPA 13:

- Light Hazard.
- Ordinary Hazard (Group 1), i.e., OH1.
- Ordinary Hazard (Group 2), i.e., OH2.
- Extra Hazard (Group 1), i.e., EH1.
- Extra Hazard (Group 2), i.e., EH2.

The classification is based on the quantity and combustibility of contents, the expected heat release rates, the total potential for energy release, the height of any stockpiles and the presence of flammable and combustible liquids within the occupancy.

Table 7 shows examples of occupancies given in the 2019 edition of NFPA 13 that could be considered to have similarities with the fire hazard present in ro-ro spaces on vehicle carriers, and the sprinkler protection criteria in terms of minimum water discharge densities and area of sprinkler operation.

*Table 7 The classification of occupancies used in NFPA 13 together with occupancy examples, characterization of the hazard and the sprinkler protection criteria.*

| Hazard class | Occupancy examples for comparison with ro-ro spaces | Fuel quantity and combustibility | Sprinkler protection criteria |
|---|---|---|---|
| Ordinary Hazard Group 1 (OH1) | Automobile parking, automobile showrooms | Moderate quantity and low combustibility, stockpiles <2,4 m high. | 6,1 mm/min over 139 $m^2$ or 4,1 mm/min over 372 $m^2$ |
| Ordinary Hazard Group 2 (OH2) | Mercantile, repair garages, exterior loading decks, tire manufacturing | Moderate to high quantity and combustibility of contents, stockpiles <3,7 m. | 8,2 mm/min over 139 $m^2$ or 6,1 mm/min over 372 $m^2$ |
| Extra Hazard Group 1 (EH1) | Aircraft hangars, upholstering with plastic foams | Very high quantity and combustibility of contents, dust, lint or other similar materials present introducing the probability for rapidly developing fires. | 12,2 mm/min over 232 $m^2$ or 8,2 mm/min over 465 $m^2$ |
| Extra Hazard Group 2 (EH2) | Manufactured homes, modular building assembly, "miscellaneous" palletized, shelf or rack storage of plastics | Very high quantity and combustibility of contents, substantial amounts of flammable or combustible liquids present, shielding of combustibles is extensive. | 16,3 mm/min over 232 $m^2$ or 12,2 mm/min over 465 $m^2$ |

From this summary, it appears that OH1 and EH2 occupancies have similarities with ro-ro spaces on vehicle carriers. Ordinary Hazard Group 1 (OH1) occupancies are described as "Occupancies or portions of other occupancies where the quantity and combustibility of the contents does not exceed the amount miscellaneous storage of Class 2, 3, 4, plastics, tires, and roll paper provided in Table 4.3.1.7.1". Extra Hazard Group 2 (EH2) occupancies are described as "Occupancies or portions of other occupancies with moderate to substantial amounts of flammable or combustible liquids or occupancies where shielding of combustibles is extensive".

The recommended water discharge densities and sprinkler operating areas vary from 6,1 mm/min over 139 $m^2$ to 16,3 mm/min over 232 $m^2$ for the different occupancies. It is, however, allowed to decrease the water discharge densities if the area of operation is increased, as indicated in the table.

The area of sprinkler operation is allowed to be reduced under certain conditions, without revising the water discharge density. Relevant for hazards similar to ro-ro decks is that the area of operation can be reduced by 25 % when using high-temperature sprinklers for Extra Hazard occupancies. The area is, however, not allowed to be less than 186 $m^2$. High--temperature sprinklers are defined as sprinklers having a nominal activation temperature of between 121 °C to 149 °C.

Fast-response sprinklers are not allowed for Extra Hazard occupancies or other occupancies where there are substantial amounts of flammable liquids or combustible dusts. The reason is the risk that more sprinklers than included in the sprinkler operating area would activate during the fast growing fires than could be expected in such occupancies.

For dry-pipe systems, the sprinkler operating area should be increased by 30 % without revising the water discharge density.

The maximum allowed sprinkler coverage areas and spacing of standard pendent and upright spray sprinklers for light, ordinary and extra hazard occupancies is given in Table 8.

*Table 8 The sprinkler maximum allowed coverage area and spacing for light, ordinary and extra hazard occupancies (hydraulically calculated systems) from NFPA 13 (2019).*

| Hazard class | Ceiling construction type | Maximum allowed sprinkler coverage area ($m^2$) | Maximum allowed sprinkler spacing (m) |
|---|---|---|---|
| Ordinary Hazard | All | 12,1 | 4,6 |
| Extra Hazard (<10,2 mm/min) | All | 12,1 | 4,6 |
| Extra Hazard (≥10,2 mm/min) | All | 9,3 | 3,7* |

*) In buildings, where solid structural members create bays up to 7,6 m wide, the maximum spacing between sprinklers is permitted up to 3,8 m.

For the 2022 edition of NFPA 13, some potential code changes are underway. Automobile parking will likely be reclassified as Extra Hazard Group 2. The reason is a concern that the hazard classification is inadequate. Automobile design has continuously been evolving and now modern vehicles contain significantly more plastics than older cars, hybrid/electric drive cars pose a different risk and the distance between cars is close in parking garage, which promotes fire spread [36].

#### 9.2.4.3 EN 12845:2015+A1:2019

EN 12845:2015+A1:2019 uses a classification of occupancies as follows:

- Light Hazard occupancies (LH).
- Ordinary Hazard (OH) occupancies, Groups 1 to 4.
- High Hazard Production (HHP) occupancies, Groups 1 to 4.

The classification is based on the quantity and combustibility of contents, the expected heat release rates, the total potential for energy release, the height of any stockpiles and the presence of flammable and combustible liquids within the occupancy.

The recommended water discharge densities and sprinkler operating areas vary from 2,25 mm/min over 84 $m^2$ to 12,5 mm/min over 260 $m^2$ for the different occupancies. HHP4 hazards are usually protected with deluge systems, which are not covered in the standard. For dry-pipe systems, the sprinkler operating area should be increased by 25 % without revising the water discharge density. Quick-response sprinklers are not allowed to be used in dry-pipe systems.

Fire hazards similar to “Car parks” fall under OH2. A wet-pipe or pre-action system should be designed for a water discharge density of 5 mm/min and an area of operation of 144 $m^2$. A dry-pipe system should be designed for an area of operation of 180 $m^2$. “Car workshops” fall under OH3. A wet-pipe or pre-action system should be designed for a water discharge density of 5 mm/min and an area of operation of 216 $m^2$. A dry-pipe system should be designed for an area of operation of 270 $m^2$.

“Depots for buses, un-laden lorries and railway carriages” fall under HHP2. A wet-pipe or pre-action system should be designed for a water discharge density of 10 mm/min and an area of operation of 260 $m^2$. A dry-pipe system should be designed for an area of operation of 325 $m^2$.

#### 9.2.4.4 FM DS 3-26 (2019)

The 2019 edition of FM DS 3-26 provides recommendations for fire protection using automatic sprinkler systems in non-storage occupancies, i.e., an area or building consisting of equipment, processes, and/or materials that are not maintained in a storage arrangement. Three different hazard categories are described in the document, HC-1, HC-2 and HC-3. Table 9 shows occupancies from a list of Appendix C of the document that are relevant for closed ro-ro spaces on vehicle carriers.

*Table 9 Examples of occupancies listed in FM DS 3-26 that are relevant for closed ro-ro spaces on vehicle carriers.*

| Hazard category | Examples of relevant occupancies listed in FM DS 3-26 |
|---|---|
| HC-1 | None |
| HC-2 | • Parking garage.<br>• Car parks.<br>• Car workshops. |
| HC-3 | • Car-sized vehicle repair garages and assembly operations where unfuelled vehicles are repaired, tested or assembled.<br>• Truck loading docks - loading and unloading canopies.<br>• Aircraft hangar.<br>• Manufacturing/assembly of wind turbines, boats, highway trailers, trucks, boxcars, mobile homes, or similar.<br>• Manufacturing and assembly of boats, highway trailers and trucks, boxcars, mobile homes, or similar metal vehicles with combustible interiors with the potential for a shielded fire. |

The design recommendations for ceiling heights up to 9 m in the 2019 edition FM DS 3-26 are summarised in Table 10.

*Table 10 A summary of the sprinkler design recommendations given in FM DS 3-26 for ceiling heights up to 9 m.*

| Hazard category | Ceiling height up to 9 m | |
|---|---|---|
| | Wet-pipe system | Dry-pipe system |
| HC-1 | 4 mm/min over 140 $m^2$ | 4 mm/min over 140 $m^2$ |
| HC-2 | 8 mm/min over 230 $m^2$ | 8 mm/min over 330 $m^2$ |
| HC-3 | 12 mm/min over 230 $m^2$ | 12 mm/min over 330 $m^2$ |

Storage of plastic commodities up to 1,8 m high and no more than 6 $m^2$ in area (approximately four pallets) in HC-2 and HC-3 occupancies shall be treated as related to the occupancy and is covered by the protection recommendations.

The design requirements of these three standards can be compared by multiplying the discharge density with the area of operation. This provides the minimum total system water flow rate when all sprinklers in the area of operation have activated.

The minimum and maximum linear and area spacing as well as minimum and maximum coverage area recommendations is dependent on hazard category, the ceiling height, the type of sprinkler and its K-factor, etc. Table 11 shows relevant the recommendations (for a ceiling height up to 9 m) for sprinklers and conditions relevant for ro-ro spaces. The maximum allowed sprinkler spacing, and coverage area is the largest for HC-1, reflecting the lower fire hazard.

*Table 11 Spacing of ceiling-level pendent and upright non-storage sprinklers for Hazard Categories HC-1, HC-2 and HC-3 given in FM DS 2-0. Note: Additional information for higher ceiling heights and sprinklers is given in the reference.*

| Hazard category | Ceiling height (m) | Ceiling type | K-Factor | Orientation | Response | Linear Spacing (m) | | Area coverage (m²) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Min. | Max | Min. | Max |
| HC-1 | Up to 9.0 | Non-combustible unobstructed, non-combustible obstructed, or combustible unobstructed | 80, 115 or 160 | Pendent or Upright | Quick or Standard | 2,1 | 4,6 | 6,5 | 20,9 |
| HC-2 | Up to 9.0 | Detailed installation guidance given in the standard. | 80, 115 or 160 | Pendent or Upright | Quick or Standard | 2,1 | 3,7 | 6,5 | 12,1 |
| HC-3 | Up to 9.0 | Detailed installation guidance given in the standard. | 80, 115 or 160 | Pendent or Upright | Quick or Standard | 2,4 | 3,7 | 7,5 | 11,1 |

When sprinklers are provided in every channel bay formed by obstructed construction, the minimum linear and area spacing recommendations do not apply to the sprinklers located in adjacent channel bays.

### 9.2.5 A comparison of the design densities and areas of operation

The automatic sprinkler system design discussed above can be compared by multiplying the recommended minimum discharge density with the area of operation. Table 12 compares the sprinkler protection criteria for ro-ro spaces having a free height less than 2,5 m with the criteria for OH1 occupancies per NFPA 13 (2019), OH2 occupancies per EN 12845:2015+A1:2019 and hazard category HC-2 per FM DS 3-26 (2019).

*Table 12 A comparison of the sprinkler protection designs in MSC.1/Circ. 1430 with those for OH1 per NFPA 13, OH2 occupancies per EN 12845:2015+A1:2019 and HC-2 per FM DS 3-26.*

| Standard | Wet-pipe system | | | Dry-pipe system | | | Sprinkler coverage area (m²) |
|---|---|---|---|---|---|---|---|
| | Density (mm/min) | Area (m²) | Total water flow rate (l/min) | Density (mm/min) | Area (m²) | Total water flow rate (l/min) | |
| MSC.1/Circ. 1430, free height below 2,5 m | 6,5 | 280 | **1 820** | 6,5 | 280 | **1 820** | 10,24 |
| NFPA 13, OH-1 | 6,1 | 139 | **848** | 6,1 | 181 | **1 102** | 12,1 |
| EN 12845:2015, OH2 | 5 | 144 | **720** | 5 | 180 | **900** | 12,0 |
| FM DS 3-26, HC-2 | 8 | 230 | **1 840** | 8 | 330 | **2 640** | 12,1 |

It is concluded that the sprinkler protection design requirements are similar in MSC.1/Circ. 1430 and in FM DS 3-26 in terms of the total water flow rate for wet-pipe systems. For dry-pipe systems, the design recommendations are identical with those of wet-pipe systems in MSC.1/Circ. 1430, FM DS 3-26 require a higher water flow rate. It is noted that the design recommendations in NFPA 13 (2019) and EN 12845:2015+A1:2019 is significantly less, however, as previously mentioned potential code changes are underway where higher design recommendations are expected in NFPA 13.

Table 13 shows a similar comparison for EH2 occupancies per NFPA 13 (2019), HHP2 occupancies per EN 12845:2015+A1:2019 and hazard category HC3 per FM DS 3-26 (2019). The data is for spaces up to 9 m in height.

*Table 13 A comparison of the sprinkler protection designs in MSC.1/Circ. 1430 with those for EH1 per NFPA 13, HHP2 occupancies per EN 12845:2015+A1:2019 and HC-3 per FM DS 3-26.*

| **Standard** | **Wet-pipe system** | | | **Dry-pipe system** | | | **Sprinkler coverage area ($m^2$)** |
|---|---|---|---|---|---|---|---|
| | Density (mm/min) | Area ($m^2$) | Total water flow rate (l/min) | Density (mm/min) | Area ($m^2$) | Total water flow rate (l/min) | |
| MSC.1/Circ. 1430, free height 6.5 m - 9 m | 20 | 280 | **5 600** | 20 | 365 | **7 300** | 10,24 |
| NFPA 13, EH2 | 16,3 | 232 | **3 782** | 16,3 | 302 | **4 916** | 9,3 |
| EN 12845:2015, HHP2 | 10 | 260 | **2 600** | 10 | 325 | **3 250** | 9,0 |
| FM DS 3-26, HC-3 | 12 | 230 | **2 760** | 12 | 330 | **3 960** | 11,1 |

MSC.1/Circ. 1430 have the highest sprinkler design recommendations and EN 12845:2015+A1:2019 the least recommendations.

#### 9.2.5.1 Suggested design densities and areas of operation

Typical geometries of ro-ro spaces can be exemplified by information on the website of Höegh Autoliners [37]. The company lists the vessels of their fleet and specifies the year of built, the cargo capacity, the maximum height of the spaces and the maximum ramp capacity. Table 14 list some examples.

*Table 14 Examples of vessels in the fleet of Höegh Autoliners.*

| **Vessel** | **Year built** | **Cargo capacity** | **Max deck height** | **Max ramp capacity** |
|---|---|---|---|---|
| Alliance Fairfax | 2005 | 6000 ceu | 5.1 m | 150 meters |
| Höegh Antwerp | 2013 | 6500 ceu | 5.2 m | 150 meters |
| Höegh Asia | 2000 | 7850 ceu | 5.0 m | 150 meters |
| Höegh Tracer | 2016 | 8500 ceu | 6.5 m | 375 meters |
| Höegh Traveller | 2016 | 8500 ceu | 6.5 m | 375 meters |

Wallenius Wilhelmsen Ocean operates a fleet of about 50 ro-ro vessels and incorporates five classes of vessels, with each class differing in terms of dimensions, capacity, deck configuration and cargo carrying capabilities [38]. Table 15 list some examples. The Large Car and Truck Carriers (LCTC) built between 2004 and 2012, are specifically designed for the carriage of heavy equipment and breakbulk cargo whilst maintaining significant car capacity. The vessels can accommodate products up to 7,1 m in height and 12 m in width.

*Table 15 Examples of vessels in the fleet of Wallenius Wilhelmsen Ocean.*

| **Vessel** | **Year built** | **Capacity cars** | **Hoistable decks** | **Max ro-ro height (m)** | **Max ro-ro width (m)** |
|---|---|---|---|---|---|
| Asian Emperor | 1999 | 6 246 | 4 | 6,50 | 7,00 |
| Parsifal | 2011 | 6 004 | 3 | 7,10 | 12,00 |
| Theben | 2016 | 8 000 | 5 | 6,50 | 12,00 |
| Traviata | 2019 | 7 656 | 5 | 6,50 | 12,00 |
| Tortugas | 2006 | 6 354 | 4 | 5,20 | 7,00 |

From this list, it appears that the maximum height is in the order of 5,0 m to 7,1 m and the length of a space can be several hundred meters. The width of the spaces is not given, but typically between around 25 m to 30 m dependent on the deck. The following design densities and operation areas are suggested for ro-ro spaces on vehicle carriers, refer to Table 16.

*Table 16 The recommended design for wet-, dry-, pre-action and (water only) deluge systems for ro-ro spaces on vehicle carriers.*

<table>
<tr><th>Type of system</th><th>Clear height</th><th>Nominal temperature rating (°C)</th><th>RTI rating</th><th>Minimum discharge density (mm/min)</th><th>Minimum operation area (m²)</th></tr>
<tr><td>Wet-pipe</td><td rowspan="3">≤2.4 m</td><td>70</td><td>Fast- or standard-response</td><td rowspan="2">10</td><td>144</td></tr>
<tr><td>Dry- or pre-action</td><td>70</td><td>Fast- or standard-response</td><td>180</td></tr>
<tr><td>Deluge</td><td>-</td><td>-</td><td>7.5</td><td>2 or 4 deluge sections</td></tr>
<tr><td>Wet-pipe</td><td rowspan="3">>2.4 m - ≤4.0 m</td><td>70</td><td>Standard-response</td><td rowspan="2">15</td><td>144</td></tr>
<tr><td>Dry- or pre-action</td><td>140</td><td>Standard-response</td><td>180</td></tr>
<tr><td>Deluge</td><td>-</td><td>-</td><td>10</td><td>2 or 4 deluge sections</td></tr>
<tr><td>Wet-pipe</td><td rowspan="3">>4.0 m - ≤7.0 m</td><td>70</td><td>Standard-response</td><td rowspan="2">20</td><td>144</td></tr>
<tr><td>Dry- or pre-action</td><td>140</td><td>Standard-response</td><td>180</td></tr>
<tr><td>Deluge</td><td>-</td><td>-</td><td>15</td><td>2 or 4 deluge sections</td></tr>
</table>

### 9.2.6 Freeze protection

Where system piping is in areas not permanently maintained above +4 °C, the system piping may be protected against freezing by using of one of the following methods:

1. The use of a dry-pipe system or pre-action systems.
2. Antifreeze system, i.e., that a wet-pipe system is filled with an antifreeze solution.
3. The use of dry pendent or dry sidewall sprinklers extended from pipe in heated areas into unheated areas.
4. Heat tracing and thermal insulation of the sprinkler pipe.

The methods and their applicability on vehicle carriers are briefly discussed below:

**The use of a dry-pipe or pre-action systems**

Dry-pipe (or if desired pre-action) systems are generally installed in buildings where the ambient temperatures are expected to drop below +4 °C, either as the building is unheated, improperly heated, or that it must be partly open to outside cold temperature for substantial time periods. Dry-pipe systems commonly freeze due to water accumulating in improperly pitched pipes. It is therefore important to eliminate accumulated water from low point drains and to drain the system properly after trip testing or an actual system activation.

The choice of sprinklers (either upright sprinklers or dry pendent sprinklers) and protection against corrosion was discussed earlier in the report. However, there are other aspects that are important. For dry-pipe and double-interlock pre-action systems, NFPA 13 require that the area of operation shall be increased by 30 % without revising the density. The system piping and water supply need therefore be designed for a larger total water flow rate as compared to a wet-pipe system.

In non-refrigerated areas, NFPA 13 require that the branch lines shall be pitched at least 4 mm/m pipe and mains shall be pitched at least 2 mm/m pipe to facilitate the drainage of the piping.

In storage occupancies, NFPA 13 require that high-temperature rated sprinkler shall be used for dry-pipe systems. Gridded dry-pipe systems shall not be used. The system size (i.e., internal pipe volume) shall be such that initial water is discharged from the system test connection (located at the most remote point of the system) in not more than 60 s. The maximum system size is 1 900 l (500 gal) if no quick-opening device is used, and no specific water delivery time requirements to the system test connection need to be met. For a system using a quick-opening device, the maximum system size is 2 850 l (750 gal). Calculation of the water delivery time for dry-pipe systems shall be based on the hazard, refer to Table 17.

*Table 17 The water delivery time for dry-pipe systems according to NFPA 13.*

| Hazard category | Number of most remote sprinklers initially open | Maximum time of water delivery (s) |
|---|---|---|
| Light hazard | 1 | 60 |
| Ordinary Hazard (Group 1) | 2 | 50 |
| Ordinary Hazard (Group 2) | 2 | 50 |
| Extra Hazard (Group 1) | 4 | 45 |
| Extra Hazard (Group 2) | 4 | 45 |
| High piled | 4 | 40 |

FM DS 2-0 require that a dry-pipe sprinkler system shall be arranged to provide a single-path flow within all parts of the sprinkler system and meet the maximum recommended water delivery time once the first sprinkler has operated. The maximum recommended water delivery time is related to the occupancy being protected. For non-storage occupancies, refer to FM DS 3-26, water delivery shall occur within 60 s from the operation of the single most remote sprinkler or within 40 s from the operation of the most remote four sprinklers (two sprinklers on two lines).

Disadvantages of using dry-pipe fire sprinkler systems include [39]:

- Increased complexity. Dry-pipe systems require additional control equipment and air or Nitrogen supply components which increases system complexity. The system may therefore be less reliable than a comparable wet-pipe system.
- Higher installation and maintenance costs. The added complexity impacts the overall dry-pipe installation cost and added labour costs for inspection, control, and maintenance work.
- Lower design flexibility. There are strict requirements regarding the maximum permitted pipe volume (size). These limitations may require the use of more control valves as compared to a wet-pipe system and may affect the possibilities for system additions.
- Increased fire response time. Up to 60 s may pass from the time an individual sprinkler activates until water is discharged from the sprinkler. This time delay may result in increased fire damage.
- Increased corrosion potential. Following trip testing or operation, dry-pipe sprinkler systems must be completely drained and dried. Otherwise, remaining water may cause pipe corrosion and premature failure.

**The use of antifreeze**

An antifreeze solution generally contains water and water-soluble liquid, such as a glycerine or certain glycols. NFPA 13 require that antifreeze solutions shall be listed for use in sprinkler systems.

Underwriters Laboratories, Inc. have developed a standard, UL 2901, that covers requirements for the performance of antifreeze solutions for sprinkler systems. Issue 2, dated November 15, 2018 of the standards contain the following sections and related test methods and requirements [40]:

1. Solution Characterization & Stability of Solutions.
2. Conductivity.
3. Material Compatibility Testing.
4. Toxicity.
5. Fire Performance.
6. Manufacturing and Production Control.
7. Installation Instructions.

The standard does not contain requirements to evaluate the risk associated with products of combustion of antifreeze solutions.

Currently, there is one antifreeze solution product that has been listed by UL, the TYCO® LFP® Antifreeze [41, 42]. The solution is a glycerin-based, patented, and proprietary formulation. The premixed antifreeze solution has passed all tests in UL 2901, considering it safe for use in fire sprinkler systems when used as specified in the product technical data sheet. The minimum use temperature for the solution is -32 °C (-25 °F). For NFPA 13 ordinary hazard occupancies as well as storage applications, the system volume is limited to 150 l (40 gal). LFP® is currently not listed for use with galvanized pipe. The antifreeze solution should be tested annually to ensure proper solution-to-water mixture.

**The use of dry pendent or dry sidewall sprinklers extended from pipe in heated areas**

This method is likely not possible to apply on vehicle carriers, as most of the cargo areas does not face a heated area.

**Heat tracing of the sprinkler pipe**

Heat tracing is an electrical system used to maintain or raise the temperature of the sprinkler pipe so that the water in the pipe does not freeze. A protective barrier is recommended around the thermal insulation to protect it from moisture intrusion and physical damage. NFPA 13 require that a heat tracing system used to protect branch lines shall be specifically listed for this use. Water-filled piping shall be permitted to be installed where the temperature is less than +4 °C when heat loss calculations performed by a professional engineer verify that the system will not freeze.

# 10 The design and installation of Compressed Air Foam Systems (CAFS)

Main author: Martijn Teela, F4M.

## 10.1 General

This section describes design and installation aspects of Compressed Air Foam Systems (CAFS) for closed ro-ro spaces on vehicle carriers. The design and installation requirements that are discussed are based on information from the standards identified in the literature review, with the additional references provided in the text.

A CAFS releases a fire-fighting foam for the extinguishment of a fire or for the protection of unaffected adjacent areas. System components of CAFS are typically a water source, a centrifugal pump, a foam concentrate tank, a foam proportioning and injection component, a mixing chamber or device, an air compressor, and a control system ensuring suitable mixing of the water, foam concentrate and air. CAFS are typically used for the protection of spaces where flammable liquids are stored, handled, or processed, in other words applications that may include exposed or shielded Class B pool or spill fires. Systems are usually pre-engineered and must be designed by the manufacturer for the specific application.

To provide a discharge distribution over a large area, rotation nozzles or rotor nozzles are generally used. Alternatively, multi-orifice nozzles have been developed. The foam consists of a homogeneous bubble structure generated using low proportioning rates, typically from 0,3 % to 1,0 % with either Class A or B foam concentrates. NFPA 11 [43] includes recommendations for the design and installation of foam fire-extinguishing systems, including CAFS. The generation of foam is considered to provide better foam quality than nozzles where foam generation occurs in the nozzle itself. For fire hazards (indoors) in buildings where spill fires may occur, NFPA 11 recommends an application equivalent to 4,1 mm/min with film-forming foams and 6,5 mm/min with protein foams. For CAFS, NFPA 11 recommends a design density according to the system's approval requirements but not lower than 1,63 mm/min for petroleum products. No design and installation recommendations are given for Class A fires in NFPA 11, but CAFS are used for wildland fires (portable equipment) and for example for the protection of waste bunkers in recycling plants and cable tunnels. The foam provides a certain adhesion to vertical surfaces, helping to prevent or delay spread of fire between different objects. With rotating nozzles located at the ceiling, each nozzle can cover a relatively large surface area.

CAFS are usually fire tested with Class B fuel spill fires, for example to UL 162 [44] or FM 5130 [45] standards. After a hydrocarbon pool fire has been extinguished, there is a water spray discharge for 5 minutes. After this water spray application period, re-flash and burn-back tests are conducted to verify the integrity of the foam blanket. What is important here to note is that CAF can work with sprinklers. Therefore, a system design with both over-head water sprinkler application and CAF is possible, where CAF nozzles integrated in the deck can limit or extinguish a flammable liquid spill fire and over-head sprinklers or water spray nozzles would provide cooling and limit the heat exposure from a shielded fire to adjacent vehicles and the space above.

A concern with a ceiling mounted CAFS in a ro-ro space is that the vehicles would block the effect of foam application. The shielding effect of vehicles is not unique for a CAFS. Only a fire-fighter will be able to extinguish a fire concealed by vehicles. To supplement the fixed system, CAF fire-fighting hose lines are proposed which would work for both Class A and B fires.

## 10.2 CAF system piping layout

It should be noted that the generation of foam occurs at the mixing chamber of the system and finished foam is transported in the system piping. The foam travel time inside piping is rapid, as the foam to a large extent constitutes of air. The drawback is that the delivery of finished foam may require large diameter piping if the flow rate is high.

Installation is made using standard sprinkler piping and hangers, but a balanced piping configuration should be used with CAFS to provide each nozzle in the design to discharge the same amount of CAF. To achieve this, the flow path from the foam mixing chamber or device to each nozzle must have approximately the same pressure loss. The most practical way to achieve this is by grouping the nozzles in groups of 2, 4, 8, 16 or 32 and by using the same pipe length, pipe diameter, and fittings for each branch of piping. Figure 27 shows an example of a balanced piping layout for a system that consists of 32 nozzles.

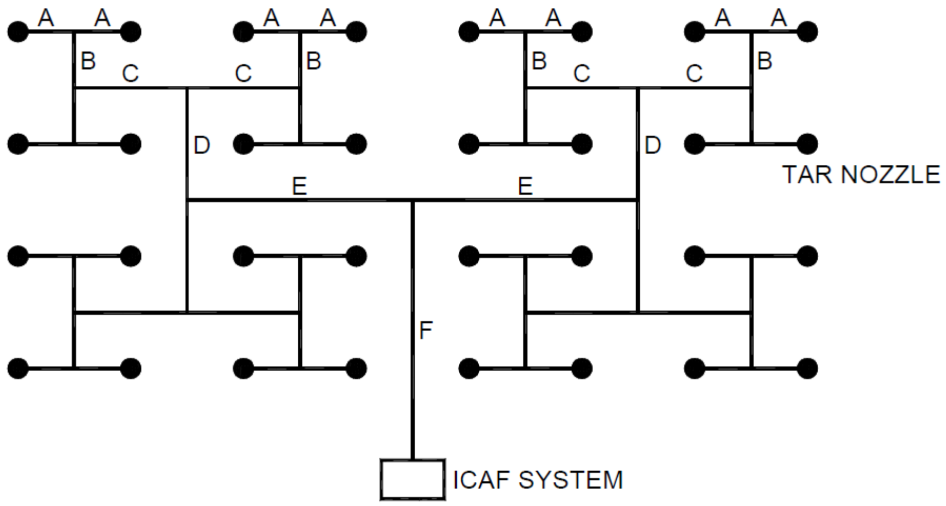



*Figure 27 An example of a balanced piping layout for larger CAFS [46]. This layout is required to ensure that each nozzle in the design discharge the same amount of CAF.*

If each nozzle in the illustration is assumed to cover 9 m$^2$, the full system coverage equals 288 m$^2$. This is approaching the section size that would be required for a closed ro-ro spaces on vehicle carriers. An alternative to a fully balanced piping configuration may be to use larger diameter piping, however, this would have implications on the system cost and overall weight.

## 10.3 System type

As indicated, CAFS need to be designed as a deluge system with open discharge nozzles attached to a piping system. The system is connected to the foam generator supply through a deluge valve. This valve is opened manually and/or by the operation of a fire detection system installed in the protected area.

## 10.4 Types of CAF nozzles and nozzle coverage areas

As CAF is generated through aeration in a mixing chamber versus agitation at the nozzle, the foam has higher expansion ratios and longer drain times than traditional low-expansion foam systems.

There are commercial nozzle providing a nozzle coverage area similar to that of foam-water spray nozzles or sprinklers, between approximately 9 m$^2$ and 12 m$^2$. The nozzle spacing shall be based on the spray pattern design principle, i.e., nozzles shall be spaced and aimed so that their spray patterns will cover all surfaces adequately. Figure 28 shows the distribution of foam from a rotating CAFS nozzle and the adhesion of foam on a vertical steel sheet plate with the CAFS nozzles used in the FIRESAFE II tests [25] discussed previously in the report.

*Figure 28 The distribution of foam from a rotating CAFS nozzle and the adhesion of foam on a vertical steel sheet plate.*

Similar to water spray nozzles, CAFS nozzles shall be positioned to distribute CAF to all locations in the area being protected and the presence of obstructions at or below the ceiling shall be considered to avoid shielding of the spray patterns.

Automatic CAFS nozzles are currently not commercially available.

## 10.5 Examples relevant CAF system applications

There are examples of fixed-pipe CAFS installations in roadway tunnels and even an incident where a fixed system successfully controlled a freight truck fire after manual operation of the system [47].

CAFS have also been installed in aircraft hangars with ceiling-mounted nozzles positioned at the ceiling. A case study compared traditional fire protection system alternatives with CAFS, indicating several benefits as lower total water flow demand and less foam agent supply demand [48]. For this application CAFS are open nozzle deluge type systems and are designed based on the surface coverage of the discharge nozzles. For a typical small aircraft hangar measuring 2 378 $m^2$ a total of 192 nozzles were required to adequately cover the whole area. The system was split into six sections with 32 nozzles each in three fire zones, each connecting to integrated cabinets connected to a single common foam supply tank and bank of compressed air cylinders. The water flow required for the CAFS was 4 500 l/min as compared to 17 800 l/min for a standard foam-water deluge system that would require 252 nozzles to protect the same hazard.

## 10.6 The principle CAFS installation requirements in ro-ro spaces

An automatic CAFS for a ro-ro space is principally design and installed as an automatic deluge water spray system in terms of the number of deluge valves and discharge nozzles. Installation is made using standard sprinkler piping and hangers.

The primary difference would be the need for a foam concentrate tank, a foam proportioning and injection component, a mixing chamber or device, an air compressor, and a control system ensuring suitable mixing of the water, foam concentrate and air. The system piping layout would also be different, due to the need for a balanced piping configuration, and the pipe diameters likely larger.

Even if using Class A foam, it is likely that the performance for fuel spill fires would improve as compared to water only. However, for vehicle carriers it is expected that the amount of fuel in vehicles are limited, at least if new vehicles are carried. A fuel spill fire is thereby relatively limited in size and duration.

Irrespective of the type of foam that is used (Class A or B) it needs to be fluorine-free and biodegradable from an environmental point of view.

# 11 Sprinkler piping and internal corrosion protection of piping

Main author: Magnus Arvidson, RISE.

## 11.1 General

There are primarily three aspects that are important for sprinkler piping on vehicle carriers, 1) the external and internal corrosion protection of piping given the environment on board the ship, 2) the overall weight of the system and 3) the durability of the piping under fire conditions. If metallic piping is used, the last aspect is typically no concern. Steel, which is the usual pipe material in buildings and on boards ships is considered strong, durable, and resistant to fire. With a melting point of about 1 400 °C, steel pipe can withstand the heat from a fire, especially if water is flowing through the pipe. However, non-metallic piping may be advantageous to improve the first two characteristics but suffer from less heat resistance.

Other aspects include the possibilities for piping system modifications. However, it is likely that the need for system extensions and system modifications is far less common on board a ship than in an on-shore facility. The external size of the ship will not change over its service life, although the addition of decks or a ship extension may be possible, and the fire hazards remain reasonably constant over time. For an on-shore facility, the fire hazards may virtually change over-night, for example if a part is rebuilt to change the business operation or if there is a new occupant who stores completely different goods than the previous occupant.

Internal corrosion in a sprinkler system can result in partial or full blockage, limiting or damaging the system performance. Internal corrosion can also result in pinhole leaks, creating impairments to the fire protection system and result in damage to contents underneath the piping. Most internal sprinkler system corrosion is due to the presence of water and air inside the piping. In wet-pipe sprinkler systems, oxygen in the water and trapped air is consumed over a relatively short time and the corrosion process ceases until fresh air or water is reintroduced into the system. In typical dry-pipe sprinkler systems where compressed air is used as the supervisory gas, the presence of water in the piping will result in rapid corrosion of the system [12].

## 11.2 Steel piping

Standard weight pipe is denoted Schedule 40 pipe, extra strong pipe is called Schedule 80 and double extra strong pipe is called Schedule 160. The Schedule number corresponds to the wall thickness of the steel pipe, the lower the number, the thinner the wall. For a sprinkler system, only Schedule 40 pipe is used [49].

Steel pipe for sprinkler systems can be joined by threaded joints, welded joints as well as using couplings for rolled and cut grooved pipe. Threading is only permitted for Schedule 40 or heavier pipe unless the pipe is specifically tested and approved for threading. A cut groove connection is only permitted on Schedule 40 and heavier piping, as the joints cut a straight groove into the wall of the pipe to allow the connection of a grooved fitting. The joint is sealed with an elastomeric gasket. Roll grooving require a special machine that rotates the end of a pipe through a roll set, displacing the metal and forming a groove on the outside surface of the pipe, rather than cutting a groove. There are several tested and approved mechanical fittings and couplings for sprinkler system piping. Most mechanical joints rely on an elastomeric gasket or seal to make the connection [49].

Roll grooving technology is the most common today. The process is faster, and the roll grooving process also removes the need for cutting oil and the necessity for cleaning up the metal shavings that are removed from the pipe. Although roll grooving is the most common technology, cut groove is beneficial, for example, if the pipe is internally lined or coated, cut grooving is recommended to keep the integrity of the internal lining and coating [50].

Steel has a low coefficient of thermal expansion, minimizing the need for expansion loops and joints. Additionally, steel has a high strength and rigidity, which means that the handling of pipes during installation will typically not cause damage to the pipe. Rigidity is also important which allows a long distance between hangers during installation.

A major drawback with steel piping is the risk for internal and external corrosion. The sensitivity to internal corrosion results in a hydraulic C-factor (friction loss coefficient), which measures the roughness on the inside of pipes and its ability to impede water flow. Black steel pipes have a C-factor of 120 in wet-pipe systems.

An observation from the information given above is that light-weight sprinkler pipe typically requires that the pipe be rolled grooved, with associated couplings. The wall thickness of light-weight pipe is not sufficiently thick for either threading or cut grooves.

## 11.3 Recommendations to avoid internal pipe corrosion

FM DS 2-1 [34] contains several recommendations on how to minimize or prevent internal pipe corrosion. The recommendations include issues like the choice of material, storage of piping awaiting installation, cleaning of contamination, internal inspection during the service life, etc. The recommendations related to the choice of sprinkler piping can be summarised as follows:

- Use Schedule 40 (or equivalent thickness) pipe for wet-, dry-, and pre-action systems installed over occupancies deemed sensitive to leaks.
- Do not use galvanized pipe in wet-pipe systems.

The first requirement relates to the fact that corrosion generally impacts steel pipes with thinner walls the fastest, reducing their effective lifespan compared to thicker Schedule 40 pipes. A reason for not recommending galvanized pipe in wet-pipe systems is that hydrogen ($H_2$) can accumulate in the piping due to corrosion. This can lead to a significant pressure increase or (if the hydrogen gas leaks and an and ignition source is present) to explosion hazards. There are several cases reported from Norway where the high pressure in the piping have led to the separation of pipe couplings and water damage. In one case, a blue flame was observed when a hole in a pipe was drilled. Two incidents with explosions have been reported from installations in Denmark [51].

For dry-pipe and pre-action systems <u>using</u> Nitrogen as the supervisory gas, it is recommended in FM DS 2-1 that:

- Pressurize the system using an FM Approved Nitrogen generator. Alternatively, Nitrogen cylinders may be used, or another suitable supply if compressed air is provided as backup.
- Black steel pipe is acceptable in dry-pipe and pre-action sprinkler systems if Nitrogen will be used throughout the life of the system.

For dry-pipe and pre-action systems <u>not</u> using Nitrogen, it is recommended that:

- Use galvanized steel pipe. Black steel pipe can be used when an FM Approved vacuum system is used.
- Install pipe with proper pitch to promote drainage of all testing water and water vapor condensate within piping.
- Install low-point drains to remove all water that can be trapped in these systems following system activation or during testing.

- Keep low-point drains (including those at the riser) clean and drain condensate at the frequency required to prevent water accumulation.
- Avoid the use of rolled groove joints. Rolled groove joints in a dry-pipe sprinkler system promotes water accumulation that can result in corrosion spots. Authors note: As notified above, rolled groove joints are associated with light-weight sprinkler pipe, i.e., the implication of this requirement is that the use of light-weight sprinkler piping in dry-pipe systems require Nitrogen as the supervisory gas.
- In humid regions or in areas that are subject to rapid drops in temperature, install an air-drying system so the dew point temperature of the supply air is 6 °C (20 °F) below the lowest expected room temperature. Check air-drying systems at regular intervals as needed to prevent saturation of the drying media and excessive humid air from entering the system.
- Fix air leaks to keep system as tight as possible.
- Orient longitudinal pipe weld seam toward building roof to mitigate pipe weld seam corrosion.
- Keep piping dry throughout the year, i.e., do not alternate between wet- and dry-pipe systems.

As indicated, one corrosion mitigation approach is to use Nitrogen gas instead compressed air in the system piping. This can remove oxygen, thereby decreasing oxygen-related electrochemical reactions.

From the list of recommendations given above, it can be observed that black steel piping is acceptable in dry-pipe and pre-action sprinkler systems if Nitrogen is used, but galvanized steel pipe is required otherwise. Internal corrosion in galvanized steel piping will not occur if the piping is maintained dry, by sufficient pitching and/or drainage of residual water from system commissioning pressure tests, trip testing and actual sprinkler system activation. The list of measures that need to be fulfilled if using Nitrogen is also significantly shorter. As noted above, the use of Nitrogen as the supervisory gas is required if using rolled grooved lightweight sprinkler pipe in dry-pipe systems.

A Research Technical Report [52] by FM Global contain comprehensive explanation of corrosion in fire protection systems, due to for example pipe weld corrosion, residual water in dry-pipe systems, trapped air in wet-pipe systems and microbiologically influenced corrosion (MIC). The report concludes that pinhole leakage can occur within 2-3 years after initial installation even in new dry- or pre-action systems, due to residual water causing corrosion in galvanized steel pipe. The underlying reason could be inadequate pitching and/or drainage, resulting in trapped residual water from system commissioning and trip testing in the piping. This results in high concentrations of dissolved oxygen and carbon dioxide in trapped water. Dissolved oxygen and carbon dioxide in water can increase corrosion for galvanized steel pipe. Water in piping may also be introduced via condensation. Research by FM Global indicate that compressed Nitrogen as the supervisory gas can reduce corrosion of galvanized steel pipe containing trapped water. Another strategy is to use treated water such as freshwater (municipal water) for better water quality and less corrosion.

A relatively unknown drawback of galvanized piping is that the corrosion process causes galvanized steel to discard $Zn^{2+}$ ions into the discharge water when dry- or pre-action sprinkler systems are tested, creating a heavy metal contamination environmental hazard. Another drawback is that galvanized steel pipe costs about 30 % more than black steel pipe [53].

For wet-pipe systems, the possibility for air venting is very important to prevent or limit internal pipe corrosion. The following example from a sprinkler installation in Sweden may serve as an illustration of the problem, although it should be regarded as just an illustration. A wet-pipe sprinkler system consisted of 9 000 m galvanized piping and was installed in 2015. In 2020, just five years after the installation, severe corrosion was observed with several leakages along the longitudinal seam weld of the pipe. The main reason for the corrosion was likely that air venting valves were missing, although included in the design drawing. In addition, the section flow alarm devices w-ere tested quarterly, which regularly introduced fresh water to the system piping [54].

The 2019 edition of NFPA 13 require that a single air vent shall be provided on each wet-pipe system utilizing metallic pipe. The vent shall be located near a high point in the system to allow air to be removed from that portion of the system. The valve may be either a manual ½" valve, an automatic air vent or any other approved means.

## 11.4 Polymer-enhanced steel pipe

In December 2020, FM Global announced that the first polymer-enhanced steel pipe has received the FM Approved mark [55]. The approved Fendium pipe features a special polymer that protect it against corrosion both on the outside and the inside. Because of the smooth finish, it provides a Hazen-Williams coefficient (C-factor) of 140 for both wet- and dry-pipe systems. The higher C-value corresponds to less pressure loss, which may allow the use of smaller pipes or smaller pumps. The C-factor is a roughness coefficient of piping and can be significantly changed by internal corrosion. Carbon steel, for example, has a C-value of 120 when used in wet-pipe systems, but about 100 in dry-pipe systems. As the Fendium pipes are factory-finished with a continuous polymer enhancement on-site, grooving of pipe should be avoided as the industry standard grooving machines cause damage to the inside of the pipe. It is recommended by the manufacturer that Fendium pipes are factory pre-fabricated as far as possible [56].

## 11.5 Weight comparison between standard and light-weight sprinkler piping

The use of light-weight piping will reduce the weight of the individual pipe considerably. For buildings, the primary benefit is that the installation time is reduced as handling is easier. For ships, however, a reduced overall weight of the sprinkler piping could also result in less fuel consumption and/or increased cargo weight capacity.

The weight difference of two commercially available lightweight piping systems is illustrated with two examples given below.

**Example 1**

NordicFlow® are seam-welded, factory-grooved light-weight steel sprinkler pipe. The pipe is epoxy powder-coated or hot-dip galvanized and approved by FM Global for both wet- and dry-pipe system applications. The pipe is used with rigid grooved end coupling. The piping is pressure rated to 16 bar and have a C-factor of 130.

Table 18 shows the dimensions and weight of NordicFlow® pipes as compared to standard piping.

*Table 18 The dimensions and weight of NordicFlow® pipes as compared to standard piping.*

| **Light-weight piping** | | | | **Standard piping** | | | |
|---|---|---|---|---|---|---|---|
| **ISO DN** | **DO [mm]** | **t [mm]** | **Weight [kg/m]** | **Weight [kg/m]** | **t [mm]** | **DO [mm]** | **ISO DN** |
| 25 | 33,7 | 2,0 | **1,57** | **2,4** | 3,2 | 33,7 | 25 |
| 32 | 42,4 | 2,0 | **1,99** | **3,1** | 3,2 | 42,4 | 32 |
| 40 | 48,3 | 2,0 | **2,29** | **3,6** | 3,2 | 48,3 | 40 |
| 50 | 60,3 | 2,0 | **2,88** | **5,0** | 3,6 | 60,3 | 50 |
| 65 | 76,1 | 2,0 | **3,66** | **N/A** | N/A | N/A | 65 |
| 80 | 88,9 | 2,0 | **4,29** | **6,8** | 3,2 | 88,9 | 80 |
| 100 | 114,3 | 2,3 | **6,36** | **9,9** | 3,6 | 114,3 | 100 |
| 125 | 139,7 | 2,9 | **9,79** | **13,5** | 4,0 | 139,7 | 125 |
| 150 | 168,3 | 2,9 | **11,84** | **18,1** | 4,5 | 168,3 | 150 |
| 200 | 219,1 | 3,6 | **19,15** | **33,2** | 6,3 | 219,1 | 200 |

The weight savings range from 27 % (DN80) to 43 % (DN50) but are generally around 35%.

**Example 2**

Alvenius FlowMax® pipes are spirally welded using pressure equipment classed steel. The steel quality result in strong thin-walled pipe and the spiral welding ensures that pipes remain straight. The pipe is surface coated to provide high resistance to acidic water, aggressive chemicals, the effects of weather, wind, and salt laden air in outdoor systems. The pipe is available in dimensions ranging from DN80 to DN500 and is pressure rated to either 16 bar, 25 bar or 40 bar.

Table 19 shows the dimensions and weight of Alvenius FlowMax® pipes as compared to standard piping.

*Table 19 The dimensions and weight of Alvenius FlowMax® pipes as compared to standard piping.*

| **Light-weight piping** | | | | **Standard piping** | | | |
|---|---|---|---|---|---|---|---|
| **ISO DN** | **DO [mm]** | **t [mm]** | **Weight [kg/m]** | **Weight [kg/m]** | **t [mm]** | **DO [mm]** | **ISO DN** |
| 80 | 88,9 | 2,1 | **4,8** | **6,8** | 3,2 | 88,9 | 80 |
| 100 | 114,3 | 2,0 | **5,8** | **9,9** | 3,6 | 114,3 | 100 |
| 125 | 139,7 | 2,1 | **7,5** | **13,5** | 4,0 | 139,7 | 125 |
| 150 | 168,3 | 2,1 | **9,1** | **18,1** | 4,5 | 168,3 | 150 |
| 200 | 219,1 | 3,0 | **16,7** | **33,2** | 6,3 | 219,1 | 200 |

The weight savings range from almost 30 % (DN80) to 50 % (DN150 and DN200).

## 11.6 Non-metallic sprinkler piping

Steel has traditionally been used for fire sprinklers, although thermoplastic pipes now dominate in residential and light hazard occupancies. Chlorinated polyvinyl chloride (CPVC) pipe have been used since the 1980s. Previously, NFPA 13 identified both CPVC and polybutylene (PB) as acceptable plastic piping materials. However, PB has not been available in North America for approximately 15 years [49] and is not recognized in the 2019 edition of NFPA 13. But other pipe material is permitted where installed in accordance with their listing limitations.

Cross-linked polyethylene (PEX) is also used for sprinkler piping in residential applications. PEX is very flexible and is available in long coil lengths. Therefore, an installer can bend the pipe to make a change in direction without having to stop and cut in a fitting. The flexibility makes highly resistant to freeze damage. It can expand to accommodate frozen water in the pipeline and then contract back down to its original shape once the water thaws [57].

NFPA 13 allows the use of non-metallic pipe or tube to be used if certified and installed in accordance with their certification limitations. In an NFPA 13 occupancy, non-metallic pipe certified for light hazard occupancies can be installed concealed or exposed in a room up to 37 $m^2$ in area and concealed in a private garage up to 93 $m^2$ in area.

Notarianni and Jackson have made a comparison [58] of fire sprinkler piping materials for residential and light hazard applications that include steel, copper, chlorinated polyvinyl chloride (CPVC) and polybutylene (PB). At the time of the review (1994), PEX sprinkler pipe was not available in the market.

CPVC pipe will noticeably expand or contract when exposed to substantial temperature differences as the it has a coefficient of linear expansion that is over five times that of steel and about three times that of copper. There is negligible expansion or contraction circumferentially. Reasonable care must be applied when handling CPVC pipe and fittings. If they are dropped, stepped on, or have objects dropped into them, they should be checked for scratches, splits, or cavities. If the pipe is exposed to ultraviolet rays from sunlight, the pipe tends to lose drop impact resistance and become flexible. However, the pipe does not lose any of its long term hydrostatic strength capability.

The weight thermoplastic sprinkler pipe and steel pipe are summarised in Table 20.

*Table 20 Sprinkler pipe weight comparison of steel, copper CPVC and PB [58].*

| **Nominal size** | | **Steel pipe Schedule 40 (kg/m)** | **Typical light-weight steel (kg/m)** | **Copper Type M (kg/m)** | **CPVC (kg/m)** | **PB (kg/m)** |
|---|---|---|---|---|---|---|
| DN (mm) | NPS (inch) | | | | | |
| 20 | 0,75 | N/A | N/A | 0,49 | 0,25 | 0,13 |
| 25 | 1,0 | 2,50 | 1,82 | 0,68 | 0,39 | 0,20 |
| 32 | 1,25 | 3,38 | 2,35 | 1,01 | 0,62 | 0,31 |
| 40 | 1,5 | 4,05 | 2,80 | 1,40 | 0,82 | 0,43 |
| 50 | 2,0 | 5,43 | 3,75 | 2,17 | 1,28 | 0,73 |
| 65 | 2,5 | 8,62 | 6,07 | 3,02 | 1,87 | N/A |
| 80 | 3,0 | 11,3 | 7,46 | 3,99 | 2,78 | N/A |

This sprinkler pipe weight comparison indicates significant pipe saving using thermoplastic sprinkler pipe, which would be attractive for ships. However, as mentioned thermoplastic fire sprinkler piping is typically used for residential and other light hazard occupancies and are therefore not possible to use for the protection of ro-ro spaces on vehicle carriers.

# 12 Fire detection systems

Main author: Magnus Arvidson, RISE.

## 12.1 General

Fire detection systems used for the activation of a pre-action or a deluge system section in closed ro-ro spaces should, regardless of the detection technology, be designed to:

- Provide rapid and reliable detection of a fire within the pre-action or deluge section.
- Minimize the susceptibility of false alarms.
- Provide a signal for the activation of the correct section control valve.
- Immediately alert the ship's crew so that they may intervene.
- Withstand the environmental conditions experienced in these spaces.

The 2011 edition of FM DS 5-48 [59] describes the basic types of automatic fire detectors and provides recommendations for installation and testing of fire detection systems. Section 2.2.1.14 of FM DS 5-48 provides recommendations for detection systems for pre-action and deluge sprinkler systems, selected to ensure operation but protect against premature operation of sprinklers, based on normal room temperature and draft conditions.

It is stated that an FM Approved heat detector will operate at least as quickly as an FM Approved, automatic sprinkler on 3 m by 3 m (10 ft. by 10 ft.) spacing having similar temperature rating and under the same conditions of heat exposure. An FM Approved detector is also designed to operate within 3 % of its intended fixed temperature rating or, if of the rate-of-rise type, to operate at an ambient temperature increase of between 8,3 °C (15 °F) and 13,9 °C (25 °F) per minute.

The recommendations in FM DS 5-48 are considered valid for fire detection systems for the activation of pre-action or deluge systems in closed ro-ro spaces and are summarised and commented below.

## 12.2 Type of fire detectors

FM DS 5-48 recommends fixed-temperature, rate-of-rise, or combination fixed-temperature/rate of-rise fire detection devices. Smoke or flame detectors are not recommended unless recommended by the applicable occupancy-specific [FM Global] data sheet.

It is recognized that smoke detectors provide rapid fire detection for fires generating smoke, but for this application they are susceptibility of false alarms and smoke spreading may result in activation of the wrong deluge section. Smoke detectors may, however, be useful for the case a single pre-action system section covers the entire space. For that case, the probability for activating the wrong system section can be considered negligible and false alarm would only trip the pre-action valve without any significant consequences.

FM DS 5-48 additionally recommends that heat detection using fixed-temperature detectors is used to activate a pre-action system in refrigerated areas, as rate-of-rise detectors may false trip when doors are opened or when other abrupt localized temperature changes occur. Although refrigerated areas are not specifically valid for closed ro-ro spaces, the recommendation justifies that fire detection devices should be adjusted to accommodate expected temperature gradients.

In general, rate-of-rise devices may alarm more rapidly than fixed-temperature detectors in cold environments and in fast developing fires. Fixed-temperature devices may be more reliable in detecting slowly developing fires, and they usually require less attention to prevent false alarms. With a combination fixed-temperature and rate-of-rise heat detector, the detector would respond rapidly to both fast-acting and slow-acting fires. For that reason, it appears that such detectors would be suitable for vehicle spaces.

## 12.3 Positioning of fire detector devices

FM DS 5-48 recommends that spot-type heat detectors should be located on or under the ceiling, optimally at about 1 %, but not more than 6 %, of the ceiling height below the ceiling.

Line-type heat detectors should be located under the ceiling, optimally with the bulk of the detector wire at about 1 %, but not more than 6 % of the ceiling height below the ceiling. The wire should never be firmly attached to ceiling, pipe, joists, etc. For example, if attached to a sprinkler pipe, hangers should be used to offset the wire from the pipe by at least one pipe diameter. The wire can be hung above or below a pipe, but if installed on the side of a pipe, hang it on the same side of every pipe.

Closed ro-ro spaces on vehicle carriers have a clear ceiling height typically ranging from about 1,8 m to 6,5 m (in some cases somewhat higher). Assuming that the beam depths is 0,3 m and 0,6 m, respectively, this results in a corresponding ceiling height of 2,1 m and 7,1 m. For these cases, the recommended vertical detector or detector wire installation distance from the ceiling would be between 21 mm and 126 mm for the low-height case and between 71 mm and 426 mm for the high-height case.

FM DS 5-48 does also include installation recommendations for beamed constructions, where D is the beam depth, H the ceiling height, and W the width between beams. If D/H is greater than 0,10 and W/H is greater than 0,30, detectors should be installed in each pocket formed by the beams.

These recommendations can be illustrated with the figures relevant for a low-height and high height space, respectively, discussed above:

- For a beam depth (D) of 0,3 m and a ceiling height (H) of 2,1, then D/H = 0,14, which is greater than 0,10. If the distance between the beams is 1,5 mm, W/H = 0,71, which is greater than 0,30. Then detectors should be located in each pocket formed by the beams.
- For a beam depth (D) of 0,6 m and a ceiling height (H) of 7,1 m, then D/H = 0,08, which is less than 0,10. If the distance between the beams is 1,5 m, W/H = 0,21, which is less than 0,30. For this case, the detectors need not to be located in each pocket formed by the beams.

These two examples illustrate that ceiling constructions with deep beams positioned on a short distance (c-c), could require many fire detectors unless the ceiling height is high.

## 12.4 Fire detector spacing

FM DS 5-48 recommends that the spacing of heat detectors for the activation of pre-action systems under smooth ceilings should not exceed that for which it was FM Approved. For other than smooth ceilings, the spacing of heat detectors should not exceed one-half the FM Approved linear detector spacing or the full allowable sprinkler spacing, whichever is greater. This criteria are exemplified as follows; if a detector is FM Approved for 9,15 m by 9,15 m (30 ft. by 30 ft.) spacing and the allowable sprinkler spacing is 12 $m^2$ (130 $ft^2$), then the maximum allowable linear detector spacing is 4,6 m by 4,6 m (15 ft. by 15 ft.).

A ‘smooth’ ceiling is per the definition in FM DS 5-48 a ceiling where beams project below the ceiling no more than 3 % of the ceiling height. From the example in the sub-section above, it can be concluded that beams no deeper than 63 mm would be permitted in a low-height case and beams no deeper than 213 mm would be permitted in the high-height case. From this exercise, it can be concluded that few ceilings in a closed ro-ro spaced would be considered as ‘smooth’. Therefore, fire detectors need to be installed on a relatively short spacing.

The spacing guide for FM Approved heat detectors on smooth ceilings is dependent on the Response Time Index (RTI) of the detector, i.e., the sensitivity of the heat sensing element as it responds to rising temperature. Table 21 provides the spacing guidelines in FM DS 5-48 for spot-type detectors having different RTI when placed in best case orientation on a smooth ceiling.

*Table 21 Heat detector spacing on smooth ceilings according to FM DS 5-48 given the RTI rating of the detector.*

| Detector spacing label | Spacing (m) | Spacing (ft.) |
|---|---|---|
| SPECIAL | 3 × 3 | 10 × 10 |
| STANDARD | 4,5 × 4,5 | 15 × 15 |
| QUICK | 6 × 6 | 20 × 20 |
| FAST | 8 × 8 | 25 × 25 |
| V-FAST | 9 × 9 | 30 × 30 |
| $V^2$-FAST | 10,5 × 10,5 | 35 × 35 |

For joisted and beamed ceilings deeper than 3 % of the ceiling height, FM DS 5-48 recommends to not exceed 50 % of the detector’s smooth ceiling spacing, as measured at right angles to the joists and beams. The smooth ceiling spacing is allowed to be used in the direction parallel to beams. If beams project more than 15 % of the ceiling height, each section between beams should be treated as a separate area.

Using the ceiling height examples given above, beams deeper than 315 mm in a 2,1 m high space and 1 065 mm in a 7,1 m high space, respectively, would require that the sections between them is treated as a separate area.

For ceilings higher than 3 m (10 ft.) and up to 9 m (30 ft.), prior to space reductions made for beams, joists, or slopes, the spacing shall be reduced where a small, steady-state fire might occur and where there are no sprinklers, refer to Table 22. This spacing reduction does not apply in warehouses where a fast-growing fire can be expected. The purpose of reducing the spacing is to allow a 1 000 kW fire to be detected in a certain amount of time regardless of ceiling height. This table does not apply to line-type detectors.

*Table 22 Heat detector spacing reductions for ceilings higher than 3 m (10 ft.) according to FM DS 5-48.*

| Ceiling height (m) | Ceiling height (ft.) | Multiply spacing by: |
|---|---|---|
| >3,0 to 4,5 | >10 to 15 | 0,85 |
| >4,5 to 6,0 | >16 to 20 | 0,70 |
| >6,0 to 7,5 | >21 to 25 | 0,55 |
| >7,5 to 9,0 | >26 to 30 | 0,40 |

If the recommendations discussed above are applied in a vehicle space, the actual spacing between heat detectors and the corresponding coverage area would be significantly reduced even for a smooth ceiling. For space having a ceiling height of 7,1 m, as per the example used above, the detector spacing need to be reduced with a factor of 0,55 to account for the ceiling height.

It is worth noting that FM DS 5-48 expresses the coverage of a fire detector in spacing, i.e., the horizontal distance between detectors and does not provide the corresponding coverage area. A 50 % reduction of the detector spacing therefore results in a coverage area that is only one-fourth the original area.

## 12.5 Temperature rating of heat detectors

FM DS 5-48 recommends the use of heat detectors with a temperature rating slightly higher than the highest expected ambient temperature. Table 23 gives the temperature ratings of detectors that can be used for various maximum expected ceiling temperatures.

*Table 23 Selection of heat detector temperature rating according to FM DS 5-48.*

| Temperature Rating Range of Detector | | Maximum Expected Ceiling Temperature | |
|---|---|---|---|
| °F | °C | °F | °C |
| 135 to 174 | 57 to 79 | 100 | 38 |
| 175 to 249 | 79 to 121 | 150 | 66 |
| 250 to 324 | 121 to 162 | 225 | 107 |
| 325 to 399 | 163 to 204 | 300 | 149 |
| 400 to 499 | 204 to 260 | 375 | 191 |
| 500 to 575 | 260 to 302 | 475 | 246 |

It is assumed that the ambient temperature inside closed ro-ro spaces on vehicle carriers could vary considerably over season and with the geographical position of the ship. This aspect needs to be considered for the selection of the temperature rating.

FM DS 5-48 concludes that rate-of-rise detector devices have a set point that is usually between 8,3 °C (15 °F) and 13,9 °C (25 °F) rise per minute. These detectors should not be used in an area where temperature can change rapidly such as near some machinery.

## 12.6 Activation and controls

For pre-action or deluge system activation, FM DS 5-48 recommends the use of single-zone circuitry for detection and actuation devices. Cross-zoned circuits unnecessarily delay system activation. It should be ensured that the circuitry is designed to be operational despite the occurrence of a single fault (ground fault or open circuit).

Separate detection systems should be provided, with control panels, and release device circuitry for each sprinkler system. Control panels that can control multiple systems via separate modules in the same panel are acceptable.

## 12.7 Requirements in SOLAS

SOLAS Chapter II-2, Regulation 20, “Protection of vehicle, special category and ro-ro spaces” provides the applicable requirements for fire detection systems. Section 20.4.1 require a fixed fire detection and fire alarm system complying with the requirements of the International Code for Fire Safety Systems (the FSS Code in short). The overall requirement is that the system shall be capable of rapidly detecting the onset of fire. The type of detectors, their spacing and location shall be to the satisfaction of the Administration considering the effects of ventilation and other relevant factors. After installation, it is required that the system shall be tested under normal ventilation conditions and shall give an overall response time to the satisfaction of the Administration.

The FSS Code contains detailed requirements. Section 2.3.1.3 of the FSS Code require that heat detectors shall be certified to operate before the temperature exceeds 78 °C, but not until the temperature exceeds 54 °C, when the temperature is raised to those limits at a rate less than 1 °C per minute. At higher rates of temperature rise, the heat detector shall operate within temperature limits to the satisfaction of the Administration having regard to the avoidance of detector insensitivity or oversensitivity. Section 2.3.1.5 of the FSS Code require that all detectors shall be of a type such that can be tested for correct operation and restored to normal surveillance without the renewal of any component.

Detectors shall be located for optimal performance. Positions near beams and ventilation ducts or other positions where patterns of air flow could adversely affect performance and positions where impact or physical damage is likely shall be avoided. Table 24 shows the maximum spacing of detectors given in the FSS Code.

*Table 24 The maximum spacing of fire detectors given in the FSS Code.*

| Type of detector | Maximum floor area per detector | Maximum distance apart between centres | Maximum distance away from bulkheads |
|---|---|---|---|
| Heat | 37 $m^2$ | 9 m | 4,5 m |
| Smoke | 74 $m^2$ | 11 m | 5,5 m |

The Administration may require or permit different spacing if based upon test data which demonstrate the characteristics of the detectors. It can be concluded that this requirement indirectly recognizes that heat detectors may have different thermal response characteristics and offers the possibility to install heat detectors on larger coverage area than that given.

It should be noted that the requirements for the positioning and coverage area of detectors are related to all types of spaces and not specifically ro-ro spaces.

MSC.1/Circ. 1430 recognise manual deluge systems as well as automatic deluge and pre-action systems. The fire detection system used for these systems should comply with the FSS Code and should consist of flame, smoke, or heat detectors of approved types. For automatic deluge and pre-action systems, the discharge of water should be controlled by the fire detection system. The detection system should provide an alarm upon activation of any single detector and discharge if two or more detectors activate. Automatically released systems should also be capable of manual operation (both opening and closing) of the section valves. Means should be provided to prevent the simultaneous release of multiple sections. The automatic release may be disconnected during on- and off-loading operations, provided that this function is automatically reconnected after a pre-set time being appropriate for the operations in question.

There are two specific installation requirements for spot-type heat detectors:

- Section 4.9: Where beams project more than 100 mm below the deck, the spacing of spot-type heat detectors at right angles to the direction of the beam travel should not be more than two thirds [i.e., no more than 6,0 m] of the spacing permitted under Chapter 9 of the FSS Code.
- Section 4.10: Where beams project more than 460 mm below the deck and are more than 2,4 m on centre, detectors should be installed in each bay formed by the beams.

The FIRESAFE II project have investigated means for early detection of fire and quick activation of the fire extinguishing system. The study covered open ro-ro spaces, closed ro-ro spaces as well as weather decks, for both new and existing ships [60]. The report mention that several Flag States and classification societies (Bureau Veritas, US Coast Guard, Swedish Flag and Maritime & Coastguard Agency) require smoke detectors exclusively or in combination with other detectors in ro-ro spaces. Standard heat or flame detectors were considered to provide relatively long activation times and flame detectors were expected to lead to false alarms due to reflections, etc.

## 12.8 Conclusion

The fire detection system technologies discussed in this section of the report is intended to be installed for the automatic activation of pre-action or deluge systems in a ro-ro space of a vehicle carrier. The recommendations of FM DS 5-48 were consulted as they provide relevant and comprehensive information.

It is concluded that fixed-temperature, rate-of-rise, or combination fixed-temperature/rate of-rise fire detection devices should be used. These devices could be of spot-type or line-type. Smoke or flame detectors are not recommended.

A heat detector device installed under a smooth, ceiling, in other a ceiling where beams project below the ceiling no more than 3 % of the ceiling height may cover a large area, especially if the heat detector has a low RTI. Beams and other obstructions, which are commonly found in these spaces, will introduce obstacles to the flow of gases underneath a ceiling, which require a narrower detector spacing. The obstructed ceiling construction on vehicle carriers will result in quite many spot-type heat detectors or a narrow sensor wire spacing for line-type detector devices. It is observed that FM DS 5-48 is not as detailed on the reduction of spacing for line-type detector devices, but the essential approach should be similar.

WP09 in the LASH FIRE project have studied fire detection systems solutions for ro-ro spaces, as documented in D09.2, “Developed ro-ro spaces fire detection solutions and recommendations”.

# 13 Requests by ship operators and potential installation and operation challenges

Main author: Magnus Arvidson, RISE.

Discussions with Wallenius Marine AB provided input to this section of the report.

One concern is related to unintentional activations (no fire) or water leakage with potential damage to the cargo, that is often new vehicles. For automatic sprinkler systems, a solution to limit the probability of inadvertent activations and leakage is the use of a double-interlock pre-action system, refer to the description earlier in the report. Two separate incidents must occur to initiate sprinkler discharge. Firstly, a fire detection system must discover a developing fire and then open the pre-action valve. Secondly, an individual sprinkler must activate to permit water flow onto the fire. The system piping is pressurized with air or Nitrogen to hold water from system piping in the event of inadvertent fire detector operation, but also to monitor the piping for leaks.

As double-interlock- pre-actions systems add a level of protection against inadvertent discharge, they are often used in applications like heritage buildings, rare collection storage rooms and computer and server rooms. Drawbacks of using pre-action fire sprinkler systems include [61]:

- Higher installation and maintenance costs. Pre-action systems are more complex with several additional components, most notably a fire detection system. This adds to the overall system installation and maintenance costs.
- Modification difficulties. As with dry-pipe systems, pre-action sprinkler systems have specific system volume limitations which may impact future system modifications. Additionally, system modifications must incorporate changes to the fire detection and control system to ensure proper operation.
- Potential decreased reliability. The higher level of complexity creates an increased possibility for malfunctions. Periodical inspection, control and maintenance routines are essential to ensure reliability.

For automatic deluge water spray or CAF systems, the most obvious solution to prevent inadvertent discharge is that two individual spot-type fire detectors need to alarm prior the system is activated. To further limit the probability for inadvertent discharge, the system solution may also involve human interaction before discharge. In other words that an actual fire is verified before discharge. The drawback of this solution is apparently that the system is not fully automatic. But a time delay of say 60 s may be incorporated, after which discharge is initiated unless human involvement occurs.

# 14 Large-scale validation fire tests

Main author: Magnus Arvidson, RISE.

## 14.1 General

This section describes the large-scale validation fire tests that were conducted in September 2021 at RISE in Borås, Sweden. The tests focused on the two system technologies that were found to be the least expensive to install and maintain:

- An automatic dry-pipe sprinkler system.
- An automatic deluge water spray system.

The tests were conducted inside the large fire test hall at RISE. The hall has a floor area of 400 $m^2$ and a corresponding volume of 6 000 $m^3$. The facility is equipped with a ventilation system with air inlet through gratings at the floor, along the sides of the long side walls. The outlets are positioned at the top of the ceiling of the test hall.

## 14.2 The suspended ceiling

The tests were conducted under a flat, smooth, suspended ceiling measuring 10,2 m (L) by 10,4 m (W), i.e., 106 $m^2$, installed to provide a realistic clear height (measured from the floor to the underside of the ceiling beams) for ro-ro spaces on vehicle carriers. The ceiling is constructed from non-combustible 12 mm thick Promatect-T® boards in a metal frame construction. The underside of the full area of the ceiling was protected by nominally 20 mm fire insulation and the area within the 'ceiling pockets' (described below) had an additional layer of 20 mm fire insulation.

The ceiling had 530 mm deep transversal (related to the orientation of the vehicles) beams on a centre-to-centre distance of 3,0 m. Vertical steel sheet barriers were installed to two create two 8,4 m long 'ceiling pockets', each containing three sprinklers on a branch line. The beams and the vertical barriers were made from nominally 1 mm thick steel sheets. Figures 29 and 30, respectively, shows the suspended ceiling during the preparation work prior the tests and Figure 31 a sketch of the suspended ceiling arrangement.

*Figure 29 The suspended ceiling during the preparation work for the first four tests. For these tests, the clear height was 2,0 m, i.e., the ceiling was slightly raised as compared to the height at the photo.*

*Figure 30* *The installation of the sprinkler system for the first two tests, that utilized a dry-pipe system with upright sprinklers. The two centremost sprinkler branch lines were inside 'ceiling pockets' formed by the transversal beams and vertical steel sheet barriers, such that the furthest three of the four sprinklers on a branch line were inside a ceiling pocket. Each pocket was 3,0 m wide and 8,2 m long.*

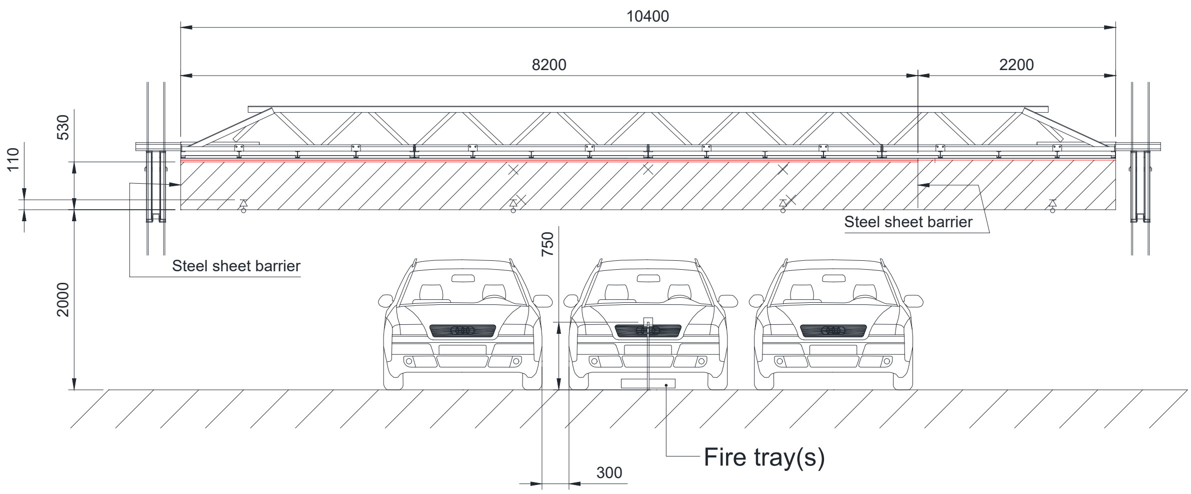



*Figure 31* *A sketch of the suspended ceiling and beam arrangement.*

## 14.3 The vehicles used in the tests

### 14.3.1 Passenger cars

The passenger cars used in Tests 1 through 4 were used cars, purchased from a local auto wrecker in Borås, Sweden. All cars were standard sized cars from the early 2000s and reasonably representative of present day's modern cars with regards to construction, fire load and design.

The cars were drained from all fluids as petrol or diesel, engine oil, gear box oil, power steering fluid, transmission oil, coolant, brake fluid and windshield washer fluid by the auto wrecker. Additionally, the catalytic converter, battery and the air bags were removed or punctured. If considered valuable, the start engine and the generator were also removed. The cars were then transported to RISE where they were stored indoors (overnight) prior to each test. For safety reasons, all tires, shock absorbers and gas dampers were de-pressurized or punctured. The cars were thereafter placed on small wood blocks to achieve the correct height over the floor. Figure 32 shows the fundamental test set-up.

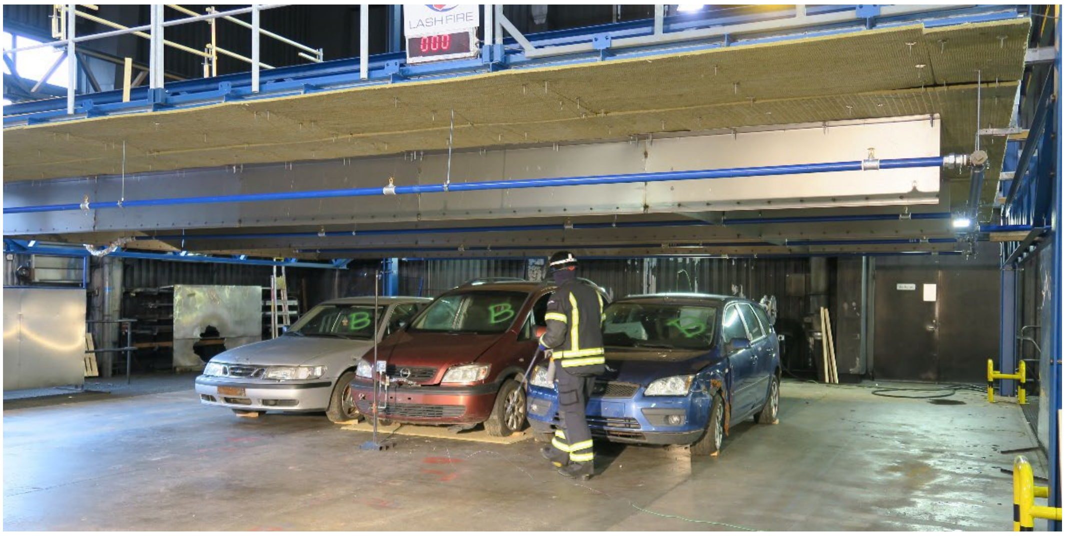



*Figure 32 The test set-up as seen prior to Test 1.*

The horizontal distance measured from the side of the middle car and the target car at each side, respectively, was approximately 300 mm. The distance was measured wheel-to-wheel.

After having been burnt, all cars were returned to the auto wrecker for final destruction. The target cars were re-used if no damages occurred in a test. If minor damage occurred, the positions of the target cars were switched, such that an undamaged side faced the middle car.

### 14.3.2 The van

The van used in Test 5 was prepared for the test similar to the passenger cars, as described above. One passenger car, respectively, was positioned at each side of the van at a horizontal distance of approximately 300 mm. Figure 33 shows the test set-up.


*Figure 33 The test set-up as seen prior to Test 5.*

### 14.3.3 The freight truck

The freight truck was a Volvo FH 62 TT “Globetrotter”. The truck had no engine and gear box and therefore three EUR wood pallets were positioned inside the engine compartment to represent the combustibles on and around an engine. To be able to remove the freight from the fire test hall after the test, it was essential that the rear tires were not damaged. Therefore, these tires were protected by fire insulation boards.

Vertical steel sheet screens with surface thermocouples were positioned parallel with the sides of the truck, refer to a more detailed description later in the report. Figures 34 through 36, respectively, shows the test set-up and the arrangements described above.


*Figure 34 The test set-up as seen prior to Test 6.*

*Figure 35 The protection of the rear tires with fire insulation boards.*

*Figure 36 Three EUR wood pallets were positioned inside the engine compartment to represent the combustibles on and around an engine.*

## 14.4 The system pipe-work, the sprinklers, and the nozzles

### 14.4.1 System layout

Sixteen sprinklers or water spray nozzles were installed at a 3,0 m by 3,0 m spacing, with the centre point of the suspended ceiling between the four centremost sprinklers or water spray nozzles. The pipe-work consisted of DN40 (1 ½") branch lines connected to a DN50 (2") distribution pipe that was connected via a water flow meter to the water pump of the fire test hall. The water pump is equipped with a frequency control such that the flow rate and pressure can be adjusted during a test.

The middle car was positioned with its centre point (the centre point between the four tires) centred between the centremost four sprinklers or water spray nozzles. The freight truck was positioned with the front wheel axle aligned between the two centre branch lines.

### 14.4.2 Automatic sprinklers

#### *14.4.2.1 General*

The tests using automatic sprinklers were conducted with upright, standard coverage sprinklers having glass bulbs. The sprinklers had different operating temperatures, thermal response characteristics and K-factors dependent on the clear height, i.e., the vertical distance from floor to the underside of the ceiling beams.

#### *14.4.2.2 Clear height of 2,0 m*

The sprinklers used for these tests were upright TYCO model Series TY-FRB, Quick Response, Standard Coverage sprinklers. The sprinklers were fitted with a 3 mm glass bulb with a nominal operating temperature of 68 °C and had a nominal K-factor of 80,6 (l/min)/√bar. When installed, the plane of the sprinkler frame arms was parallel to the branch lines of the pipe-work. The vertical distance from the deflector of the individual sprinklers and the ceiling was 420 mm, as measured at the ceiling area covered by the thermal insulation. The vertical distance outside this area was 440 mm. The deflector of the sprinklers was thereby vertically 110 mm above the underside of the ceiling beams. Figure 37 shows the sprinkler system and the sprinklers prior Test 1.

*Figure 37 The sprinkler pipe-work and position of sprinklers relative to the cars as depicted prior Test 1.*

The desired water discharge density during these tests was 10 mm/min.

#### *14.4.2.3 Clear height of 2,8 m*

The sprinklers used for these tests were upright TYCO model Series TYB, Standard Response, Standard Coverage sprinklers. The sprinklers were fitted with a 5 mm glass bulb with a nominal operating temperature of 141 °C and had a nominal K-factor of 115 (l/min)/√bar. The sprinklers were installed as per the description above.

The desired water discharge density during these tests was 15 mm/min.

#### *14.4.2.4 Clear height of 4,6 m*

The sprinklers used for these tests were upright TYCO model Series TY-B, Standard Response, Standard Coverage sprinklers. The sprinklers were fitted with a 5 mm glass bulb with a nominal operating temperature of 141 °C and had a nominal K-factor of 115 (l/min)/√bar. The sprinklers were installed as per the description above.

The desired water discharge density during these tests was 20 mm/min.

### 14.4.3 Water spray nozzles

#### *14.4.3.1 General*

The nozzles used in the tests were open (non-automatic), pendent directional discharge water spray nozzles. The nozzles had an external deflector that discharged a uniformly filled cone of medium-velocity water droplets. The nozzles used in the tests had no nozzle strainer. The nozzles are available in a wide variety of orifice sizes and spray angles, however, the type listed in Table 25 was used during these tests.

*Table 25 The open, commercial type of water spray nozzle that was used.*

| Nozzle designation | K-factor ((l/min)/√bar)) | Spray angle (°) | Coverage area (m²) | Nominal discharge density (mm/min) | Flow rate (l/min) per nozzle | Nominal water pressure (bar) | Total flow rate (l/min) of all sixteen nozzles |
|---|---|---|---|---|---|---|---|
| 28 | 59.0 | 180 | 9,0 | 7,5 | 67,5 | 1,3 | 1 080 |

The recommended discharge pressures range from 1,4 bar to 4,1 bar. Discharge pressures in excess of 4,1 bar will result in a decrease in coverage area since the spray pattern tends to draw inwards at higher pressures. The maximum recommended working pressure is 12,1 bar.

As the water spray nozzles were pendent, the system branch lines were rotated, and height adjusted such that the deflector was vertically 110 mm above the underside of the ceiling beams, similar to the automatic sprinklers. The nozzles were installed with their frame arms parallel with branch lines. Figure 38 shows the pipe-work and the water spray nozzles prior Test 3.

*Figure 38 The pipe-work and position of water spray nozzles relative to the cars as depicted prior Test 3.*

The nozzles were provided by TYCO Fire Suppression & Building Products. However, it is recognized that similar nozzles in terms of spray angles and orifice sizes are available from several other sprinkler manufacturers.

### 14.4.3.2 Clear height of 2,0 m

The tests were conducted at a nominal system operating pressure of 1,3 bar in order to provide a nominal discharge density of 7,5 mm/min (67,5 l/min per sprinkler). When flowing all sixteen nozzles, the total water flow rate corresponded to 1 080 l/min.

### 14.4.3.3 Clear height of 2,8 m and 4,6 m

No tests at this ceiling height were conducted with the water spray system.

## 14.5 Instrumentation and measurements

### 14.5.1 General

All measurements were connected to a data acquisition system and a data logger. The measurements data was recorded at a rate of one scan per second.

### 14.5.2 The measurement of ceiling gas temperatures above the fire

Sheathed thermocouples (Ø=1 mm) were used to measure ceiling gas temperatures directly above and to the side of the middle of the vehicles, to determine the thermal exposure of the fire on the ceiling. In total, twelve thermocouples (C1 – C12) were used, positioned in three rows with four thermocouples above the middle vehicle. The centermost row was directly above the longitudinal centerline of the vehicle. The thermocouples were spaced 1,5 m by 1,5 m and were installed 75 mm below the ceiling.

### 14.5.3 The measurement of gas temperatures at the sprinkler

Sheathed thermocouples (Ø=1 mm) were installed close to glass bulbs of the eight (C13 – C20) sprinklers closest to the vehicles.

### 14.5.4 Measurements using Plate Thermometers

One Plate Thermometer was positioned in front (C21) of the middle vehicle and another at the back (C22) of this vehicle. Both Plate Thermometers were positioned with the center point 750 mm above floor level and at a vertical distance of 300 mm from the vehicle. The distance was measured from the furthest point along the centerline the vehicle. The Plate Thermometers were not shielded from direct water impingent, to reflect realistic conditions, as the body of an actual car would be wetted by water. Therefore, the sides were carefully protected with tape to prevent water from entering. Additionally, the insulation material was changed after every test. Figure 39 shows the positions of the Plate Thermometers.

*Figure 39 One Plate Thermometer, respectively, was positioned in front and at the back of the middle vehicle.*

The Plate Thermometer consists of one piece of a 0,7 mm thick Inconel 600 steel plate with a front face measuring 100 mm by 100 mm. A sheathed thermocouple is spot-welded to the backside of plate and the backside is insulated. The Plate Thermometer is sensitive to heat radiation and heat convection, but compared to a conventional thermocouple, significantly more sensitive to heat radiation.

### 14.5.5 Surface temperature measurements of the target cars and steel sheet screens

#### 14.5.5.1 Target cars

In Test 1 to Test 5, surface temperatures on each of the target cars, on the sides facing the middle car, were measured with four wire (Ø=0,5 mm) thermocouples spot-welded to the steel body. A small area of the paint of the body was sanded before the thermocouple was welded to the steel. Figure 40 shows one of the target cars and the positions of these measurement points.


*Figure 40 The positions of the four thermocouples on one of the target cars.*

One thermocouple was installed on the front and back fender, respectively, directly above the center point of the wheel. One thermocouple, respectively, was installed on the front door and on the back door. The horizontal distance between the thermocouples on the front fender and front door was 750 mm. The horizontal distance between the thermocouples on the back fender and the back door was 750 mm. All thermocouples (C23 – C26 and C27 – C30, respectively) were installed at a vertical distance of 750 mm above the floor.

#### 14.5.5.2 Steel sheet screens

In Test 6, vertical steel sheet screens were positioned parallel with the sides, respectively, of the freight truck at a horizontal distance of 300 mm. The screens had a height (4,0 m) which was slightly higher than the height of the freight truck. The length of the screens was 1,8 m. The nominal thickness of the steel sheets used for the screens was 1,5 mm.

The surface temperatures of each of the steel screens were measured at four different measurement points, along the vertical centreline of each screen. The topmost position was 500 mm below the top, the bottommost position was 500 mm above floor and the two measurement points in between was symmetrically between these two positions, i.e., separated 1000 mm. The vertical centreline of each screen was aligned with the front wheel axle of the freight truck.

### 14.5.6 Measurements of system operating pressure and water flow rates

The system operating pressure was measured using a pressure transducer positioned at one of the two centermost system branch lines. The pressure transducer was positioned at the end of the pipe, i.e., there was a minimal static pressure difference between the nozzles and the transducer. The water flow rate was measured using a flow meter installed after the water pump unit.

### 14.5.7 Summary of all measurement point and channels

The measurement points and the associated channels are given in Table 26.

*Table 26 Measurement points and associated channels. All measurement points oriented opposite with the cars in their direction of travel.*

| Channel | Type* | Position |
|---|---|---|
| **Ceiling gas temperatures above the vehicles** | | |
| C1 | S. Ø=1 mm | Above the front hood of the middle vehicle |
| C2 | S. Ø=1 mm | Above the windshield of the middle vehicle |
| C3 | S. Ø=1 mm | Above the roof of the middle vehicle |
| C4 | S. Ø=1 mm | Above the rear window and back of the middle vehicle |
| C5 | S. Ø=1 mm | To the right of C1 |
| C6 | S. Ø=1 mm | To the right of C2 |
| C7 | S. Ø=1 mm | To the right of C3 |
| C8 | S. Ø=1 mm | To the right of C4 |
| C9 | S. Ø=1 mm | To the left of C1 |
| C10 | S. Ø=1 mm | To the left of C2 |
| C11 | S. Ø=1 mm | To the left of C3 |
| C12 | S. Ø=1 mm | To the left of C4 |
| **Ceiling gas temperatures at sprinklers or nozzles** | | |
| C13 | S. Ø=1 mm | Furthest sprinkler on the second branch line** |
| C14 | S. Ø=1 mm | Second sprinkler on the second branch line |
| C15 | S. Ø=1 mm | Third sprinkler on the second branch line |
| C16 | S. Ø=1 mm | Fourth sprinkler on the second branch line (outside ceiling pocket) |
| C17 | S. Ø=1 mm | Furthest sprinkler on the third branch line** |
| C18 | S. Ø=1 mm | Second sprinkler on the third branch line |
| C19 | S. Ø=1 mm | Third sprinkler on the third branch line |
| C20 | S. Ø=1 mm | Fourth sprinkler on the third branch line (outside ceiling pocket) |
| **Measurements using Plate Thermometers** | | |
| C21 | P/T | In front of vehicle |
| C22 | P/T | To the back of vehicle |
| **Surface temperatures of the target vehicles (Test 1 to Test 5)** | | |
| C23 | W. Ø=0,5 mm | Right hand side vehicle: Above the front wheel |
| C24 | W. Ø=0,5 mm | Right hand side vehicle: On front door |
| C25 | W. Ø=0,5 mm | Right hand side vehicle: On back door |
| C26 | W. Ø=0,5 mm | Right hand side vehicle: Above the back wheel |
| C27 | W. Ø=0,5 mm | Left hand side vehicle: Above the front wheel |
| C28 | W. Ø=0,5 mm | Left hand side vehicle: On front door |
| C29 | W. Ø=0,5 mm | Left hand side vehicle: On back door |
| C30 | W. Ø=0,5 mm | Left hand side vehicle: Above the back wheel |
| **Surface temperatures of the target steel sheet screens (Test 6)** | | |
| C23 | W. Ø=0,5 mm | Right hand side screen: 500 mm below its top |
| C24 | W. Ø=0,5 mm | Right hand side screen: 1500 mm below its top |
| C25 | W. Ø=0,5 mm | Right hand side screen: 2500 mm below its top |
| C26 | W. Ø=0,5 mm | Right hand side screen: 3500 mm below its top (500 mm above floor) |
| C27 | W. Ø=0,5 mm | Left hand side screen: 500 mm below its top |
| C28 | W. Ø=0,5 mm | Left hand side screen: 1500 mm below its top |

| | | |
|---|---|---|
| C29 | W. Ø=0,5 mm | Left hand side screen: 2500 mm below its top |
| C30 | W. Ø=0,5 mm | Left hand side screen: 3500 mm below its top (500 mm above floor) |
| **Water pressure and water flow rate** | | |
| C31 | Not applicable | Water pressure at one of the branch lines |
| C39 | Not applicable | Water flow rate |

*) S = sheathed thermocouple, W = wire thermocouple, P/T = Plate Thermometer.

**) Moved to 75 mm from the underside of the ceiling for the water spray system tests. Simulated spot-type heat detectors along with C9 and C12.

## 14.6 Fire test procedures

### 14.6.1 Fire ignition scenarios

Two different fire ignitions scenarios were used:

- **Test 1 and Test 3:** Fire ignition inside the centremost car with the driver's side window folded down. The ignition source consisted of a cube, sized 60 mm × 60 mm × 75 mm, made from pieces of insulating fibre board. The cube was soaked with 120 ml of heptane and wrapped in a polyethylene plastic foil bag prior to the test. The cube was positioned in the driver’s seat, up against the backrest of seat. Refer to Figure 41.

- **Tests 2, 4, 5 and 6:** Fire ignition using two fire trays positioned centred underneath the centremost vehicle. Each tray measured 900 mm × 600 mm × 75 mm (0,54 $m^2$) and were filled with 15 l (28 mm) of heptane on a 15 l (28 mm) of water. The fire trays were positioned on 20 mm insulation boards to protect the concrete floor of the fire test hall. For Test 2, the fire trays were positioned long side-to-long side under the middle car. For Test 4 and Test 5, the fire trays were positioned short side-to-long short under the middle car. For Test 6, with the freight truck, the fire trays were oriented long-to-long short under freight truck but separated by concrete blocks that supported the front wheel axle of the truck. Refer to Figures 42 and 43, respectively.

*Figure 41 The position of the fire igniter in the driver’s seat, as used in Test 1 and Test 3.*

*Figure 42 The short-to-short side arrangement of the fire trays in Test 2 (left) and the long-to-long side arrangement in Test 4 and Test 5 (right).*

*Figure 43 The arrangement of the fire trays in Test 6. The other tray was positioned at the other side of the front wheel axle.*

### 14.6.2 Activation of the dry-pipe system

For the tests simulating a dry-pipe system, the system piping was pressurized with compressed air to about a 1 bar over-pressure. The main control valve to the system was closed. When a pressure drop in the system pipe-work was recorded, a delay time of approximately 45 s was applied before the main valve was opened to allow water entering the pipe-work. The water travel time was short, in the order of a few seconds. Discharge at the intended (full) water flow rate was achieved about 10 s to 20 s thereafter.

### 14.6.3 Activation of the water spray system

For the deluge water spray system tests, the system valve was opened 60 s after the recording of a gas temperature of 78 °C of at least two of the thermocouples denoted C9 , C13 (moved to 75 mm below the ceiling), C12 or C17 (moved to 75 mm below the ceiling). These thermocouples simulated spot-type heat detectors. Two thermocouples were installed in each of the ceiling pockets, horizontally separated 6,0 m.

### 14.6.4 Discharge duration time

Water was supposed to be applied for 30 min, but the application time had to be reduced to 28:30 [min:s] in Test 3 to prevent a water run-off collection basin of the fire test hall to overfill.

### 14.6.5 The vehicles used in the tests

Table 27 lists the vehicles that were used in the tests and their year of make.

*Table 27 The vehicles used in the tests and their year of make.*

| Test | Right hand side car | Middle car | Left hand side car |
|---|---|---|---|
| 1 | SAAB 9-3 Sedan (1999) | Opel Zafira DTL16 Station Wagon (2001) | Ford Focus Flexifuel Station Wagon (2007) |
| 2 | SAAB 9-3 Sedan (1999) | Opel Zafira Station Wagon (2001) | Ford Focus Flexifuel Station Wagon (2007) |
| 3 | SAAB 9-3 Sedan (1999) | SAAB 9-5 Station Wagon (2000) | Renault Megane Sedan (2002) |
| 4 | SAAB 9-3 Sedan (1999) | Ford Mondeo ST220 Station Wagon (2005) | Renault Megane Sedan (2002) |
| 5 | Renault Megane Sedan (2002) | Citroen Jumpy HDI Van (2004) | SAAB 9-3 Sedan (1999) |
| 6 | None. Steel sheet target screens used. | Volvo FH 62 TT "Globetrotter" freight truck (2021) | None. Steel sheet target screens used. |

### 14.6.6 The ventilation system

The ventilation system of the test hall was run at a ventilation rate of 20 000 $m^3/h$ prior to the activation of the sprinklers, to avoid influence of any draught on the activation sequence. After it was determined that the fire was under control, the ventilation rate was increased to a ventilation rate of 50 000 $m^3/h$ and thereafter to 100 000 $m^3/h$, to keep clear sight at floor level and improve the possibilities for visual observations. The ventilation system does not create any significant wind speed in the test area.

## 14.7 Fire test observations

### 14.7.1 Test 1: Dry-pipe system test (2,0 m clear height)

Fire developed fast as it quickly involved the driver's seat and the inner ceiling, with flames projecting out the open front side window. System air pressure drop was recorded at 02:13 [min:s] after fire ignition, indicating that one or several sprinklers had activated. The valve to the system was opened 45 s thereafter, allowing water to discharge from the opened sprinklers a few seconds thereafter, refer to Figure 44.

*Figure 44* ***Test 1:*** *The fire size at 02:49 [min:s], moments before water was discharging through the three automatic sprinklers that had activated.*

The average ceiling gas temperature reached at most around 164 °C but was rapidly reduced at sprinkler discharge and was thereafter at most 84 °C. From the measured total water flow rate, it was judged that three sprinklers (the ones inside the pocket formed by the closest beams) had operated. The total flow rate was therefore adjusted to around 270 l/min, corresponding to the minimum design density of 10 mm/min. During the test, refer to Figure 45, it was observed that the top part of the windscreen partly burnt through, but this seemed to have minor effect on the fire inside the car.

*Figure 45* ***Test 1:*** *The fire when it was visually the most intense, at 15:10 [min:s].*

The total water flow was shut off at about 32:30 [min:s], 30 min after the activation of the sprinklers, which resulted in a surprisingly fast and intense fire re-growth and the activation of three additional sprinklers (in the adjacent ceiling pocket). The pump was re-started, with was followed by prompt fire suppression, as illustrated in Figure 46. During the short time the water flow was off (about 50 s), it is likely that the side windows of the car broke. The average ceiling gas temperature peaked at around 214 °C but dropped rapidly once the water was flowing again. The fire was manually extinguished during sprinkler water discharge using hose streams.

*Figure 46* ***Test 1:*** *Fire re-growth was experienced at the termination of the water flow, but the fire was suppressed when water was turned back on, as illustrated by photos at 32:50 [min:s], 33:20 [min:s] and 33:30 [min:s].*

The interior of the middle car was severely burnt, but all combustibles were not consumed. The windscreen was to a large extent broken, which visually occurred gradually during the test. The front side window on the right hand side was broken, the back side window on that side almost completely gone and the rear side window was broken to half. These windows did likely break when the water flow was turned off. No damage to the adjacent cars were observed and they were re-used in the following test. Refer to Figure 47.

*Figure 47* ***Test 1:*** *The fire damage to the middle car.*

After the test, the discharge of water was documented with photos, refer to Figure 48.

Figure 48 **Test 1:** *Discharge of the sprinklers that operated during the tests, i.e., the three sprinklers in the closest ceiling pocket that activated during the actual test and the three sprinklers that activated when the water flow was turned off.*

### 14.7.2 Test 2: Dry-pipe system test (2,0 m clear height)

Flames from the pool fire trays were observed between the cars just a few seconds after fire ignition. System air pressure drop was recorded at 02:23 [min:s] after fire ignition, indicating that one or several sprinklers had activated. The valve to the system was opened 45 s after the air pressure drop, allowing water to discharge from the opened sprinklers a few seconds thereafter. The fire size shortly before water discharge is documented in Figure 49. In total, six sprinklers operated (those inside the two ceiling pockets), and the total water flow rate was adjusted to provide 540 l/min, corresponding to a 10 mm/min discharge density.


Figure 49 **Test 2:** *The fire size at 02:49 [min:s], moments before water was discharging through the six automatic sprinklers that had activated.*

Larger flames were observed between the middle car and the left hand side car than between the middle car and the right hand side car. This may be due to the ventilation air draft inside the fire test hall.

An unintentional stop of water pump occurred at between 07:25 [min:s] and 07:52 [min:s]. This had no significant influence on the ceiling temperatures, but the visibility improved for a short period of time. The average ceiling gas temperature reached at most around 425 °C, at around 08:00 [min:s], but started to decline soon thereafter. The heptane fuel was, based on visual observations, consumed after approximately 10:00 [min:s]. This corresponds well with a significant reduction in the measured ceiling gas temperatures. The fire had visually established in the rear tires of the middle car, that continued to burn relatively intense to about 14:00 [min:s]. At that time, the average ceiling gas temperature approached 100 °C. The flow of water was turned off at 32:30 [min:s] and small flames inside the cars were manually extinguished.

The windscreen of the middle car was intact, but the side window on the left hand side was broken as well as the rear window on the right hand side. The interior was severely burnt but a great portion of the combustibles remained unburnt. Both rear tires were partly burnt, but the fire never involved the front tires. No fire spread to the engine compartment occurred. Figure 50 through Figure 52 documents the fire damage.

*Figure 50* ***Test 2:*** *The fire damage to the middle car.*

The fire spread to the left hand side car. The back tire was partly burnt, the rear side window broken, and the fire had involved parts of the luggage compartment. A large area on the side of the car was blackened and blistered. A small area of the rear door of the right hand side car was blackened, but there was no fire damage on the car, allowing it to be re-used in the following test.

*Figure 51* **Test 2:** *The fire damage to the car to the left that was partly involved in the fire.*

*Figure 52* **Test 2:** *The fire damage to the car to the right.*

### 14.7.3 Test 3: Deluge water spray system test (2,0 m clear height)

The fire-growth rate was rapid as the fire involved the front seat and the inner ceiling of the middle car. The temperature threshold of 78 °C of the thermocouples mimicking spot-type heat detectors was firstly exceeded for channels C9 and C12, i.e., the two thermocouples closest to the fire but on opposite sides of the centremost beam, at 02:01 [min:s]. The water flow rate was initiated 60 s thereafter, but full discharge was not achieved until 03:16 [min:s], which was 75 s after the temperature threshold of the thermocouples was exceeded. The application of water virtually suppressed the fire immediately. The fire size before and after discharge is documented in Figures 53 and 54, respectively.

No measurement data indicated a fire, but visual observations were obscured by smoke. The application of water was terminated at around 28:30 [min:s] instead of after 30 min, as a water level alarm indicated that the basins of the fire test hall started to become filled. Upon manual fire extinguishment, two small fires were observed inside the car, one at the front seat where the fire was started and one in the backseat.

The average ceiling gas temperature peaked at about 139 °C prior the activation of the system, dropped rapidly when water was discharging and stayed below approximately 40 °C for the remainder of the test.


*Figure 53* ***Test 3:*** *The fire size at 03:10 [min:s], moments before the activation of the deluge water spray system.*

*Figure 54* ***Test 3:*** *The fire size at 03:30 [min:s], moments after the activation of the deluge water spray system.*

All windows of the middle car were intact. The interior was severely burnt but plenty of combustibles remained unburnt. No damage to the adjacent cars were observed and they were re-used in the following test. Figure 55 document the fire damage.

*Figure 55* ***Test 3:*** *The fire damage to the middle car.*

### 14.7.4 Test 4: Deluge water spray system test (2,0 m clear height)

The initial fire-growth rate was relatively slow and flames from the fire trays did not establish at the sides of the cars until after about 03:20 [min:s].

The temperature threshold of 78 °C of the thermocouples mimicking spot-type heat detectors was firstly exceeded for channels  C12 and C17, i.e., two thermocouples in the same ceiling pocket, at 02:56 [min:s] and at 03:12 [min:s], respectively. The water discharge was initiated at 04:18 [min:s], which was 64 s after the temperature threshold was exceeded. Figure 56 and Figure 57, respectively, shows the fire size before and after water discharge.

*Figure 56* ***Test 4:*** *The fire size at 04:00 [min:s], moments before the activation of the deluge water spray system.*

*Figure 57* ***Test 4:*** *The fire size at 04:30 [min:s], about 12 s after the activation of the deluge water spray system.*

The average ceiling gas temperature peaked at about 282 °C at 04:18 [min:s], which was the time the water discharge was initiated. Thereafter the ceiling gas temperature gradually declined.

An unintentional stop of water pump occurred at between 17:30 [min:s] and 18:00 [min:s]. This had no significant influence on the temperatures, but the visibility improved for a moment. The fire involved the front right tire of the middle car, but the remaining three tires were only partly burnt, refer to Figure 58. The front side window of the middle car had broken, all other windows were intact. The interior, as the dashboard, had burnt but plenty of combustible material as the front seat cushions were more or less undamaged. The fire involved the engine compartment, but the plastic panels of the front and back of the car was not involved in the fire. This may be an effect of application of water from the water spray nozzles in front of and behind the cars.

*Figure 58* ***Test 4:*** *The fire damage to the middle car.*

No fire spread to the adjacent cars occurred, but the area above the rear wheelhouse of the car at the right hand side were blackened and the rubber strips of the rear (small) window above the wheelhouse were affected by heat as well as the rear door handle. The car to the left had also an area above the rear wheelhouse where the paint was blackened and blistered, and the rear door handle was affected by the heat. The fire damage to the target cars is documented in Figure 59 and Figure 60, respectively.

*Figure 59* ***Test 4:*** *The fire damage to the car to the right.*


*Figure 60* ***Test 4:*** *The fire damage to the car to the left.*

The target cars were re-used in the following test, but they were oriented such that the undamaged side of each cars was facing the middle car.

### 14.7.5 Test 5: Dry-pipe system test (2,8 m clear height)

For this test, the ceiling was raised to provide a clear height of 2,8 m, to allow space for the van.
A dry-pipe system using automatic sprinklers was tested..

System air pressure drop was recorded at 02:43 [min:s] after fire ignition, indicating that one or several sprinklers had activated. The valve to the system was supposed to be opened 45 s thereafter, allowing water to discharge from the opened sprinklers. However, the solenoid valve did not open due to an electrical failure, and the fire had to be controlled and extinguished by manual operations using hose streams and fire-fighting foam. Figure 61 through Figure 65 shows the full sequence.

*Figure 61* ***Test 5:*** *The fire size at 02:49 [min:s], a few moments after air pressure drop inside the system piping was recorded, indicating that one or several sprinklers had activated.*

*Figure 62* ***Test 5:*** *The fire size at 03:29 [min:s], when water was supposed to be discharged if the system valve had opened correctly.*

*Figure 63* ***Test 5:*** *Initiation of manual fire-fighting at 05:19 [min:s] using hose streams.*

*Figure 64* ***Test 5:*** *Continued manual fire-fighting at 07:08 [min:s] using hose streams.*

*Figure 65* ***Test 5:*** *The fire was under control at 11:10 [min:s] using hose streams of water and foam.*

The average ceiling gas temperature approached 700 °C. The Plate Thermometer in front of the middle car (C21) peaked at 117 °C and the one behind the middle car (C22) peaked at 154 °C. Fire spread in the longitudinal direction, had there been cars, is therefore unlikely during the duration of the test.

The thermocouples at the sides of the adjacent cars peaked at between 728 °C and 876 °C. The average surface temperature was slightly lower on the car to the right.

After the test, it was determined that seven sprinklers had activated.

Due to non-operation of the valve for the sprinkler system, fire damage was relatively extensive, and fire spread to the adjacent cars was observed. The windscreen and both side windows had broken, and the fire had involved both rear tires of the middle car, refer to Figure 66. The fire had spread to the interior with fire damage to the inner ceiling and the seats, although the seats had only been consumed to a smaller extent.

*Figure 66* ***Test 5:*** *The fire damage to the middle car.*

The windscreen of the car to the right had partly broken and all side windows facing the middle car were completely broken, refer to Figure 67. This allowed fire spreading to the interior that was partly burnt.

*Figure 67* ***Test 5:*** *The fire damage to the car to the right.*

The rear window and all side windows facing the middle car of the car to the left were completely broken, refer to Figure 68. This allowed fire spreading to the interior that was partly burnt.

*Figure 68* ***Test 5:*** *The fire damage to the car to the left.*

### 14.7.6 Test 6: Dry-pipe system test (4,6 m clear height)

For this test, the ceiling was raised to provide a clear height of 4,6 m, to allow space for the freight truck. A dry-pipe system using automatic sprinklers was tested.

The fire was started using the heptane pool fire trays positioned symmetrically under the front wheel axle. Flames from the pool fire trays were observed at the left hand side of the freight truck at about 00:45 [min:s]. Flames coming from the back side of the freight truck reaching the ceiling was observed at about 01:10 [min:s]. System air pressure drop was recorded at 01:29 [min:s] after fire ignition, indicating that one or several sprinklers had activated. The valve to the system was opened 40 s thereafter, allowing water to flow from the sprinklers a few seconds later, refer to Figure 69. Full discharge from the opened sprinklers was recorded at about 02:29 [min:s], which was 60 s after the activation of the first sprinklers. In total, seven sprinkler operated (those inside the two ceiling pockets and one outside this area), and the total water flow rate stabilised at 1 105 l/min, corresponding to a 17,5 mm/min discharge density. This was the maximum water flow rate provided by the sprinkler pump given the friction losses of the pipe-work.

*Figure 69* ***Test 6:*** *The fire size at 02:00 [min:s], a few seconds prior water was discharging from the sprinklers that had activated. Full discharge from the opened sprinklers was recorded at about 02:29 [min:s].*

The average ceiling gas temperature peaked at 890 °C but was rapidly reduced as water started to discharge through the sprinklers. Visual observations are documented in Figure 70. The average surface temperature of the steel sheet target screens peaked at 580 °C (left hand side) and 390 °C, respectively, but were reduced to below 30 °C within five minutes from the start of the application of water. The Plate Thermometers positioned in front of the vehicle peaked at about 57 °C and 43 °C, respectively.


*Figure 70* ***Test 6:*** *A series of photos illustrating the fire size at about one to four minutes, respectively, after full discharge of water was recorded.*

At approximately 25:05 [min:s], the side window at the left hand side broke, which increased the fire size, refer to Figure 71. The average ceiling gas temperature reached to approximately 140 °C.

*Figure 71* ***Test 6:*** *At approximately 25:05 [min:s], the side window at the left hand side broke, which increased the fire size.*

The water flow was terminated at 32:45 [min:s], and the fire was allowed to re-develop in order to confirm that it was indeed controlled by the sprinkler system. This sequence is documented in Figure 72. Thereafter, the fire was manually extinguished using hose streams, refer to Figure 73.

*Figure 72* ***Test 6:*** *The water flow was terminated at 32:45 [min:s], and the fire was allowed to re-develop in order to confirm that it was indeed controlled by the sprinkler system before it was manually extinguished using hose streams.*

*Figure 73* ***Test 6:*** *The final phase of the manual extinguishment of the fire.*

The area above and beside the tires had plastic panels that were completely consumed in the fire. The tread and sides of the front tires were burnt but the tires were not punctured. The grill (plastics) at the front had only partly melted. The external fire damage to the freight truck is documented in Figure 46 and Figure 47, respectively. The upper portion of the windscreen was broken as well as both side windows and the skylight at the roof. It is likely that these damages to some extent allowed water from the sprinklers to enter the cabin. However, the combustibles inside the cabin, that included a bunk bed mattress was to a large degree consumed. Figure 48 documents the internal fire damage.

*Figure 74* ***Test 6:*** *External fire damage to the freight truck.*

*Figure 75* ***Test 6:*** *External fire damage to the freight truck.*

*Figure 76* ***Test 6:*** *Internal fire damage to the freight truck.*

## 14.8 Discussion

The intent of the six large-scale tests was to validate the performance of two water-based systems and system designs recommended in the project, an automatic dry-pipe sprinkler system and an automatic deluge water spray system.

The tests were conducted using actual vehicles: passenger cars (four tests), a van (one test) and a freight truck (one test). For the tests using the passenger cars, the ceiling was installed to provide a clear height of 2,0 m, the test with the van had a clear height of 2,8 m and the test with the freight truck a clear height of 4,6 m. These ceiling heights are representative of those found on vehicle carriers.

The average ceiling gas temperature was the primary parameter used to compare the performance of the tested systems. As previously mentioned, the ceiling gas temperatures were measured above the vehicles with a total of 12 thermocouples. There was a significant variation in temperature between the individual measurement points during a test. However, the advantage of using an average value for the test-to-test comparison is that a single measurement point, whether it be high or low, have lesser influence on the overall assessment. The average gas temperature captures the trends of the fire and the performance of the systems. Still, the test-to-test comparisons should be regarded as indicative, as it is virtually impossible to replicate the fire test scenarios as different makes of cars where used and due to random effects associated with any fire testing.

Tests 1 and 2, respectively, were conducted with a dry-pipe system discharging 10 mm/min. The fire was either started inside the middle car (Test 1) or by using two heptane pool fire trays underneath the middle car (Test 2). For both tests, three sprinklers activated. The average ceiling gas temperature was significantly higher in Test 2. The reason is primarily that the water discharging from the sprinklers had limited, if any effect on the shielded pool fire underneath the car and the flames from the pool fire trays reached to the ceiling. As soon as the heptane fuel was consumed, the gas temperatures dropped rapidly.

Tests 3 and 4, respectively, were conducted with a deluge water spray system discharging 7,5 mm/min, with fire ignition inside (Test 3) or by pool fire trays below (Test 4) the middle car. The average ceiling gas temperature was significantly higher in Test 4, which strengthen the observation that a pool fire tray ignition scenario underneath a car is more severe than fire ignition inside a car. Figure 77 shows the average ceiling gas temperatures for all four tests.

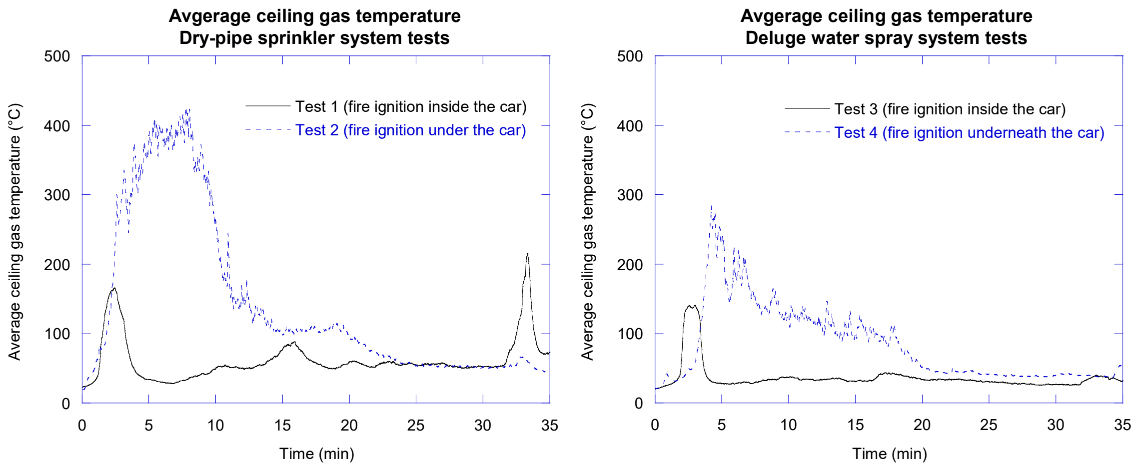



*Figure 77 The average ceiling gas temperatures in the dry-pipe sprinkler tests (Tests 1 and 2) and deluge water spray system tests (Tests 3 and 4).*

Another observation is that the average ceiling gas temperature generally was lower in the tests using the deluge water spray system than in the tests with the dry-pipe system, despite the lower discharge density. The fact that the open water spray nozzles had a smaller orifice size (K-factor of 59,0) than the automatic sprinklers (K-factor of 80,6) and thereby providing smaller water droplets could justify this observation. The overall discharge of water was also more uniform and over a larger floor area with the open water spray nozzles. However, an investigation of the influence of these factors on the cooling of hot combustion gases at the ceiling would require more test data and in particular a fire test scenario that is much more repeatable than the fire scenario generated by actual cars. It should be noted that the orientation of the pool fire trays was different in Test 2 as compared to in Test 4. The orientation used in Test 2 likely generates larger flames from the underside of the car, whilst the orientation in Test 4 is likely to enhance fire spread to all four tires as well as the engine compartment of the car.

Fire spread to adjacent cars was only observed in one (Test 2) of the four tests with passenger cars. It cannot be determined at which time this spread occurred, but it is observed that fire spread occurred at the rear part of the car when the rear tire of the left hand side car caught fire and the rear window broke. Despite the fire spread, the overall fire size did not increase. The residual fire could be manually extinguished at the end of the test.

The average surface temperatures on the adjacent cars were significantly higher when the fire was started with the pool fire trays underneath the middle car. This is expected as the flames from under the car exposed the adjacent cars much more than did the flame from the open side window associated with the fire being started inside the car. Figures 78 and 79, respectively, shows the average surface temperatures on the adjacent cars for the passenger tests.

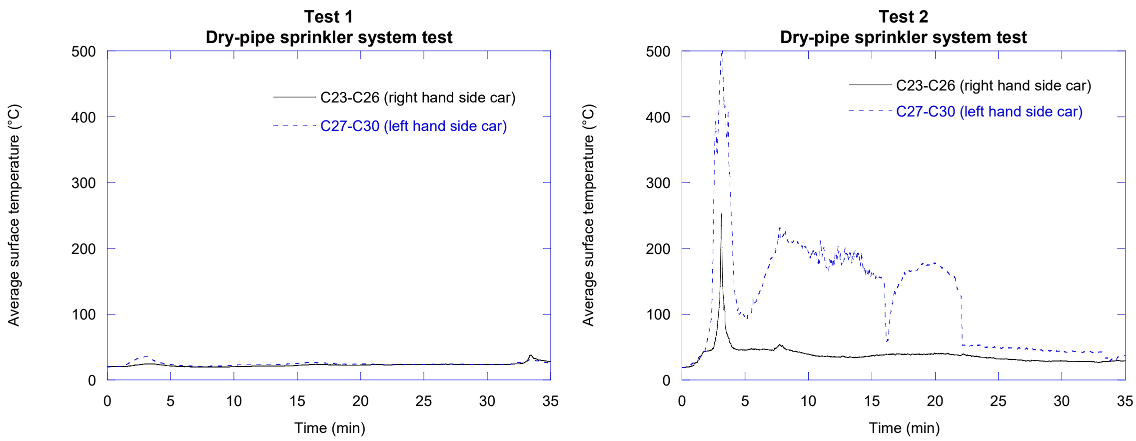
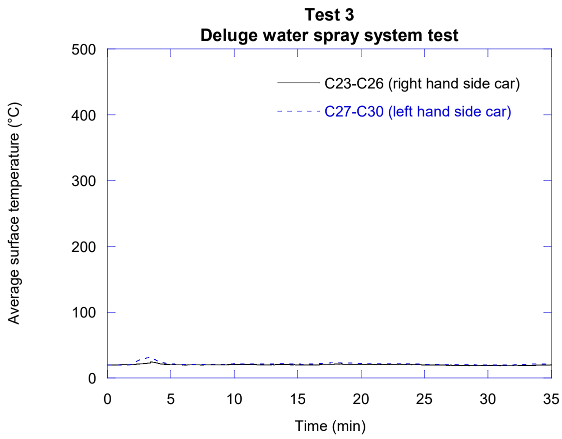



*Figure 78 The average surface temperatures on the right and left hand side cars, respectively, in Test 1 and Test 2. In Test 1, the fire was initiated inside the middle car, in Test 2, it was initiated under the middle car.*



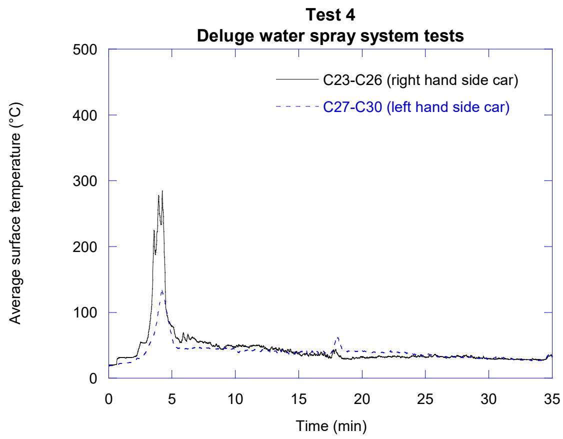
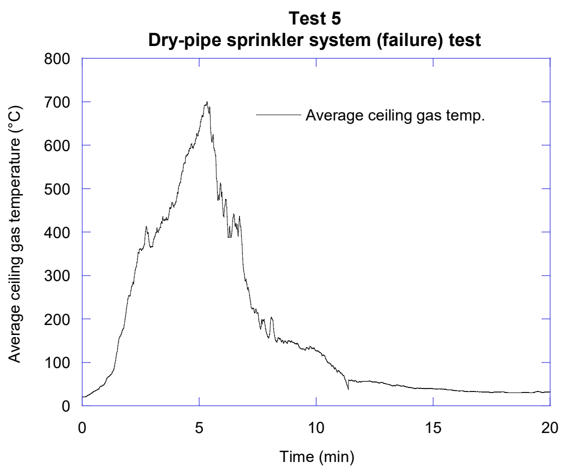




*Figure 79* *The average surface temperatures on the right and left hand side cars, respectively, in Test 3 and Test 4. In Test 3, the fire was initiated inside the middle car, in Test 4, it was initiated under the middle car.*

For all four tests described above, it was observed that combustible material inside the middle car remained unburnt after the fire. This is an indication that water entered the car through the side window that was intentionally open (Test 1 and Test 3, respectively) and through the windows that broke during the course of the test. It is recognised that a fire inside a car need to be supplied by air to grow large. This requires that one or several windows breaks, but it allows water to the reach the interior thereby preventing the fire from growing large.

In Test 5, the discharge of water from the automatic sprinklers that had activated failed due to an electrical malfunction of the solenoid valve of the water supply. This fire is thereby an illustration of the severity of a fire in vehicles (in this case a van surrounded by two passenger cars) without a sprinkler system. The average ceiling gas temperature exceeded 700 °C in a few minutes and several of the individual measurement points exceeded 1000 °C. Fire spread to both adjacent cars occurred and the average surface temperatures on the sides of the adjacent cars peaked at between 728 °C and 876 °C. Without manual firefighting, the fire had run out of control and all three vehicles had been burning almost simultaneously. Figure 80 shows the measurement data.



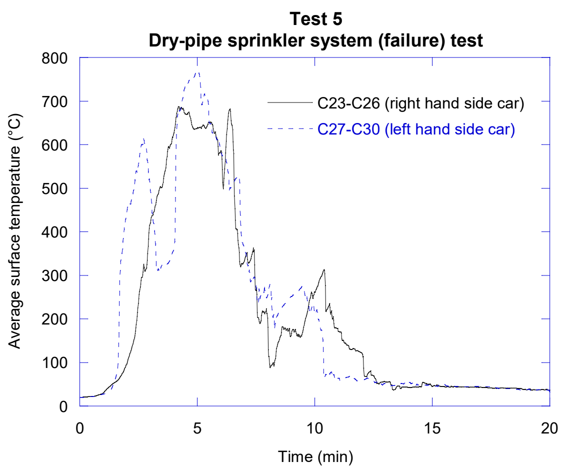




*Figure 80* *The average ceiling gas temperature and the average surface temperatures on the sides of the adjacent cars in Test 5, where water discharge failed due to an electrical malfunction of the system control valve.*

Test 6 included a freight truck and adjacent vehicles were simulated by two vertical steel sheet screens. A dry-pipe system was tested, and the water flow rate was pre-set with six flowing sprinklers to provide a discharge density of 20 mm/min. However, a total of seven sprinklers activated corresponding to a 17,5 mm/min discharge density. The fire was controlled by the sprinkler system and the gas temperatures at the ceiling and the surface temperatures of the steel sheet screens were promptly reduced. During the course of the fire, the windscreen and the side windows broke, which on one hand increased the severity of the fire but on the other hand allowed water to partly reach the fire. The fire re-growth that occurred once the water flow to the system was turned off, illustrating the benefit of the sprinkler system, refer to Figure 81.

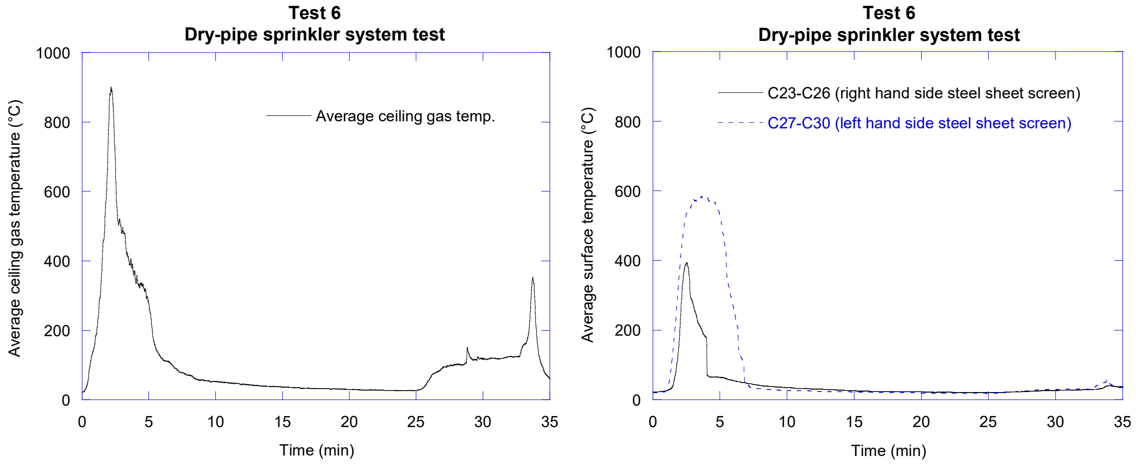



*Figure 81 The average ceiling gas and the average surface temperatures on the steel sheet screens in Test 6.*

One of the challenges of using automatic sprinklers in ro-ro spaces on vehicle carriers is the deep transversal beams. These beams could channel the hot gases from the fire in two directions which prevents them from spreading out under the ceiling uniformly to the nearest four sprinklers. To limit the number of automatic sprinklers that would operate in a fire, steel sheet barriers were used to form two ceiling pockets that included three sprinklers, respectively, on a branch line. The deflectors of the sprinklers were 420 mm below the ceiling, which typically would significantly delay the operation of sprinklers without the presence of any barriers that stops the flow of hot gases under the ceiling. The steel sheet barriers proved very efficient. The hot combustion gases filled the ceiling pockets and the sprinklers closest to the fire operated properly by the heat. The order of sprinkler operation could not be determined as the system pipe-work was filled with compressed air (which does not cool any thermocouple adjacent to a sprinkler), but at the time the water was allowed to enter the pipe-work (to mimic the delay time of a dry-pipe system), several sprinklers had activated.

Relatively high ceiling gas temperatures were recorded in Test 2. One of the reasons is apparently that the pool fire underneath the middle car was shielded from direct application of water. Another reason may be the relatively long vertical distance (420 mm) between the underside of the ceiling and the sprinkler deflectors. This vertical distance occurs from the desire to provide an unobstructed (by the ceiling beams) discharge of water. However, the large distance from the ceiling will limit the cooling capability by the water spray of the ceiling jets from the fire and the hot combustion layer that formed above the sprinklers. To reduce ceiling gas temperatures and provide direct cooling of the steel ceiling in an actual ship, it is therefore suggested that conventional upright or pendent sprinklers should be used if the vertical distance from the underside of the ceiling to the deflector exceeds 300 mm. These types of sprinklers are designed to discharge 40% to 60% of the water upwards to provide direct cooling of the ceiling construction and the remaining water is directed downwards. If installed in excess of 300 mm vertically from the underside of the ceiling, the circular ceiling area above and around the sprinkler that is directly wetted by the water spray is relatively large.

# 15 Installation cost assessments

Main author: Magnus Arvidson, RISE.

## 15.1 General

The installation cost for three systems was calculated:

- A dry-pipe system using automatic sprinklers.
- An automatic deluge water spray system.
- An automatic deluge CAFS.

The latter two systems were assumed to be activated by a heat detection system using spot-type or line-type heat detectors.

The installation cost assessments were made for MS Torrens, the generic vehicle carrier ship in the project, refer to figure 82. The ship has a total length of 199,99 m and a total width of 32,26 m. There are 12 ro-ro decks, including four hoistable decks. The ship and its representability of the world fleet is further described in D05.1, “Definition of generic ships”.


*Figure 82 MS Torrens, the generic vehicle carrier in the project.*

Table 28 summarises the designation of the decks, the clear height, and the deck area. The total deck area is 54 050 $m^2$.

*Table 28 The decks on MS Torrens.*

| Deck | Description | Clear height (mm) | Deck area ($m^2$) |
|---|---|---|---|
| 12 | NO. 12 CAR DECK | 1850 | 5 760 |
| 11 | NO. 11 CAR DECK | 2000 | 5 800 |
| 10 | NO. 10 CAR DECK (GAS TIGHT) | 2200 | 5 810 |
| 9 | NO. 9 CAR DECK | 2200 | 5 810 |
| 8 | NO. 8 CAR DECK (LIFT.DK) | 2000/1850/1700/0 | 5 770 |
| 7 | NO. 7 CAR DECK (WATER TIGHT) | 2000/2150/2300/4000 | 5 010 |
| 6 | NO. 6 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 5 100 |
| 5 | NO. 5 CAR DECK (WATER TIGHT) | 2800/3200/3500/5200 | 4 950 |
| 4 | NO. 4 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 3 300 |
| 3 | NO. 3 CAR DECK | 2400/2800/3100/4600 | 3 140 |
| 2 | NO. 2 CAR DECK (LIFT.DK) | 2000/1700/0 | 1 810 |
| 1 | NO.1 CAR DECK | 2000/2300/4000 | 1 790 |

Decks 1, 3, 5 and 7 have a clear height equal to or exceeding 4 000 mm, if the hoistable decks are fully raised. These decks have the possibility to carry larger vehicles in terms of both geometry and weight. Decks 1 and 3 have a load capacity for up to 30 tonnes trucks and decks 5 and 7 the capacity for up to 15 tonnes trucks. In total, the ship can carry up to around 5 250 standard type passenger cars. Figure 83 shows a cross-section of the ship.

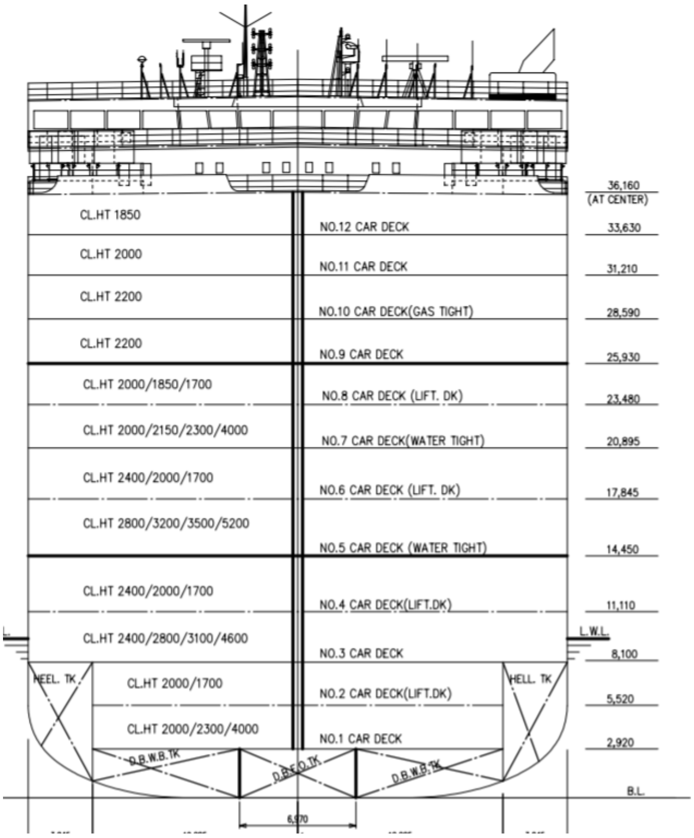



*Figure 83 A cross-section of the MS Torrens, the generic vehicle carrier in the project.*

The ship has two freshwater tanks, with a capacity of 237,3 $m^3$ and 338,1 $m^3$, respectively, totalling 575,4 $m^3$.

The hoistable decks initiate practical fire protection system issues that need to be dealt with. Each hoistable deck segment generally covers half the width of the space and a length of about 12 m. Most deck segments are rectangular and similar sized; however, odd segment shapes and sizes are used to increase the cargo loading area. For some areas, there are three deck segments in width, where the centremost segment is relatively narrow and, in a few cases, a single segment covers the full width of that part of the area. Table 29 summarises the number of hoistable decks on the ship.

*Table 29 The hoistable decks on MS Torrens and the number of deck segments.*

| Deck | Description | Clear height (mm) above the deck segment | Maximum clear height (mm) below the deck segment | Deck area (m²) | No. of hoistable deck segments | Typical approximate size, W × L (m × m) |
|---|---|---|---|---|---|---|
| 8 | NO. 8 CAR DECK (LIFT.DK) | 2000/1850/1700/0 | 4000 | 5 770 | 33 | 15 × 12 (180 m²) |
| 6 | NO. 6 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 5200 | 5 100 | 36 | 15 × 12 (180 m²) |
| 4 | NO. 4 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 4600 | 3 300 | 21 | 15 × 12 (180 m²) |
| 2 | NO. 2 CAR DECK (LIFT.DK) | 2000/1700/0 | 4000 | 1 810 | 16 | 15 × 12 (180 m²) |
| | | | | | 106 | |

From the table it can be observed that the maximum clear height on the deck (with the deck segment in its lowermost position) is between 2 000 mm and 2 400 mm. When position it its uppermost position, i.e., when the clear height above the segment is “0”, the maximum clear height below the deck is between 4 000 mm and 5 200 mm. The piping for the system installed below each of the deck segments therefore need to by hydraulically designed for a fire in a large type of vehicle.

As each deck segment can be positioned up against the fixed ceiling above it or up to 2 400 mm below it, the fixed sprinkler pipe underneath the segment needs to be fed by a flexible stainless steel hose. Figure 84 illustrates the arrangement.

It is observed that the flexible hose arrangement creates a low-point where drainage of any stagnant water is difficult without removing the flexible hose or by including a drainage valve at the low-point.

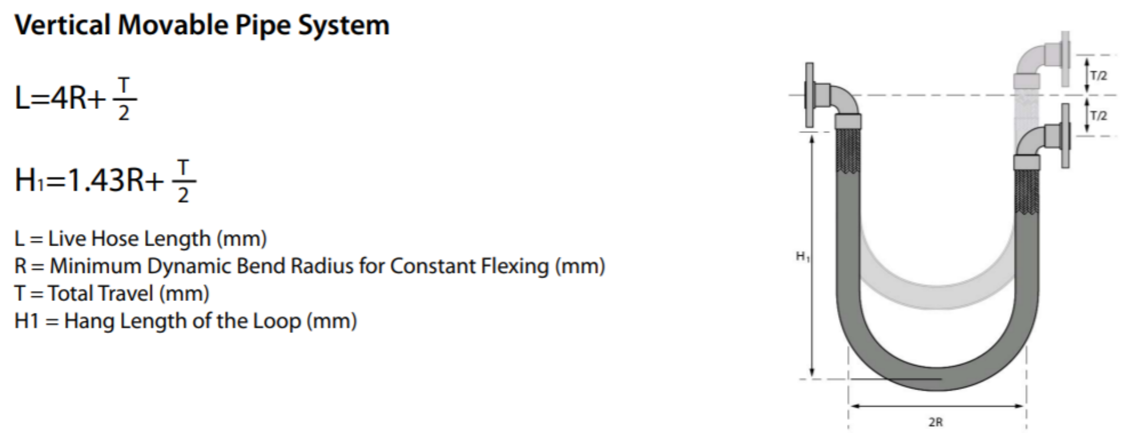



*Figure 84 An example of the arrangement of flexible stainless steel hose that allows vertical movement. From Pacific Hoseflex PTY LTD.*

A dry-pipe or deluge valve could serve system piping underneath several hoistable deck segments, but a deluge section layout where each segments constitutes a single section may be a logical alternative. The number of dry-pipe or deluge valve in each ro-ro space is discussed later in the report.

Independent of the system, the installation cost assessment was divided into three parts with associated costs:

1. The cost for components as the pump, air compressor (if used), Nitrogen generator (if used) the valves, control panels and the sprinklers or nozzles.
2. The cost for the piping, couplings, and hangers.
3. The labour cost for the engineering, shipyard administration, installation work as well commissioning and training.

The costs for each part were estimated based on figures from system component suppliers and sprinkler system installers. Sprinkler system contractors have knowledge, for example, of number of work hours that it normally takes to install a valve or the pipework for a certain number of sprinklers.

For the automatic deluge water spray and CAF systems, a fire detection and control system are required. The cost for this installation was estimated by a fire detection system supplier.

## 15.2 Labour cost assumptions

It was assumed that the fictive ship was built in Asia, but the engineering (hydraulic design and installation drawings) was made by a system component supplier or fire protection consultant in Europe. The labour cost estimates were as follows:

- Engineering: €75 per man hour.
- Shipyard administration and project management: €50 per man hour.
- Installation work: €25 per man hour.

## 15.3 Labour time assumptions

The estimation of the labour time for different parts of the systems was based on judgement of several sprinkler system contractors that were interviewed. The following figures were used:

- The installation of the sprinkler pump and associated connections and equipment: 40 hours.
- The installation of water distribution pipe and risers, excluding thermal insulation of the pipe: 1 man hours per meter pipe.
- The installation of one sprinkler or nozzle and the corresponding branch line: 1,5 man hours per sprinkler/nozzle.
- The installation of a dry-pipe or deluge valve: 20 man hours per valve.

## 15.4 General system type assumptions

Independent on the type of system, the following was assumed:

- Although the cost assessment was based on information and conditions of an existing ship, it was assumed that the installation was made during the construction of the ship and not as a retrofit installation.
- No sea water connection was assumed. The water supply is from of one of the freshwater tanks on the ship.
- A single, electrical motor driven centrifugal pump is used.
- The pump is connected to the main electric supply of the ship, i.e., no redundant means for the power supply is used.
- It is assumed that dry-pipe or deluge valves are installed inside fire rated cabinets positioned at each long side of the ship, to facilitate the system layout. The distribution piping to each valve is pressurized with water and the piping is thermally insulated with heat tracing.

No full hydraulic design of the system pipe-work was made, however, hydraulic calculations by hand was made to select the appropriate pipe sizes for each part of the system, as the branch lines, distribution piping and risers. The dry-pipe system require the smallest pipe sizes due to the smallest design area, resulting in the lowest design flow rate of all three system types.

### 15.4.1 Dry-pipe system assumptions

As mentioned, it was assumed that the dry-pipe valves were installed inside the space they were supplying. This will reduce the water delivery times once the automatic sprinklers are activated by a fire. The concept requires a water filled distribution pipe to each deck. To obtain freeze protection, the stand-pipe and distribution pipe needs to be thermally insulated and be heated by self-regulating heating cable. The dry-pipe valves are assumed to be installed in separate cabinets having at least Class 'A-15' fire rating.

It was also assumed that dry pendent sprinklers having standard-response characteristics and a nominal temperature rating of 141 °C were used for certain spaces having deep beams, i.e., the ceiling of decks 2, 4, 6 and 8. In total, 1 776 dry pendent sprinklers were assumed. For spaces having lesser deep beams, a total of 4 230 regular upright sprinklers were assumed to be used. Independent of the type, the sprinklers were made from brass. For the calculation of the total number of sprinklers, it was assumed that one sprinkler per 9 $m^2$ was installed. This corresponds to a total of 6 006 sprinklers.

Each dry-pipe section had a size such that the internal pipe volume was less than 1 900 litres, which would ensure a short water delivery time at the activation of one of more automatic sprinklers. This resulted in a total of 31 dry-pipe valves. Table 30 summarises the number and type of dry-pipe valves for each deck and the design flow rate.

*Table 30 The number and type of dry-pipe valves and the design water flow rate.*

| Deck | Description | Clear height (mm) | Deck area ($m^2$) | No. of dry-pipe valves | Type of valve | Design flow rate (l/min) |
|---|---|---|---|---|---|---|
| 12 | NO. 12 CAR DECK | 1850 | 5 760 | 3 | DN80 | 1800 |
| 11 | NO. 11 CAR DECK | 2000 | 5 800 | 3 | DN80 | 1800 |
| 10 | NO. 10 CAR DECK (GAS TIGHT) | 2200 | 5 810 | 3 | DN80 | 1800 |
| 9 | NO. 9 CAR DECK | 2200 | 5 810 | 3 | DN80 | 1800 |
| 8 | NO. 8 CAR DECK (LIFT.DK) | 2000/1850/1700/0 | 5 770 | 3 | DN80 | 1800 |
| 7 | NO. 7 CAR DECK (WATER TIGHT) | 2000/2150/2300/4000 | 5 010 | 3 | DN100 | 2700 |
| 6 | NO. 6 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 5 100 | 3 | DN80 | 1800 |
| 5 | NO. 5 CAR DECK (WATER TIGHT) | 2800/3200/3500/5200 | 4 950 | 3 | DN100 | 3600 |
| 4 | NO. 4 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 3 300 | 3 | DN80 | 1800 |
| 3 | NO. 3 CAR DECK | 2400/2800/3100/4600 | 3 140 | 2 | DN100 | 3600 |
| 2 | NO. 2 CAR DECK (LIFT.DK) | 2000/1700/0 | 1 810 | 1 | DN80 | 1800 |
| 1 | NO. 1 CAR DECK | 2000/2300/4000 | 1 790 | 1 | DN100 | 2700 |

For the low-height decks, the design density of 10 mm/min results in a minimum theoretical water flow rate of 1 800 l/min. The higher decks require either 15 mm/min or 20 mm/min, resulting in a total demand of either 2700 l/min or 3 600 l/min. These design flow rates determine the capacity of the pump, the size of the water distribution piping, the size of the dry-pipe valves and the hydraulic design of the system pipe-work. As a rule of thumb, the actual flow rate is typically approximately 20 % higher than the minimum theoretical flow rate, due to hydraulic imbalances in the system pipe-work.

For the low-height deck, a DN80 valve is sufficient, for the higher decks a DN100 should be used to provide the desired water flow rate. All dry-pipe valves were assumed to be fed by a common DN150 riser with distribution pipe along each deck.

### 15.4.2 Automatic deluge water spray system assumptions

The system layout was similar to that of the dry-pipe system, i.e., the deluge valves are assumed to be installed inside fire rated cabinets positioned at each long side of the ship. The time delay from fire detection to water discharge is thereby very short, as the pipe length from the valve to the hydraulically most remote nozzles is short.

It was assumed that each deluge section generally covered the full width of the deck and a maximum of 15 m in length, except for the areas under the hoistable deck segments, which constituted a single section. The capacity and the hydraulic design of the pipe-work need to include simultaneous discharge of at least two sections covering the full width of a deck or at least four sections associated with the hoistable deck segments. In practice, both alternatives result in similar water flow rate demands.

With a water discharge density of 7,5 mm/min, relevant for the low-height decks, a minimum theoretical water flow rate of 6 750 l/min applies. The higher decks require 10 mm/min, with a total demand of 9 000 l/min. These design flow rates determine the capacity of the pump, the size of the water distribution piping, the size of the deluge valves and the hydraulic design of the system pipework.

Table 31 summarises the number and type of deluge valves for each deck and the design flow rate per section.

*Table 31 The number and type of deluge valves and the desired water flow rates.*

| Deck | Description | Clear height (mm) | Deck area ($m^2$) | No. of dry-pipe valves | Valve size | Design flow rate (l/min) per section |
|---|---|---|---|---|---|---|
| 12 | NO. 12 CAR DECK | 1850 | 5 760 | 13 | DN100 | 3 375 |
| 11 | NO. 11 CAR DECK | 2000 | 5 800 | 13 | DN100 | 3 375 |
| 10 | NO. 10 CAR DECK (GAS TIGHT) | 2200 | 5 810 | 13 | DN100 | 3 375 |
| 9 | NO. 9 CAR DECK | 2200 | 5 810 | 13 | DN100 | 3 375 |
| 8 | NO. 8 CAR DECK (LIFT.DK) | 2000/1850/1700/0 | 5 770 | 13 | DN100 | 3 375 |
| 7 | NO. 7 CAR DECK (WATER TIGHT) | 2000/2150/2300/4000 | 5 010 | 33 | DN100 | 4 500 |
| 6 | NO. 6 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 5 100 | 12 | DN100 | 3 375 |
| 5 | NO. 5 CAR DECK (WATER TIGHT) | 2800/3200/3500/5200 | 4 950 | 36 | DN100 | 4 500 |
| 4 | NO. 4 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 3 300 | 8 | DN100 | 3 375 |
| 3 | NO. 3 CAR DECK | 2400/2800/3100/4600 | 3 140 | 21 | DN100 | 4 500 |
| 2 | NO. 2 CAR DECK (LIFT.DK) | 2000/1700/0 | 1 810 | 4 | DN100 | 3 375 |
| 1 | NO. 1 CAR DECK | 2000/2300/4000 | 1 790 | 16 | DN100 | 4 500 |

In total, 195 deluge valves are required for the ship.

For the calculation of the total number of water spray nozzles, it was assumed that one nozzle per 9 $m^2$ was installed, corresponding to 6 006 water spray nozzles. All nozzles were made from brass.

### 15.4.3 Compressed Air Foam Systems (CAFS) assumptions

The system layout was similar to that of the automatic deluge water spray system, i.e., the CAFS deluge valves are assumed to be installed inside fire rated cabinets positioned at each long side of the ship.

The minimum design density (water) was set to 6 mm/min for the low-height decks and 10 mm/min for the higher decks. It is presumed that the coverage area per nozzle is 9 $m^2$ and the water flow rate is 54 /min and 90 l/min, respectively per CAF nozzle. The design density and design area of sections correspond to a design water flow rate of approximately 5400 l/min. The actual flow rate is typically approximately 10 % higher than the minimum theoretical flow rate, due to hydraulic imbalances in the system pipe-work.

The full 30 minutes duration will require a total 162 $m^3$ of water from the water tanks and the foam supply shall be sufficient an equal time. At a 0,6 % foam concentration, the effective foam concentrate supply should be at least 1000 l. A Class B foam that is fluorine-free and biodegradable was assumed to be used.

Table 32 summarises the number and type of deluge valves for each deck and the design flow rate per section.

*Table 32 The number and type of CAFS deluge valves and the desired water flow rates.*

| Deck | Description | Clear height (mm) | Deck area ($m^2$) | No. of dry-pipe valves | Valve size | Design flow rate (l/min) per section |
|---|---|---|---|---|---|---|
| 12 | NO. 12 CAR DECK | 1850 | 5 760 | 13 | DN100 | 2 700 |
| 11 | NO. 11 CAR DECK | 2000 | 5 800 | 13 | DN100 | 2 700 |
| 10 | NO. 10 CAR DECK (GAS TIGHT) | 2200 | 5 810 | 13 | DN100 | 2 700 |
| 9 | NO. 9 CAR DECK | 2200 | 5 810 | 13 | DN100 | 2 700 |
| 8 | NO. 8 CAR DECK (LIFT.DK) | 2000/1850/1700/0 | 5 770 | 13 | DN100 | 2 700 |
| 7 | NO. 7 CAR DECK (WATER TIGHT) | 2000/2150/2300/4000 | 5 010 | 33 | DN100 | 1 550 |
| 6 | NO. 6 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 5 100 | 12 | DN100 | 2 700 |
| 5 | NO. 5 CAR DECK (WATER TIGHT) | 2800/3200/3500/5200 | 4 950 | 36 | DN100 | 1 550 |
| 4 | NO. 4 CAR DECK (LIFT.DK) | 2400/2000/1700/0 | 3 300 | 8 | DN100 | 2 700 |
| 3 | NO. 3 CAR DECK | 2400/2800/3100/4600 | 3 140 | 21 | DN100 | 1 550 |
| 2 | NO. 2 CAR DECK (LIFT.DK) | 2000/1700/0 | 1 810 | 4 | DN100 | 2 700 |
| 1 | NO. 1 CAR DECK | 2000/2300/4000 | 1 790 | 16 | DN100 | 1 550 |

In total, 195 deluge valves are required for the ship.

For the calculation of the total number of water spray nozzles, it was assumed that one nozzle per 9 $m^2$ was installed, corresponding to 6 006 CAFS nozzles. All CAFS nozzles were made from brass.

### 15.4.4 Fire detection system assumptions

The automatic deluge water spray and CAF system, respectively, requires a separate fire detection system. A cost estimate was made for two different types of systems, a system using spot-type heat detectors and a line-type heat detection system using fibre optic cables. As there should be a fire detection system installed per SOLAS II-2/20.4, the estimated installation costs for the fire detection system using spot-type heat detectors reflect the difference in cost for the system already required and the system that need to be installed to activate the water spray system.

It was estimated that the line-type heat detection system had fibre optic cables on a 4 m spacing, which required a total of approximately 16 000 m cables.

## 15.5 Cost estimation results

### 15.5.1 Dry-pipe system cost estimation results

The cost for the pipe-work assumed that DN100 and less sized galvanized distribution piping and DN40 galvanized branch lines were used. DN150 stand-pipe was assumed. The cost for the pump unit includes associated equipment such as the electric motor, the support frame, the control panel, valves, a flow meter, etc.

A Nitrogen generator and associated air compressor positioned close to the pump unit with hoses to each dry-pipe valve was assumed. Each system section does also require oxygen removal vent to facilitate removal of oxygen from the system pipe-work. Table 33 shows the estimated installation cost for an installation on MS Torrens.

*Table 33 The estimated installation cost of a dry-pipe system for the ro-ro spaces of MS Torrens.*

| **Part or action** | |
|---|---|
| Components as the pump unit, system shut-off valves, the Nitrogen generator and associated air compressor, oxygen removal ventilation valves, control panels and sprinklers | €486 690 |
| Pipe-work, flexible hoses, pipe couplings, mechanical T-fittings for sprinklers and hangers | €357 203 |
| Design and installation drawings, project management, installation work | €343 225 |
| Overall cost | **€1 187 118** |

### 15.5.2 Automatic deluge water spray system cost estimation results

The cost for the pipe-work assumed that DN100 and less sized galvanized distribution piping and DN40 galvanized branch lines were used. A DN150 riser was assumed. The cost for the pump unit includes associated equipment such as the electric motor, the support frame, the control panel, valves, a flow meter, etc.

Table 34 shows the estimated installation cost for an installation on MS Torrens. A fire detection system using spot-type heat detectors is more expensive than a line-type heat detection system using fibre optic cables. However, both alternatives are provided in the table.

*Table 34 The estimated installation cost of an automatic water spray system for the ro-ro spaces of MS Torrens.*

| **Part or action** | **Cost (€)** |
|---|---|
| Components as the pump unit, system shut-off valves, deluge valves, control panels and open nozzles | €575 529 |
| Pipe-work, flexible hoses, pipe couplings, mechanical T-fittings for sprinklers and hangers | €385 649 |
| Design and installation drawings, project management, installation work | €426 725 |
| Alternative 1: Fire detection system (spot-type heat detectors) | €446 000 |
| Alternative 2: Fire detection system (line-type heat detection) | €206 205 |
| Overall cost | **€1 833 903 (Alt. 1)**<br>**€1 594 108 (Alt. 2)** |

### 15.5.3 Compressed Air Foam Systems (CAFS) cost estimation results

The CAFS is similar to the automatic deluge water spray system in terms of the number of deluge valves and that a fire detection system is required. The primary difference is that system components are required to generate the foam, including an air compressor, the system pipe-work need to be balanced and larger system diameter piping is needed. Table 35 shows the estimated installation cost for an installation on MS Torrens.

*Table 35 The estimated installation cost of an automatic CAFS for the ro-ro spaces of MS Torrens.*

| **Part or action** | **Cost (€)** |
|---|---|
| Components as the pump unit, system shut-off valves, the foam concentrate tank, a foam proportioning and injection component, a mixing chamber or device, an air compressor, deluge valves and CAF nozzles | € 785 601 |
| Pipe-work, flexible hoses, pipe couplings, mechanical T-fittings for nozzles and hangers | €385 649 |
| Design and installation drawings, project management, installation work | €426 725 |
| Alternative 1: Fire detection system (spot-type heat detectors) | €446 000 |
| Alternative 2: Fire detection system (line-type heat detection) | €206 205 |
| Overall cost | **€ 2 043 975 (Alt. 1)**<br>**€ 1 804 180 (Alt. 2)** |

# 16 Cost assessments for system inspections, testing, and maintenance

Main author: Magnus Arvidson, RISE.

## 16.1 General

Inspections, testing, and maintenance of fire protection systems and appliances are required in accordance with SOLAS Chapter II-2/14.2.2:

***"2.2 Maintenance, testing and inspections***

*2.2.1 Maintenance, testing and inspections shall be carried out based on the guidelines developed by the Organization (Refer to MSC.1/Circ. 1432 as amended, including the amendments by MSC.1/Circ. 1516) and in a manner having due regard to ensuring the reliability of fire-fighting systems and appliances.*

*2.2.2 The maintenance plan shall be kept on board the ship and shall be available for inspection whenever required by the Administration."*

Surveyors are required to approve that inspections, testing and maintenance are carried out as part of the safety equipment survey, in accordance with the maintenance plan on the ship. Classification societies typically considers MSC.1/Circ. 1432 [62] and MSC.1/Circ. 1516 [63], as minimum guidelines on which such inspections are to be based. The first document superseded MSC/Circ. 850, recognizing the need to include maintenance and inspection guidelines for the latest advancements in fire protection systems and appliances. It applies to all ships and provide the minimum recommended level. The guidelines may be used as a basis for the ship's onboard maintenance plan required by SOLAS regulation II-2/14. The second document includes amendments to MSC.1/Circ. 1432.

Table 36 provides an overview of the requirements in MSC.1/Circ. 1432 and MSC.1/Circ. 1516 for fixed foam fire-extinguishing, water mist, water spray and sprinkler systems.

*Table 36 Overview of inspections, testing and maintenance of main fire-fighting systems based on MSC.1/Circ. 1432 and MSC.1/Circ. 1516 as amended.*

| Equipment | Time interval | Requirement | Guideline |
|---|---|---|---|
| Fixed foam fire-extinguishing systems | Monthly | Verification of valves and gauges, etc. | MSC.1/Circ. 1432, paragraph 5.3 |
| | Quarterly | Verification of quantity of foam concentrate | MSC.1/Circ. 1432, paragraph 6.2 |
| | Annually | Functional test, and foam sample testing, etc. | MSC.1/Circ. 1432, paragraph 7.4 |
| | 5-yearly | Inspection of each part | MSC.1/Circ. 1432, paragraph 9.2 |
| Water mist, water spray and sprinkler systems | Weekly | Visual inspection, etc. | MSC.1/Circ. 1432, paragraph 4.7 |
| | Monthly | Verification of valves and gauges, etc. | MSC.1/Circ. 1432, paragraph 5.4 |
| | Quarterly | Assessment of system water quality | MSC.1/Circ. 1516, paragraph 6.5 |
| | Annually | Blowing air, blowing water test, etc. | MSC.1/Circ. 1516, paragraph 7.5 |
| | 5-yearly | Internal inspection of all control/section valves, etc. | MSC.1/Circ. 1516, paragraph 9.3 |
| | 10-yearly | Hydrostatic test for gas and water pressure cylinders | MSC.1/Circ. 1432, paragraph 10.2 |

Certain inspection and maintenance procedures may be performed by competent crew members, while others should be performed by trained external personnel. The onboard maintenance plan should indicate which parts that are to be completed by trained personnel. Records of inspections must be carried on board the ship and may be computer-based. In cases where the inspections and maintenance are carried out by external parties, inspection reports must be provided at the completion of the testing. In addition, manufacturer's inspection, control, and maintenance recommendations must be followed. The quality of water in automatic sprinkler systems is of particular importance and must be maintained, tested, and recorded on board.

Table 37 details the requirements in MSC.1/Circ. 1432 and MSC.1/Circ. 1516, specifically for the automatic (dry-pipe) sprinkler system, the automatic deluge water spray system, and the automatic deluge CAFS covered in this report. Some of the requirements are not listed as they are not relevant for the fictive installation on board MS Torrens. Other requirements have been slightly re-worded for clarity. It should be emphasized that the automatic deluge water spray system and CAFS require inspections, testing and maintenance of the separate fire detection and control system.

A key amendment in MSC.1/Circ. 1516 relates to “Water mist, water spray and sprinkler systems” and the requirement that the water quality in the header tank and pump unit should be assessed against the manufacturer's water quality guidelines. Another important amendment is an annual functional test (‘field sampling test’) of automatic sprinklers or nozzles to ensure the operation and flow of water. The systems covered in this report are not as susceptible to clogging of nozzles, as the orifice sizes are relatively large, and the intended primary water supply is the freshwater tank of the ship. Testing of automatic sprinkler samples is, however, essential to improve the reliability of an automatic sprinkler system.

*Table 37 The minimum requirements for the inspections, testing and maintenance relevant for automatic sprinkler systems and automatic deluge water spray systems and CAFS in MSC.1/Circ. 1432 and MSC.1/Circ. 1516 as amended.*

| Time interval | Type of system | Action |
|---|---|---|
| Weekly | Automatic sprinkler system | • Verify that all control panel indicators and alarms are functional.<br>• Visually inspect pump unit(s) and its fittings<br>• Check the pump unit(s) valve positions, if valves are not locked, as applicable. |
| | Automatic deluge water spray system | • As per above, plus verify that all fire detection and fire alarm control panel indicators are functional by operating the lamp/indicator test switch. |
| | Automatic deluge CAFS | • As per above. |
| Monthly | Automatic dry-pipe sprinkler system | • Verify that all control and section valves are in the proper open or closed position, and all pressure gauges are in the proper range.<br>• Control water levels in tanks.<br>• Test automatic starting arrangements on all system pumps so designed.<br>• Verify that all standby pressure and air/gas pressure gauges are within the proper pressure ranges.<br>• Test a selected sample of system section valves for flow and proper initiation of alarms. Note: The valves selected for testing should be chosen to ensure that all valves are tested within a one-year period. |
| | Automatic deluge water spray system | • As per above plus, test a sample of fire detectors such that all devices have been tested within five years. |
| | Automatic deluge CAFS | • As per above. |
| Quarterly | Automatic dry-pipe sprinkler system | • No recommendations. |
| | Automatic deluge water spray system | • No recommendations. |
| | Automatic deluge CAFS | • Verify that the proper quantity of foam concentrate is provided in the foam system storage tank |
| Annual | Automatic dry-pipe sprinkler system | • Verify proper operation using the test valves for each section. Note: It is assumed that dry and pre-action systems are tested using a partial trip test annually and a full trip test every third year (as per the recommendations per NFPA 25). This approach prevents the |

| | | |
|---|---|---|
| | | pipework from being filled with water. It saves labor time and reduces the probability for internal pipe corrosion.<br>• Visually inspect all accessible components for proper condition.<br>• Functionally test all fixed system audible and visual alarms.<br>• Flow test all pumps for proper pressure and capacity.<br>• Verify all pump relief valves, if provided, are properly set.<br>• Examine all system filters/strainers to verify they are free of debris and contamination.<br>• Verify that all control/section valves are in the correct position.<br>• Blow dry compressed air or nitrogen through the discharge piping of dry-pipe systems, or otherwise confirm the pipework and nozzles are clear of any obstructions. This may require the removal of nozzles, if applicable.<br>• Test emergency power supply switchover, where applicable.<br>• Visually inspect all sprinklers or nozzles focusing in areas where sprinklers are subject to aggressive atmosphere and subject to physical damage so that all sprinklers or nozzles are inspected within one year. Sprinklers or nozzles with obvious external damage, including paint, must be replaced.<br>• Check for any changes that may affect the system such as obstructions by ventilation ducts, pipes, etc.<br>• Test the function (‘field sampling testing’) of automatic sprinklers or nozzles in accordance with the flow chart included in MSC.1/Circ. 1516. |
| | Automatic deluge water spray system | • All relevant parts per above, plus:<br>• Test all fire detection systems used to automatically release fire-extinguishing systems for proper operation, as appropriate.<br>• Visually inspect all accessible detectors for evidence of tampering obstruction, etc., so that all detectors are inspected within one year. Note: The latter part of the sentence may be a misprint as this is supposed to be made annually.<br>• Test a minimum of one section deluge system section by flowing water through the nozzles. The sections tested should be chosen so that all sections are tested within a five-year period. |
| | Automatic deluge CAFS | • All relevant parts per above plus:<br>• Flow test all water supply and foam pumps for proper pressure and capacity and confirm flow at the required pressure in each section (Ensure all piping is thoroughly flushed with fresh water after service.).<br>• Blow dry compressed air or nitrogen through the discharge piping or otherwise confirm the pipework and foam nozzles are clear of any obstructions, debris and contamination. This may require the removal of nozzles, if applicable.<br>• Take samples from all foam concentrates carried on board and subject them to the periodical control tests in MSC.1/Circ.1312, for low expansion foam, or MSC/Circ. 670 for high expansion foam. Note: Except for non-alcohol resistant foam, the first test need not be conducted until 3 years after being supplied to the ship. |
| Two-year | Automatic dry-pipe sprinkler system | • No recommendations. |
| | Automatic deluge water spray system | • No recommendations. |
| | Automatic deluge CAFS | • No recommendations. |
| Five-year | Automatic dry-pipe sprinkler system | • Perform internal inspection of all control/section valves.<br>• Check condition of any batteries or renew in accordance with manufacturer’s recommendations. |

| | | |
|---|---|---|
| | Automatic deluge water spray system | • As per above plus:<br>• Flush all ro-ro deluge system piping with water, drain and purge with air. |
| | Automatic deluge CAFS | • As per above plus:<br>• Check all foam nozzles to prove they are clear of debris.<br>• Test all foam proportioners or other foam mixing devices to confirm that the mixing ratio tolerance is within +30 to -10% of the nominal mixing ratio defined by the system approval. |
| 10-year | Automatic dry-pipe sprinkler system | • These systems should be inspected and tested by a competent person as per the manufacturer's instructions, and as a minimum should include a hydrostatic test and internal examination for gas and water pressure cylinders according to EN 1968:2002. |
| | Automatic deluge water spray system | • As per above. |
| | Automatic deluge CAFS | • As per above. |

## 16.2 Cost assessment assumptions

For each of the three systems, an assessment of the cost for the inspections, testing and maintenance over a 10-year period was made. Based on that, an average annual cost was calculated. It was assumed that most of the actions (the least complicated) are undertaken by competent crew members. For these actions, the estimated labor time was multiplied with the internal cost for a crew member. Based on input from Wallenius Marine AB, the cost was set to €22 per work hour.

The more complex actions, like internal inspection of control/section valves and testing of foam proportioners and specific system service and maintenance, external competence is needed. The cost of labor varies depending on the part of the world in which the work is performed. Based on input from Wallenius Marine AB, service engineers in the European Union for original equipment suppliers is between €120 to €150 per work hour. For this cost assessment, €135 per work hour was used.

Finally, some actions require laboratory testing, as the control test of foam concentrate. This service is available at several different fire test laboratories, which provided input on the cost including an estimated freight cost for the shipment of the foam sample.

The large number of deluge valves associated with the automatic water spray system and the CAFS substantially increase the total labor time for these systems. As an example, every month it should be verified that that all control and section valves are in the proper open or closed position, and every fifth year an internal inspection of all these valves should be made. The use of foam in the CAFS will also add additional measures to be taken. The fact that these systems also necessitate a separate fire detection system require extensive time for inspection and testing. A fire detection installation on MS Torrens would require in the order of 2 000 to 2 500 spot-type heat detectors. A line-type heat detection system would likely require less time for inspection and testing.

The required time for some of the measures were purely estimated. As an example, it was judged that the weekly inspections would require no more than one working hour irrespective of the type of system.

The cost for an annual service to fulfil the manufacturer's recommendation for inspection, control and maintenance recommendations was added. The cost for spare parts as gaskets for valves, filters, sprinklers or nozzles and foam was estimated to be 25 % of the estimated cost for the annual system service.

Some of the require actions are very time demanding, for example the requirement the action "Check all foam nozzles to prove they are clear of debris" that should be undertaken every five years. For the CAFS that is envisioned, more than 6 000 foam nozzles are needed on MS Torrens. If the dismantling and control of one nozzle is assumed to require 15 minutes, the inspection of all nozzles require 1 500 work hours. This action should be undertaken after the flushing of water through the particular deluge system section, an action that is also very time consuming given the large number of deluge sections.

## 16.3 Cost assessment results

Table 38 summarizes estimated annual costs for inspections, testing and maintenance of the three systems.

*Table 38 The estimated cost for inspections, testing and maintenance of a dry-pipe sprinkler system, an automatic deluge water spray system and an automatic CAFS on MS Torrens.*

| Type of system | Average, annual cost (€) |
|---|---|
| Automatic dry-pipe sprinkler system | €13 743 |
| Automatic deluge water spray system | €34 140 |
| Automatic deluge CAFS | €35 186 |

From this assessment, it can be concluded that the annual cost is more than a factor of two higher for the two deluge systems as compared to the dry-pipe sprinkler system. The reason is that the deluge systems are more complex and include more components, resulting in more extensive inspection, testing and maintenance and higher costs for spare parts. The use of foam and the equipment related to the generation of will make the CAFS the most expensive system to maintain serviceable.

## 16.4 Estimation of system weights

Based on the individual weight and number of components used for a system installation, the overall weight of each system was estimated. It was assumed that lightweight steel piping was used, in order to fulfil the project objective related to low weight.

The overall weight of the dry-pipe system is approximately 100 tons and the weight of the deluge water spray system approximately 110 tons. The pipe, couplings, and hangers accounts for approximately 85% of the total weight. The weight for the CAFS is even higher as larger system piping is required.

# 17 Discussion

Main author: Magnus Arvidson, RISE.

## 17.1 General approach

Automatic fire sprinkler systems are used for fire hazards that are similar to those found on vehicle carriers, as car parking garages and facilities for manufacturing and assembly of boats, highway trailers and trucks, boxcars, mobile homes, or similar metal vehicles with combustible interiors. A fire in such facilities is characterised by a moderate to substantial amounts of flammable or combustible material and liquids where shielding of combustibles is extensive.

The literature survey that was undertaken identified relevant fire test data (from RISE, BRE Global, the IMPRO project and the FIRESAFE II project). Field experience (from United Kingdom) with automatic sprinklers in parking garages and from fires within ro-ro spaces on ro-pax vessels, vehicle carriers and general ro-ro cargo vessels (compiled by DNV GL) was also found. The information that was discovered provides a good understanding of how to design and install the systems that were developed.

The use of automatic sprinklers is recognized in the design and installation recommendations in MSC.1/Circ. 1430, as amended. These recommendations were used as the starting point for the design and installation guidelines that were written. The recommendations cover aspects as the system type, positioning of sprinklers, design densities and operating areas. Additional information was offered in the 2019 edition of NFPA 13, the 2019 edition of FM DS 3-26 and the 2018 edition of FM DS 2-0 as well as in and EN 12845:2015+A1:2019. Protection of sprinkler system piping from internal corrosion is essential to maintain a long service life of a system. The 2018 edition of FM DS 2-1 provided such recommendations.

The recommendations of the 2017 edition of NFPA 15 was also considered. This standard provides the minimum requirements for the design, installation, and system acceptance testing of fixed water spray systems. The standard does not list or describe any hazards or applications that are directly applicable for the fire hazards in closed ro-ro spaces on vehicle carriers. However, the standard contains installation recommendations that are valuable.

Much less information related to the design of CAFS was found, simply because these systems have not been used for similar fire hazards. NFPA 15 provide some information for the protection of flammable liquid hazards that was summarised. As there are no automatic nozzles for CAFS, the system needs to be designed as a deluge system.

## 17.2 Essential design and installation aspects

Some essential aspects of the system design and installation is summarised and discussed below, under relevant headlines.

### 17.2.1 System types

Where system piping is in areas not permanently maintained above +4 °C freezing may occur, which require the use of antifreeze in a wet-pipe system, a dry-pipe or a pre-action system. Deluge systems are per definition not subject to freezing as the system piping downstream of the deluge valve is not filled with water. Heat tracing and thermal insulation of the sprinkler pipe may be used where distribution piping is filled with water. The system types and some of the benefits and drawbacks on vehicle carriers can be summarised as follows:

For **wet-pipe systems** water discharges immediately as one or more sprinklers are activated by the heat from a fire. An antifreeze is required for spaces where the system is subject to low ambient temperature. The carriage of water in piping is undesired due to the increased weight and therefore a wet-pipe system is the least likely to be used. Additionally, the use of antifreeze increases the complexity of the system and results in high installation and maintenance costs.

Compared to a wet-pipe system (without antifreeze), a **dry-pipe system** results in increased system complexity, higher installation and maintenance costs, lower design flexibility, increased fire response time and increased corrosion potential. To limit the fire response time, it suggested that dry-pipe valves should be permitted to be installed inside the protected space, if positioned inside a separate cabinet. To overcome the increased internal pipe corrosion potential, it is recommended that Nitrogen and not compressed air is used as the supervisory gas. The use of Nitrogen is required to use internally untreated carbon (black) steel piping. Externally, the pipe can be galvanized or coated to protect against corrosion.

One concern raised by ship operators is related to unintentional activations (no fire) or water leakage with potential damage to the cargo, that is often new vehicles. A double-interlock **pre-action system** may resolve this concern. Two separate incidents must occur to initiate sprinkler discharge. Firstly, a fire detection system must discover a developing fire and then open the pre-action valve. Secondly, an individual sprinkler must activate by the heat to permit water flow onto the fire. However, the system type results in higher installation and maintenance costs, system modification difficulties and potential decreased reliability. As with dry-pipe systems, the use of Nitrogen and not compressed air as the supervisory gas will overcome the increased internal pipe corrosion potential.

An automatic **deluge system** necessitates a fire detection system installed in the same area as the (open) nozzles. A fire detection system with fixed-temperature, rate-of-rise, or combination fixed-temperature/rate detection devices should be used. Smoke or flame detectors are not desired as there is a probability that the fire is detected in another area than the actual deluge section area. Accidental system operation is also a higher concern with smoke and flame detectors. A major advantage of a deluge system is that it can be activated both automatically (as intended for these applications) and manually by a remote or manual operation of the deluge valve. Another benefit is that the system can be flow tested when there is no cargo on board the ship. The major drawback is that numerous deluge valves are required, and the total flow rate is higher than for dry- or pre-action systems where only the automatic sprinklers closest to a fire activates. The higher water flow rates would also require larger diameter piping.

### 17.2.2 Sprinkler system piping

There are primarily three aspects that are important for sprinkler piping on vehicle carriers, the external and internal corrosion protection of piping, the overall weight of the system and the durability of the piping under fire conditions. If metallic piping is used, the last aspect is typically no concern, especially for wet-, dry- or pre-action systems. However, non-metallic piping may be advantageous to improve the first two characteristics but suffer from less heat resistance. The review concludes that thermoplastic fire sprinkler piping is typically used for residential and other light hazard occupancies and is therefore not possible to use for the protection of ro-ro spaces on vehicle carriers. But there is new type of corrosion resistant sprinkler steel pipe in the marketplace that features a special polymer-enhancement that protect it against corrosion both on the outside and the inside.

The use of light-weight steel piping (i.e., piping with thinner walls) will reduce the weight of the individual pipe considerably. For buildings, the primary benefit with light-weight steel piping is reduced installation labour time as handling is easier. For ships, however, a reduced overall weight of the sprinkler piping could also result in less fuel consumption and/or increased cargo weight capacity. The weight analysis of two commercially available light-weight piping systems were made. It is concluded that weight savings range from about 30 % to 50 % dependent on the pipe dimensions. For a full system using light-weight piping, the weight savings are around 35 % compared to a system using standard piping.

### 17.2.3 Internal corrosion protection of piping

Choice of material, storage of piping awaiting installation, cleaning of contamination, internal inspection during the service life, etc. will reduce internal pipe corrosion. The recommendations related to the choice of sprinkler piping for wet-pipe systems can be summarised as follows; use Schedule 40 (or equivalent thickness) pipe installed over occupancies deemed sensitive to leaks and do not use galvanized pipe in wet-pipe systems. Experience indicates that galvanized pipe in wet-pipe systems offer no advantage over black steel piping regarding corrosion.

For dry-pipe and pre-action systems the use of Nitrogen as the supervisory gas will allow black steel pipe to be used. For dry-pipe and pre-action systems <u>not</u> using Nitrogen, it is recommended that galvanized steel pipe shall be used, pipe shall be pitched to promote drainage of all testing water and water vapor condensate within piping, low-point drains shall be installed, rolled groove joints should be avoided as they promote water accumulation, etc. As indicated, the use is to use Nitrogen gas instead of compressed air in the system piping as a corrosion mitigation approach is therefore recommended.

### 17.2.4 The choice and orientation of automatic sprinklers

For dry-pipe or pre-action systems, only upright or dry pendent sprinklers (see below) are utilized. A standard pendent sprinkler on dry-pipe systems would trap water in the sprinkler and fitting to which it is attached, which would have the potential to freeze and cause mechanical damage to the sprinkler or prevent the sprinkler from operating during a fire.

A dry sprinkler is a sprinkler secured in an extension nipple that has a seal at the inlet to prevent water from entering the nipple until the sprinkler operates. Dry sprinklers may be used in dry-pipe or pre-action systems to allow pendent sprinklers. For the application in ro-ro spaces, pendent sprinkler orientation will improve the possibilities for installing the sprinklers to minimize the influence from structural members and other potential obstructions on the spray pattern.

### 17.2.5 The K-factor of sprinklers

Some installation standards, as NFPA 13 and FM DS 3-26 specify the appropriate K-factor, minimum operating pressure, and number of sprinklers (or design area) to be calculated for each applicable design criteria. For storage applications, NFPA 13 specifies that standard-response K115 sprinklers must be used with a density between 8,2 mm/min and 13,9 mm/min. Standard-response K160 sprinklers or larger that are listed for storage applications shall be used for densities greater than 13,9 mm/min. To reduce the system operating pressure and to maximize the flow rate of the first sprinkler that operates in a fire, these recommendations should be adopted.

### 17.2.6 The nominal operating temperature of automatic sprinklers

For hazards where flammable or combustible liquids are present or where shielding of combustibles are extensive, as with fires in vehicles, NFPA 13 permits that the area of operation can be reduced by 25 % when using high-temperature (rated between 121 °C and 149 °C) sprinklers. The area is, however, not allowed to be less than 186 m$^2$. For dry-pipe sprinkler systems, FM DS 3-26 recommends the use of upright or dry-pendent sprinklers with a nominal 140 °C temperature rating. Nominal 70 °C sprinklers are acceptable for HC-1 and HC-2 occupancies. Examples of occupancies classified as HC-2 is parking garages, car parks and car workshops.

Based on this, it is recommended that high-temperature automatic sprinklers are used for ro-ro spaces where transportation of larger vehicles is possible.

### 17.2.7 The thermal sensitivity of automatic sprinklers

Thermal sensitivity is the measure of how fast the thermal element (glass bulb or fusible link) operates in a standardised test. Based on this time, the Response Time Index (RTI) can be calculated. The lower the RTI of a sprinkler, the faster it activates in a fire. But a low RTI is not necessarily the best option. For dry-pipe sprinkler systems, FM DS 3-26 recommends the use of upright or dry pendent sprinklers with standard-response characteristics. Fast-response sprinklers are, however, acceptable for HC-1 and HC-2 occupancies. The reason that standard-response sprinklers should be used with dry-pipe systems is to prevent too many sprinklers from operating before water fills the pipe-work.

Based on this, it is recommended that standard-response automatic sprinklers are used, except for spaces where passenger cars are carried, where either fast or standard-response automatic sprinklers are acceptable.

### 17.2.8 Positioning of sprinklers relative to the ceiling construction

For automatic sprinklers or nozzles, it is essential that the vertical distance from the underside of the deck (ceiling surface) to the thermal element is within certain limits to provide as fast activation as possible. But automatic sprinklers need also be positioned such that the ceiling construction in terms of beams, trusses, or other members do not affect the water distribution spray pattern. Both NFPA 13 and FM DS 2-0 provides recommendations of the minimum and maximum allowed vertical distances from the ceiling surface for obstructed ceiling constructions and guidance to ensure that the water discharged from sprinklers is not significantly obstructed. These recommendations and recent research made by FM Global proved to be valuable for the design and installation that were written.

### 17.2.9 The use of an antifreeze

If an antifreeze solution is used for a wet-pipe system to protect the system from freezing, it should be third-party tested and certified for use in fire sprinkler systems. This is essential as there are many characteristics that are important for the functionality, as the stability of the solution over time, material compatibility, toxicity, and fire performance. The installations instructions of the manufacturer should be met. The antifreeze solution should be tested annually to ensure proper solution-to-water mixture. Currently, there is only one antifreeze product in the marketplace that is certified by a third party.

### 17.2.10 Fire suppressing enhancing additives or foam

Fire suppressing enhancing additives or foam need to be fluorine-free and biodegradable. The foam agent needs to be compatible with sea water if the potable water supply on a ship is not sufficiently large and a sea water connection is required.

### 17.2.11 Design densities and areas of operation

The recommended design densities and areas of operation in the current versions of MSC.1/Circ. 1430, NFPA 13, FM DS 3-26 and EN 12845:2015+A1:2019 were evaluated to provide input to the project. For the 2022 edition of NFPA 13, some potential code changes are underway. Automobile parking will likely be reclassified as Extra Hazard Group 2. The reason is a concern that the hazard classification is inadequate. Automobile design has continuously been evolving and modern vehicles contain significantly more plastics than older cars, hybrid/electric drive cars pose a different risk and the distance between cars is close in parking garage, which promotes fire spread.

### 17.2.12 The size of dry-pipe or pre-action systems

Dry-pipe sprinkler and pre-action systems shall be arranged to provide a single-path flow within all parts of the sprinkler system and meet a maximum recommended water delivery time once the first sprinkler has operated. Gridded systems shall not be used. The system size (i.e., internal pipe volume) shall be such that initial water is discharged from the system test connection, located at the most remote point of the system, in not more than 60 s. Alternatively, a maximum system size applies. Both these requirements limit the size of a dry-pipe section. The implication is that large ro-ro spaces, such as those found on MS Torrens, will require several dry-pipe (two or three for each deck) system sections.

### 17.2.13 The use of Compressed Air Foam Systems (CAFS)

It should be noted that the generation of foam occurs at the mixing chamber of the system and finished foam is transported in the system piping. The foam travel time inside piping is rapid, as the foam to a large extent constitutes of air. If the water flow rate is less than that of regular foam-water sprinkler or foam-water spray systems where the foam is generated at the actual sprinkler or nozzle, the pipe dimensions can generally be smaller. However, large water flow rates could result in larger diameter piping with CAFS.

Balanced piping configuration should be used with CAFS to provide each nozzle in the design to discharge the same amount of CAF. To achieve this, the flow path from the foam mixing chamber or device to each nozzle must have approximately the same pressure loss. The most practical way to achieve this is by grouping the nozzles in groups of 2, 4, 8, 16 or 32 and by using the same pipe length, pipe size, and fittings for each branch of piping. This requirement may be challenging in a ro-ro space, due to that fact that the routing of piping need to account for the presence of beams, pipe, cable ladders and other installations.

## 17.3 Installation cost assessment results

An installation cost assessment was made for a dry-pipe system using automatic sprinklers, an automatic deluge water spray system and an automatic deluge CAFS. The results indicate that the dry-pipe sprinkler system is the least expensive and CAFS the most expensive of the three systems. The main reason for the results is that the dry-pipe sprinkler system need significantly fewer section valves and no fire detection system for its activation. The dry-pipe sprinkler system is also the system that weighs the least, as this system use the smallest diameter piping and the least overall pipe length. The overall total system weight is in the order of 100 tons for a ship like MS Torrens.

## 17.4 Inspection, testing, and maintenance cost assessment results

For each of the three systems, an assessment of the cost for the inspections, testing and maintenance over a 10-year period was made. Based on that, an average annual cost was calculated. It was assumed that most of the actions (the least complicated) are undertaken by competent crew members. The more complex actions, like internal inspection of control/section valves and testing of foam proportioners, external competence is needed. Some actions require laboratory testing, as the control test of automatic sprinklers and quality verification of foam concentrate. The cost for spare parts as gaskets for valves, filters, sprinklers or nozzles and foam was estimated and added to the costs discussed above.

It was concluded that the annual cost was more than a factor of two higher for the two deluge systems as compared to the dry-pipe sprinkler system. The reason is that the deluge systems are more complex and include more components, resulting in more extensive inspection, testing and maintenance and higher costs for spare parts. The use of foam and the equipment related to the generation of foam will make the CAFS the most expensive system to maintain serviceable.

## 17.5 Intermediate-scale fire tests

Intermediate-scale fire tests with water spray system nozzles were conducted to supplement the information on system design that was found in the literature review. These tests did also serve as a system development opportunity of the CAFS in terms of choice of nozzles, foam agent and discharge densities. Two different Class A type fire scenarios (commodities) were used, the EUR Std plastic commodity and stacks of idle wood EUR pallets.

For the EUR Std plastic commodity tests, it seems that the critical water application rate for fire suppression is around 10 mm/min. An increase in water discharge density above this threshold does not result in a significant improvement in fire suppression performance. The critical water application rate for fire suppression for the idle wood pallets is between 10 mm/min and 12,5 mm/min.

Foam distribution tests with the CAF nozzles indicate that the rotating nozzle was the best choice for the fire tests. The stacks of idle wood pallets seemed more difficult to suppress and control as compared to the EUR Std plastic commodity, based on a strict test-to-test comparison. Based on the test results, is was concluded that that a pre-mix flow rate that is two-thirds of the water flow using water only would be needed to suppress the test fires. Improved foam distribution through the fire plume of the nozzles is desired. This could be achieved with a significantly narrower spray pattern. It is also essential that the distribution of foam directly under a nozzle improves, which would be the result of a reduced spray angle. A wetter (lower expansion ratio) would improve the penetration of the fire plume. On the other hand, this will reduce the ability of the foam to stick to vertical surfaces, which is a feature that is important for shielded fires in vehicles, to obtain a barrier to heat radiation that prevent fire from spreading to adjacent vehicles.

## 17.6 Large-scale validation fire tests

Two types of systems were tested in large-scale validation tests, a dry-pipe system using automatic sprinklers and a deluge water spray system. The deluge CAFS system that was developed in the project was not tested, as it was considered that this system was the most expensive to install and maintain serviceable. Additionally, the intermediate-scale fire tests did not indicate any fire suppression performance advantage of CAF for the fire scenarios exapted in vehicle spaces.

Overall, the test results verified that the systems were able to provide fire control of realistic vehicle fires. The fire spread between vehicles was prevented or delayed and the gas temperatures at the ceiling were reduced. It was judged that the draft design and installation guidelines only needed minor adjustments. One adjustment is that that conventional upright or pendent sprinklers should be used if the vertical distance from the underside of the ceiling to the deflector exceeds 300 mm. This will improve direct cooling of the underside of the ceiling by direct water discharge, which will reduce the probability of fire spread from one space to the space above.

One of the challenges of using automatic sprinklers in ro-ro spaces on vehicle carriers is the deep transversal beams. These beams could channel the hot gases from the fire in two directions which prevents them from spreading out under the ceiling uniformly to the nearest four sprinklers. To limit the number of automatic sprinklers that would operate in a fire, a concept with steel sheet barriers were developed to limit the length of these channels. This concept proved efficient. The hot combustion gases filled the ceiling pockets and the sprinklers closest to the fire operated properly by the heat.

# 18 Conclusion

Main author: Magnus Arvidson, RISE.

Ro-ro spaces on vehicle carriers are typically protected by a total-flooding Carbon Dioxide system. If properly designed, it acts as an effective fire suppressant, it is also colourless, odourless, electrically non-conductive, and leaves no residue. But there is one important drawback; at the (high) concentrations required for fire extinguishment, it is acute lethal. Due to the toxicity of Carbon Dioxide, there could be a considerable time delay from the start of a fire until the Carbon Dioxide system is discharged, as it needs to be confirmed that there are no crew members inside the protected spaces.

The water-based fire protection systems developed in WP10 should be regarded as supplementary to the total-flooding Carbon Dioxide system. Automatic activation at an early stage will limit the size of a vehicle fire and provide more time to manually fight or to safely evacuate the space and discharge the Carbon Dioxide system. Three actual cases are documented in the report where it is judged that a supplementary water-based fire protection system probably would have made a tremendous difference in limiting the fire damage and the associated cost.

It was desired that these supplementary water-based fire protection systems should be efficient, be inexpensive and have a low weight. The development work included both theoretical evaluations (based on a comprehensive literature review) and system development testing. Additionally, an assessment of the system installation costs, the cost for the inspections, testing and maintenance and the system weights was undertaken.

The conditions in ro-ro spaces on board vehicle carriers, that may result in freezing, prevents system piping to be filled with water. Although an antifreeze solution may be used to prevent freezing, the added weight of solution in system piping is undesired. Therefore, either a dry-pipe system utilizing automatic sprinklers, or a deluge system is preferred. For that reason, the work focused on three different system solutions: a dry-pipe sprinkler system, a deluge water spray system, and a deluge CAFS. All systems are commercially available, and it was investigated how the systems can be adapted and optimised for this application. To provide generic system concepts, design and installation recommendations were written that defines minimum system installation requirements. A deluge system requires a separate fire detection system that is installed in the deluge section protection areas. To reduce the time from system activation, whether it be by the activation of automatic sprinklers or from a signal from the fire detection system it is suggested that dry-pipe or deluge valves are installed inside the protected spaces. The valves are assumed to be installed in separate cabinets having at least Class ‘A-15’ fire rating. This is an entirely new approach compared to a system design in accordance with MSC.1/Circ. 1430. Another benefit is that system piping (and thereby the overall weight of a system) can be reduced as all valves can be fed from a common stand-pipe.

The objectives of Action 10-A were fulfilled, from the aspect that at least two system solutions were identified, examined, and implemented in the design and installation guidelines. International standards and recommendations offered guidance on how to design and install dry-pipe sprinkler and deluge water spray systems for similar hazards. Field experience from fires on ships and parking garages indicate that the systems are effective in controlling, suppressing or even extinguishing fires in vehicles. Much less information related to the design of CAFS was found, simply because these systems have not been used for similar fire hazards.

The system development testing revealed that Class A fires may be challenging for CAFS. A wetter foam (lower expansion ratio) would improve foam distribution through the fire plume. On the other hand, a wet foam will reduce the ability of the foam to stick to vertical surfaces, which is a feature that is important for shielded fires in vehicles, preventing fire from spreading. Overall, the tests indicate that the CAFS flow rate need to be high, approaching that of a water spray system.

None of the systems discussed above are inexpensive to install and maintain serviceable. But it is no doubt that a dry-pipe sprinkler system is the least expensive and CAFS the most expensive of the three systems that were studied. The dry-pipe sprinkler system is also the system that weighs the least, as this system use the smallest diameter piping, the least overall pipe length, and the fewest number of valves.

The large-scale validation fire tests verified that the systems were able to provide fire control of realistic vehicle fires. The fire spread between vehicles was prevented or delayed and the gas temperatures at the ceiling were reduced. Fire control may offer the possibility to undertake manual fire-fighting of vehicle fires by using fire hoses or other means. However, the most significant improvement is that automatic activation of a water-based system is offering more time to safely discharge the fixed-installed Carbon Dioxide system.

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# 20 Indexes

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# 21 ANNEX

## GUIDELINES FOR THE DESIGN, INSTALLATION AND APPROVAL OF FIXED AUTOMATIC FIRST RESPONSE FIRE PROTECTION SYSTEMS FOR CLOSED VEHICLE AND RO-RO SPACES ON VEHICLE CARRIERS

**Introduction**

Ro-ro spaces on vehicle carriers are typically protected by a total-flooding Carbon Dioxide system. Due to the toxicity of Carbon Dioxide, there could be a considerable time delay until the system is discharged, as it needs to be confirmed that there are no crew members inside the protected spaces.

These guidelines provide the minimum requirements for the design, installation, and approval of fixed automatic first response fire protection systems intended for closed vehicle and ro-ro spaces on vehicle carriers. The fire protection systems are water-based and the term "first response fire protection system" reflects that the system should activate at an early stage of a fire without no human intervention.

The guidelines are written with the assumption that system shall be designed to protect against a single fire originating inside the protected spaces. The system should be regarded as supplementary to the fixed-installed total-flooding system in the space and the water supply is therefore designed for a limited discharge duration.

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**Field of application**

These guidelines are applicable to closed vehicle and ro-ro spaces on vehicle carriers. The guidelines should not be used for other types of vessel or ro-ro spaces.

**1 General**

1.1 These guidelines are intended for the design, installation, and approval of fixed automatic first response fire protection systems intended for closed vehicle and ro-ro spaces as defined in SOLAS II-2/3.

1.2 The guidelines are applicable to wet-pipe, dry-pipe, pre-action and deluge water-based fire protection systems using water, foam, CAF, or water with other additives.

1.3 The system should be considered as a supplement to the main fixed gas, high-expansion foam or water-based system required to be installed according to SOLAS II-2/20.

1.4 The system should provide fire control by a discharge of water (only), foam, CAF, or water with other additives for at least the specified duration, to allow time for manual fire-fighting or the activation of the main fixed fire-extinguishing system.

## 2 Definitions

2.1 *Additive* is a liquid such as foam concentrates, emulsifiers, and hazardous vapor suppression liquids and foaming agents intended to be added to the water to enhance the fire suppression performance.

2.2 *Area of coverage* is the maximum coverage area in $m^2$ of an individual sprinkler or nozzle.

2.3 *Area of operation* is the minimum area in $m^2$ over which the minimum required water discharge density is to be maintained.

2.4 *Automatic sprinkler or nozzle* is a single or multiple orifice water discharge device that activates automatically when its heat-activated element is heated to its thermal rating or above, allowing water under pressure to discharge in a specific, directional discharge pattern. Note: For this document, the term sprinkler is used.

2.5 *Automatic system* is a system utilizing either automatic sprinklers or nozzles or a deluge system that is automatically activated by a fire detection system.

2.6 *Class A foam* is a foam for use on fires in Class A fuels, i.e., materials such as vegetation, wood, cloth, paper, rubber, and some plastics in which combustion can occur at or below the surface of the material.

2.7 *Class B foam* is a foam intended for use on Class B fires, i.e., fire in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.

2.8 *Clear height* is the height of the space that is usable for cargo. The figure is measured from the flooring to the underside of any obstructions such as structural ceiling members, lights, ducts, piping or similar.

2.9 *Closed vehicle spaces* are vehicle spaces which are neither open vehicle spaces nor weather decks (SOLAS II-2/3).

2.10 *Compressed Air Foam (CAF)* is a homogenous foam produced by the combination of water, foam concentrate and air or nitrogen under pressure.

2.11 *Compressed Air Foam System (CAFS)* is a system employing compressed air foam discharge devices attached to a piping system through which foam is transported from a mixing chamber.

2.12 *Deluge* system is a system employing open nozzles that are attached to a piping system that is connected to a water supply through a valve that is opened by the operation a fire detection system installed in the same area as the nozzles. When this valve opens, water flows into the piping system and discharges from all nozzles attached thereto.

2.13 *Dry sprinkler* is an automatic pendent, upright or side-wall sprinkler secured in an extension nipple that has a seal at the inlet end to prevent water from entering the nipple until the sprinkler activates.

2.14 *Dry-pipe system* is a system employing automatic sprinklers attached to a piping system containing air or nitrogen under pressure, the release of which (as from the activation of a sprinkler or nozzle by heat from a fire) permits the water pressure to open a valve known as a the dry-pipe valve. The water then flows into the piping and discharge from the sprinklers that has activated.

2.15 *Electronically activated sprinkler* is a sprinkler that is possible to remotely activate by an electrical signal, either manually or by means of a fire detection system. The sprinkler may or may not have a heat-activated element.

2.16 *Fire control* is limiting fire spread while reducing heat radiation and cooling of combustion gases to avoid structural damage.

2.17 *Fire detector* is an automatic device designed to detect the presence of fire and initiate action.

2.18 *Fire detection system* is a system that senses the presence of fire, smoke, or heat and activates a deluge system section, a group of electronically activated sprinklers and/or an automatic alarm system.

2.19 *Flow rate* is the rate in litres per minute of water, or the mixture of water and additive concentrate that is required for the design of the system.

2.20 *Foam* is an aggregation of bubbles lighter than water created by forcing or entraining air into a foam solution by means of suitably designed equipment or by cascading it through the air.

2.21 *K-factor* is a sprinkler or nozzle discharge coefficient determined by testing, that is used to calculate flow rate at any given pressure through the relationship $Q=K \cdot P^{1/2}$, where $Q$ is the flow rate in litres per minute, and $P$ is the pressure in bars.

2.22 *Open sprinkler or nozzle* is an open single or multiple orifice water discharge device that, when discharging water under pressure, will distribute the water in a specific, directional discharge pattern. Note: For this document, the term nozzle is used.

2.23 *Open vehicle spaces* are those vehicle spaces either open at both ends or having an opening at one end and are provided with adequate natural ventilation effective over their entire length through permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10% of the total area of the space sides (SOLAS II-2/3).

2.24 *Other fire detector* is a device that detect a phenomenon other than heat, smoke, flame, or gases produced by a fire.

2.25 *Pre-action system* is a system employing automatic sprinklers attached to a piping system containing air that may or may not be under pressure, with a supplemental fire detection system installed in the same area as the sprinklers. Activation of the fire detection system opens a valve that permits water to flow into the system piping and discharge from the sprinklers that has activated.

2.26 *Primary structural ceiling members* are the transversal load bearing beams of the protected space.

2.27 *Response Time Index (RTI)* is a measure in $(ms)^{1/2}$ of the rapidity with which the thermal element operates as installed in a specific sprinkler or sprinkler assembly when measured under standardized test conditions.

2.28 *Ro-ro spaces* are spaces not normally subdivided in any way and normally extending to either a substantial length or the entire length of the ship in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction (SOLAS II-2/3).

2.29 *Water delivery time* is the time interval, measured in seconds, from the activation of the most hydraulically remote automatic sprinkler(s) or deluge section until the water pressure at the sprinklers or nozzles reaches or exceeds the design pressure for the system.

2.30 *Water discharge density* is the average unit rate of water application from sprinklers or nozzles to an area or surface expressed in mm/min (equal to (litres/minute)/$m^2$).

2.31 *Wet-pipe system* is a system employing automatic sprinklers attached to a piping system containing water and connected to a water supply so that water discharges immediately from sprinklers opened by heat from a fire.

**3 Principle requirements for all systems**

3.1 The system should be automatically activated, with (if technically possible) provisions for manual activation.

3.2 All systems should be divided into sections. Each section should be capable of being isolated by one section control valve.

3.3 The section control valves should be located outside the protected space, be readily accessible without entering the protected spaces and their locations should be clearly and permanently indicated. Alternatively, the section control valve may be located inside the protected space if installed inside a separate cabinet having class “A-15” fire rating. The cabinets and their locations should be clearly and permanently indicated.

3.4 Means should be provided to prevent the unauthorized use of, or access to, the section control valves.

3.5 Deluge section valves should be possible to open and close, both directly on the valve and remotely via a control system routed outside of the protected spaces.

3.6 Sprinklers or nozzles should be positioned at the ceiling with supplemental sprinklers or nozzles located to protect spaces above and below intermediate decks, hoistable decks and ramps.

3.7 The piping system should be sized using either the Hazen-Williams or Darcy-Weisbach hydraulic calculation techniques. System piping flow calculations for CAFS should be conducted using a calculation method technique for compressed air foam.

3.8 The system and its components should be designed to withstand ambient temperatures, vibration, humidity, shock, impact, clogging and corrosion normally encountered.

3.9 Any parts of the system that may be exposed to temperatures below +4°C should be protected from freezing either by having temperature control of the space, heating coils and thermal insulation on pipes, antifreeze agents or other equivalent measures.

3.10 Means for flushing of piping systems, including additive concentrate piping, with fresh water should be provided.

3.11 Spare parts should be provided as recommended by the manufacturer. A supply of spare sprinklers or nozzles of each type installed, as well as any equipment required for installing them should be provided on board. The minimum number of each type should equal the number used in the largest area of operation or 20% of the number of nozzles in the largest deluge section.

3.12 A warning notice should be displayed outside each entry point stating the type of medium used (i.e., water, foam, or water with additive) and the possibility of automatic operation.

3.13 Operating instructions for the system should be displayed at each operating position.

3.14 Installation plans, operating manuals, and instructions for inspection, testing and maintenance should be provided and be readily available on board. All information should be in the working language of the ship. If the working language of the ship is not English, French, or Spanish, a translation into one of these languages should be included.

**4 Water, foam (if used) or additive (if used) concentrate supply**

4.1 The water supply should be permitted to be hard or soft, fresh, or salt, but be of a quality such that adverse effects on foam formation or foam stability do not occur.

4.2 The system should be provided with a means of pumping supplying water or foam concentrate to the system. Hydraulic calculations should be conducted to assure that sufficient flow rate and pressure are delivered to the hydraulically most demanding sprinkler or nozzle.

4.3 Systems requiring an external power source need only be supplied by the main power source.

4.4 A means for testing the required pressure and water flow rate provided by the pump system should be provided.

4.5 The water supply of the system should be sufficient for continuous discharge for at least 30 minutes, otherwise the system should be fitted with a permanent sea inlet to be capable of operation using sea water.

4.6 If the system is pre-primed with water containing a fire suppression enhancing additive and/or an antifreeze agent, periodic inspection, and testing, as specified by the manufacturer, should be undertaken to assure that their effectiveness is being maintained. Fire suppression enhancing additives should be approved for fire protection service by an independent authority. The approval should consider possible adverse health effects to exposed personnel, including inhalation toxicity, and any environmental impact.

4.7 A Class B foam concentrate complying with the revised Guidelines for the performance and testing criteria and surveys of foam concentrates for fixed fire-extinguishing systems (MSC.1/Circ. 1312) should be used. The foam concentrate should be fluorine free. A CAFS may use either a Class A or a Class B foam.

4.8 Foam or additive concentrate storage tanks should be fabricated or lined with material compatible with the concentrate and be designed to minimize evaporation of concentrate.

4.9 The effective amount of foam or additive concentrate should be enough for a continuous discharge for at least 30 minutes, at the maximum flow rate of the system.

4.10 There should be a reserve supply of foam or additive concentrate on board the ship to put the system back into service after operation, alternatively, concentrate of the correct brand and type should be able to be obtained from an external source within 24 hours.

4.11 The system supply equipment should be located outside the protected spaces and all power supply components (including cables) should be installed outside of the protected space. The electrical components of the pressure source for the system should have a minimum rating of IP 23.

**5 Fire detection and alarm**

5.1 The fire detection and alarm requirements described within this section are in addition to, and not an alternative to the requirements in SOLAS II-2/20.4.

5.2 For system installations using a wet- or dry-pipe system, no additional fire detection and alarm requirements than given in SOLAS II-2/20.4 apply.

5.3 For system installations using a pre-action or deluge system, provide fixed-temperature, rate-of-rise, or combination fixed-temperature/rate-of-rise heat detection devices. Heat-actuated devices are subject to premature operation in certain locations. In such cases, affected heat-actuated devices should be adjusted to accommodate expected temperature gradients.

5.4 Multi-sensor sensor (smoke and heat) detectors may be used to fulfil the requirements in SOLAS II-2/20.4, any requirements by the Administration and the recommendations given in these guidelines.

5.5 Fixed-temperature heat detection devices should have a temperature rating that fulfils the requirements in Chapter 9 of the FSS Code. Rate-of-rise heat detection devices should have a set point between 6°C and 14°C rise per minute.

5.6 Locate spot-type heat detectors on or under the ceiling. If not mounted on the ceiling the maximum distance from the detector to the ceiling surface should be 150 mm. For ceiling constructions having transversal primary structural ceiling members less than 100 mm in depth, install spot-type heat detectors at a maximum horizontal detector spacing of 9.0 m and at a maximum distance of 4.5 m from bulkheads. Each detector should cover a maximum floor area of 37 $m^2$. For ceiling constructions having transversal primary structural ceiling members deeper than 100 mm, install spot-type heat detectors in every channel bay formed by these members. The maximum horizontal detector spacing should be 6.0 m and the maximum distance 3.0 m from bulkheads. Each detector should cover a maximum floor area of 25 $m^2$.

5.7 Locate line-type heat detector wire under the ceiling. Use hangers to offset the wire from the ceiling surface. Arrange detector wire parallel with the transversal primary structural ceiling members. Locate the detector wire in every channel bay formed by these members unless the members are less than 100 mm in depth. The horizontal spacing between parallel detector wire should never exceed 4.5 m.

5.8 For spot-type heat detector systems, use cross-zone detection for activation devices, either using physical detection circuits or with an addressable control panel programmed for cross-zone logic. The alarm from the first detector should activate a pre-alarm signal, the alarm from a detector assigned to the second (alternate) circuit should activate the pre-action or deluge system section.

5.9 For line-type heat detector systems that continuously measures the temperature along the sensor cable, the alarm threshold should be exceeded during two consecutive measurement cycles to activate the pre-action or deluge system section. Such line-type heat detector cable should be tested and approved for functional integrity for two hours at flame temperatures up to 750°C according to IEC 60331-25. For other types of line-type heat detector systems, the pre-action or deluge system section is permitted to be activated once the alarm threshold is exceeded.

5.10 For deluge systems, an activation delay time of a maximum of 60 seconds from the second alarm (where applicable) is permitted to allow time for fire confirmation prior automatic activation of the system section.

5.11 Provide separate fire detection systems, control panels, and activation device circuitry for each pre-action or deluge system section. Control panels that can control multiple systems via separate modules in the same panel are acceptable.

5.12 Activation of a system should give a visual and audible alarm at a continuously manned station. The alarm in the continuously manned station should indicate the specific section of the system that is activated.

5.13 Different settings for specific operation sequences, such as during loading or unloading and during voyage is not permitted.

5.14 For systems using electronically activated sprinklers, the fire detector, and the sprinkler to which it is connected should be located up to a maximum distance of 300 mm laterally from each other. The fire detector may be mounted directly on the ceiling. If not mounted on the ceiling, the maximum distance from the detector to the ceiling surface should be 150 mm.

**6 Specific requirements for wet-, dry- and pre-action systems**

6.1 Wet-, dry- or pre-action sections should cover no more than one deck, being it a fixed or hoistable deck.

6.2 Each wet-pipe section should be fitted with an air vent located near a high point in the system, or where it will be the most effective, to allow air to be removed from that portion of the system. Each section should be vented every time the system is filled.

6.3 Arrange the piping of a dry- or pre-action section to provide single-path flow within all parts of the system.

6.4 Fill dry- or pre-action sections with at least 98% pure nitrogen as the supervisory gas to mitigate against internal corrosion. The use of compressed air is not allowed. The supply of nitrogen should be from a continuous, reliable source and have a capacity capable of restoring normal gas pressure in the largest system section within 30 minutes. Provide means for manual or automatic oxygen removal from system section piping.

6.5 For dry- and pre-action sections, the calculated maximum water delivery time should not exceed 45 seconds with the operation of the most remote four sprinklers (two sprinklers on two branch lines). Alternatively, a system capacity (volume) of not more than 1 900 litres should be permitted without a quick-opening device or not more than 2 850 litres with a quick opening device, with no need for water delivery calculation verifications.

6.6 Provisions should be made to drain water from all parts of the system pipe-work. For wet-pipe systems, sprinkler piping is permitted to be installed level. Arrange branch lines in dry- and pre-action systems to be pitched at least 4 mm/m and all other sprinkler piping at least 2 mm/m.

6.7 Arrange pre-action systems to be activated both automatically and manually. Provide means for the pre-action valve to be remotely and manually activated during a fire.

**7 Choice and installation of automatic sprinklers**

7.1 Sprinklers should have a nominal operating temperature rating according to Section 11. If required by ambient conditions, higher temperature ratings may be acceptable.

7.2 Sprinklers should have fast- or standard-response RTI rating according to Section 11. Sprinklers defined as fast-response should have a thermal element with an RTI of 50 $(ms)^{1/2}$ or less and sprinklers defined as standard-response an RTI of 80 $(ms)^{1/2}$ or more.

7.3 For discharge densities exceeding 10 mm/min, either nominally K115, K160 or larger K-factor sprinklers should be used.

7.4 Sprinklers should provide a maximum area of coverage of 12 $m^2$. The horizontal spacing between sprinklers should be at least 2.4 m but should not exceed 3.6 m. The minimum spacing may be shorter if direct wetting between sprinklers is prevented by continuous ceiling structural members. Sprinklers should be installed at a maximum horizontal distance of 1.8 m from bulkheads.

7.5 Standard coverage pendent or upright spray sprinklers should be used if the vertical distance from the sprinkler deflector to underside of the ceiling does not exceed 300 mm. If this distance is exceeded, standard coverage conventional pendent or upright K80 or K115 sprinklers, or, alternatively, standard coverage K160 pendent or upright spray sprinklers should be used.

7.6 Sprinklers should be positioned and orientated to provide satisfactory performance with respect to both activation time and distribution of water. An object located at or near ceiling level that extends downward into the area located below the discharge pattern is considered an obstruction to the pattern, except under the following conditions; i) the object located at or near ceiling level is a structure member or similar that is at least 70% open, or ii) the object located at or near ceiling level is no wider than 75 mm in its least dimension and is separated from other objects by a minimum of 300 mm.

7.7 For ceiling constructions having structural ceiling members less than 300 mm in depth, install sprinklers with the deflector a minimum of 50 mm and a maximum of 150 mm (for upright sprinklers) or a maximum of 300 mm (for pendent sprinklers) vertically below the underside of the ceiling.

7.8 For a ceiling construction having transversal primary structural ceiling members deeper than 300 mm that are forming channels where more than one sprinkler branch line can be installed (ensuring that hot gases produced during a fire can reach the nearest four ceiling-level sprinklers anywhere within a single channel), install sprinklers with the deflector a minimum of 50 mm and a maximum of 150 mm (for upright sprinklers) or a maximum of 300 mm (for pendent sprinklers) vertically below the underside of the ceiling.

7.9 For a ceiling construction having transversal primary structural ceiling members deeper than 300 mm that are forming channels where no more than one sprinkler branch line can be installed, sprinklers should be positioned as follows:

i) in every channel bay formed by these members, with the deflector a minimum of 50 mm and a maximum of 150 mm (upright sprinklers) or a maximum of 300 mm (pendent sprinklers) below the underside of the ceiling, or,

ii) in every channel bay formed by these members, with the deflector vertically aligned with, or, no more than 150 mm higher than, the bottom edge of the members. For this alternative, vertical barriers made from sheet metal should be installed in every channel to reduce the length of the channels formed by the beams. The barriers should extend from the ceiling to the bottom edge of the members and the maximum channel length should include no more than three sprinklers on a branch line. Note: Secondary structural ceiling members that is either solid or no more than 10% open serves the purpose of the barriers.

iii) in every other channel bay formed by these members, given that the centre-to-centre distance between the members is less than or equal to 1.8 m. Install the sprinklers per section 7.9 i) or ii) with steel sheet barriers per section 7.9 ii) in every channel.

7.10 As an alternative irrespective of the ceiling construction, install a smooth, solid continuous, non-combustible, sub-ceiling that is positioned aligned parallel to the floor at a given vertical distance below the primary ceiling and install automatic sprinklers per section 7.7.

7.11 Position additional sprinklers under any flat or non-flat, continuous, solid objects that are positioned below the sprinklers and are more than 600 mm wide.

7.12 Only upright or dry-pendent sprinklers are allowed for dry- and pre-action systems.

## 8 Specific requirements for deluge systems

8.1 Each deluge section should be at least 12 m in length but not longer than 30 m. The sections should normally cover the full width of the space, unless i) the ro-ro space is divided by longitudinal permanent or non-permanent bulkheads made from steel or other fire-resistant material, or, ii) that the width of each deluge section equals half the width of the space and a design per section 8.5 ii) is utilized.

8.2 Balanced piping configuration should be used with CAFS to provide each nozzle in the design to discharge the same amount of CAF.

8.3 Nozzles should be positioned in order to distribute water or foam over and between all vehicles or cargo in the area being protected. The maximum horizontal spacing between nozzles should not exceed 3.0 m. Nozzles should be installed at a maximum horizontal distance of 1.5 m from bulkheads.

8.4 Position additional nozzles under any flat or non-flat, continuous, solid objects that are positioned below the sprinklers and are more than 600 mm wide.

8.5 The system should be capable of the simultaneous operation of at least either, i) two adjacent deluge sections covering the full width of the space and having the greatest hydraulic demand, or, ii) at least four adjacent deluge sections having the greatest hydraulic demand.

8.6 The maximum water delivery time should not exceed 60 seconds with the operation of the most remote deluge section.

**9 Specific requirements for systems using electronically activated sprinklers**

9.1 Systems using electronically activated sprinklers should be of the wet-pipe system type.

9.2 Electronically activated sprinklers should meet the requirements of ISO 6182-1:2021 or later editions.

9.3 Electronically activated sprinklers having a heat-activated element should have a nominal operating temperature rating of 140°C and standard-response RTI rating.

9.4 The maximum area coverage and spacing of electronically activated sprinklers should be per section 7.4.

**10 Sprinkler system piping**

10.1 Use only new sprinkler system piping.

10.2 Use externally galvanized or externally coated carbon (black) steel, approved polymer-enhanced steel pipe, or stainless steel pipe in wet-, dry- and pre-action systems. Note: Internally untreated carbon (black) steel pipe is acceptable in dry- and pre-action systems as the piping system should be filled with nitrogen gas.

10.3 Use externally galvanized or externally coated Schedule 40 (or equivalent thickness) carbon (black) steel pipe, approved polymer-enhanced steel pipe, or stainless steel pipe in deluge systems.

10.4 Do not use internally galvanized pipe in any type of system.

10.5 To help reduce the potential for accelerated internal pipe corrosion of longitudinally-welded black steel pipe, install such pipe with the weld line rotated at least 45° in relationship to the deck (for reference, the weld line points at the deck at 0°).

10.6 When using flexible metallic pipe, follow the manufacturer’s guidelines for installing the pipe and refer to their guidelines for analysis of the anticipated friction loss through the length of pipe installed.

## 11 Discharge densities and operation areas

11.1 For wet-, dry-, pre-action and deluge systems discharging water only or foam, the temperature and RTI rating (where applicable) and minimum water discharge density and area of operation should be in accordance with Table 1.

11.2 For electronically activated sprinkler systems discharging water only or foam, the minimum water discharge density and minimum number of sprinklers in the design should be in accordance with Table 2.

11.3 For CAFS, the minimum discharge density and area of operation should be in accordance with Table 3. The discharge density should be calculated based on the pre-mix flow of water and foam agent.

*Table 39 The recommended design for wet-, dry-, pre-action and deluge systems discharging water only or foam.*

| Type of system | Clear height | Nominal temperature rating (°C) | RTI rating | Minimum discharge density (mm/min) | Minimum operation area (m²) |
|---|---|---|---|---|---|
| Wet-pipe | ≤2.4 m | 70 | Fast- or standard-response | 10 | 144 |
| Dry- or pre-action | | 70 | Fast- or standard-response | | 180 |
| Deluge | | - | - | 7.5 | 2 or 4 deluge sections |
| Wet-pipe | >2.4 m - ≤4.0 m | 70 | Standard-response | 15 | 144 |
| Dry- or pre-action | | 140 | Standard-response | | 180 |
| Deluge | | - | - | 10 | 2 or 4 deluge sections |
| Wet-pipe | >4.0 m - ≤7.0 m | 70 | Standard-response | 20 | 144 |
| Dry- or pre-action | | 140 | Standard-response | | 180 |
| Deluge | | - | - | 15 | 2 or 4 deluge sections |

*Table 40 The recommended design for electronically activated sprinkler systems discharging water only or foam.*

| Type of system | Clear height | Nominal temperature rating (°C)* | RTI rating* | Minimum discharge density (mm/min) | Minimum number of sprinklers |
|---|---|---|---|---|---|
| Wet- or dry-pipe | ≤2.4 m | 140 | Standard-response | 10 | 9 |
| Wet- or dry-pipe | >2.4 m - ≤4.0 m | 140 | Standard-response | 15 | 12 |
| Wet- or dry-pipe | >4.0 m - ≤7.0 m | 140 | Standard-response | 20 | 12 |

*) Applicable for electronically activated sprinkler having a heat-activated element.

*Table 41 The recommended design for CAFS.*

| Type of system | Clear height | Minimum discharge density (mm/min) | Minimum operation area ($m^2$) |
|---|---|---|---|
| Deluge | ≤2.4 m | 6 | 2 or 4 deluge sections |
| Deluge | >2.4 m - ≤4.0 m | 8 | 2 or 4 deluge sections |
| Deluge | >4.0 m - ≤7.0 m | 12 | 2 or 4 deluge sections |

**References**

MSC.1/Circ. 1312, "Revised guidelines for the performance and testing criteria, and surveys of foam concentrates for fixed fire-extinguishing systems", International Maritime Organization, June 10, 2009

ISO 6182-1:2021, "Fire protection — Automatic sprinkler systems — Part 1: Requirements and test methods for sprinklers", International Organization for Standardization, publication date: 2021-05

IEC 60331-25:1999, "Tests for electric cables under fire conditions - Circuit integrity - Part 25: Procedures and requirements - Optical fibre cables", International Electrotechnical Commission, adopted April 23, 1999

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