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Description of the development of weather deck fire-extinguishing systems and selected solutions

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Abstract

Currently, fire monitor systems (the terminology “fixed fire-extinguishment systems” is used by IMO) are not mandatory on ro-ro weather decks, although the fire load is substantial and manual firefighting operations are both difficult and hazardous. This report addresses the development of fire monitor system solutions that can activate early in case of fire, be remotely and safely operated, and suppress a fire in the typical cargo whilst withstanding the potentially harsh environmental conditions on a weather deck. The most recent technological advances, ideas and features in the field were identified and formed the basis for this work.

The development work focussed on water-based fire monitor systems. Such systems may discharge water only, foam, or water with any other fire suppression enhancing additive. Independent of the fire suppression agent, the systems may be remotely controlled by an operator from a safe position on a ship or be autonomously operated with the possibility for remote-control by an operator if desired. The system may also be semi-autonomous, which means that it can be remotely controlled by an operator but can also be set to operate in a pre-determined discharge mode.

The systems are described in detailed design and installation guidelines. The guidelines were written to define a system that can suppress and control a high hazard fire in a cargo trailer. Although written with the solutions developed within the project in mind, the guidelines are directly applicable to any standard water-based fire monitor system. The performance of the solutions detailed in the design and installation guidelines was evaluated in terms of fire detection, precision, and fire suppression in large-scale fire tests. The test results proved that the concepts work as intended.

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Content

1 Executive summary

This report includes a description of the regulatory, operational, and shipyard requirements for the use of fire monitor systems on ro-ro weather decks, establishes the necessary functions of these systems, documents the development work of the system suppliers, documents fire testing of the feasibility and effectiveness of the systems, and presents a summary of the installation and maintenance costs of the systems.

1.1 Problem definition

Currently, fire monitor systems (Note: the term fixed fire-extinguishment systems is used by IMO) are not mandatory on ro-ro weather decks, although the fire load is substantial and manual firefighting operations are both difficult and hazardous. WP10, Action 10-B, addresses the development and demonstration of feasible and effective fire monitor systems for ro-ro weather decks.

1.2 Method

Fire monitor system solutions were developed that take the weather and other potentially harsh environmental conditions, the fire hazards, specific regulatory and physical requirements, and other challenges that influence the installation and operation of the systems into account. Other design criteria include quick system activation, safe controlling, high coverage, and fast fire suppression. In recent years, remote-controlled fire monitors, and particularly their electronics, software, and control system capabilities, have undergone significant technological advances. These advances were considered during the development work of the project.

The performance of the system solutions was evaluated in large-scale fire detection and precision as well as fire suppression tests.

1.3 Results and achievements

It is concluded that weather decks are large, vehicles are tightly stowed, and fires could be severe, including the involvement of dangerous goods. Any equipment installed should be designed to withstand harsh environmental conditions in terms of ambient temperature, direct or indirect sunlight, rain or snow conditions, wind, etc. Necessary system functions include operation from a remote and safe location and the ability to control the nozzle spray pattern as well as the horizontal and vertical monitor range of motion to aim the water stream to all points on the weather deck. The system's electronics, which control the fixed fire monitor and, where applicable, its automatic function and ancillary peripheral devices, should be CE marked and in compliance with EMC standards. The system's software should be demonstrably robust, effective and in compliance with industry standards.

The fire monitors should be installed to ensure that any fire on the weather deck can be suppressed by two monitors from opposing directions, to limit the spread of fire and to limit the effect of wind. The vertical distance from a monitor to the deck flooring should be as high as practicable, to provide a more favourable attack angle, allowing more of the water stream to hit the flames more directly.

Although the general term used by IMO is "fixed fire-extinguishment system", full fire extinguishment is not to be expected. Realistic performance objectives are that the fire is suppressed, meaning that the fire is contained to one or a few vehicles and that adjacent boundaries are cooled to limit structural damage. The design features of the guidelines were validated in large-scale suppression performance tests. These tests included a scenario that mimicked a fire in a freight truck trailer. The test results proved that the performance objectives of the system solutions were met when using water and illustrated the built-in safety factor of having two fire monitors discharging from different directions. The tests with CAF were not as successful, as a proper quality of foam was difficult to achieve, and the flow rate was too low. The use of foam, whether it is expanded at the fire monitor nozzle (non-aspirated, low-expansion foam) or CAF of proper quality is, however, expected to improve the performance of water only for fire scenarios involving flammable liquids.

1.4 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 of the space and with less crew dependence. The objective of Action 10-B is to develop and demonstrate feasible and effective fixed fire-extinguishment solutions for ro-ro weather decks. This report documents the results of Tasks 10.5 – 10.7 as follows:

- definition of conditions for use of weather deck fire extinguishing systems, including a consolidation of regulatory, environmental, operational and shipyard requirements and establishment of necessary functions of weather deck fire extinguishing systems (Task 10.5);
- development of the three solutions: an autonomous and remote-controlled fire monitor system and a compressed air foam monitor system, including installation costs and environmental impact assessment (Task 10.6); and
- large-scale fire performance validation of the system solutions and sharing of results with WP04 (Task 10.7).

Onboard demonstration and testing of the selected system solutions by real installations onboard a ro-ro passenger ship on a relevant weather deck (Task 10.8) are documented in D10.2.

1.5 Exploitation

The overall results of Action 10-B were the design and installation guidelines for fire monitor systems, as documented in Annex A of this report. The guidelines were based on the latest knowledge and technological advances of fire monitor system technology, and they were validated by the results of fire performance evaluations and onboard demonstrations (refer to the report D10.2).

The guidelines reflect differences in conditions in terms of ship design, size, and not least, system technologies. However, the design and installation recommendations provide minimum requirements related to safety and environmental aspects. The design and installation guidelines also provide flexibility regarding protection alternatives that address different desires, views and requirements of ship designers, ship operators, classification societies and regulatory and standardisation bodies.

2 List of symbols and abbreviations

3D	Three dimensional
BLDC (motors)	Brushless Direct Current (motors)
BV	Bureau Veritas
CAFS	Compressed Air Foam Systems
CE	Conformité Européenne. Note: CE marking is a mandatory administrative marking asserting conformity with relevant standards, applied to certain products offered for sale within the European Economic Area
CoSWP	Code of Safe Working Practices for Merchant Seaman
DoA	Description of Actions
DC	Direct Current
EMC	Electromagnetic Compatibility
EPS	Expanded Polystyrene
EU	European Union
F4M	FiFi4Marine B.V. (partner in the LASH FIRE project)
FLOW	FLOW Ship Design d.o.o. (partner in the LASH FIRE project)
GUI	Graphical User Interface
HD	High Definition
HRR	Heat Release Rate
IACS	International Association of Classification Societies
ICAO	International Civil Aviation Organization
IMDG Code	International Maritime Dangerous Goods Code
IMO	International Maritime Organization
I/O	Input/Output
IR	Infrared
ISM Code	International Management Code for the Safe Operation of Ships and for Pollution Prevention
LAN	Local Area Network
LCA	Life Cycle Assessment
LMIU	Lloyds Maritime Information Unit
MCA	Maritime and Coastguard Agency
P/T	Plate Thermometer

PLC	Programmable Logic Controller
PU	Polyurethane
RISE	RISE Research Institutes of Sweden
SOLAS	Safety of Life at Sea
TCP/IP	Transmission Control Protocol/Internet Protocol
UNF	Unifire AB (partner in the LASH FIRE project)
WAN	Wide Area Network
WiFi	Wireless networking

3 Introduction

Main author of the chapter: Magnus Arvidson, RISE

Fire monitor systems are not currently required to be installed for the protection of ro-ro weather decks on ships, although the fire load is substantial and manual firefighting operations are both difficult and hazardous. Recently, the International Maritime Organization (IMO) has recognized the use of “fixed fire-extinguishing measures on weather decks” in the Interim guidelines of MSC.1/Circ.1615 [1]. Member States are invited to bring the Interim guidelines to the attention of all parties concerned and to recount their experience gained using the guidelines to the IMO. The guidelines use the term “fire monitors” to describe the system technology. Although the term is not defined in the document, it is recognized as a fixed, remote-controlled device that can deliver a large water or foam stream and is mounted on a stationary support that is elevated above the deck flooring. The nozzle tip can also be adjusted to control the spray angle from jet to spray. Fire monitors are widely known to be a highly effective means of suppressing fire, particularly when intervention is rapid.

The objective of WP10, Action 10-B, is to develop and demonstrate feasible and effective fixed fire-extinguishment solutions for weather decks. The Description of Actions (DoA) states that “Quick system activation, safe controlling, high coverage and fast fire suppression are fundamental criteria for the systems, which also need to sustain the harsh environmental conditions.”

The system solutions were developed by project partners Unifire AB (UNF) and FiFi4Marine B.V. (F4M), who independently developed the novel technologies, i.e., an autonomous and remote-controlled fire monitor system (UNF) and a Compressed Air Foam (CAF) fire monitor system (F4M) for weather deck protection. The development included theoretical evaluations and system development testing. The task also included installation and maintenance cost assessments.

This report includes a description of the regulatory, operational, and shipyard requirements for the use of weather deck fire extinguishing systems, establishes the necessary functions of these systems, documents the development work of the system suppliers, including fire testing of the feasibility and effectiveness of the systems and presents a summary of the cost and environmental impacts of the systems. Demonstration of an installation on board a ro-ro passenger ship weather deck is documented in the report D10.2.

A “monitor” is defined in the 2018 edition of NFPA 1925 [2] as “A fixed master stream device, manually or remotely controlled, or both, capable of discharging large volumes of water or foam”. However, often the term “fire monitor” is used as in MSC.1/Circ.1615 [1]. This term was adopted in the project, and it is emphasised that a fire monitor is able of discharging water (only) or water with a fire suppression enhancing agent such as foam.

4 Regulation review

Main author of the chapter: Blandine Vicard, BV.

4.1 General

4.1.1 Scope

This section aims at giving an overview of the requirements applicable to ro-ro spaces regarding weather deck fixed fire-extinguishment systems.

4.1.2 Applicable regulations

The present review is based on currently applicable regulations, refer to Table 1. Therefore, some of the requirements detailed may not be applicable on old ships.

Table 1. List of documents used for the review of regulations for Action 10-B.

IMO Documents	SOLAS Convention, as amended
	IBC Code, as amended
	IGC Code, as amended
	MSC.1/Circ.1615, "Interim Guidelines for minimizing the incidence and consequences of fires in ro-ro spaces and special category spaces of new and existing ro-ro passenger ships"
IACS & Class Rules	IACS Blue book dated January 2019
	BV Rules for Steel Ships (NR467), as amended in July 2019
	DNVGL Rules for the Classification of Ships, January 2017
	LR Rules and Regulations for the Classification of Ships, July 2016
Flag Administration Rules	MMF (French Flag Administration) Division 221 "Passenger ships engaged in international voyages and cargo ships of more than 500 gross tonnage", 28/12/17 edition
	MCA (UK Flag Administration) Guidance on SOLAS Ch.II-2

4.1.3 Definitions

The following key terms are used in the relevant regulations:

IACS International Association of Classification Societies

IMO International Maritime Organization

SOLAS International Convention for the Safety of Life at Sea

4.1.3.1 Ro-ro spaces, vehicle spaces and special category spaces

The following is a list of definitions per SOLAS II-2/3 [3]:

- *"Vehicle spaces are cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion."*
- *"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."*

- *"Special category spaces are those enclosed vehicle spaces above and below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10 m."*

In other words, ro-ro spaces are vehicle spaces into which vehicles can be driven. It is to be noted, however, for the purpose of the application of SOLAS II-2/19 [2], the following interpretation can be found in MSC.1/Circ.1120 [4] and IACS UI SC 85 [5]: "*Ro-ro spaces include special category spaces and vehicle spaces*". Special category spaces are ro-ro spaces to which passengers have access, possibly during the voyage. Special category spaces are the most frequent type of closed ro-ro spaces on ro-ro passenger ships. It is to be noted that open ro-ro spaces are not considered as special category spaces.

4.1.3.2 Closed, open and weather deck

The following is a list of definitions per SOLAS II-2/3 [3].

- A "*weather deck is a deck which is completely exposed to the weather from above and from at least two sides.*"
- IACS UI SC 86 [5] additionally details that: "*For the purposes of Reg. II-2/19 a ro-ro space fully open above and with full openings in both ends may be treated as a weather deck.*"
- For practical purposes, a drencher fire-extinguishing system cannot be fitted on weather decks due to the absence of a deckhead. This criterion is often used for a practical definition of weather decks.
- An open vehicle or ro-ro space is "*either open at both ends or [has] an opening at one end and [is] provided with adequate natural ventilation effective over [its] 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.*"
- A closed vehicle or ro-ro space is any vehicle or ro-ro space which is neither open nor a weather deck. As a reference criterion, it can be considered that a vehicle space that needs mechanical ventilation is a closed vehicle space.

4.2 Requirements

In general, SOLAS [3] includes very limited fire protection requirements applicable to weather decks where vehicles may be stored. Especially, no fixed fire-extinguishment system is required in such areas.

SOLAS II-2/20

Traditionally, SOLAS [3] includes very few cases where fixed fire-extinguishment systems are required on weather decks, both because the risk of fire has often been considered limited and because it was deemed impracticable.

More recently however, it is to be noted that IMO Interim guidelines MSC.1/Circ.1615 [1] for minimizing the incidence and consequences of fires in ro-ro spaces and special category spaces of new and existing ro-ro passenger ships recommends that a fixed fire-extinguishment system, e.g. fire monitors, be provided on weather decks intended for the storage of vehicles on passenger ships.

MSC.1/Circ.1615 §3.4

At this stage, this recommendation is goal-based and not fully defined. Member States are invited to bring the Interim guidelines [1] to the attention of all parties concerned and to recount their experience gained through their use to IMO. To be easily and uniformly applicable, the following aspects would be worth clarifying:

- Requirements for the capacity of the system:
  - Required flow rate.
  - Rovered area, length of throw of the monitors, minimum number of monitors.
  - The number of fire monitors required to work simultaneously.
- Fire suppression agent: sea water, fresh water, foam, etc. In the last two cases, an expected functioning duration is needed to size the tanks for the fire suppression agent.
- Pumping redundancy requirements.
- Material and component approval requirements.
- Drainage system – already mentioned in MSC.1/Circ.1615 [1].
- Monitoring and control requirements for the whole system, including monitor orientation and operation, pump, and valve controls.

4.3 Other regulations

This section lists regulatory references for weather deck fixed fire-extinguishment or water-based systems not directly applicable to vehicle weather decks, but which could be used to propose solutions that might be relevant for Action 10-B.

Weather deck monitor systems can be found on:

- Firefighting ships. Such systems are not covered by IMO regulations but specifications can be found in Class Rules, e.g. BV NR467 Pt E, Ch 4, Sec 3, [5], [1] and [6] (ref. = [6]);
- Ships constructed on or after 1 January 2016 designed to carry containers on or above the weather deck as per SOLAS II-2/10.7.3 [3]. In the relation to the aforementioned SOLAS paragraph, more details about mobile fire monitors can be found in MSC.1/Circ.1472 [7]; and
- Containerships with reinforced fire protection measures, as described in BV ECFP (Enhanced Cargo Fire Protection for Container Ships) additional Class notation, BV NR467 Pt F, Ch 11, Sec 30 [3.5] (ref. = [8]). This class notation comes as a complement of SOLAS requirements mentioned above.

Other systems installed on open decks include:

- Water-based cooling systems installed in the cargo area of liquefied gas carriers, as specified in IMO IGC Code 11.3 [9];
- Dry chemical powder fire-extinguishing systems installed in the cargo area of liquefied gas tankers, as specified in IMO IGC Code 11.4 [9];
- Fixed deck foam system required in the cargo area of chemical tankers, as specified in IBC Code 11.3 [10]; and
- Fixed foam fire-extinguishing systems required for helidecks as per SOLAS II-2/18.5.1 [3] and IMO FSS Code Ch.17 [11].

Finally, it can be noted that the outer surface of superstructures facing high fire risk external areas may be protected by:

- A-60 fire insulation on oil tankers, as per SOLAS II-2/4.5.2.2 [3] and on chemical carriers, as per IBC Code 3.2.3 [10];
- A-60 fire insulation and self-protection water-spray systems on liquefied gas carriers (IGC Code 3.2.5 and 11.3 [9]); and
- A-60 fire insulation or self-protection water-spray systems on firefighting ships (NR467 Pt E, Ch 4, Sec 4 (ref. = [6])).

5 Functional design and ship integration requirements

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5.1 Performance objectives

As discussed in Chapter 4, there are no rules or requirements for weather deck fixed fire-extinguishment systems. The implementation of such systems is therefore currently a decision left to the ship operators. Only a system that can guarantee a significant improvement in the protection of cargo and lives, but at the same time be cost-effective and not decrease the space on cargo decks, will motivate ship operators to install it.

Although the general term used by IMO is *"fixed fire-extinguishment system",* full fire extinguishment should not be expected nor required. Realistic performance objectives are that the size of a fire is suppressed and thereafter controlled, that the fire is contained to one or a few vehicles and that adjacent boundaries are cooled to limit structural damage. For weather deck fire-extinguishing systems, the focus is on offering sufficient coverage to protect the ship from fire spread and on the protection of vital safety functions, rather than focussing on full coverage to extinguish a fire potentially located on every/any square meter of the deck area.

The project description states that *"Quick system activation, safe controlling, high coverage and fast fire suppression are fundamental criteria for the systems, which also need to sustain the harsh environmental conditions."* There are other necessary functions of a fixed fire-extinguishment system installed on a weather deck, as well as ship integration requirements, that impact the design of the system. These functions and requirements are discussed in the following sections.

5.2 Operational aspects

The challenges for designing a fire suppression system on a weather deck include a very high fire load due to tightly packed vehicles, open areas with an unlimited supply of air (oxygen), limited access on deck to a potential source of fire, etc. Automatic fire detection on weather decks is also not regulated, so manual detection is the normal method. The weather deck may also carry dangerous cargo, which increases the probability for a fire, and the propagation of fire is a risk to consider due to the tightly packed cargo.

Means of activation and control/operation of fire-extinguishing systems on weather decks from a secure position should be taken into consideration during development of the system. It is undesirable that crew members should be exposed to fire, smoke, heavy weather, or other hazardous conditions. Fire monitors, irrespective of the type of system, shall be remotely controlled or installed in a "safe location" if they are manually controlled[1]. Fire monitors shall have provisions for manual activation[2] and remote-control from i) either a continuously manned station, or from a

[1] In this report, manually controlled refers to direct human manipulation of the fire monitor using the levers to direct the flow and change the spray pattern.

[2] A fire monitor is manually activated when a human starts its operation, either by remote control or by physically switching on the monitor, as compared with an autonomous system that is self-activating.

protected location from which the operator can visually obtain knowledge about fire conditions; and ii) a portable, wireless control device to enable remote-control from an alternative position. Robotic nozzles that automatically guide/point to the source of the fire should be considered, but individual monitors should always have provisions for manual activation and remote-control (i.e., have a manual override).

If the primary objective is boundary cooling, provisions shall be made for remote water flow control where the monitors are operated in a pre-set throw configuration. While remote-controlled operation of the monitors allows greater flexibility in the design of the system, there are existing weather deck layouts where mechanically controlled operation can be performed safely, and in such cases, this shall be allowed.

There are ships with very large weather decks and almost no superstructure upon which to install fire monitors. Rigid prescriptive requirements on location, cross coverage, coverage from two or more directions, redundancy, even full coverage may not be practicable to implement. A ro-pax ship with limited possibilities for the location of fire monitors is illustrated in Figure 1. This ship has a 135 m long weather deck arranged such that only one position for fire monitors in the aft part of the deck is structurally suitable unless specific structures are designed and installed for the fire monitors.

If no superstructure is present, fire monitors may need to be installed on dedicated supports to obtain full coverage of the deck area. Such supports may be challenging to realize due to vibrations, high strain locations, and avoiding interference with cargo capacity and operation. Positioning of fire monitors is addressed in the detailed guidelines for the design, installation and approval of fixed water-based fire monitor systems for the protection of ro-ro weather decks found in Annex A.

Figure 1. Ro-pax vessel with large weather deck at the aft.

5.3 Design and production aspects

Generally, cargo decks are designed to maximise the area for cargo stowage. This is emphasized on weather decks, which limits the available area for ship equipment and systems. Therefore, the impact of fixed firefighting systems on the cargo area should be minimized.

As discussed in Chapter 6, the cargo is stored close together, where the height of the cargo (for example trailers or special cargo) can limit access to the fire source and thus increase the risk of fire propagation. It should also be emphasised that heavy weather conditions, such as strong wind and large waves could influence the possibilities for water reaching a fire.

The fire monitors of the system should have enough throw from an appropriate number of positions onboard, at heavy weather conditions, for effective performance, i.e., to suppress or contain a fire and to cool down adjacent boundaries to limit structural damage.

Any fixed fire-extinguishment system shall be preferably designed to:

- Avoid interference with the cargo loading routes and stowage areas;
- Minimise obstruction of visibility from the command bridge;
- Be robust, possibly standalone or with limited bracing to the surrounding structure;
- Withstand a harsh environment, including ice build-up, saltwater spray, fog, direct sun, heavy corrosion potential, high temperatures, with the possibility of drainage to prevent freezing;
- Minimise instability of the ship; adequate drainage of the suppression agent (water, foam or water with any other type of fire suppression enhancing agent) from the deck must be ensured;
- Be intuitive and simple to operate;
- Discharge the fire suppression agent immediately after activation;
- Provide the desired performance objectives in terms of fire suppression, fire control and fire containment;
- Be remotely controlled or, if automatically operated, have features that prevent or limit the probability of false activation;
- Handle different types of fires (electrical, flammable liquid spills, IMDG goods etc.);
- Be class approved and fulfil any relevant IMO standards at such time as these processes are established;
- Utilise the least possible space on the vessel;
- Preferably be incapable of exhausting the suppression agent and be capable of continuous operation using sea water if the suppression agent supply runs low;
- Be safe for humans and the marine environment;
- Preserve vessel, cargo, and equipment as much as possible;
- Be able to reach the fire reliably without faults and/or delays when activated;
- Be possible to activate remotely;
- Be possible to activate if electricity fails, i.e., have redundant means for power supply;
- Be easy to inspect, control and maintain;
- Minimise the number of components and sub-components;
- Be easy to include in full scale fire-drills;
- Be easy to clean up after the fire is extinguished;
- Preserve crew access to the section where the system is activated;

- Provide easy overview of the section where the system is activated; and
- Be easy to shut-down and re-start if necessary.

Automatic solutions should be taken into consideration as a next step in the evolution of weather deck fire protection systems, however this progress comes in close correlation with the development of fire detection systems on weather decks and all the aspects and challenges of these systems.

5.4 Drainage system

Drainage of water from the deck shall be adequate to prevent instability of the ship due to added weight and free surfaces.

There is no available calculation requirement specifically for the drainage system on weather decks. Rules and regulations for drainage systems in ro-ro spaces that are fitted with a fixed pressure water-spraying fire-extinguishing system may be considered, see excerpt from BV Rules [12] below:

- *"In such case, the drainage system shall be sized to remove no less than 125 % of the combined capacity of both the water-spraying system pumps and the required number of fire hose nozzles, taking into account IMO Circular MSC.1/Circ.1320.*
- *Bilge wells shall be of sufficient holding capacity and shall be arranged at the side shell of the ship at a distance from each other of not more than 40 m in each watertight compartment."*

Further, according to the BV Rules, weather decks shall be designed with "freeing ports" [13]. These are openings arranged on the side bulwark to enable a rapid discharge of the green loads[3] from the weather deck. The minimum required area of the openings depends on the deck design and the opening arrangement (vertical position, i.e., distance from deck), where the (vertical) discharge/drainage is not to be considered in the calculation. Generally, the lower edge of such openings shall be as close as possible to the deck.

The weather deck drainage and freeing port arrangement shall especially be considered for "confined" weather deck designs, such as on the Stena Jutlandica shown in Figure 10 and discussed in Chapter 7, state of the art.

A common drainage arrangement on a ro-ro weather deck considers scuppers/piping of DN80 to DN150 arranged along the deck borders at about 30 m intervals, and parts of the deck where water pockets may occur. Further, larger piping diameters may be placed on the deck ends (aft/fore).
A typical drainage arrangement on a ro-ro weather deck is given in Figure 2.

[3] Green loads are sea water loads on the exposed deck due to wave impact during extreme weather conditions.

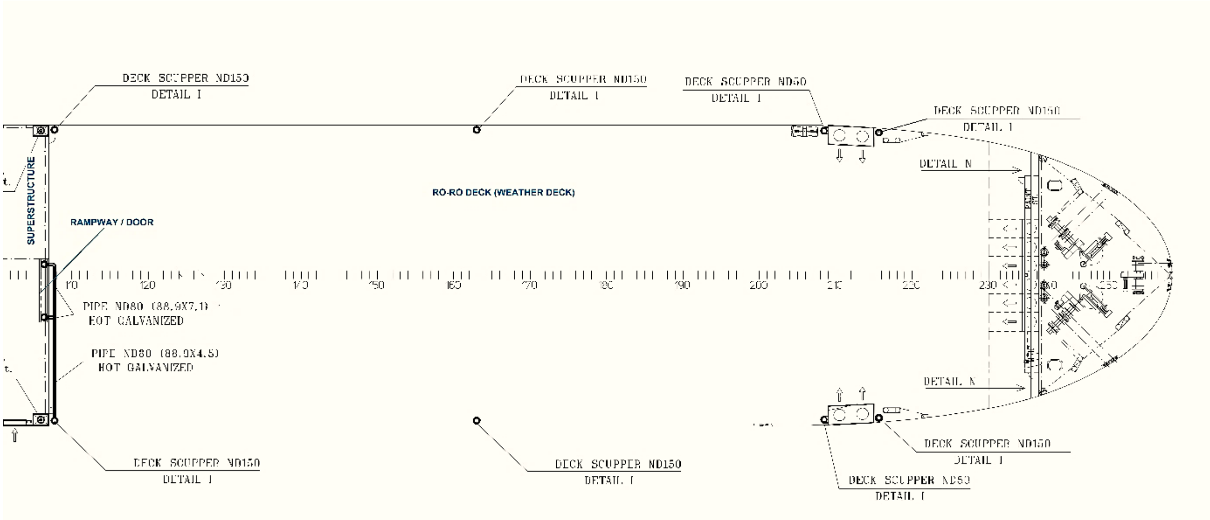


Figure 2. Typical ro-ro weather deck drainage arrangement with the position of the deck scuppers.

The drainage line is led to the outer shell where the liquids from the deck are discharged into the sea. The scuppers may be designed with plugs to prevent the spill of oil or fuel from the ro-ro cargo units into the sea. If fitted, the plugs are used in harbour or other “no-spill” zones according to the ship operator, flag state or harbour requirements. A typical detail is provided in Figure 3.

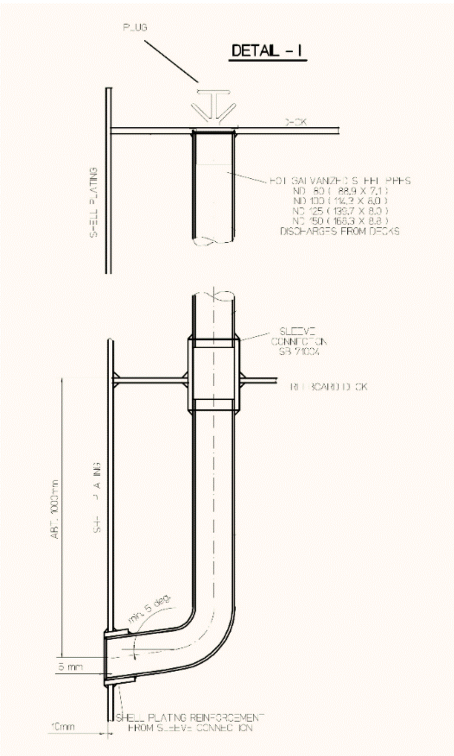


Figure 3. Typical scupper detail on a ro-ro weather deck where water or other any liquids are discharged into the sea.

5.5 Weather and other environmental considerations

5.5.1 Weather conditions

Weather conditions could affect the performance of fixed fire monitor systems. The outdoor conditions will also affect the choice of suppression agent (if used). Weather conditions include, but are not limited to extreme ambient temperature (low or high), temperature fluctuations, direct or indirect sunlight, rain or snow conditions, salt water or saltwater spray atmosphere, wind conditions and waves.

High ambient temperature, temperature fluctuations and sunlight can lead to deformation, blistering or fracturing of components. Rain or snow combined with ambient temperatures below freezing can result in the formation of ice on the fire monitor nozzle and assembly. This could affect the flow rate. The formation of ice on the outside can affect the movement in both the horizontal and vertical planes.

Wind conditions could affect the water flow path and throw distance. Waves make the ship roll and yaw its inclination, potentially resulting in poor precision of the water stream.

The term “heavy weather” is defined as a combination of strong winds of Beaufort scale 7 or more and waves with a height of 4 m or more.

5.5.2 Operating on deck in heavy weather

The International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code) provides an international standard for the safe management and operation of ships at sea [14]. The purpose of the ISM Code is to ensure safety at sea and prevent damage to property, personnel, and the environment. All ships of at least 500 gross tonnage are required to operate a safety management system in compliance with the ISM Code. The ISM Code is a chapter in SOLAS, and if SOLAS does not apply to the ship, then conforming to ISM is not mandatory. Compliance with the ISM Code is sometimes required by a vessel client regardless of gross tonnage.

The Code of Safe Working Practices for Merchant Seaman (CoSWP) is the internationally accepted document on safe working practices on board ships [15]. The Code is published by the Maritime and Coastguard Agency (MCA) as best practice guidance for improving health and safety on board ship. It is intended primarily for merchant seafarers on UK-registered ships.

These recommendations should be consulted to determine whether work on deck is deemed necessary. If the task to be carried out is not necessary to preserve the safe operation of the ship, it may be reasonable to delay this work until the ship reaches calmer waters. The lashings of all deck cargo should be inspected and tightened, as necessary, when rough weather is expected.

5.5.3 Environmental aspects

While fighting a fire on a weather deck, large quantities of fire suppression agent mixed with fire by-products are released into the environment. Any fire suppression enhancing agent used with water should not be harmful to human or marine life to a similar extent to the requirements for other parts of the ship. It is important that the same requirements are applied throughout the ship and no special requirements are introduced only for weather decks.

5.6 Life Cycle Assessment of solutions

The overall goal of including Life Cycle Assessment (LCA) analysis in the development of the LASH FIRE solutions is to ensure that environmental impacts are considered, together with other important factors such as monetary costs and materials availability. The LCA compares the environmental impacts of the lifecycle of the two chosen systems with a reference case in which no system is installed on the weather deck. In this manner, the analysis can predict whether using a fixed fire-protection system improves the environmental consequences of a fire on the weather deck. The results of the comparative LCA are documented in the report IR05.65, which is not publicly available.

5.7 Necessary functions

Where an individual portable wireless control device is used for, or is capable of, controlling more than one fire monitor, there should be at least two such control devices, to ensure that the loss of function of one wireless control device does not result in the inability to control a fire monitor. Additionally, the fire monitor system may also be controlled autonomously by means of fully automatic functionality.

At a minimum, each control station or remote-control device shall have the following functional capabilities:

- The ability to steplessly adjust the nozzle tip's spray pattern from fog to jet stream;
- A minimum horizontal range of motion to be able to aim to all points on the weather deck, and in no event less than 180 degrees;
- A minimum vertical range of motion of at least 130° (-90° / +40° from horizontal) to be able to aim straight down and aim upwards to a minimum of 40° above horizontal;
- The ability to open and close the valve (or valves) that supply water and foam (when used); and
- In the case of a fully automatic system, the ability to turn off the automatic function and ability to take over with mechanically controlled or remote-control operation.

When autonomous or semi-autonomous systems are used, the following considerations and potential shortcomings should be considered and mitigated to the extent practicable:

- The possibility of false alarms and resulting unintentional system activation;
- The possibility of human failure to activate the autonomous system if deactivated during loading and unloading of the ship; and
- The possibility of the system to become uncalibrated over time.

5.8 Durability requirements

Other environmental conditions to consider include those generated by the operation of the ship and the equipment itself, such as vibration, mechanical impact, careless handling, etc.

Fixed fire monitors and all their components should be designed to withstand ambient temperatures, vibration, humidity, shock, impact, clogging and corrosion normally encountered, based in international standards acceptable to the IMO. The fire monitor chassis should be made of stainless steel 316L or other material highly resistant to corrosion in marine environments.

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.

All system ancillary equipment hardware, such as the electronics cabinet or housing, valves, cables, and joysticks, should be suitable for the atmospheric and environmental conditions in which they are installed, and should be CE marked where appropriate.

The system's electronics, which control the fixed fire monitor and, where applicable, its automatic function and ancillary peripheral devices, should be CE marked and in compliance with applicable electromagnetic compatibility (EMC) standards.

The system's software should be demonstrably robust, effective and in compliance with industry standards.

5.9 Arrangement and possible positions of fire monitors

5.9.1 Quantity of fire monitors to protect the entire weather deck

Considering that the fire monitor system should have sufficient coverage to control the fire and protect critical ship infrastructure, ro-ro weather decks shall be outfitted with enough fire monitors so that all critical areas of the weather deck can be covered by the streams of water or foam from at least two individual fire monitors, considering the minimum flow and pressure provided to each fire monitor when two fire monitors are in operation simultaneously. In no event shall there be fewer than two fire monitors protecting the weather deck and in no event shall there be any critical location on the weather deck that cannot be covered by two fixed fire monitors simultaneously in the event of a fire.

5.9.2 Vertical positioning of fire monitors

Typically, the fire can be expected to start in, under, or between parked vehicles or trailers. In such cases, reaching the base of the flame directly with the water stream will be very difficult. Installing the fire monitors at an elevated position (as high as practicable) will provide a more favourable attack angle, allowing more of the water stream to hit the flames and the seat of the fire more directly.

It is suggested that the vertical distance from the deck flooring to a fire monitor, as measured to its inlet, should be at least 25 % of the width of the weather deck, but never less than 7 m. The minimum requirement of 7 m will place the monitor 3 m above the roof-level of a 4 m height trailer. Figure 4 provides a visual representation of the concept.

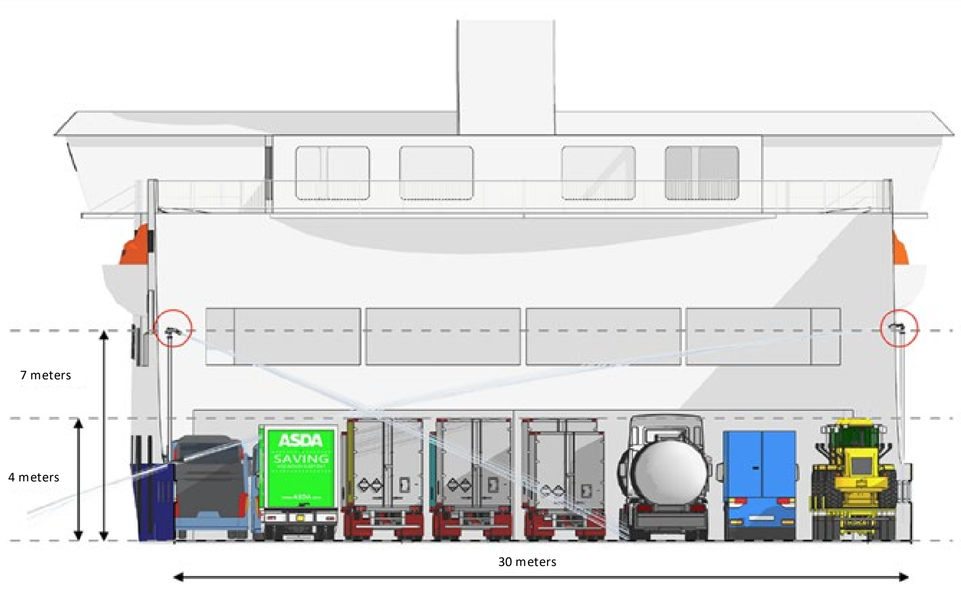


Figure 4. An elevated fire monitor position will provide a more favourable attack angle, allowing more of the water stream to hit the flames more directly.

5.9.3 Locations of fire monitors

The fire monitors shall be installed in opposite or opposing angles of not less than 90° of each other to ensure that any fire on the weather deck can be suppressed by two fire monitors from opposing directions. The 90° can be illustrated by one fire monitor being positioned along the long side of a weather deck and another fire monitor at its short side. A 180° angle would be the result if both fire monitors are positioned at each of the long sides of the weather deck. Such fire monitors could be lined up directly facing each other, but they may also be positioned offset to each other along the length of the weather deck.

The positioning of the monitors should seek to maximize the opposing angles of suppression to limit the spread of fire and to limit the effect of wind. With only one fire monitor, the flame will be pushed and fire will likely spread due to the suppression attempt. The second reason for this requirement is to compensate for wind conditions. Wind will impede the reach of the stream. With two fire monitors strategically located, however, it is likely that the effect of wind conditions will be mitigated.

Figure 5 to Figure 7 show examples of monitors appropriately located at opposing angles.

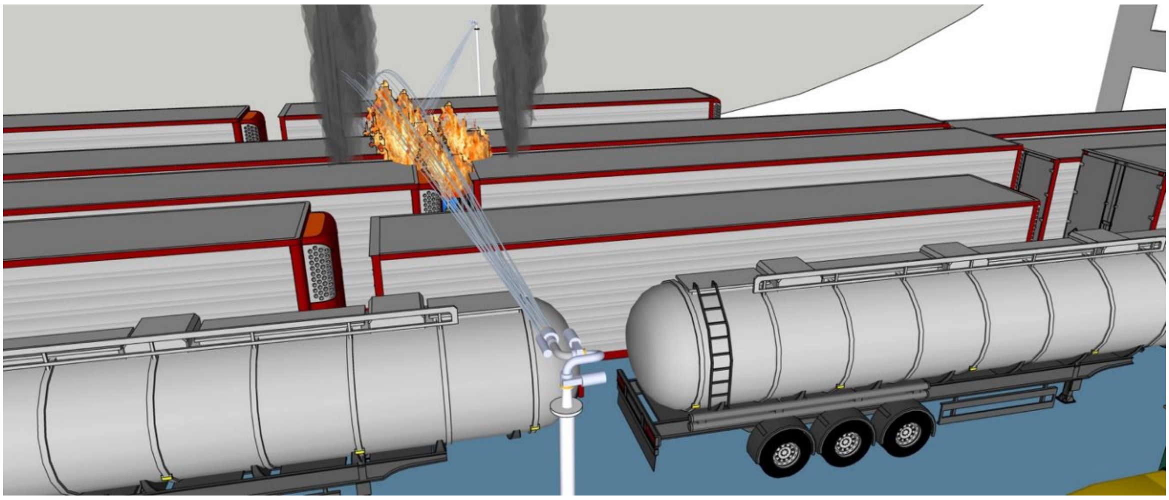


Figure 5. Fire monitors in opposite angles, i.e., positioned directly opposite each other at both sides of the weather deck.

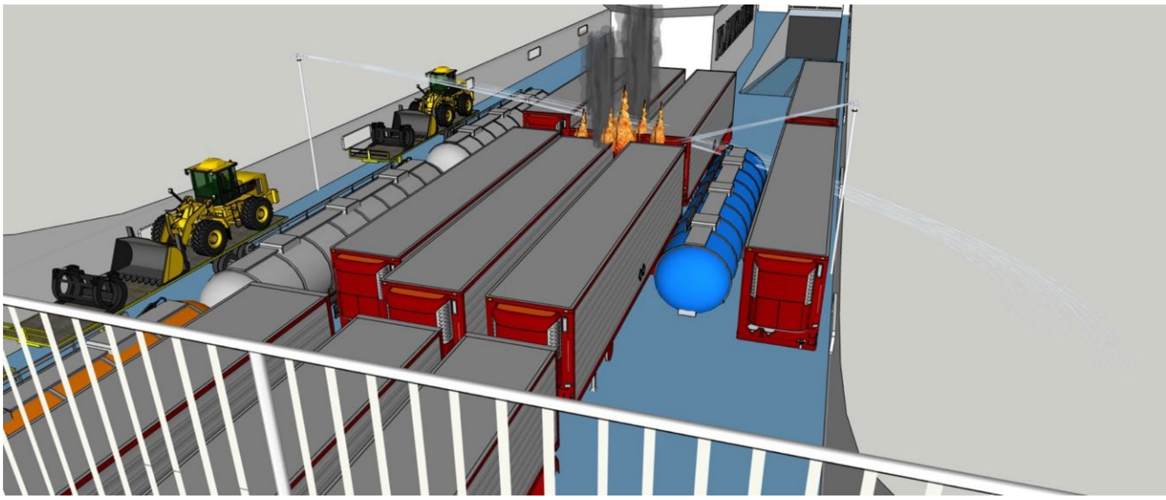


Figure 6. Fire monitors in opposite angles.

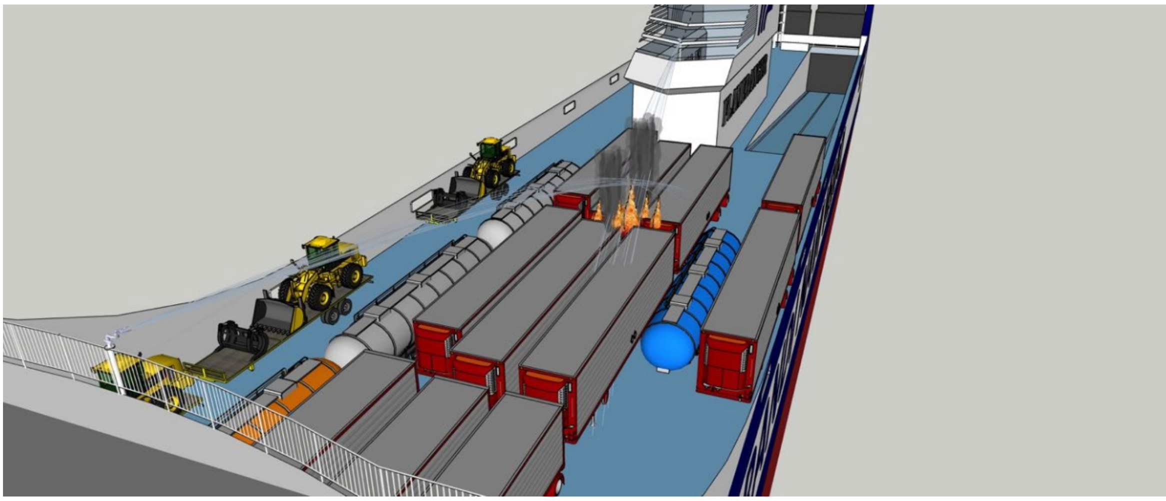


Figure 7. The opposite angles can also be achieved by installing the fire monitors' mid-ship on superstructures of the ship.

As discussed above, one of the fundamental elements of the system concepts is that all areas of the protected weather deck should be reached by two streams of water, foam, or water with any other fire suppression enhancing additive from opposing angles. This configuration will improve fire suppression performance and make the system performance less vulnerable to wind conditions. But in a practical perspective, there may be cases where a literal interpretation of these recommendations leads to an overall large number of fire monitors. It was therefore judged that limited areas of a ro-ro weather deck may be protected by a single fire monitor if: i) the area is shielded from the application of two fire monitors by a permanent structure of the ship, and ii) the complete protected area is no longer than 15 m from the single fire monitor. These limitations will ensure that the influence of wind conditions is minimized as the maximum throw distance of the single fire monitor is modest.

5.10 Fire suppression agents or additives

5.10.1 The use of additives

Any fire suppression enhancing foam concentrate or additive shall be fluorine-free and biodegradable. Furthermore, it 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.

The effective amount of foam concentrate (or additive) should be enough for a discharge of at least 30 minutes at the maximum flow rate of the system. There should be a reserve supply of foam concentrate (or additive) on board the ship to put the system back into service after operation. Alternatively, it should be possible to obtain concentrate (or additive) of the correct brand and type within 24 hours.

5.10.2 Water supply requirements

The flow rate of the system should be sufficient for the simultaneous operation of at least two monitors. At a minimum, each fire monitor should provide a flow rate of 1 250 l/min, irrespective of whether water, foam or additive is used.

The system should be provided with a redundant means of pumping water to the system, but not the foam concentrate or the additive. The flow rate should be sufficient to compensate for the loss of any single supply pump or alternative source. Failure of any one component in the power and control system should not result in a reduction of the required pump capacity. This requirement may be fulfilled by using the pumps intended for water-based systems in the closed vehicle spaces on the ship if they are of sufficient capacity.

Hydraulic calculations should be conducted to assure that sufficient flow rate and pressure are delivered to the hydraulically most demanding two fire monitors both in normal operation and in the event of failure of any one component. The necessary equipment for testing the pressure and water flow rate provided by the pump system should be provided.

The system should be fitted with a permanent sea inlet and be capable of continuous operation using sea water.

6 Cargo and cargo loading considerations

Main author of the chapter: Magnus Arvidson, RISE.

6.1 Type of cargo

6.1.1 General cargo and vehicles

Trucks, cars, trailers, and other wheeled cargoes may be carried providing that their dimensions, axle/total load, and tire print correspond to the design of the ship and the deck.

The vehicles themselves may contain combustibles such as rubber, plastics, textiles, fluids, oil, fuel, etc., which may constitute a large energy content. These combustibles are to a large extent shielded by the body of the vehicle. The cargo on trailers may, if combustible, represent an energy content that is even more significant. But if the tarpaulin cover burns off or trailer box sides burn through, it is likely that the cargo will be exposed to the application of water from any hose streams or one or more fire monitors.

6.1.2 Dangerous goods

Dangerous goods present a risk to the crew, the ship or could pollute the marine environment. Most dangerous goods at sea are carried as cargo in liquid or solid form by bulk carriers or tankers. The protection of bulk carriers or tankers is not part of the objectives of WP10. Other types of dangerous goods may be carried as packaged cargo by general cargo ships, container ships or passenger ships. Packaged dangerous goods could include truckloads of goods in bulk, or tank vehicles carried by sea, on board ro-ro ships or passenger ships [16].

The IMDG Code regulates the transportation of dangerous goods at sea [17]. It contains a list of dangerous substances and requirements for the marking, packaging, separation from other dangerous substances and location on board of the dangerous substance. The nine classifications applicable to ro-ro ships are listed below.

- Class 1: Explosives. This classification has six sub-categories dependent on the explosion hazard;
- Class 2: Gases. This classification has three sub-categories: highly inflammable, non-flammable, and toxic;
- Class 3: Flammable liquids. This classification has no sub-categories;
- Class 4: Flammable solids or substances. This classification has three sub-categories: flammable solids, substances liable to spontaneously combust;
- Class 5: Oxidizing substances (agents) and organic peroxides. This classification has two sub-categories: oxidizing substances, and organic peroxides;
- Class 6: Toxic and infectious substances. This classification has two sub-categories: toxic substances, and infectious substances;
- Class 7: Radioactive material. This classification has no sub-categories;
- Class 8: Corrosive substances. This classification has no sub-categories;
- Class 9: Miscellaneous dangerous substances and articles. This class is for those substances that cannot be classified in any of the categories above, and marine pollutants that are not of an otherwise dangerous nature.

The direct application of water is unsuitable for some of the dangerous substances, but application of water to prevent their involvement in a fire is desired. For some substances, such as those in Class 3, the use of a foam additive or similar fire suppression enhancing additive may improve the performance of a fire monitor system.

6.1 Length and width of the weather deck

The effective width of the weather deck varies with the type of ship but is typically on the order of 25 m to 30 m. The length of the weather deck could be more than 100 m.

The lane width also differs from ship to ship, and there are several applicable industry standards. For road trailers, semi-trailers and roll trailers, the width of the lane is typically 2,90 m, i.e., the width of the weather deck is a multiple of 2,90 m so that 10 or more lanes may be possible.

6.2 Length, width and height of truck and semi-trailers

In Europe, heavy goods vehicles, buses, and coaches must comply with certain rules on weights and dimensions for road safety reasons and to avoid damaging roads, bridges, and tunnels. Directive (EU) 2015/719 (which amends Directive 96/53/EC) [18] sets maximum dimensions and weights for international traffic. The maximum vehicle length is 18,75 m and the maximum width is 2,55 m (2,60 m for refrigerated vehicles). An individual trailer is permitted to be up to 12,0 m in length. The restrictions on height (4,0 m) and weight (40 tonnes) authorised for international traffic are not extended to national traffic. Sweden and Finland have an exception to the directive that allows freight trucks with trailers to be a maximum of 25,25 m long. In addition, it is common that the freight trucks are up to 4,50 m high in these countries.

Trailers covered by tarpaulins are common in Europe, but not as common in the Nordic countries due to the climate. In these countries solid boxes are more commonly used. The walls and ceiling of these boxes are usually made from a sandwich panel with outer sides of 2 mm plastic sheets and a core made from either plywood, polyurethane (PU) or expanded polystyrene (EPS). The overall thickness is typically 20 mm. The parts are glued together and then put into a framework of aluminium profiles.

For the transportation of food or other products that require a lower than ambient temperature, the walls and ceiling of such a box are usually up to 45 mm to 55 mm thick with a core of EPS.

6.3 Distance between cargo

Lateral distance (long side to long side) between trailers, can vary from 100 mm to 600 mm, typically closer to the smaller number. In the longitudinal direction (short end to short end) on an effectively stowed weather deck area, the distance is on the order of 400 mm to 1000 mm between trucks. Loose trailers[4] are sometimes loaded so tightly that that they almost touch. As a rule, there is a free distance of 600 mm for the passage of drivers, accessibility, firefighting, etc., but this distance is most likely found in main longitudinal passages (at the casing) and sometimes transversely.

[4] Loose trailers are not attached to a truck or tractor.

6.4 Securing (lashing) of cargo

MSC/Circ.812, “*Guidelines for securing arrangements for the transport of road vehicles on Ro-Ro ships*” [19], applies to ro-ro ships that carry road vehicles on international voyages in unsheltered waters. The guidelines are applicable to road vehicles with an authorized total mass of vehicle and cargo between 3,5 and 40 tonnes and articulated road trains with an authorized total mass not more than 45 tonnes.

The decks shall be provided with securing points with longitudinal spacing < 2,5 m and transverse spacing 2,8 m < S < 3,0 m.

Lashing shall consist of chain, or any other device made of steel or other material with equivalent strength and elongation characteristics. The use of steel or other metal would prevent a fire from burning off the lashing. Lashings should be attached only to the dedicated securing points in the deck plates, using hooks or other devices.

7 State-of-the-art review

Main authors of the chapter: Roger James and Mattias Eggert, UNF, Goran Pamic, FLOW and Martijn Teela, F4M.

7.1 Weather deck fire protection

Common fire protection on ro-ro weather decks includes sea water system fire hydrants and portable firefighting equipment, e.g., portable fire extinguishers and foam applicator units, as drawn in Figure 8. A typical weather deck arrangement on a ro-ro cargo ship is shown in Figure 9.

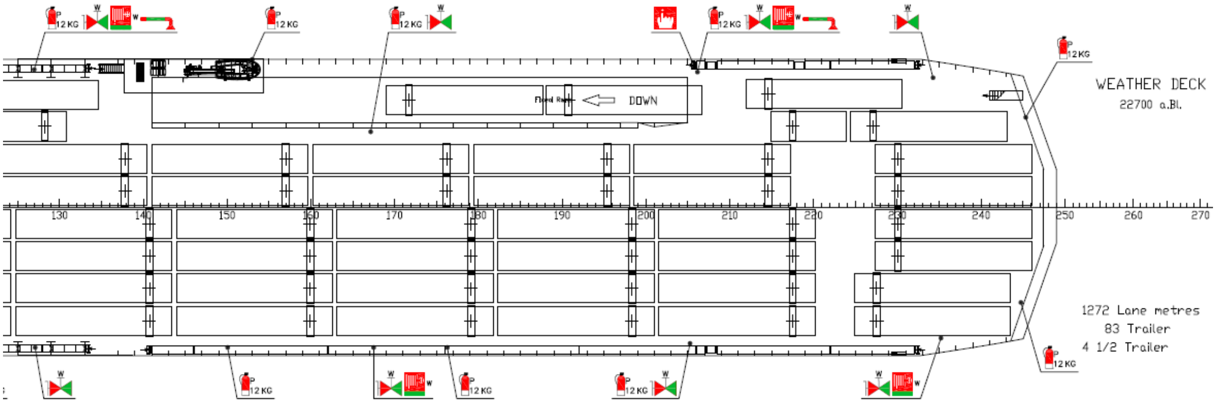


Figure 8. Fire protection appliances plan (detail) from Magnolia Seaways. The valve symbols indicate the positions of the fire hydrants and the other symbols the positions of the portable fire extinguishers and foam applicator units.

Figure 9. A view of the ro-ro weather deck of Magnolia Seaways, which is divided in two parts, one at the aft and one at the front.

7.2 Fire monitors

Fire monitors can be installed on ro-ro and ro-pax ships, where the design of a weather decks allows an elevated position for the installation. There are shipowners that have already installed fire monitors on weather decks, covering all or almost all the deck area. The fire monitors in these installations are either manually controlled or remote-controlled. An example of a fire monitor installation is illustrated in Figure 10.

Figure 10. A demonstration of a fire monitor on board Stena Germanica.

The specific parameters and specifications of remote-controlled fire monitors that are appropriate for weather decks vary by manufacturer. They are generally able to rotate horizontally and vertically and are outfitted with a nozzle tip that can adjust the spray pattern from a jet stream to a wide-angle spray pattern. The movements are achieved by electric motors that turn gears and/or, in the case of the nozzle tip, an actuator. Monitors of this type often have 24V DC motors (either brushed or brushless).

Fire monitors for marine applications, such as weather decks, are usually made of stainless-steel type 316L or of bronze but may be made of other materials if proven durable in harsh marine environments. They can typically provide optimal performance at pressures ranging from 5 – 10 bar, but often have a maximum operating pressure of 12 bars.

The control of the monitor is achieved by sending signals from a remote-control device, such as a joystick or wireless device, to a Programmable Logic Controller (PLC). The PLC, in turn, processes the controller input data and sends the appropriate signals to open and close the system’s valve as well as to control the monitor’s motors to achieve the desired control.

Some remote-control fire monitors can rotate horizontally a full 360°, and vertically up to 180° (±90° from horizontal). The horizontal and vertical ranges of motion of modern fire monitors can typically be limited to a desired range by means of software settings entered during system set-up and calibration. Some fire monitors, however, achieve the range of motion limits by means of physical bolts or limit switches, but this can cause damage and wear and tear over time to the monitor's gears and/or motors.

Remote-controlled fire monitors of the type suitable for use on weather decks will typically have an internal pipe diameter of 50 mm (2") or 80 mm (3"), with a maximum theoretical reach of up to approximately 65 m and 80+ m, respectively. The effective reach can in practice, however, vary greatly depending on several factors, particularly including wind conditions, but also the piping and valves and restrictions in the supply of water up to the base of the monitor, the distance from the pump, the pump performance itself, and the height of installation above the pump. For this reason, it is important that the actual reach be very conservatively estimated during planning and be tested, adjusted, and optimized once installed.

Fire monitors with a 50 mm (2") internal pipe diameter will typically have a maximum flow capacity of approximately 2 000 l/min at 10 bars. Fire monitors with an 80 mm (3") internal pipe diameter will typically have a maximum flow of approximately 5 000 l/min at 10 bars.

Normally, the flow and reach characteristics of the monitor's nozzle tip can be mechanically (or sometimes remotely) adjusted to provide optimized performance given the available pump and installation parameters.

Figure 11 is an image of a 50 mm (2") electric, remote-controlled stainless-steel monitor and Figure 12 shows approximate performance curves at various flows and pressures and with varying nozzle tip flow settings.

Figure 11. Example of a Unifire FORCE 50 (2") stainless-steel remote-controlled fire monitor with three 24V Brushless DC motors (BLDC) motors and adjustable jet/spray nozzle tip.

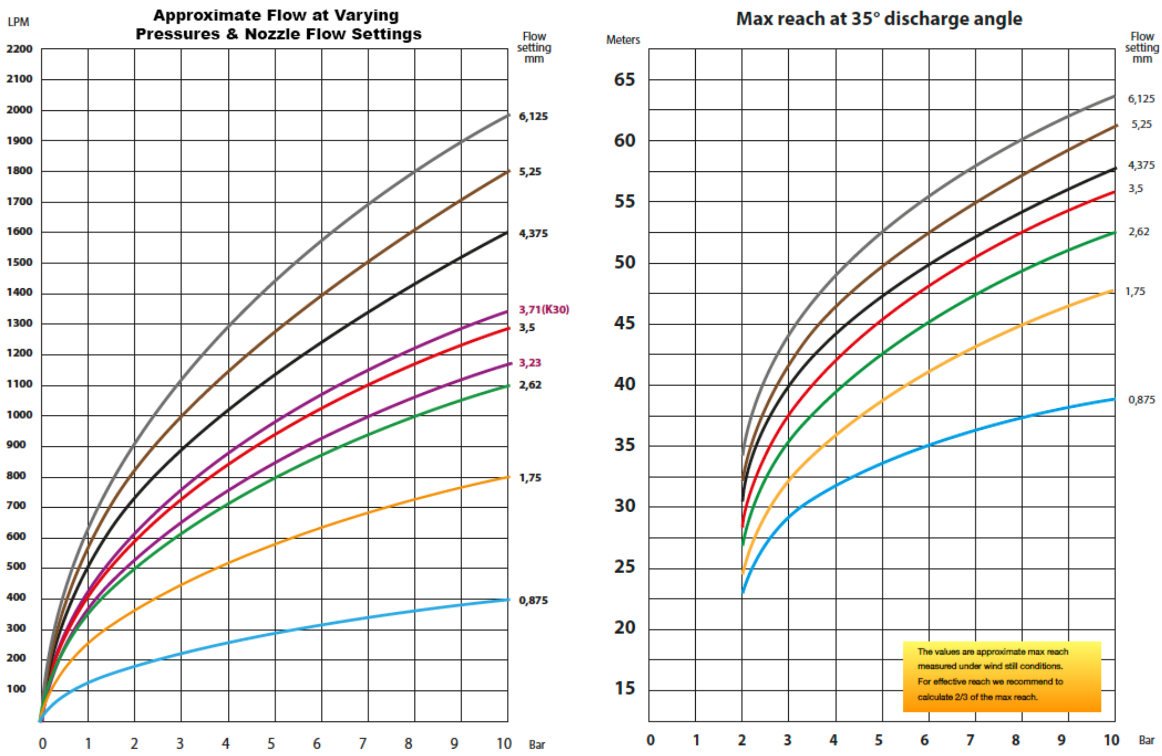


Figure 12. Example of 2" monitor flows at varying pressures and settings (left) and monitor theoretical stream reach @ 35° discharge angle at varying pressures and settings (right).

Figure 13 and Figure 14 are images of an 80 mm (3") electric, remote-controlled stainless-steel monitor and Figure 15 shows approximate performance curves at various flows and pressures and with varying nozzle tip flow settings.

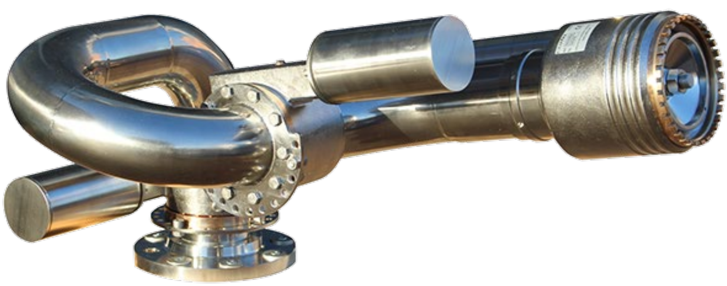


Figure 13. Example of a Unifire FORCE 80 (3") stainless-steel remote-controlled fire monitor with three 24V BLDC motors and adjustable jet/spray nozzle tip.

Figure 14. Unifire FORCE 80 (3") remote-controlled fire monitor protecting a weather deck on a Stena ship.

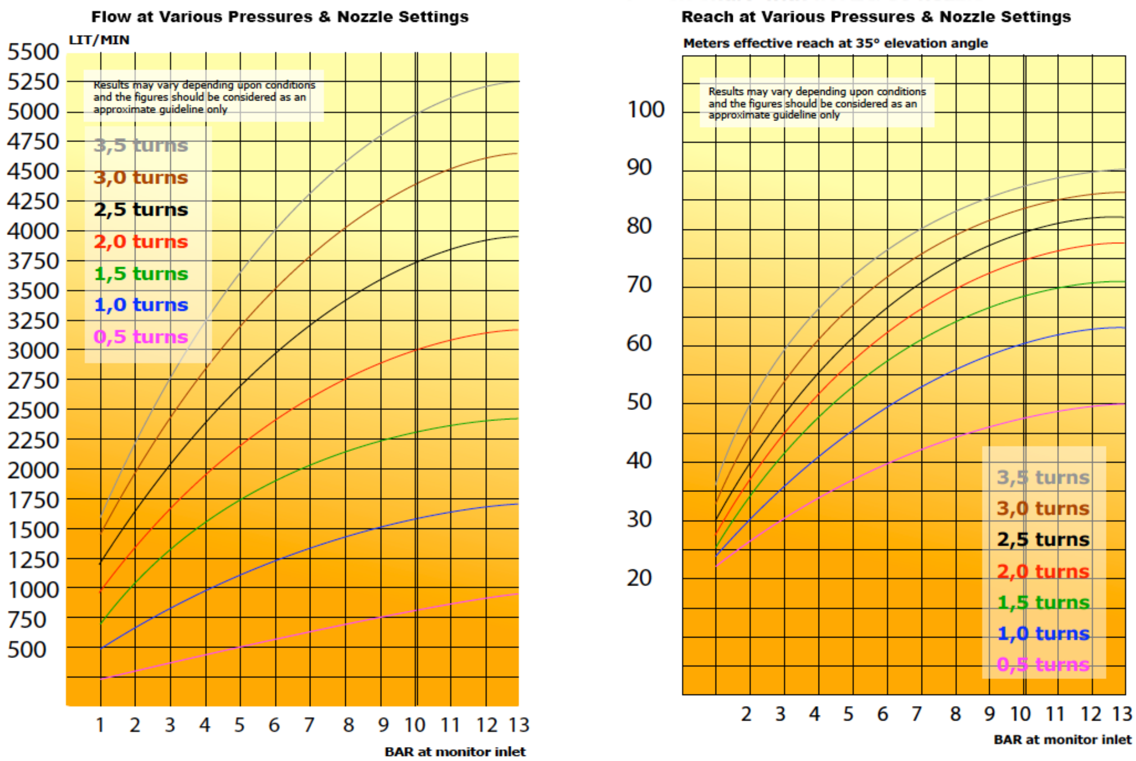


Figure 15. Example of 3" monitor flows at varying pressures and settings (left) and monitor theoretical stream reach @ 35° discharge angle at varying pressures and settings (right).

7.3 Recent technological advances

In recent years, remote-controlled fire monitors, and particularly their electronics, software, and control system capabilities, have undergone significant technological advances. The current state-of-the-art of remote-controlled fire monitors includes the following features and capabilities:

- Progressive movement/varying speed control, allowing an operator to quickly move the monitor to the right position, and then control the monitor with slow, accurate motion;

- Simultaneous movement horizontally, vertically and nozzle spray pattern;
- Stepless nozzle spray pattern control from spray to jet stream and everything in between;
- Brushless DC motors (BLDC), which provide long life, high torque, and extremely high position accuracy;
- Position feedback with an accuracy of 1/50th of a degree or better;
- Advanced programmable logic controllers (PLC), i.e., electronic hardware and software, which includes such features as:
  - A graphical user interface (GUI) for easy system setup, configuration, calibration, and display of system data (including motor loads) and faults;
  - A web server enabling local- and wide-area network (LAN/WAN) connections, allowing for tethered and/or wireless control from an app on any iOS or Android device and/or from a remote computer, and allowing for remote technical support, configuration, and software updates by the manufacturer;
  - Digital and analogue input/output (I/O) cards allowing for the control of, and input from, peripheral devices such as fire detection technologies for automatic responses, valves, lights, alarms, and tank levels;
- Semi-automatic response with the ability to store and playback one or more pre-recorded spray patterns either on demand or upon an alarm input from a fire detector, thermal imaging camera or other detection technology; and
- Fully automatic suppression with autonomous aiming of the monitor based on fire detection and position data from one or more fire detection technologies.

An autonomous fire monitor system is a system comprised of a fire detection system, a fire monitor, and electronic hardware and software enabling the system to process signals from the fire detection system to effectively guide the fire monitor to achieve fire suppression, without any human intervention.

The benefits of these systems are that a fire can be detected and fought at a very early stage. Naturally, individual fire monitors should have provisions for manual activation and remote-control as a fire may be detected by the crew earlier than a fire detection system. It is also essential that the crew be able to take full control of the system at any time.

A semi-autonomous monitor system is a fire monitor system that requires human interaction for activation and control, which has a record and play function built into the system's controller(s), whereby an operator can record, in real-time, all monitor movements--including monitor rotation, inclinations and nozzle spray angle adjustments, as well as the variable speeds and pauses of such movements, and play them back at any time. The ability to record a spray pattern in real time is a feature offered by many modern fire monitors at little-or-no extra cost. It is expected that semi-autonomous monitor systems, having a record and play feature, may in some circumstances bring additional benefits and further risk reduction potential by allowing the operator to record an effective suppression sequence during a fire, then play it back in a continuous loop and thereby free him or her up to tend to other firefighting efforts while the monitor continues repeating the recorded spray pattern protecting the fire area. In essence, this provides an additional crew member to aid in the fire's suppression and other safety activities during a weather deck fire.

It is understood that an autonomous or semi-autonomous fire monitor system probably will not be specifically required to be installed for fire protection on weather decks in the very near future. In a longer perspective, however, it is likely that the number of crew members on ships will decrease, safety requirements will become more rigorous, and requests for higher fire safety requirements are likely. Therefore, there should be no restrictions on using them.

7.4 Fire detectors

Fire detectors on open ro-ro weather decks, regardless of the detection technology, should be designed to provide rapid and reliable detection of a fire, minimize the susceptibility of false alarms, immediately alert the ship's crew so that they may intervene, when part of an autonomous fire monitor system they should be capable of locating the fire with as much accuracy as possible (to be able to efficiently aim the fire monitor to suppress the fire at and around its source, withstand the harsh environment experienced on weather decks.

7.4.1 Detection technologies

Fire detection technologies are rapidly developing and include flame detectors, thermal imaging cameras, video analytics, detectors that combine thermal imaging and video analytics, and linear heat detectors. Although any of these technologies can be considered if it maximizes the objectives listed above, a review of the current state of the art implies that the detection technologies that are generally best suited for weather decks are flame detectors, thermal imaging cameras and possibly hybrid fire detectors that combine thermal imaging and video analytics. The fire detection technologies identified above are described below.

7.4.1 Flame detectors

Flame detectors are available that are capable of rapidly detecting flames, have a low susceptibility to false alarms, and are designed to withstand the harsh environment on weather decks. Flame detectors are also typically able to detect a fire at a 50 m distance or more, thus requiring relatively few detectors to cover the entire weather deck. These features make them a good candidate for fire detection on weather decks. Very few flame detectors, however, can provide the location of a flame, which may limit their ability to be used with autonomous fire monitor systems.

7.4.2 Thermal imaging cameras

Thermal imaging cameras are available that are also capable of rapidly detecting heat build-up (and even allow for the setting of alarm criteria), can provide the location information of a fire, often with a high degree of accuracy, and can be designed to withstand the harsh environment on weather decks. Furthermore, like flame detectors, thermal imaging cameras are also typically able to detect a fire at a 50 m distance or more, thus requiring relatively few thermal imaging cameras to cover the entire weather deck.

A further advantage of thermal imaging cameras is that they can detect heat build-up even where the flames may not be directly visible, such as inside of a vehicle or container. Because they detect heat, however, thermal imaging camera systems tend to have a higher susceptibility to false alarms, i.e., detecting a heat source that is not one that justifies suppression. Such false alarms may be caused by the sun and sun reflections, vehicle engines and other hot parts (particularly during the loading and unloading of the weather deck), or other benign heat sources found on the ship. Many modern thermal imaging camera systems feature algorithms designed to minimize false alarms (such as by ignoring moving hot objects or known, benign hot objects, etc.), and this technology continues to be developed at a rapid pace.

A thermal imaging camera system that otherwise meets the objectives set out above and features sufficiently low susceptibility to false alarms (or can mitigate them), is also a good candidate detection technology for weather decks. When used for fire detection on a weather deck, care must be taken when setting the system’s sensitivity to strike a proper balance between detecting a fire and minimising false alarms.

7.4.3 Video analytics

Video analytics is a promising emerging fire detection technology. These systems are capable of rapidly detecting a fire, as well as smoke, can provide the location data associated therewith, and can be designed to withstand the environmental conditions on weather decks. They also typically can detect fire or smoke at distances of 50 m or more, thus requiring relatively few cameras to cover a weather deck.

Typically, however, video analytics systems have a relatively high susceptibility to false alarms from sources such as those associated with thermal imaging cameras. Such sources include vehicle engines and other hot parts (particularly during the loading and unloading of the weather deck), or other benign heat sources found on the ship, as well as the sun, reflections from the sun, or, unlike thermal imaging cameras, can even be triggered by objects such as tarps, flags or other objects that flap in the wind.

Like thermal imaging camera systems, however, clever algorithms reduce the occurrence of such false alarms, and this technology is developing rapidly. Any video analytics system considered for fire detection on a weather deck should be carefully analysed to ensure fulfilment of the objectives criteria and that the likelihood of false alarms is minimal and tolerable.

7.4.4 Hybrid fire detectors combining thermal imaging & video analytics

New hybrid fire detection technologies are emerging on the market, which, in a single unit, combine visual and infrared image processing analytics. For purposes of this report, we refer to these as “hybrid fire detectors”, although other terms for such systems may be used in the market.

Hybrid fire detectors are fast-acting and can detect fires at ranges comparable to thermal imaging cameras and video analytics systems and are able to withstand the harsh environment of weather decks.

While there are common sources of false alarms from thermal imaging cameras and video analytics systems, they are often different. Thermal imaging cameras tend to provide false alarms when they sense heat sources that are indeed hot and within their alarm setting thresholds, but which are not in fact an actual fire threat. Such heat sources are typically produced from hot exhaust pipes, engines, or other machinery. False alarms from video analytics systems, on the other hand, are more typically associated with visual data that appear to the system’s algorithms to be similar to flames, such as solar reflections or materials flapping in wind, such as a flag or tarp.

Hybrid fire detectors are designed to minimise false alarms by requiring a positive fire detection from both the thermal imaging data and the video analytics before a fire alarm is signalled. For example, a flapping tarp, which might raise an alarm from the video analytics, will not trigger an alarm from the hybrid fire detector because the infrared data show no actionable heat source. Similarly, a hot engine that would otherwise trigger an alarm based on infrared data alone will not trigger an alarm on the hybrid fire detector because the video analytics rules out the presence of a flame.

In addition to the significant benefit of reducing false alarms, hybrid fire detectors are also capable of providing the coordinates of a detected fire. These coordinates can be utilized by an autonomous fire monitor system or other fire suppression system to achieve an automatic suppression response.

It is anticipated that hybrid fire detectors may bring significant advantages—specifically, providing rapid fire detection and location, as well as minimising false alarms associated with either of the respective technologies alone.

7.4.5 Linear heat detectors

Although linear heat detection systems typically have a low susceptibility to false alarms and can withstand the environment of weather decks, they also present several drawbacks for use as fire detectors on weather decks. For one, they tend to be much slower to detect a heat build-up than the other detection technologies described above. Another disadvantage is that the heat they detect may travel some distance from the heat's source, thereby possibly providing a relatively inaccurate location of the fire. For these reasons, linear heat detection is generally considered unsuitable for weather deck fire detection.

7.5 The use of foam or other fire suppression enhancing additives

Adding foam provides significant improvement to fire suppression efficiency, particularly for flammable liquid spill fires, so the use of foam additives and induction systems is highly recommended from a fire suppression point of view.

Managing foam compounds in large volumes, however, is logistically challenging, where large volumes of foam need to be stored on board to provide sufficient discharge duration time. Foam compounds have a limited shelf life and need to be replaced and recycled frequently. Moreover, foam proportioning systems are costly and complex.

Hence, from a practical point of view it is envisioned that the fire monitor system for weather decks will normally use fresh water (from a freshwater tank) and at a later stage seawater from a sea water connection. Fresh water is desired for testing and training to limit the probability for internal pipe and component corrosion. A seawater connection will provide a virtually unlimited supply of water.

The use of foam is recommended where practicably possible and should be used for certain high-risk vessels. It is suggested that the foam concentrate tank should have a capacity corresponding to a minimum duration of at least 30 minutes at the maximum discharge rate of the fire monitor system.

7.6 CAF fire monitor systems

7.6.1 General

A Compressed Air Foam (CAF) system releases a firefighting foam for the extinguishment of a fire or for the protection of unaffected adjacent areas. System components of CAF systems 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. CAF systems are normally used for the protection of spaces where flammable liquids are stored, handled, or processed and are applicable for the protection of specific hazards and equipment. Applications may include exposed or shielded Class B pool or spill fires.

CAF 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 and low proportioning rates, typically from 0,3 % to 1,0 % with either Class A or B foam concentrates. NFPA 11 [20] includes recommendations for the design and installation of foam fire-extinguishing systems, including CAF systems. The generation of foam is considered to provide better foam quality than nozzles where foam generation occurs in the nozzle itself. For indoor fire hazards in buildings where spill fires may occur, NFPA 11 recommends an application rate equivalent to 4,1 mm/min with film-forming foams and 6,5 mm/min with protein foams. For CAF, 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 CAF systems 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 objects. With rotating nozzles located at the ceiling, each nozzle can cover a relatively large surface area. CAF systems are usually fire tested with Class B fuel spill fires, for example to UL 162 [21] or FM 5130 [22] standards.

7.6.2 Type of foam agents

A CAF system does not need a specific foam agent, but the foam agent should be approved for the application and could be standard foam concentrates that are used for hydrocarbon fires or alcohol-resistant used for hydrocarbons and polar solvents. The foam agent concentrations must be approved with the CAF system.

The foam concentrates used in the CAF system are typically biodegradable and fluorine-free. However, as with any substance, care should be taken to prevent discharge from entering ground or surface water.

7.6.3 Foam agent storage and reserve supply

For smaller sized, standalone systems, the foam concentrate is usually stored in a stainless-steel pressure vessel. This vessel and the water supply tank, if applicable, are pressurized with compressed air upon system actuation. Pressure proportioning tanks shall have means for filling, for gauging the level of agent, and for drainage, cleaning, and inspection of interior surfaces.

For larger sized systems, as expected for the protection of weather decks, a dedicated air compressor is required to generate the foam, which allows the foam agent to be stored in an atmospheric type of storage tank. Storage tanks shall have capacities to accommodate the needed amounts of foam agent plus space for thermal expansion. The foam concentrate outlet shall be located to prevent sedimentation from being drawn into the system. When determining the quantity of foam agent, the volume of sediment pocket shall be added to the amount of agent needed for system operation. Tanks shall be equipped with conservation-type vents, access handles, or manholes that are located to provide for inspection of the internal tank surfaces, connections for pump suction relief, testing lines, filling, and draining connections, etc.

Foam agents shall be stored within the listed temperature limitations and markings shall be provided on storage vessels to identify the type of agent and its intended concentration in solution. There shall be a reserve supply of foam agent to put the system back into service after operation. The reserve supply shall be in separate tanks or compartments, in drums or cans on the ship, or shall be able to be obtained from an external source within 24 hours.

7.6.4 CAF fire monitors

The usage of a fire monitor is good for large areas where other systems are not effective. The combination of fire monitors and CAF is a proven solution and accepted in standards for offshore helicopter landing areas [23]. In this standard the required waterflow for CAF units is about 55 % less in comparison to an International Civil Aviation Organization (ICAO) performance level B foam.

There are no dedicated CAF monitors. However, most CAF systems use a smooth bore type nozzle or straight piece of pipe to maintain the quality of the foam that is discharging through the nozzle. A separate jet or water spray nozzle can be used in combination with CAF if desired. At similar pressures at the inlet of a fire monitor, the throw of foam is very similar to that using water only.

8 Large-scale development testing of an autonomous fire monitor system

Main authors of the chapter: Magnus Arvidson, RISE and Mattias Eggert, UNF.

8.1 Objectives of the tests

The objective of the tests was to determine the capability and effectiveness of a system denoted the FlameRanger system, a fully autonomous system developed by UNF. The tests were designed to determine whether a fixed, autonomous monitor system is able, within an area roughly comparable to an open ro-ro weather deck, to: 1) quickly detect multiple, separately-placed fires; 2) determine the three-dimensional positions of the fires; and 3) effectively guide the water streams of the monitors towards the fires.

The tests were conducted at Guttasjön, located just outside of Borås, Sweden. Guttasjön is one of Sweden's most modern facilities for realistic and technically advanced rescue exercises, with daily operations. The tests were conducted during May 25-29 and June 8-12, 2020. The test plan was developed by UNF, and RISE and the actual testing was conducted by RISE, with support from UNF and the staff at Guttasjön.

The testing offered the possibilities to fine-tune parameters of the software for the application and use on weather deck. The specific challenges and objectives in the development of an autonomous fire monitor system for the weather decks include:

- Determining the placement/installation constraints of the detectors;
- Verifying the ability of the detection system to detect and locate fires throughout the entire simulated weather deck area;
- Verifying the ability of the suppression system (fire monitors) to reach each of the detected fires on the simulated weather deck and provide a reasonable volume of water to each detected fire;
- Verifying, analysing, and adjusting the system’s oscillation pattern and response behaviour (including the spray pattern adjustment) with respect to the detected fires, taking into consideration their distance from the monitor; and
- Documenting the above information for purposes of further development.

8.2 The FlameRanger system

Each autonomous system is comprised of two IR flame detector arrays, a fire monitor and electronic hardware and software enabling the system to automatically and autonomously detect and track, in real time, the presence and three-dimensional size and location of a fire. During a fire, the software dynamically guides the fire monitor to direct the water stream to the fire location, without any human intervention. As tested, the system consisted of two IR array flame detectors, two FORCE 50 fire monitors connected to a water supply, and electronic hardware and software.

Additional (independent) FlameRanger systems can be used to protect a large area, such as a ro-ro weather deck, with several monitors.

In an actual installation, the autonomous function can be overridden by an operator at any time.

8.3 The test area

The tests were conducted on a flat gravel plane, sized 30 m wide by 50 m long. The width was chosen to mimic the width of an actual weather deck and the length represents the maximum horizontal distance between fire monitors of the tested capacity along the length of a weather deck. Two complete autonomous systems as described above were installed. The two fire monitors were positioned opposite each other on the long sides of the simulated deck area, the separation distance was thereby 30 m. Two systems were used to provide adequate coverage of the area from two streams of water, and to compensate for the influence of wind. Figure 16 illustrates the testing configuration.

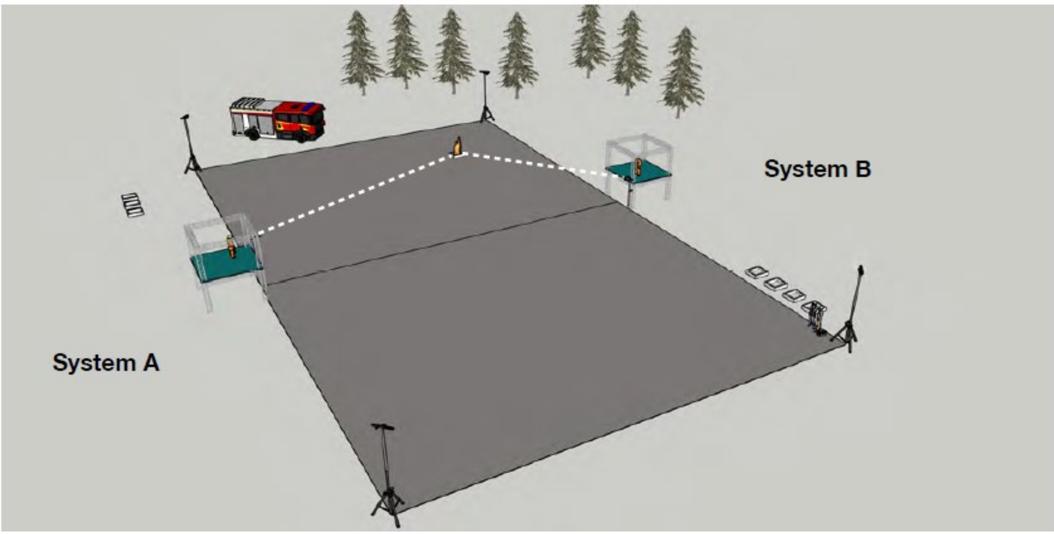


Figure 16. An illustration of the testing approach, where two complete autonomous systems (denoted System A and System B, respectively) were installed to provide full coverage of the 30 m x 50 m test area.

The area was divided into a grid with 5 m x 5 m large squares using polyester wires that were secured and stretched over the ground surface. The square grid simplified the positioning of the fire test sources and facilitated the documentation of the precision of the water streams from the fire monitors. Figure 17 shows the grid.

Figure 17. The area was divided into a grid with 5 m x 5 m squares to simplify the positioning of the fire test sources and facilitate documentation of the precision of the water streams from the fire monitors.

8.4 The fire monitors

The fire monitors in an actual installation are typically installed at a vertical distance of 7 m or more over the surface of the weather deck. However, for these tests, the ground surface was assumed to represent the top of the cargo (freight trucks, semitrailers, and similar types of vehicles) on a deck. In Europe, their maximum allowed height is 4,0 m. Based on this restriction on height of vehicles, the fire monitors were installed vertically 3 m above the ground. Figure 18 shows one of the two fire monitors and the truss tower used for the installation. Water was supplied via DN63 fire hoses laid on the ground.

Figure 18. One of the two fire monitors and the truss tower used for the installation. Water was supplied via DN63 fire hoses laid on ground.

Unifire FORCE 50 fire monitors were used. This monitor has a nominal water flow rate of 1 200 l/min at 5 bar. To suppress and contain the fire, the fire monitors oscillate in both X° and Y° around the flame to effectively prevent the fire from spreading. The autonomous system will adjust for trajectory angle, and the spray pattern can be adjusted to wider spray.

All tests were conducted in fully autonomous mode. The fire monitor can be controlled by wired joystick, radio remote-control or via transmission control protocol/internet protocol (TCP/IP) or wireless network (WiFi) from a computer and/or smartphone App.

8.5 The fire detectors

At each corner of the test area a crank stand with a fire detector was positioned, refer to Figure 19. The detectors were positioned vertically 5 m above the surface of the ground (2 m above the fire monitors) and orientated towards the midpoint of the test area.

Figure 19. The support for the fire detector. The fire detector was positioned at the top and a video camera was positioned below each detector.

8.6 The fire test sources

The fire test sources were commercial fire generators developed and used for training purposes. Each device consists of a propane gas burner connected via a hose to a propane gas cylinder. The flow of gas is remotely controlled and electrically ignited. The fire could therefore be ignited and turned off with a push-button and the gas flow was turned off as soon as water from the fire monitors was applied, i.e., the fires were not extinguished by the application of water. The flame height was approximately 1 meter. The fire sources were positioned on a tarpaulin that protected the ground from the impact of the water stream. Figure 20 shows the burner arrangement.

Figure 20. A propane gas burner used as a fire source.

8.7 The water supply

Water was supplied from on-site fire hydrants and from an open water course, refer to Figure 21. Water was pumped to the internal water tank of a fire engine that provided the desired water flow and pressure. The water pressure was constantly adjusted by a pump operator.

Figure 21. The water supply arrangement.

Water was distributed through DN63 fire hoses to each of the two monitors. A control valve was installed in each of the lines to adjust the pressure. This provided a balanced system with equal flow rate from each fire monitor.

8.8 Measurements and documentation

The total water flow rate and the water pressure at each of the fire monitors were measured during the tests.

Each test was documented using still photos and video cameras positioned on each of the fire monitors and at each of the stands for the fire detectors. Video documentation was also made from above using a drone. A weather station recorded ambient temperature, wind velocity, speed and direction.

As the detectors located the fire and the system software triangulated and identified the flames in three-dimensional (3D) space, all the collected data was logged and saved for future analysis. That means the X, Y and Z positions and the size of every fire during the test was logged with a timestamp. This also includes the horizontal and vertical angle of the fire monitor. Figure 22 shows an example of the real time display of the data that is also logged.

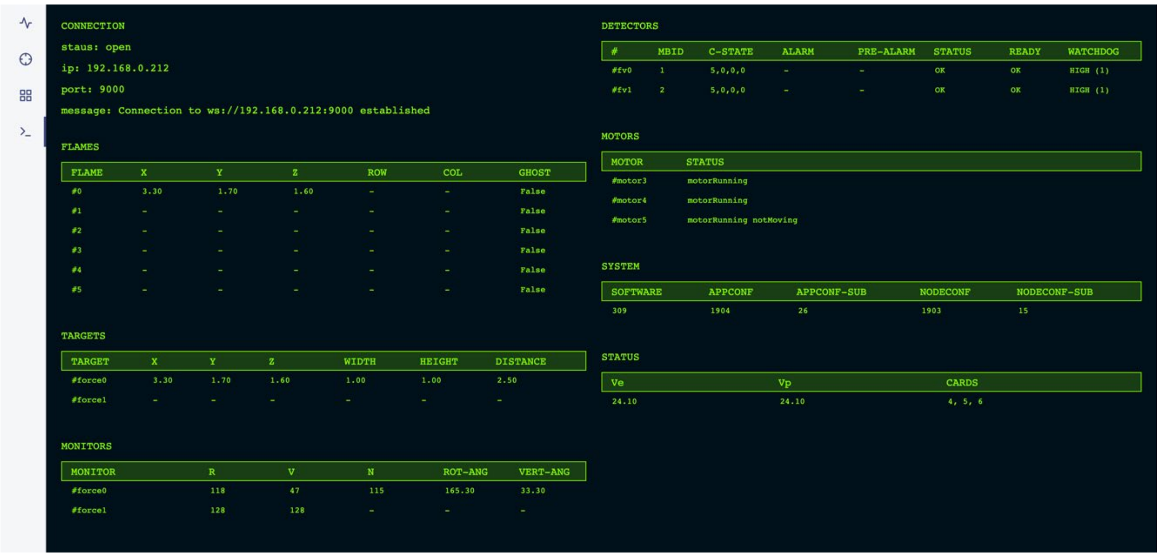


Figure 22. Example view of data from the software of the autonomous system.

8.9 Simulation of wind conditions

Wind was simulated using a snow cannon. The measured air velocity a few meters from the outlet was 20 m/s. The velocity dropped to 10 m/s at 10 m from the outlet. The device had an electric engine.

8.10 The test program set-ups

The following was tested:

- **Fire detection testing:** For these tests, the fire sources were positioned at different locations. The fires were lit in sequence and the time to detection was measured. In addition, a comparison was made between the actual coordinates and the coordinates documented in the software.
- **Precision testing using one autonomous system:** The first series of tests involved one FlameRanger system, i.e., a system with one fire monitor and two fire detectors. The fire sources were positioned at different locations and sequentially ignited and turned off. The time from the ignition of the first fire source to the last was about 70 seconds. The test was repeated to confirm results and to collect additional measurement data. The scenario was also repeated with fire ignition in a different order.
- **Precision testing using two autonomous systems:** These tests were similar to the ones described above but involved both autonomous systems simultaneously.
- **The influence of wind on the water stream:** These tests were conducted with a snow cannon that locally generated high air velocities. The cannon was either positioned perpendicular to, or directly opposite of, the water stream using different water stream throw lengths.
- **The influence on fire detection of rain and fog:** Rain and fog were simulated using a fire hose stream of water directed into the air flow of the snow cannon and by using the water spray nozzles on the perimeter of the cannon itself. The possibilities for fire detection in such weather environments was tested.

8.11 Test observations

The test observations based on the video documentations are provided in a series of still photos below, refer to Figure 23 to Figure 28.

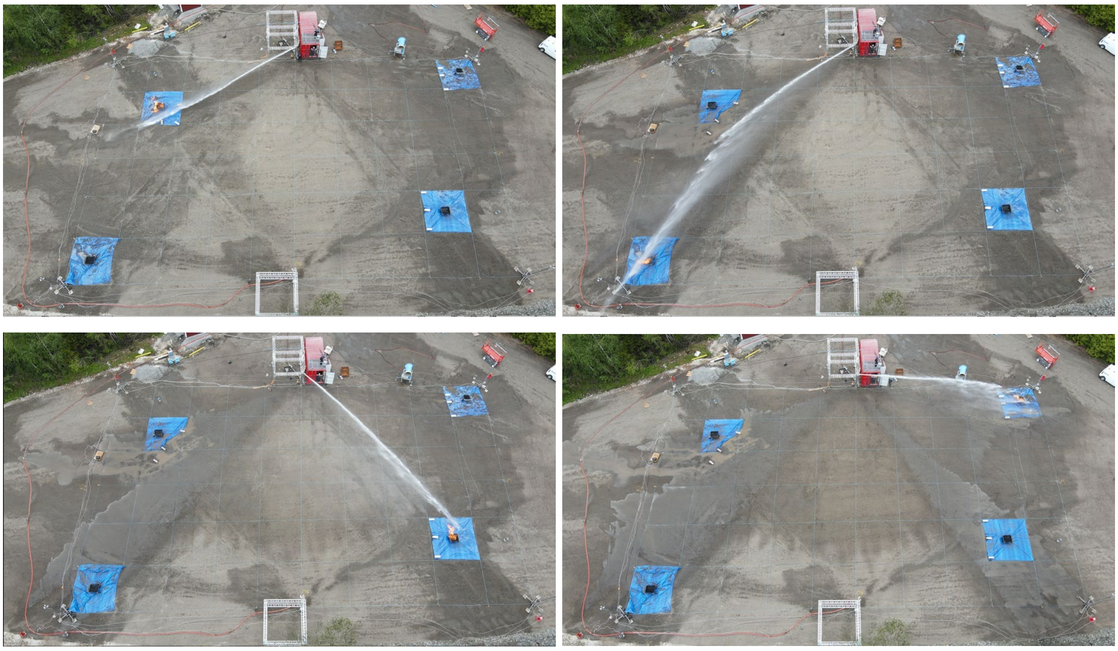
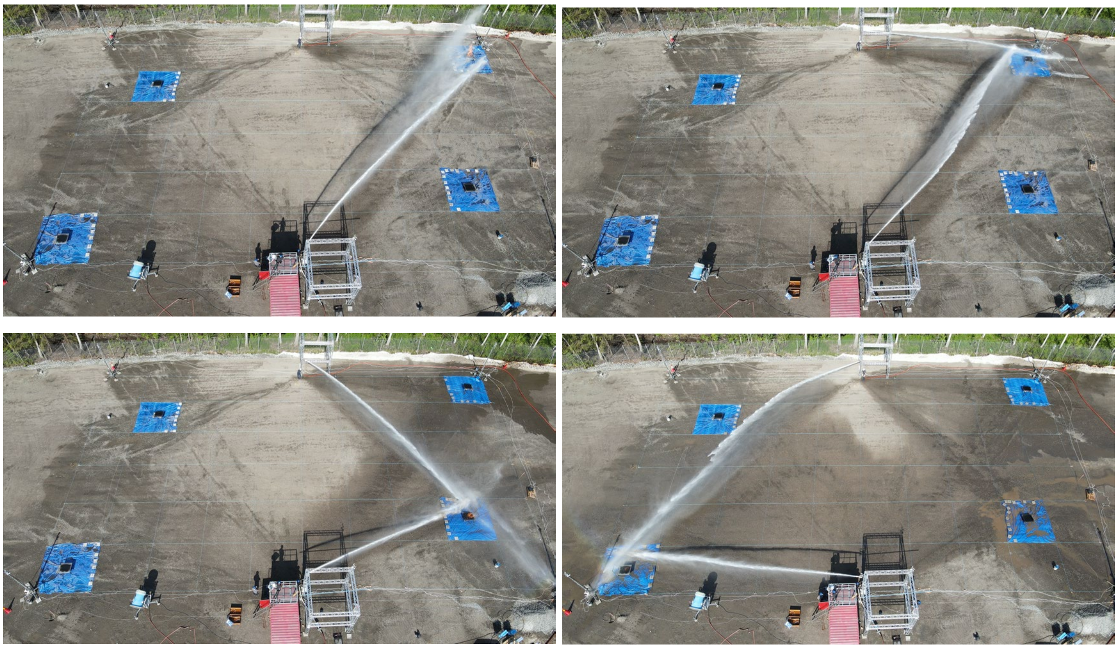


Figure 23. Sequential ignition of four fire test sources positioned symmetrically in the test area, using one autonomous system.



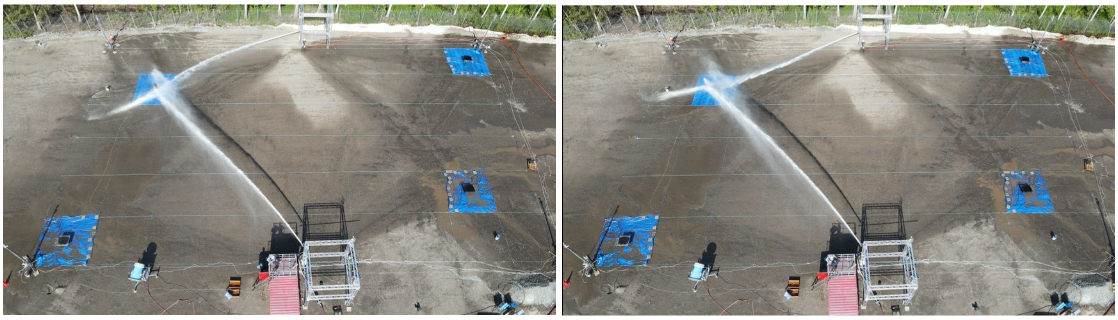


Figure 24. *Sequential ignition of four fire test sources positioned symmetrically on the test area, using two autonomous systems.*

Figure 25. *In one test, the snow cannon was perpendicularly positioned near the impact point using a relatively short monitor throw length. Break-up of the water stream was observed, but the reach of solid stream of water was not visually affected by the air velocities.*

Figure 26. In one test, the snow cannon was positioned near the impact point of the maximum monitor throw length, almost opposite to the stream of water. The throw length was reduced by between 5 m and 10 m. In addition, break-up of the water stream was observed.

Figure 27. In one test, the snow cannon was positioned near the impact point of the maximum throw length, at an angle of about 45°. Break-up of the solid water stream was observed.

Figure 28. Rain and fog were simulated using a fire hose stream of water directed into the air flow of the snow cannon. The intent was to test the possibilities for fire detection in such environment. Fire detection ability was not influenced.

8.12 Test results and conclusions

Fire detection occurred in less than 10 seconds, irrespective of the position of the fire test source. Rain and fog were simulated using a fire hose stream of water directed into the air flow of the snow cannon. Fire detection ability was not influenced.

The system was able to accurately determine the three-dimensional size and position of each of the fires and aim the water streams of the monitors to the fire location. The monitor oscillated over the fire to provide water over a larger area than that represented by the actual test fire. When the specific fire test source was turned off, and another ignited, the water streams were redirected towards that new fire location.

The detectors were positioned vertically 5 m above the surface of the ground (2 m above the fire monitors) and orientated towards the midpoint of the test area. The vertical height represents a clearance of 1 m above cargo. The data that was collected during the tests indicate that the precision of the detectors would improve using a higher elevation, but this was not tested.

For the tests with two systems (two individually operated monitors), the water streams from both monitors were directed towards the fire.

The water flow rates and pressures used (about 1 250 l/min at 5 bar) resulted in a throw sufficient to reach the corners of the test area, i.e., approximately 40 m.

The system also tested in simulated wind conditions. The reach of the solid water stream was not influenced by the generated wind using a shorter throw (approximately 20 to 30 m), but breakup of the stream was observed. Using a longer throw, the generated wind reduced the reach and breakup of the stream was observed. The use of a fog or cone spray pattern during the wind simulation proved ineffective due to the wind's effect. It should be emphasized that the tests conditions were limited to influence by wind over a small area of the water streams. In an actual case, wind will influence the whole water stream. To reduce the effect of wind conditions under actual conditions, it is recommended that any location on a ro-ro weather deck should be accessible by at least two monitors positioned at opposite sides of the deck. With this approach, it is likely that a fire anywhere on a deck would be relatively close to a monitor, which would improve fire suppression performance.

9 Large-scale fire monitor validation tests

A series of large-scale fire performance validation tests of selected weather deck fire-extinguishing systems (Task T10.7) was conducted at the outdoor test facility at RISE Fire Research AS, Trondheim, Norway during the period September 5 to 27, 2022.

9.1 The test area

The tests were conducted on an outdoor rectangular concrete slab. The surface area measures 40 m (L) by 30 m (W), which well reflects part of a weather deck. A central, transversal dike used for drainage of water extended the full width of the area. The width of the dike was 1,8 m, it was covered by a wire rack and the surface area was slightly sloped towards the drainage dike. Figure 29 shows an illustration of the test area and the arrangement of the tests.

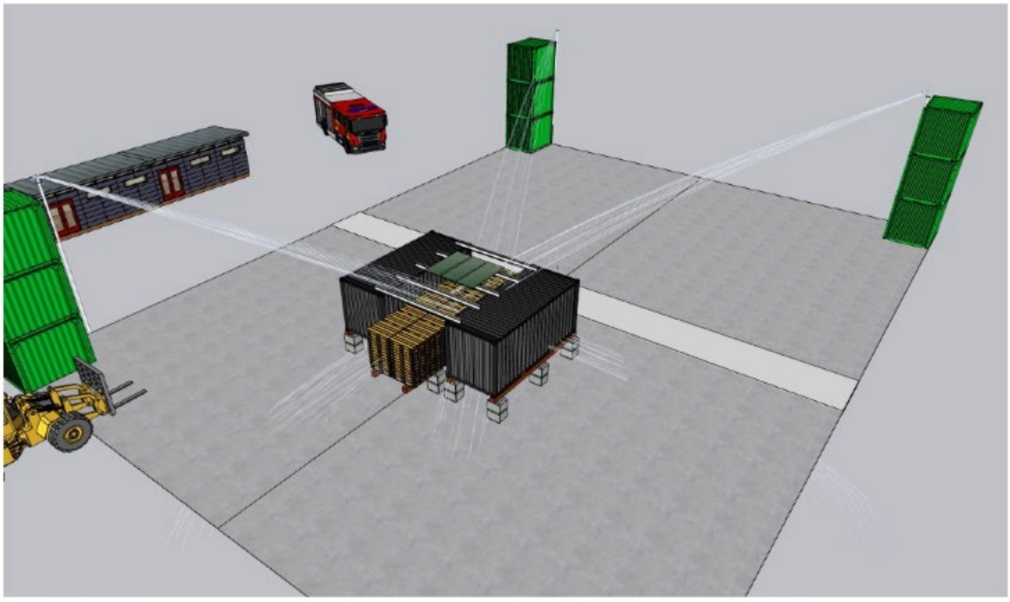


Figure 29. The test area and the principal arrangement of the tests. Illustration: UNF.

9.2 The fire test scenario

The fire test scenario simulated a fire in a freight truck trailer and consisted of a main array of stacked idle wood and plastic pallets, which was partly covered by a roof. Parallel with and 0,5 m to the sides of the main array, 20 ft. cargo containers were positioned to mimic the compactness of vehicles, trailers, and other cargo on a weather deck.

The main array contained 8 stacks (L) by 2 stacks (W) by 14 pallets (H) idle pallets. The bottom twelve pallets were made from wood and the top two pallets were made from plastic. The intent of having the plastic pallets at the top was to generate a fire scenario with plastic dripping down from the top, forming a spill of melted plastic that is associated with, for example, burning of tarpaulins on trailers. The overall height of a stack was nominally 2,06 m. Vertical wood studs supported each stack to improve the stability of the stacks during a test and facilitate handling before and after a test. The array consisted of 192 wood pallets and 32 plastic pallets, totaling 224 pallets.

EUR wood pallets nominally sized 1 200 mm (L) by 800 mm (mm) by 145 mm (H) were used. Each pallet had a nominal weight of 20 kg. The plastic pallets had an identical nominal footprint but had a height (H) of 160 mm and a nominal weight of 18,5 kg. The top deck of the plastic pallets was open, allowing water to flow through. The stacks of pallets were separated by a longitudinal and transversal flue space of 150 mm, respectively.

The overall size of the array was 7,45 m long, 2,55 m wide, and 2,06 m high.

The array was positioned on a platform made of construction steel and covered by nominally 2 mm steel plates, forming a solid deck. The platform was raised above the ground using concrete blocks, such that the solid deck was about 0,6 m above ground.

The centermost four stacks were covered by a roof sized 2,6 m wide by 1, 9 m long made of steel sheets. The intent of the roof was to prevent suppression or extinguishment of the initial fire, especially when using a short delay time from fire ignition to the application of the suppression agent. The vertical and horizontal supports of the roof were cooled by water circulating through the square iron structure. The vertical distance measured from the ground to the top of the roof and the tops of the surrounding cargo containers was about 3,15 m. The length of the cargo containers was less (nominally 6,1 m) than the overall array. Figure 30 shows the fire test scenario arrangement.

The longitudinal centerline of the main array was positioned 2,0 m offset to the longitudinal centerline of the test area and the rear end of the main array was positioned 4,2 m from the transversal centerline of the test area.

Figure 30. *The main array of stacked idle wood and plastic pallets, which was partly covered by a roof, with 20 ft. cargo containers positioned parallel with and 0,5 m to the sides.*

9.3 The fire monitor system

Three stacks of 8 ft. steel cargo containers were used to position the fire monitors above the ground. Each stack consisted of three containers, which resulted in an overall height of 6,7 m, refer to Figure 31. The stacks of containers were secured to each other using Twist locks, a device specifically designed to secure cargo containers, and the stability of the stacks was improved by heavy sandbags positioned inside the bottommost container.

Figure 31. One of the three stacks of 8 ft. steel cargo containers that were used to position the fire monitors above the ground. Each stack consisted of three containers, which resulted in an overall height of 6,7 m. The vertical distance measured from the ground to the inlet of a fire monitor was nominally 7,2 m.

A vertical 6 m tall stainless-steel standpipe was attached to the container. The pipe had an outer diameter of 60,3 mm, with a 2 mm wall thickness. The bottom end of the pipe had a 2" male BSP connection for a fire hose and the top end had a flange connection for a fire monitor. The fire hose connections were positioned about 1,5 m above ground, providing a smooth fire hose bend. The vertical distance measured from the ground to the inlet of a fire monitor was nominally 7,2 m.

One stack of containers was positioned at three of the four corners of the test area, refer to Figure 32. The fire monitors were designated as follows:

- Fire monitor A: At the North-East corner, diagonally 16,1 m from the center point of the main array;
- Fire monitor B: At the South-East corner, diagonally 28,5 m from the center point of the main array; and
- Fire monitor C: At the South-West corner, diagonally 30,5 m from the center point of the main array.

The fire monitors were connected to a water pump using large diameter (76 mm) fire hoses. Each line of fire hose had a water flow meter. The pump unit had a maximum capacity of 5 000 l/min at about 8 to 10 bar at the outlet of the pump. The inlet of the pump was connected to a large (60 m^3) tank filled with potable water.

Figure 32. The 40 m (L) by 30 m (W) test area with the positions of the fire monitors (A, B and C) and the fire test scenario set-up.

Each fire monitor (using water only) provided a nominal water flow rate of 1 250 l/min at a pressure at the inlet of the fire monitor of 5 bar. Consequently, the water flow rate using two fire monitors was 2 500 l/min.

Each fire monitor (using CAF) provided a water flow rate of 450 l/min at a nominal pressure at the inlet of the fire monitor of 5 bar. Consequently, the water flow rate using two fire monitors was 900 l/min.

9.4 Instrumentation and measurements

The surface temperature at each of the 20 ft. cargo containers was measured. A total of 21 thermocouples were evenly distributed over the long side facing idle pallet array, refer to Figure 33. The thermocouples were spot-welded to the container walls, with the metal surface being sanded prior to the attachment.

The surface temperature of a Plate Thermometer (P/T), positioned inside each of the 20 ft. cargo containers was measured. Each device was positioned a vertical distance of 100 mm from the container wall facing the idle pallet array. In height, the P/T was positioned at the location and height of the surface thermocouple at mid-height of the container wall, facing the point of fire ignition.

In addition to these measurements, the water flow rate of each fire monitor and the water pressure at the inlet of each fire monitor were measured.

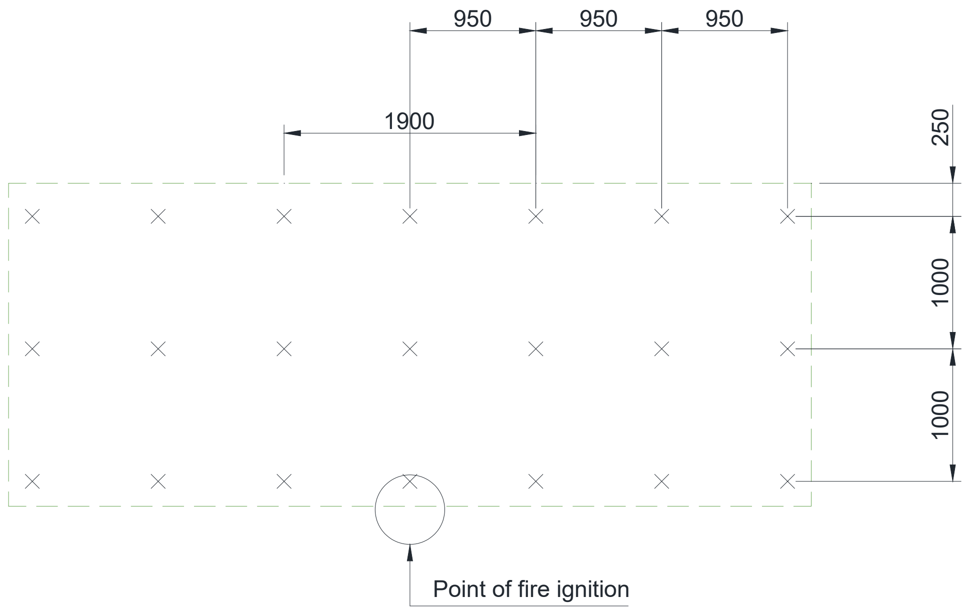


Figure 33. A drawing with the locations of surface temperature measurements on the cargo container walls that were facing the main array, i.e., the fire. Dimensions are in mm.

Table 2 provides a list of the surface temperature measurement channels.

Table 2. The surface temperature measurement channels on the cargo container walls facing the main array.

Column with thermocouples	**Position of thermocouple**	**Container to the right (East) of the main array**	**Container to the left (West) of the main array**
		Channel	**Channel**
First column (front)	Top	1	22
	Middle	2	23
	Bottom	3	24
Second column	Top	4	25
	Middle	5	26
	Bottom	6	27
Third column	Top	7	28
	Middle	8	29
	Bottom	9	30
Fourth column	Top	10	31
	Middle	11	32
	Bottom	12	33
Fifth column	Top	13	34
	Middle	14	35
	Bottom	15	36
Sixth column	Top	16	37
	Middle	17	38
	Bottom	18	39
Seventh column (rear)	Top	19	40
	Middle	20	41
	Bottom	21	42

During the evaluation of the fire test results a mean surface temperature of all measurement points on each of the walls and the measurement points involving centermost three columns of thermocouples was calculated. The latter measurement points are grey marked in the table and resulted in a higher calculated mean value than the mean value that involved all measurement points. Therefore, the mean value based on the centermost three columns of thermocouples was used when comparing individual tests.

9.5 Fire test program

The system parameters that were explored were water only vs. foam, the delay time from the start of the fire until the start of application of water or foam, thereby simulating autonomous system activation vs. mechanically controlled operation, application with two fire monitors (main approach) vs. application with one single fire monitor, and the application angle, using three different pairs of fire monitors.

Table 3 shows the fire test program.

Table 3. The fire test program.

Test	Date	Agent	No. of fire monitors	Total nominal flow rate (l/min)	Monitors used	Time to application of agent
1	September 13, 2022	Water	2	2 500	A + C	Early
2	September 14, 2022	Water	1	1 250	C	Early
3	September 15, 2022	CAF	2	900	A + C	Early
4	September 16, 2022	CAF	1	unknown	C	Late
5	September 19, 2022	Water	1	1 250	C	Late
6	September 21, 2022	Water	2	2 500	A + C	Late
7	September 22, 2022	Water	2	2 500	B + C	Late
8	September 22, 2022	Water	2	2 500	A + B	Late

9.6 Fire test procedures

Prior to the tests, the moisture content of 10 randomly selected wood pallets positioned under the roof of the array were measured with a probe type moisture meter and documented. When the weather was rainy, the stacks outside of the roof were covered by tarpaulins that were removed shortly before the tests. However, during the period of testing, weather conditions were good with little rain and wind, which necessitated coverage of the stacks of pallets in just a few tests.

Figure 34 shows the measured moisture content of individual pallets prior to each test. The mean value varied from 12,4 % to 14,7 %. The mean value for all wood pallets in the tests was 14,0 %.

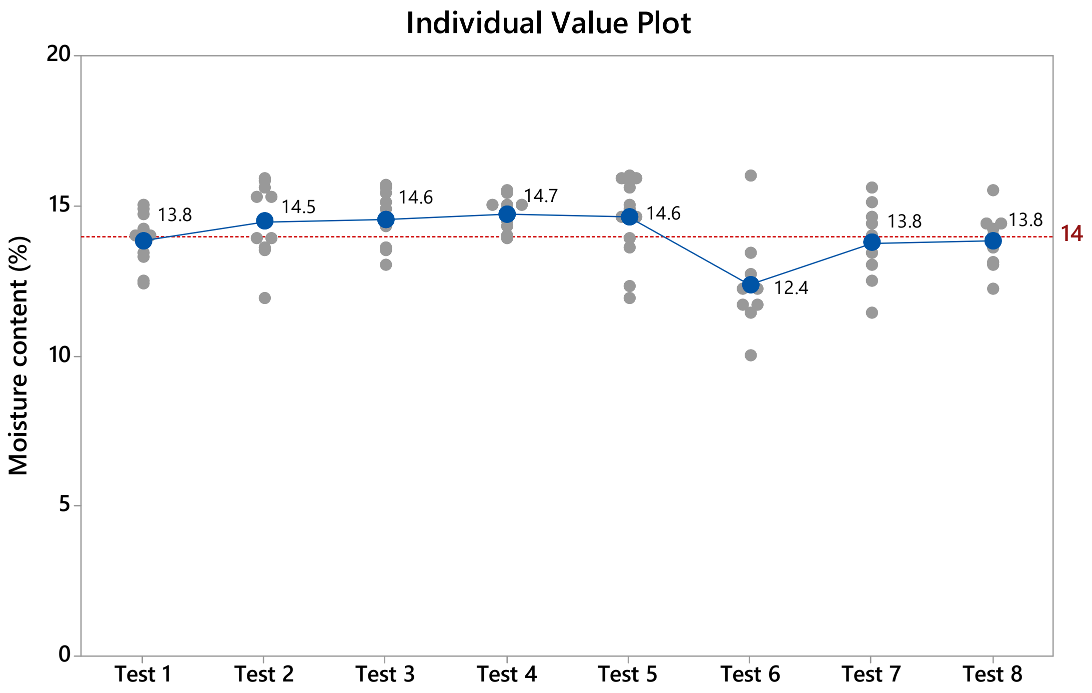


Figure 34. The measured moisture content of randomly selected individual pallets prior each test.

The fire was initiated using a fire tray sized 1200 mm (L) by 150 mm (W) by 150 mm (H) filled with 20 mm (3,6 l) of heptane on a 20 mm layer of water (3,6 l). The heptane fuel on the tray was ignited by a torch. The fire tray was positioned at the deck of the platform and symmetrically between the centermost transversal flue space of the main array of pallets, i.e., the fire ignition was at the mid-point of the array.

The fire was allowed to develop until sustained flames above the top of the pallet array were visually observed by the test engineer. Thereafter, a 30 s or 300 s delay time was applied before the application of water or CAF was initiated. The shorter delay time was designed to simulate an autonomous system activation, the longer delay time simulated remotely-control operation by the ship crew.

The fire monitors operated in a pre-determined oscillation pattern that was similar in all the tests, independent of the other test conditions in terms of delay time, number of fire monitors, or the agent used. The intent of this approach was to allow comparison of the other test parameters that were varied.

9.7 Fire test observations

Test 1: The first test was conducted with water, using two fire monitors (A and C) positioned diagonally to each other and with an early application, refer to Figure 35. The fire was almost immediately suppressed but continued to burn, shielded by the application of water. A small fire was manually extinguished using fire hose streams when the test was terminated after 30 min.

Figure 35. ***Test 1****: The application of water from fire monitors A and C, positioned diagonally to each other.*

The fire damage was limited to the central core of the four stacks of pallets under the roof, refer to Figure 36.

*Figure 36. **Test 1**: The fire damage documented after the test.*

Test 2: The second test was conducted with water, using one single fire monitor (C) and early application of water, refer to Figure 37. The fire remained burning, despite the oscillation of the water spray on the main array and the adjacent cargo containers, due to the shielding effect of the roof. After about 12 minutes of application, the fire size decreased, with flames visible only at the east side of the main array, diagonal to the application direction of water. A minute later, the flames were very small, flickering above the top edge of the stacks. After about 15 minutes of application, flames were hardly visible. The fire was virtually completely extinguished at the termination of the test.

Figure 37. ***Test 2****: The application of water from fire monitor C, positioned at the South-West corner of the test area at a horizontal distance of 30,5 m from the center point of the main array.*

Compared to Test 1, fire damage was larger, but the application of water prevented fire spread beyond the area under the roof, refer to Figure 38.

*Figure 38. **Test 2**: The fire damage documented after the test.*

Test 3: The third test was conducted with CAF, using two fire monitors (A and C) and early application of the agent, refer to Figure 39. It was initially observed that the throw of the fire monitor (fire monitor C) positioned the furthest from the fire did not reach the fire. However, the fire was suppressed by the application of CAF from the fire monitor closest (fire monitor A) to the fire within a minute, primarily by extinguishing the fire in the ignition tray. The system operating pressure was gradually increased from about 4,5 bar. After about 02:20 [min:s] from the start of application, the throw of both fire monitors reached the main array and the adjacent cargo containers and the system operating pressure approached 8 bar. Flames were observed at about 03:00 [min:s], but shortly thereafter the fire appeared to be fully extinguished. The application of CAF was terminated after five minutes, and it was confirmed that the fire had been extinguished. Fire damage was small, and concentrated to the central, transversal flue space where the fire was started. It was, however, concluded that the visual quality of the foam was not sufficient and did not look like CAF. The probable reason was that the air pressure in the foam generator was too low.

Figure 39. ***Test 3****: The application of CAF from fire monitors A and C, positioned diagonally to each other. It was initially observed that the throw of the fire monitor (C) positioned the furthest from the fire did not reach the fire, but the fire was suppressed by the application of CAF from the fire monitor (A) closest to the fire within a minute, primarily by extinguishing the fire in the ignition tray. After about 02:20 [min:s] from the start of application, the throw of both fire monitors reached the main array.*

Fire damage to the array of pallets were minor, refer to Figure 40.

Figure 40. ***Test 3****: The fire damage documented after the test.*

Test 4: The fourth test was conducted with CAF, using one single fire monitor (C) and late application of the agent, refer to Figure 41. The test was terminated at about 19:45 [min:s], by discharging water from fire hoses and a fire monitor not used in the tests. The reason the test was stopped was that no or limited quantities of CAF reached the seat of the fire. This could be due to the foam characteristics, i.e., that the foam was too light (too 'dry') to penetrate the hot fire plume and flames or that the foam flow rate was too low, refer to Figure 42. It is likely that the insufficient performance was a combination of the two. In any case, the decision was taken to discontinue the testing with CAF and focus the remaining tests on exploring the fire suppression performance using water only.

Figure 41. ***Test 4:*** *The initial application of CAF from fire monitor C.*

Figure 42. ***Test 4:*** *The application of CAF from fire monitor C as seen from different viewpoints at approximately the same time. The foam did not reach the seat of fire, which reduced the fire suppression performance.*

Figure 43 shows the fire damage to the stacks of pallets.

Figure 43. ***Test 4****: The fire damage documented after the test, as seen from the side not facing the fire monitor.*

Test 5: The fifth test was conducted with water, using one single fire monitor (C) and late application of water, refer to Figure 44 to Figure 48. The test is directly comparable to Test 2, where water was applied at an early stage.

Figure 49 shows the fire damage.

Figure 44. ***Test 5****: The fire size moments before the application of water from fire monitor C, positioned at the South-West corner of the test area, i.e., the fire monitor at the background of the photo. Fire monitor A is observed in the foreground.*

Figure 45. ***Test 5****: The application of water from fire monitor C, positioned at the South-West corner of the test area at a horizontal distance of 30,5 m from the center point of the main array.*

Figure 46. ***Test 5****: The application of water from fire monitor C, as seen from another viewpoint.*

Figure 47. ***Test 5****: The fire size about 2 min after the start of the application of water, as seen from the fire monitor C.*

Figure 48. ***Test 5****: The fire size about 3 min after the start of the application of water.*

Figure 49. ***Test 5****: The fire damage documented after the test, as seen from the side facing the fire monitor.*

Test 6: The sixth test was conducted with water, using two fire monitors (A and C), positioned diagonally to each other and with a late application. Figure 50 shows the fire size at the start of water application and Figure 51 shows the fire size 30 s later. The test is directly comparable to Test 1 where water was applied at an early stage.

Figure 50. ***Test 6:*** *The fire size at the start of water application using fire monitors A and C, positioned diagonally to each other, as seen from two different viewpoints.*

Figure 51. ***Test 6:*** *The fire size 30 s after the start of water application using fire monitors A and C, as seen from two different viewpoints.*

Test 7: The seventh test was conducted with water, using two fire monitors (B and C), positioned at the south short-side corners of the test area, with a late application. At the application of water, the top pallets on the whole array were burning with extensive flames. The fire was rapidly suppressed and the test was terminated after 10 min. Figure 52 to Figure 56 shows the course of events.

Figure 52. ***Test 7****: The initial application of water from fire monitors B and C positioned at the south short-side corners of the test area.*

Figure 53. ***Test 7****: The fire size a few seconds after the initial application of water from fire monitors B and C positioned at the south short-side corners of the test area.*

Figure 54. ***Test 7****: Almost immediate fire suppression was observed.*

Figure 55. ***Test 7****: The application of water from fire monitors B and C after fire suppression.*

Figure 56. ***Test 7****: A close-up photo of the application of water from fire monitors B and C after fire suppression.*

Fire damage primarily involved the top pallets of the array, refer to Figure 57.

*Figure 57. **Test 7**: The fire damage documented after the test.*

Test 8: The eighth test was conducted with water, using two fire monitors (B and C), positioned at the corners of the east long side of the area, with a late application. The fire was rapidly suppressed, and the test was terminated after 11 min. Figure 59 and Figure 60 show the course of events.

*Figure 58. **Test 8**: The initial application of water from fire monitors A and B positioned at the east long-side corners of the test area.*

Figure 59. ***Test 8****: The initial application of water from fire monitors A and B positioned at the east long-side corners of the test area.*

Figure 60. ***Test 8****: Immediate fire suppression was observed.*

Fire damage primarily involved the top pallets of the array, refer to Figure 61.

Figure 61. ***Test 8****: The fire damage documented after the test.*

9.8 Fire test results

The influence of the use of one vs. two fire monitors when water was applied early, i.e., 30 s after sustained flames were observed above the array, is compared in Test 1 and Test 2, refer to Figure 62. It is observed that the mean surface temperature on the cargo container east of the main array was higher when one fire monitor (Test 2) was used. For the cargo container west of the main array, the surface temperatures were comparable. It is probable that the application angle associated with the single fire monitor (C) used in Test 2 directed the flames towards the cargo container to the east. The temperature levels are, however, not critically high in any of the tests.

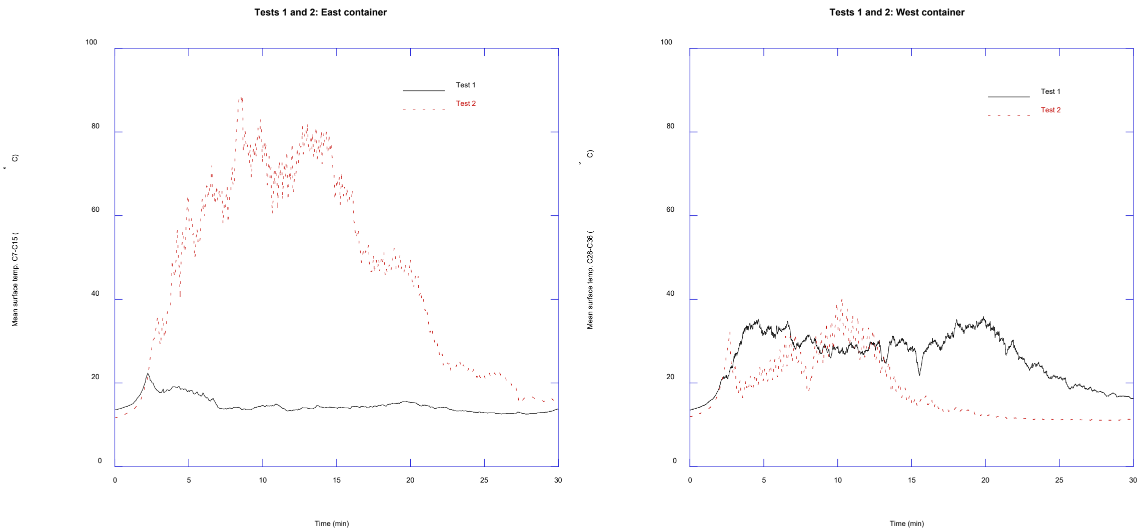


Figure 62. ***Tests 1 and 2****: The impact of the use of one vs. two fire monitors when water was applied early. Note: The temperature scale on the y-axis is significantly different than that of the tests discussed below as the surface temperatures were low.*

Test 1 and Test 6 offer a comparison of the performance of two fire monitors (A and C) with an early (Test 1) and late (Test 6) application of water, refer to Figure 63. The results of the tests show not only the importance of an early application, but also the rapid reduction of the surface temperatures once water was applied.

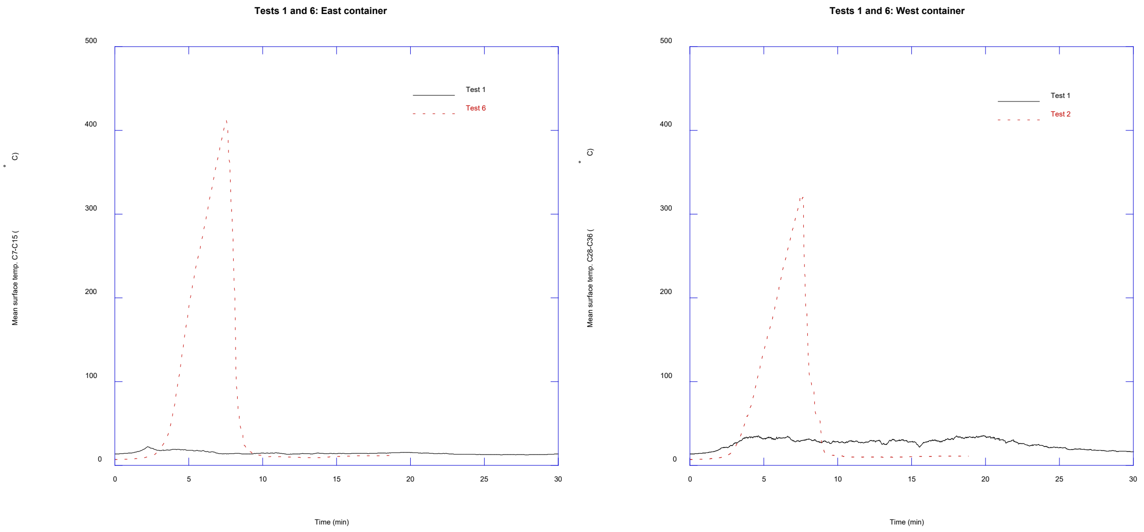


Figure 63. ***Tests 1 and 6****: The results with an early (Test 1) and late (Test 6) application of water.*

Test 2 and Test 5 offer a comparison of the performance of a single fire monitor (C) with an early (Test 2) and late (Test 5) application of water, refer to Figure 64. The results not only show the importance of an early application, but also the rapid reduction of the surface temperatures once water was applied at a late stage.

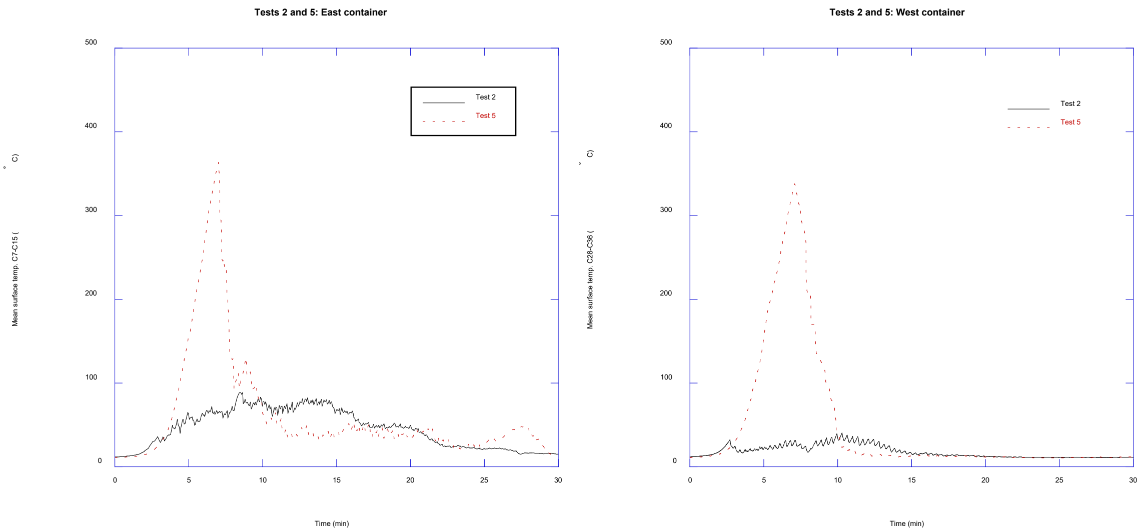


Figure 64. ***Tests 2 and 5****: A comparison of the performance of a single fire monitor (C) with an early (Test 2) and late (Test 5) application of water.*

Test 3 and Test 4 were conducted using the CAF system. In Test 3, foam was applied early from two fire monitors (A and C) and in Test 4 the application was late and from one single fire monitor (C), refer to Figure 65. These tests are therefore not directly comparable; however, they illustrate the performance when foam reached the fire (immediate fire suppression and extinguishment) and when it did not (no fire control). It should, however, be noted that the quality of the foam in both tests was not consistent and did not resemble that of CAF.

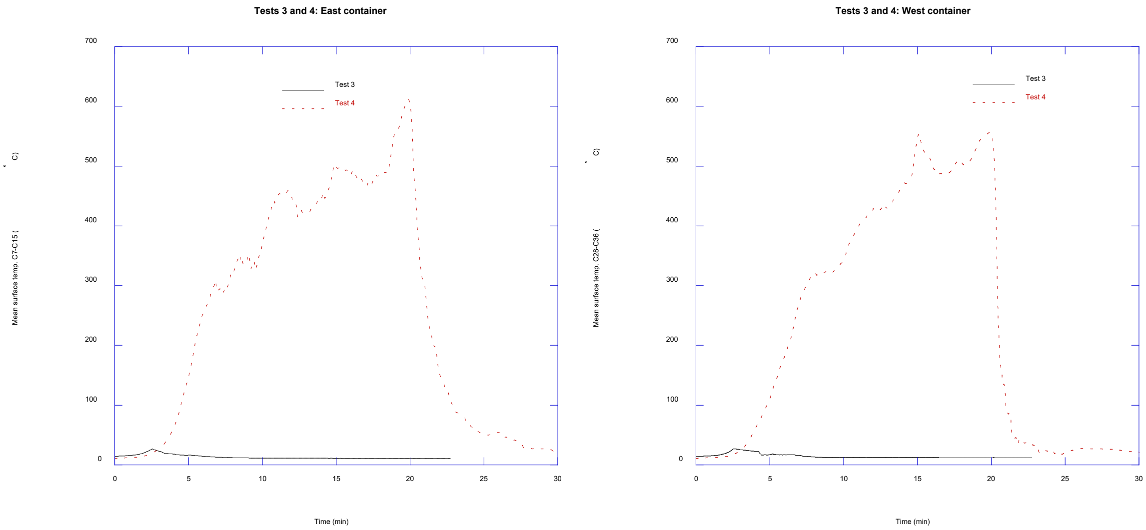


Figure 65. ***Tests 3 and 4****: The two tests with the CAF system. In Test 3, foam was applied early from two fire monitors (A and C) and in Test 4 the application was at a late stage and from one single fire monitor (C).*

Tests 6, 7 and 8 were conducted with two fire monitors (A and C, B and C as well as A and B) and late application of water, refer to Figure 66. These tests therefore offer the possibility to compare the performance due to the application angle. The conclusion is that the fire suppression performance was insignificantly influenced by which pair of fire monitors that were used.

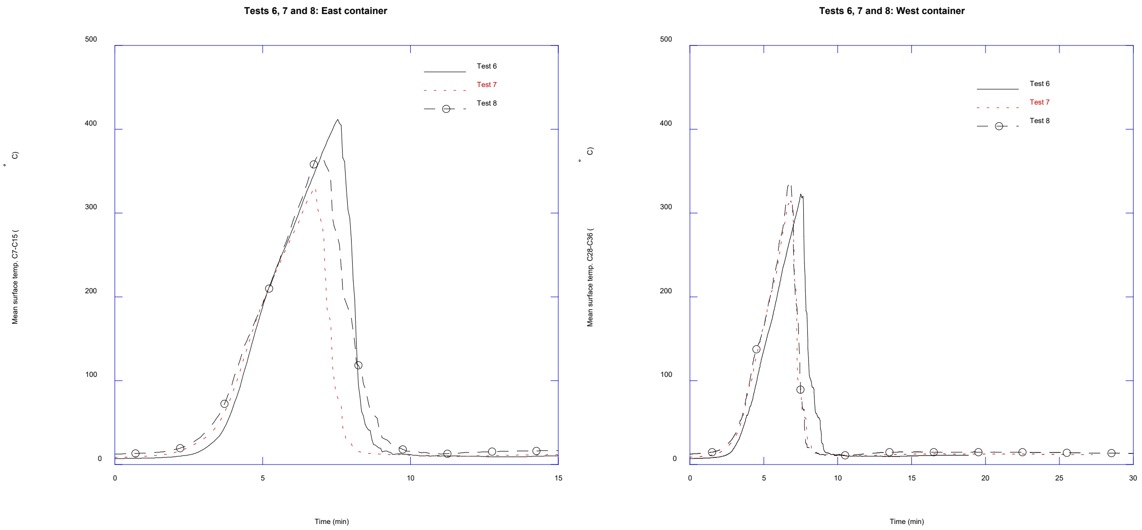


Figure 66. ***Tests 6, 7 and 8****: A comparison of using two fire monitors (A and C, B and C as well as A and B) and late application of water. These tests therefore offer the possibility to compare the performance due to the application angle.*

9.9 Overall conclusion

These validation tests proved the fire monitor system concepts described in the draft design and installation guidelines. The system concepts in these guidelines are built on a philosophy of strategically positioned smaller sized fire monitors with moderate water flow rates, 1 250 l/min per fire monitor. Under normal weather conditions, the objective is that a fire starting at any point on a weather deck should be reached by two streams of water or foam to provide prompt fire suppression. This fire protection objective was fulfilled in the tests.

Abnormal weather conditions, such as heavy wind, may influence the possibilities to reach a fire from two application angles. This scenario was simulated by using a single fire monitor in the tests. It was demonstrated that even a single fire monitor can provide fire suppression given that the water reaches the fire.

The time from the start of a fire to the application of water is a critical factor as fires on a weather deck grow both in size and intensity extremely quickly, and ro-ro ships typically must be self-reliant on their fire safety systems. The time to application, counted from presence of visual flames above the stacks of pallets, was chosen to reflect an autonomous system (30 s delay time) as well as a remotely controlled system operated by the crew members (300 s delay time). It was demonstrated that early application of water will prevent a fire from growing large and provide efficient cooling of surrounding trailers. When the application of water was delayed, the fire was significantly larger in size, but was still suppressed.

Two fire tests designed to use CAF instead of water were conducted. It was observed, however, that the quality of foam was not as good as expected. The first test that utilized two fire monitors and an early application of the foam was successful. In the second test, one single monitor was used with a delayed application of foam. For this scenario, no fire control was achieved. The reason for the unsuccessful results was that no or limited quantities of foam reached the seat of the fire. This could be due to the foam characteristics, i.e., that the foam was too light (too ‘dry’) to penetrate the hot fire plume and flames or that the foam flow rate was too low. It is likely that the insufficient performance was a combination of the two. For this reason, the test results should not be seen as evidence that CAF does not work for this application. Rather, it does show that there are many parameters that are important for a successful result and these complexities should be taken into consideration.

It should also be understood that a foam agent of any other type of fire suppression enhancing additive could be used with water where the foam is expanded at the fire monitor nozzle (non-aspirating nozzle). Although this was not specifically tested, an additive may improve fire suppression performance beyond what was experienced in the tests, for example, related to fire suppression of flammable liquid spill fires.

10 Installation cost assessments

Main authors of the chapter: Magnus Arvidson, RISE, Mattias Eggert, UNF and Martijn Teela, F4M.

10.1 General

A fire monitor system on a ship consists of the following parts:

- A water supply source, where water initially is supplied from the freshwater tank of the ship and later (if needed) from a seawater connection;
- A water pump, driven by an electrical motor. The power supply is from the main power source of the ship;
- A valve with an electric actuator that can be opened and closed by the fire monitor's control system;
- Water distribution piping arranged on either long side of the ship, with connections to the individual fire monitors;
- Strategically positioned fire monitors that are installed either on the superstructure of the ship or on separate supports to achieve the necessary elevation above deck flooring; and
- One or more means of remotely controlling the fire monitor, such as a joystick, radio remote-control and/or manual control panel.

A system using fire monitors for CAFS needs the following additional components:

- A foam agent tank
- The foam agent (concentrate)
- A direct-injection foam proportioning system on the discharge side of the pump
- An air compressor and control systems to ensure the correct mixes of foam concentrate, water, and air
- Distribution piping system hydraulically designed for a flow of finished foam
- Fire monitors specifically designed for the discharge of CAF

For an autonomous system, the following additional components and functions are required:

- A fire detection system (for each of the fire monitors) with strategically positioned fire detectors that provide an unobstructed view over the weather deck. The fire detectors are installed either on the superstructure of the ship or on separate supports to achieve the necessary elevation above deck flooring; and
- A PLC with associated software.

10.2 The generic ship

An installation cost assessment of the system technologies that were developed was undertaken, based on a reference ship selected by the project, Magnolia Seaways, operated by DFDS. Refer to Figure 67 and Figure 68, respectively.

Figure 67. The reference ship for the cost assessments, Magnolia Seaways operated by DFDS.

Figure 68. A view of the forward weather deck on Magnolia Seaways.

The overall length of the ship is 199,80 m and the width 26,50 m. The weather deck on the ship extends through a superstructure where positioning of fire monitors is not possible, however, this area is protected by a deluge water spray ('drencher') system. The drencher system is manually activated by starting two fire pumps and opening the relevant deluge valve, refer to Figure 69. The weather deck can store a maximum of 83 pcs of 14 m long trailers and the total lane meters is 1 272 m.

The weather deck contains eight parallel lanes; the maximum lane length is 180,0 m ('Lane no. 4W') and the shortest lane is 27,6 m ('Lane no. 1W').

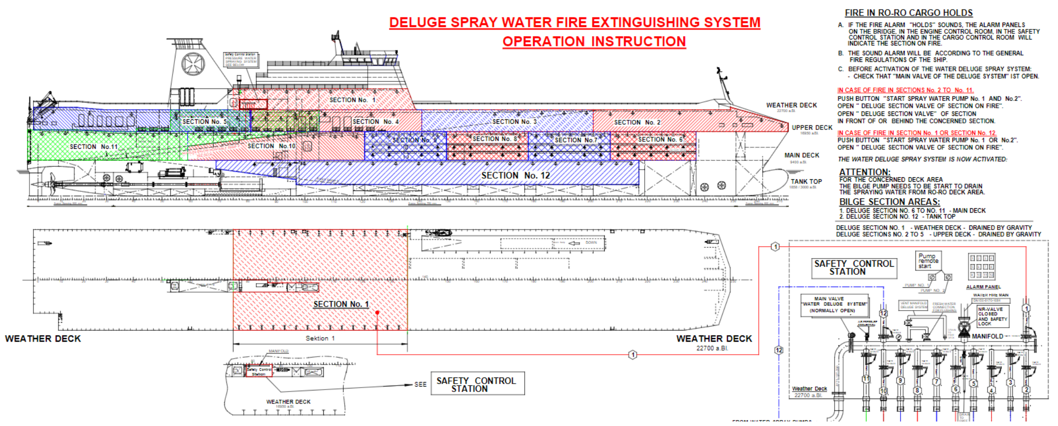


Figure 69. The weather deck on Magnolia Seaways, with the deluge water spray system protecting the deck area under the superstructure.

Two freshwater tanks are available on the ship, one having a maximum capacity of 51,5 m^3 and one having a capacity of 75,6 m^3.

10.3 Cost assessment assumptions

The following assumptions were made for the cost assessment:

- 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;
- The fire monitor system is connected to one of the freshwater tanks. This allows the piping to be flushed with freshwater (after any testing or training), to avoid stagnant sea water in the pump and piping;
- A fire may occur such that simultaneous operation of the drencher system under the superstructure and the intended fire monitor system is necessary. Therefore, a dedicated water pump for the fire monitor system is required;
- The water pump is driven by an electrical motor that is connected to the main electrical power supply of the ship;
- The water pump is designed for a total water demand of 2 500 l/min at 10 bars, providing a minimum flow rate of 1 250 l/min simultaneously to each of the two hydraulically most remote fire monitors; and
- Three fire monitors are to be installed on the aft weather deck area of the ship and two fire monitors on the front weather deck area, i.e., a total of five fore monitors are to be installed.

Figure 70 shows the assumed system layout.

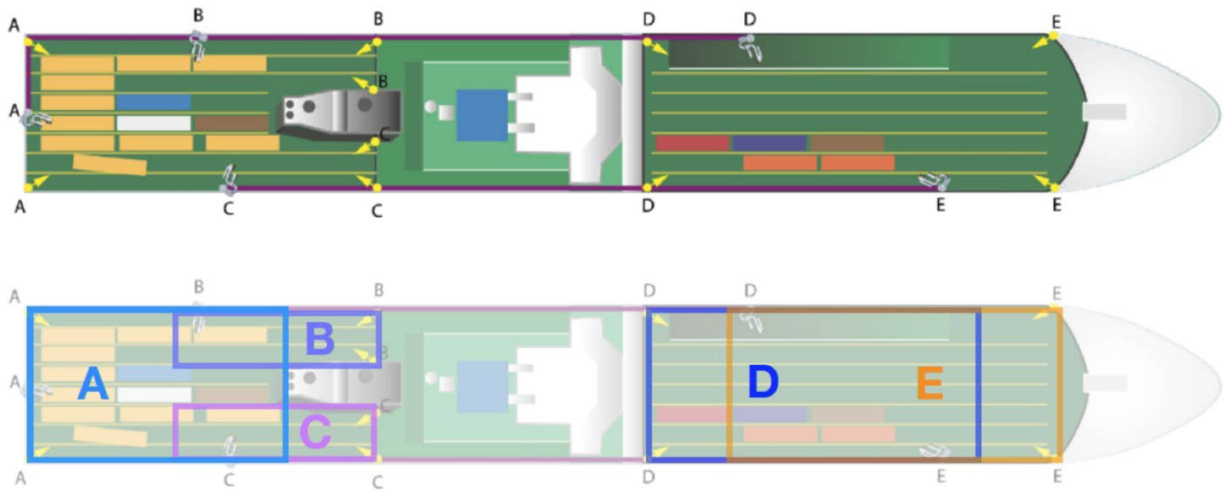


Figure 70. The layout of an autonomous fire monitor systems on the weather deck on Magnolia Seaways, with the positions of the monitors and the fire detectors.

The costs are based on price levels in 2021.

10.4 Cost assessment results

10.4.1 Remote-controlled fire monitor system (water only)

The remote-controlled fire monitor system is comprised of a DN50 (2") fire monitor chassis made of SS-316L or equivalent with 24V direct current (DC) BLDC motors or equivalent, an adjustable jet/spray firefighting monitor nozzle tip with 24V BLDC motor or equivalent, a programmable logic controller PLC in an IP66 cabinet with built-in power converter, a DN50 (2") electric valve and actuator, a joystick, a joystick cable, and fire monitor cable kit. Each fire monitor will be mounted on a stable support. The entire system will be supplied with piping running from the water pump to each of the fire monitors.

Table 4 lists the approximate costs of five sets of fire monitors meeting the above criteria.

Table 4. The approximate installation cost for five sets of remote-controlled fire monitors (water only) on Magnolia Seaways.

Components	**Cost (€)**
Water pump unit, 2 500 l/min @ 10 bar and related equipment	€ 25 000
DN150 piping (estimated 300 m)	€ 12 500
DN150 couplings	€ 4 500
Pipe supports or hangers	€ 1 500
Pipe stands for fire monitors (5 pcs)	€ 3 000
5 pcs of DN50 (2") fire monitors with a maximum capacity of 2 000 l/min at 10 bars. The monitors are made from SS-316 L have a stepless jet/spray tip, with high precision movement and position feedback. Remote-control via a PLC with joystick. Electric valve and actuator and system cable kit.	€ 75 000
Subtotal:	€ 121 500
Labour and installation costs	
Design, engineering, and workshop drawings by the system component suppliers of fire monitors and pumps and by the shipyard	€ 15 000
Installation of pump unit	€ 1 000
Installation of DN150 stand-pipe and distribution pipe (1 hour per meter)	€ 7 500
Installation of pipe stands	€ 1 000
Commissioning	€ 3 000
Operator training cost	€ 1 000

Components	Cost (€)
Subtotal:	<u>€ 28 500</u>
Total:	**€ 150 000**

10.4.2 Autonomous fire monitor system (water only)

In addition to the fire monitor equipment set out in the previous section, a fully autonomous fire monitor system will additionally require one or more fire detectors for each fire monitor, cables from that (or those) detector(s), as well as specialized electronic hardware and software to achieve the autonomous function.

Table 5 provides an estimation of the additional costs associated with the fire detectors and associated equipment to achieve fully autonomous function, while preserving the ability of an operator to remote-control each of the fire monitors.

Table 5. The approximate cost for the additional components and labour for autonomous fire monitor functionality for an installation on Magnolia Seaways.

Additional components (for five systems)	Cost (€)
Fire detectors and fire detector cabling	€ 21 000
Control room, for fire detection processing	€ 4 000
Software and license for processing inputs from fire detection system and autonomous guidance of monitor and nozzle tip	€ 13 000
Subtotal:	<u>€ 38 000</u>
Additional labour and installation costs (for five systems)	
Shipyard installation costs per suppliers' instructions	€ 1 000
Remote commissioning by suppliers	€ 2 500
Subtotal:	<u>€ 2 500</u>
Total:	**€ 40 500**

It is important to note that an autonomous fire monitor system, while more expensive in terms of up-front equipment costs, has the potential of dramatically reducing the time to detect and commence suppression of a fire on the weather deck. This rapid response is likely to substantially decrease the fire and smoke damage to vehicles, cargo and other objects on the weather deck, damage to the ship, and possibly to crew and passengers.

Moreover, an autonomous fire monitor system, by rapidly detecting and commencing suppression of a fire on a weather deck, is very likely to reduce the release of toxic smoke and particulates into the air and into the water run-off into the sea, resulting in less damage to the environment.

While it is difficult to assess the potential savings in terms of equipment costs, injuries or other harm to crew and passengers and harm to the environment, it is reasonable to assume that the overall benefits of having an automatic fire monitor system outweigh the additional up-front equipment costs, perhaps by a substantial factor.

It is anticipated that the cost of the additional components necessary for fully autonomous functionality (e.g., fire detectors and electronic hardware and software) will significantly decrease over time and therefore become increasingly economical and closer to the cost of remote-control fire monitors that do not have autonomous functionality.

10.4.3 Fire monitor system using CAF

The costs for adding a CAF system to a water only fire monitor system are mainly related to the CAFS generating unit. This includes the mixing chamber, a foam dosing system, and controls to manage the water to air ratio. The estimated cost for these additional components is given in Table 6.

To be able to use the fire monitors with both CAF and with water only it is required to have a water pump designed for water only. This way the water pump is always able to provide enough water to create the CAF. The CAF system should be large enough to supply foam to at least two monitors simultaneously. The fire monitors are assumed to be of a smooth bore type nozzle or straight piece of pipe to maintain the quality of the foam that is discharging through the nozzle.

Table 6. The approximate additional installation costs for a CAF system on Magnolia Seaways.

Additional components	**Cost (€)**
CAFS unit with mixing chamber and dosing system MC2000	€ 90 000
Air compressor	€ 50 000
Construction steel + equipment for CAFS equipment deckhouse	€ 5 000
Subtotal:	€ 145 000
Additional labour and installation costs	
Shipyard installation costs per suppliers' instructions	€ 5 000
Remote commissioning by suppliers	€ 3 000
Subtotal:	€ 8 000
Total:	**€ 152 000**

It is important to note that this is the additional cost for a CAFS unit. The cost for a water pump, piping, and fire monitors is calculated above and given in Table 3.

10.4.4 Estimation of system weights

Based on the individual weight and number of components used for a system installation, the overall weight of each of the three systems described (water only, autonomous water only, and CAF) was estimated, refer to Table 7. It is assumed that lightweight steel piping is used.

Table 7. The estimated weight of the components used for the three systems, for an installation on Magnolia Seaways.

Components	**Estimated weight (kg)**
Water pump unit, 2 500 l/min @ 10 bar and related equipment	300 kg
DN150 piping (estimated 300 m)	3 600 kg
DN150 couplings	200 kg
Pipe supports or hangers	200 kg
Pipe stands for fire monitors (5 pcs)	2 500 kg
5 pcs of DN50 (2") fire monitors	100 kg
Miscellaneous components as the PLC	100 kg
Subtotal:	7 000 kg
Additional weight for autonomous fire monitor functionality	
Fire detectors and fire detector cabling	50 kg
Subtotal:	50 kg
Additional weight for CAFS components	
CAFS unit with mixing chamber and dosing system MC2000	900 kg
Air compressor	1 900 kg
Subtotal:	2 800 kg

From this estimate, it is concluded that the overall weight for a remote-controlled fire monitor system is on the order of 7 tons. The main mass of the system relates to the piping, couplings and pipe supports as well as the pipe stands. The additional weights of the components required to upgrade to an autonomous fire monitor functionality is small.

The use of a CAF fire monitor system adds about 2 800 kg to the overall weight of a system.

11 Cost assessments for system inspections, testing, and maintenance

Main author of the chapter: Magnus Arvidson, RISE, Mattias Eggert, UNF, and Martijn Teela, F4M.

11.1 General

Inspections, testing and maintenance of fire protection systems and appliances are required in accordance with SOLAS Chapter II-2/14.2.2 [3]:

"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 firefighting 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 consider MSC.1/Circ. 1432 [24] and MSC.1/Circ. 1516 [25] as minimum guidelines on which such inspections are to be based. MSC.1/Circ. 1432 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 provides the minimum recommended guidance. The guidelines may be used as a basis for the ship's onboard maintenance plan required by SOLAS regulation II-2/14. MSC.1/Circ. 1516 includes amendments to MSC.1/Circ. 1432.

Table 8 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 8. Overview of inspections, testing and maintenance of main firefighting systems based on MSC.1/Circ. 1432 [24] and MSC.1/Circ. 1516 [25] 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

As fire monitor systems are currently not required to be installed on ships, similar guidelines do not exist for such systems. However, the guidance given above was used as a starting point for estimating the actions needed and to conduct the cost assessment.

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 are to be completed by trained personnel. Records of inspections must be kept on board the ship and may be computer-based. In cases where 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.

Table 9 details the requirements in MSC.1/Circ. 1432 and MSC.1/Circ. 1516 that were found relevant for fire monitor systems. Some of the requirements were kept in principle, but re-worded or revised to reflect fire monitor systems. It should be emphasized that an autonomous fire monitor system requires inspections, testing and maintenance of the separate fire detection and control system and that CAF systems require actions related to the use of foam.

Table 9. The estimated minimum requirements for inspections, testing, and maintenance relevant for a fire monitor system based on the requirements in MSC.1/Circ. 1432 [24] and MSC.1/Circ. 1516 [25] as amended.

Time interval	Type of system	Action
Weekly	Remote-controlled fire monitor system (water only)	• Visually inspect pump unit(s) and its fittings. • Check the pump unit(s) valve positions, if valves are not locked, as applicable. • Briefly run remote-control fire monitor in all axes (directions) to "exercise" the gears to prevent gear locking. This should be done without the use of water.
	Autonomous fire monitor system (water only)	• As per above, plus: • Verify that all fire detection and fire alarm control panel indicators are functional by operating the lamp/indicator test switch.
	Fire monitor system using CAF	• As per above, dependent if the system is remote-controlled or autonomous.
Monthly	Remote-controlled fire monitor system (water only)	• Verify that all control and section valves are in the proper open or closed position, and all pressure gauges are in the proper range. • Control water levels in tanks.
	Autonomous fire monitor system (water only)	• As per above, plus: • Test automatic starting arrangements on all system pump(s) so designed.
	Fire monitor system using CAF	• As per above, dependent if the system is remote-controlled or autonomous, plus: • Verify that all standby pressure and air/gas pressure gauges are within the proper pressure ranges.
Quarterly	Remote-controlled fire monitor system (water only)	• Visually inspect the monitors' motors, motor cables and connectors to ensure they are in good condition.
	Autonomous fire monitor system (water only)	• No recommendations.
	Fire monitor system using CAF	• Verify that the proper quantity of foam concentrate is provided in the foam system storage tank.
Annual	Remote-controlled fire monitor system (water only)	• Verify proper operation of all fire monitors by flowing water and confirm full coverage of the entire deck area. Ensure all piping is thoroughly flushed with fresh water after service. • Visually inspect all accessible components for proper condition. • Flow test all pumps for proper pressure and capacity. • Verify all pump relief valves, if provided, are properly set. • Examine all system filters/strainers to verify that they are free of debris and contamination. • Test emergency power supply switchover, where applicable. • Check for any changes that may affect the system such as obstructions.

	Autonomous fire monitor system (water only)	• As per above, plus: • Test all fire detection systems used to automatically control the system, as appropriate.
	Fire monitor system using CAF	• As per above, dependent if the system is remote-controlled or autonomous, plus: • 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. • 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	Remote-controlled fire monitor system (water only)	• No recommendations.
	Autonomous fire monitor system (water only)	• No recommendations.
	Fire monitor system using CAF	• No recommendations.
Five-year	Remote-controlled fire monitor system (water only)	• Perform internal inspection of all control/section valves and all fire monitors. • Replace motor cables.
	Autonomous fire monitor system (water only)	• As per above.
	Fire monitor system using CAF	• As per above, dependent if the system is remote-controlled or autonomous, plus: • 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	Remote-controlled fire monitor system (water only)	• 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.
	Autonomous fire monitor system (water only)	• As per above.
	Fire monitor system using CAF	• As per above.

11.2 Cost assessment assumptions

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

External competence is needed for the more complex actions, like internal inspection of fire monitors, testing of foam proportioners and specific system service and maintenance. The cost of labour depends on the part of the world in which the work is performed. Based on input from Wallenius Marine AB, service engineers for original equipment suppliers in the European Union (EU) is between €120 and €150 per work hour. For this cost assessment, €135 per work hour was used.

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

The required time for some of the activities was 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 was added. The cost for spare parts, such as gaskets for valves, filters, and foam was estimated to be 25 % of the estimated cost for the annual system service.

11.3 Cost assessment results

Table 10 summarizes estimated annual costs for inspections, testing, and maintenance of the three systems.

Table 10. The estimated annual cost for inspections, testing, and maintenance of a remote-controlled system using water only, an autonomous system using water only and a remote-controlled CAF system on Magnolia Seaways.

Type of system	**Average, annual cost (€)**
Remote-controlled fire monitor system (water only)	€ 5 700
Autonomous fire monitor system (water only)	€ 7 000
Remote-controlled fire monitor system using CAFS	€ 6 950

From this assessment, it is concluded that the annual cost is the lowest for a remote-controlled system using water only. The use of a fire detection system required for an autonomous system and the use of foam and associated equipment for a remote-controlled CAF system make these two systems comparatively more expensive both in upfront cost and to maintain.

12 Conclusions

Main author of the chapter: Magnus Arvidson, RISE and Roger James, UNF.

This report describes the development of fire monitor systems (the terminology “fixed fire-extinguishment systems” is used by IMO) for use on ro-ro weather decks. The work was based on the rules and regulations, functional design and ship integration requirements, and other considerations presented in the preceding chapters. The ro-ro ship Magnolia Seaways is used as the representation of a generic ship for the development of the systems as well as for a cost assessment of the installation and the cost for system inspections, testing, and maintenance.

The development work focussed on water-based fire monitor systems. Such systems may discharge water only, foam, or water with any other fire suppression enhancing additive. Independent of the fire suppression agent, the systems may be remotely controlled by an operator from a safe position on a ship or be autonomously operated with the possibility for remote-control by an operator if desired, regardless of whether they have detected and/or autonomously commenced suppression of fire. The system may also be semi-autonomous, which means that it can be remotely controlled by an operator but can also be set to operate in a pre-determined discharge mode.

The systems are described by detailed design and installation guidelines. The guidelines were written to define a system that can suppress and control a high hazard fire in a cargo trailer, whilst having a high reliability and resistance to the harsh maritime environment. Although written with the solutions developed within the project in mind, the guidelines are directly applicable to any standard water-based fire monitor system.

A fundamental part of the guidelines is the performance objectives, as these will determine how the system is supposed to be designed in terms of flow rates, discharge duration and positions of fire monitors. The intention is that a system designed according to the guidelines should suppress and thereafter control a fire to facilitate (if needed) manual firefighting operations to completely extinguish a fire. If such operations are deemed too hazardous, or if the on board resources are too limited, the duration of the fire monitor system should be long enough to simply allow a fire to burn out or to control it until external, onshore resources can assist. Another fundamental prerequisite is that the fire monitor system should maintain its function under heavy weather conditions. The suggested positioning (elevated positions at opposite sides of the deck) and coverage area of individual fire monitors will ensure that a fire occurring anywhere on the protected weather deck is reached by two fire monitors from different angles. If high wind speeds affect the performance of one of these fire monitors, the suggested water flow rate is sufficient to meet the expected performance with a single fire monitor.

Autonomous fire monitor systems will offer advantages in terms of faster awareness of a fire and almost immediate activation. Fire detection and precision tests proved almost instantaneous fire detection, irrespective of the position of the fire source and with no negative influence by simulated rain and fog. The system was able to accurately determine the three-dimensional size and position of each of the fires and aim the water streams of the monitors to the fire location. The monitor oscillates over the fire to provide water over a larger area than that represented by the actual test fire. When the specific fire test source was turn0 off, and another ignited, the water streams were redirected towards the new fire location. The testing offered the possibility to fine-tune parameters of the software for the application and use on weather deck. Although these large-scale tests utilized a specific fire detection system technology having IR array flame detectors, it is expected that present and future fire detection system development will offer other suitable detection technologies capable of automatic guidance and functionality. New, alternative technologies will likely reduce the overall costs, making autonomous fire monitor system even more cost attractive.

An installation cost estimation for Magnolia Seaways, the generic reference ship of the project, was made for a fully remote-controlled fire monitor system (water only), an autonomous system (water only), and a remote-controlled CAF system. It is concluded that the first is the least expensive, and the latter the most expensive to install. The additional cost for providing an autonomous function is relatively small. The annual costs for inspections, testing, and maintenance of the three systems was estimated. From this assessment, it can be concluded that the annual cost is the lowest for a remote-controlled system using water only. The use of a fire detection system required for an autonomous system and the use of foam and associated equipment for a remote-controlled CAF system made these two systems more expensive to maintain in a serviceable condition.

The design features of the guidelines were validated in large-scale suppression performance tests. These tests included a test scenario that mimicked a fire in a freight truck trailer. The tests proved that the performance objectives of the system solutions were met if using water and illustrated the built-in safety factor of having two fire monitors discharging from two directions. The tests with CAF were not as successful, as a proper quality of foam was difficult to achieve, and the flow rate was too low. The use of foam, whether it is expanded at the fire monitor nozzle (non-aspirated, low-expansion foam) or CAF of proper quality is, however, expected to improve the performance of the system for fire scenarios involving flammable liquids.

The final part of WP10, Action 10-B, is related to onboard demonstration and testing of selected fire monitor solutions, with the intent to demonstrate system installation and performance by real installations onboard a ro-ro passenger ship on a relevant weather deck. This part of the project is reported in D10.2 Onboard demonstration of weather deck fire-extinguishing solutions.

13 References

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14 Indexes

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ANNEX A

GUIDELINES FOR THE DESIGN, INSTALLATION AND APPROVAL OF FIXED WATER-BASED FIRE MONITOR SYSTEMS FOR THE PROTECTION OF RO-RO WEATHER DECKS

1 General

1.1 These guidelines are intended for the design, installation, and approval of fixed water-based fire monitor systems for the protection of weather decks as defined in SOLAS II-2/3.

1.2 The guidelines are applicable to remote-controlled, semi-autonomous and autonomous systems.

1.3 The system should provide fire suppression by an extended discharge of either water, foam, or other agent for at least the specified duration, followed by the possibility for an extended discharge of water.

1.4 These guidelines were developed in the project LASH FIRE.

The project has received founding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 81497. The Agency (CINEA) and the members of the consortium of LASH FIRE are not responsible for any use that may be made of the information in this guideline.

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 of an individual fire monitor.

2.3 *Autonomous fire monitor system* is a system comprising a fire detection system, a fire monitor and electronic hardware and software enabling the system to automatically and autonomously detect and track, in real time, the presence and position of a fire, and dynamically guides the fire monitor to achieve fire suppression, without any human intervention.

2.4 *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.

2.5 *Closed vehicle spaces* are vehicle spaces which are neither open vehicle spaces nor weather decks (SOLAS II-2/3).

2.6 *Effective throw* is the maximum throw in still air specified by the manufacturer multiplied with a factor of 0.75.

2.7 *Fire detector* is an automatic device designed to detect the presence of fire and initiate action.

2.8 *Fire monitor* is a fixed, remote-controlled device that can deliver a large stream of water, foam or other agent and is mounted on a stationary support that is elevated above the protected deck flooring.

2.9 *Fire suppression* is reducing the fire size and limiting fire spread to accomplish manual fire-fighting activities to extinguish the fire or allow the fire to burn out.

2.10 *Flow rate* is the rate in l/min of water, or the mixture of water and foam concentrate or other additive that is required for the design of the system.

2.11 *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.

2.12 *Other fire detector* is a device that detects a phenomenon other than heat, smoke, flame, or gases produced by a fire.

2.13 *Remote-controlled fire monitor system* is a system that require human interaction for the activation and remote-control of the monitors.

2.14 *Semi-autonomous fire monitor system* is a monitor system that requires human interaction for the activation and control, which has a record and play function built into the system's controller(s), whereby an operator can record, in real-time, all monitor movements--including monitor rotation, inclinations and nozzle spray angle adjustments, as well as the variable speeds and pauses of such movements--and play them back at any time.

2.15 *Weather deck* is a deck which is completely exposed to the weather from above and from at least two sides (SOLAS II-2/3).

3 Principle requirements for all systems

3.1 The piping system should be sized in accordance with a hydraulic calculation technique such as the Hazen-Williams or Darcy-Weisbach hydraulic calculation technique, to ensure the availability of the flow rate and pressure at the hydraulically most demanding fire monitors. For the foam concentrate piping, the Darcy-Weisbach hydraulic calculation technique should be used for Newtonian foam concentrates.

3.2 The system should comprise at least two fire monitors strategically mounted on opposing sides of the ro-ro weather deck (either 90° or 180° of each other) to give them opposing suppression angles. All areas of the ro-ro weather deck should be covered by the streams of water, foam or other agent from at least two individual fire monitors.

3.3 Limited areas of the of a ro-ro weather deck may be protected by a single fire monitor if; i) the area is shielded from the application of two fire monitors by a permanent structure of the ship and ii) the complete protected area is no longer than 15 m from the single fire monitor.

3.4 The vertical distance from the deck flooring to a fire monitor, as measured to its inlet, should be at least 25% of the width of the weather deck, but never less than 7 m.

3.5 Individual fire monitors, irrespective of the type of system, should have provisions for manual activation and remote-control from i) either a continuously manned station, or from a protected location from which the operator can visually obtain knowledge about fire conditions; and ii) from a portable, remote-control device (either tethered or wireless) to enable remote-control from an alternative position. At a minimum, every control device for a fire monitor should provide control of its rotation, vertical movement, the nozzle spray angle, and the opening and closing of the valve (or valves) that supply water or foam. Where an individual portable remote-control device is used for, or capable of, controlling more than one fire monitor, there should be at least two such control devices, in order to ensure that loss of function of one such remote-control device does not result in the inability to control any fire monitor.

3.6 Television surveillance systems can be used for confirmation of a fire after a fire alarm, as well as for rapid execution of related actions after the confirmation of fire. If used, it shall be provided with immediate playback capability to allow for quick identification of fire location. Continuous monitoring of the surveillance system by the crew needs not be ensured.

3.7 The system and its components should be designed to withstand ambient temperatures, vibration, humidity, shock, impact, clogging and corrosion normally encountered, based on international standards acceptable to the Organization.

3.8 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.

3.9 Means for flushing of piping systems, including foam concentrate and additive piping, with fresh water should be provided.

3.10 Operating instructions for the system should be displayed at each operating position.

3.11 Installation plans and operating manuals should be supplied to the ship and be readily available on board. A list or plan should be displayed showing the location of individual fire monitors and their area of coverage. Instructions for testing and maintenance should be available on board.

3.12 All installation, operation and maintenance instruction/plans for the system 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 and foam concentrate or additive (if used) supply

4.1 The water supply should be permitted to be hard or soft, fresh, or salt, but must be of a quality such that adverse effects on foam formation or foam stability do not occur.

4.2 The flow rate of the system should be sufficient for the simultaneous operation of at least two fire monitors. As a minimum, each fire monitor should provide a flow rate of 1 250 l/min, irrespective of whether water, foam, or other agent is used.

4.3 The system should be provided with redundant means of pumping supplying water to the system. The flow rate provided by the redundant means should be sufficient to compensate for the loss of any single supply pump or alternative source. Failure of any one component in the power and control system should not result in a reduction of the required pump capacity. Hydraulic calculations should be conducted to assure that a sufficient flow rate and pressure are delivered to the two hydraulically most fire monitors both in normal operation and in the event of the failure of any one component.

4.4 If having sufficient capacity, the requirements of section 4.3 may be fulfilled by using means of pumping intended for water-based systems used in open or closed ro-ro spaces on the ship. However, it must be possible to operate both systems simultaneously.

4.5 A means for testing the required pressure and water flow rate provided by the pump system should be provided.

4.6 The system should be fitted with a permanent sea inlet and be capable of continuous operation using sea water.

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.

4.8 Foam concentrate, or additive storage tanks should be fabricated or lined with material compatible with the concentrate and be designed to minimize evaporation of the concentrate. Concentrate below the level of the suction inlet should not be considered usable.

4.9 The effective amount of foam concentrate, or additive should be enough for a discharge for at least 30 minutes, at the maximum flow rate of the system.

4.10 There should be a reserve supply of foam concentrate, or additive, on board the ship (if used) 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 Foam concentrate, or additive 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.

5 Fire detection and alarm

5.1 A fire detection system using fire detectors or other fire detectors of a type able to detect a fire on the weather deck should be used.

5.2 When an autonomous fire monitor system is used, a fire detection system of a type able to detect a fire’s position should be utilized.

5.3 The fire detectors or other fire detectors should be strategically positioned to cover the full area of the protected weather deck.

5.4 The type of fire detectors or other fire detectors, spacing, and location should take into consideration the effects of weather, cargo obstruction and other relevant factors.

5.5 The fire detection system should activate a local alarm as well as an alarm at a continuously manned station.

5.6 If a fire monitor system is manually activated, an alarm signal should also be sent to an alarm panel to activate an alarm.

5.7 Different settings for specific operation sequences, such as during loading or unloading and during voyage is not permitted.

6 Additional requirements for autonomous systems

6.1 Activation of an autonomous system should rely on signals from two independent fire detectors or other fire detectors.

6.2 There should be a maximum delay time of 60 seconds from fire detection to discharge.

6.3 At least two autonomous fire monitor systems should be operable simultaneously and be capable of operating independently of each other. The systems should be positioned on opposing sides of the weather deck (either 90° or 180° of each other) to give them opposing detector views and opposing suppression angles.

6.4 The system should be capable of operating regardless of the number of fires.

6.5 The system must be capable of managing at least four fires detected simultaneously by the fire detection system.

6.6 In the event of more than four simultaneous fires detected on the weather deck, the autonomous fire monitor system should be programmed so as to effectively spray the entire protected part of the weather deck in an oscillating pattern.

6.7 When the autonomous fire monitor system no longer detects fire, the monitor should continue oscillating the area for at least five minutes before automatically shutting off the flow. A human operator may at any time manually shut off the flow. The system should remain ready at all times to automatically recommence active discharge upon further fire detection.

6.8 A warning notice should be displayed outside each entry point to the weather deck stating the type of medium used and the possibility of automatic release.

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