Sprinkler design guidelines relevant for ro-ro decks

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A survey of sprinkler design recommendations relevant for ro-ro decks on ships

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Abstract

A survey of sprinkler design recommendations relevant for ro-ro decks on ships

The installation guidelines for sprinkler systems for ro-ro decks on ships, IMO Resolution A.123 (V), were published in 1967. However, since the 1960s, sprinkler technology has evolved. This report summarises the outcome of a literature review focused on establishing input for new design and installation guidelines for sprinkler systems on ro-ro decks. The intention of new installation guidelines is to support the use of modern sprinkler technology in recognition of changing fire risks on-board. Modern sprinkler technology offers higher overall performance than traditional systems as prescribed in IMO Resolution A 123 (V), in many cases the use of less water and, to some extent, lesser expense.

Key words: Sprinklers, guidelines, ro-ro decks, ships

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Preface

This report was written under the IMPRO-project, "Improved water-based fire suppression and drainage systems for ro-ro vehicle decks".

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[1] SURSHIP is a coordinated collaboration involving eight EU-member states. The content and the details in the collaboration are jointly decided. Each participating country provides input to the joint efforts through nationally supported sub-projects, each of which is in line with and considered part of the joint initiative. The collaboration and its sub-projects aims to result in improvements of technologies for quantification of ship's safety and security performance and the advancement of the decision support systems, rule making and design, with a focus on ROPAX and Cruising ROPAX ships.

Sammanfattning

Fordonsutrymmen och ro-ro-lastutrymmen som inte kan tillslutas samt utrymmen av särskild kategori skall enligt kraven i SOLAS kapitel II-2 förses med ett manuellt aktiverat vattenspraysystem. För andra typer av ro-ro lastutrymmen, där personsäkerhetsrisken är lägre - eftersom passagerare inte har tillträde - används normalt koldioxidsystem. Andra typer av inertgassystem, vattensprinklersystem eller lättskumssystem kan också användas men är inte lika vanliga.

Detaljkraven för hur ett vattenspraysystem för fordonsutrymmen och ro-ro-lastutrymmen skall utformas och dimensioneras återfinns i IMO Resolution A.123(V), publicerad år 1967. Några av de detaljkrav som särskilt kan nämnas är att:

- Systemet skall dimensioneras för en vattentäthet om minst 3,5 mm/min för däck med maximalt 2,5 m höjd och för minst 5 mm/min för däck med högre takhöjd.
- Systemet tillåts att delas in i sektioner där varje sektion skall täcka hela fartygets bredd. Undantag från detta krav kan medges om däcket är avdelat i längdled av väggar i ”A” klass.
- Varje sektion skall vara minst 20 m lång och systemets pumpar skall ha en kapacitet tillräcklig för antingen hela däcket eller minst två sektioner.
- Sektionsventiler skall vara placerade utanför det skyddade utrymmet.
- Minst en handbrandsläckare skall finnas vid varje utgång från däcket och minst tre strålrör och en mobil skumvagn skall finnas ombord på fartyget.

Under senare år har man från många olika håll ifrågasatt huruvida system i enlighet med Resolution A.123(V) klarar att kontrollera en brand på ett ro-ro däck på ett modernt fartyg med dagens moderna personbilar, turistbussar och tunga lastfordon.

Rapporten diskuterar dimensionering och installation av sprinklersystem på ro-ro däck med utgångspunkt från de rekommendationer som ges i NFPA 13 och EN 12845:2004. Inte någon av dessa standarder har riktlinjer som är direkt tillämpbara för den typ av brandrisk och brandscenarier som kan förväntas på ro-ro däck, men riskklassen Ordinary Hazard (Group 1) enligt NFPA 13 omfattar ”Automobile parking and showrooms” och Ordinary Hazard (Group 2) enligt EN 12845:2004 omfattar “Car parks”.

För ro-ro däck som tar bussar, lastbilar och andra tyngre fordon användes en analogi med lagring av gods. Maximal lagringshöjd på ett lastbilsflak är mellan 2,5 m och 3,0 m. En klassificering enligt NFPA 13 pekar därför mot en dimensionering enligt Extra Hazard (Group 2). En klassificering enligt EN 12845:2004 pekar mot High Hazard Production (Group 2) eller en dimensionering enligt riktlinjer för lagring av fristående gods enligt High Hazard Storage.

Baserad på denna information har ett förslag till dimensioneringsriktlinjer tagits fram. Användningen av antingen ett automatiskt våt- eller torrörsystem skulle kunna innebära att det totala vattenflödet på ett ro-ro däck kan reduceras jämfört med dagens krav. För gruppaktiveringssystem (deulge) krävs dock att högre vattentäthet används för att förbättra systemets effektivitet.

Executive summary

Vehicle spaces and ro-ro cargo decks that cannot be closed, and special category spaces[2] shall, according to the requirements of SOLAS chapter II-2, be fitted with a manually activated water spray system. For other types of ro-ro cargo spaces, where the risk for the people is lower – as passengers do not have access – carbon dioxide system is normally used, although other types of inert gases, water spray or high expansion foam systems are permitted.

Detailed requirements for the design and installation of water spray systems for vehicle and ro-ro cargo spaces is given in IMO Resolution A.123 (V), published in 1967. Some requirements that can be mentioned in particular are that:

- The system shall be designed for a water discharge density of at least 3,5 mm/min for decks with a maximum height of 2,5 m height and at least 5 mm/min for decks with higher height.
- The system is allowed to be divided into sections where each section should cover the entire width of the ship. Exemptions from this requirement may be allowed if the deck is separated longitudinally by ‘A’ class divisions.
- Each section must be at least 20 m long and the system’s pumps must have a capacity sufficient for either the entire deck or at least two sections.
- Section valves must be located outside the protected space.
- At least one portable fire extinguisher must be available at each exit from the deck and at least three nozzles and a mobile foam cart shall be available on-board the ship.

This report discusses the design and installation of sprinkler systems on ro-ro deck based on the recommendations of NFPA 13 and EN 12845:2004. None of these standards have guidelines that are directly applicable to the type of fire hazards and fire scenarios that can be expected on a ro-ro deck, but the risk class Ordinary Hazard (Group 1) in accordance with NFPA 13 covers “Automobile parking and showrooms” and Ordinary Hazard (Group 2) according to EN 12845:2004 covers “Car Parks”.

For ro-ro decks that can accommodate buses, trucks and other heavy vehicles, an analogy with the storage of goods has been made. The maximum storage height on a truck trailer is between 2,5 m and 3,0 m. Classification in accordance with NFPA 13 would suggest sprinkler protection in accordance with Extra Hazard (Group 2) and High Hazard Storage according to EN 12845:2004.

Based on this information, draft design guidelines have been proposed. The use of either an automatic wet or dry pipe system would reduce the total water flow requirement on a ro-ro deck. However, deluge systems will require a higher discharge density than given in Resolution A.123 (V) to improve system efficiency.

[2] ”Special category spaces” are defined as enclosed spaces, situated above or below the bulkhead deck, intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion and to which passengers have access.

1 Background and scope

1.1 Background

In general, rapid detection of a fire and activation of a sprinkler system is important in order to limit the consequences of a fire. For ro-ro decks, however, the established approach set by IMO Resolution A.123 (V) [1] has been to prescribe manually activated deluge water spray systems. Some detailed requirements that can be mentioned in particular are that:

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

In recent years, questions has been raised as to whether a water spray system in accordance with Resolution A.123 (V) is able to control or suppress a fire on the ro-ro deck of a modern ship with modern cars, coaches and heavy goods vehicles [2, 3].

With the introduction of MSC.1/Circ. 1272 [4], alternative systems would be allowed to be automatically activated. However, concerns have been raised as these guidelines set a performance level of alternative systems that is only similar or slightly better than the performance of systems installed in accordance with IMO Resolution A.123 (V).

An automatic system would utilize either automatic sprinklers, i.e. that activate automatically when their heat-activated elements are heated to their thermal rating or above, or deluge systems, i.e. systems employing open nozzles attached to a piping system connected to a water supply via a valve that is opened by the operation of a separate fire detection system installed in the same area.

Systems with automatic sprinklers could either be wet or dry pipe systems. A wet pipe system employs automatic sprinklers attached to a piping system containing water so that water discharges immediately. A dry pipe employs automatic sprinklers attached to a piping system containing compressed air or nitrogen, the release of which (as from the activation of a sprinkler or nozzle) permits water to enter the system. Dry pipe systems, therefore, have a delay until water discharges from the sprinklers after activation of the system.

1.2 Scope

This report is one in a series of reports produced within the IMPRO project [5, 6, 7]. The scope of the part of the project described in this report was to:

- Summarise design and installation requirements in internationally recognized sprinkler standards that are relevant for ro-ro decks on ships
- Investigate the overall performance (the system activation reliability × system performance effectiveness) of such sprinkler systems
- Propose new design and installation requirements that will replace the requirements of Resolution A.123 (V) and could serve as a benchmark for the performance of alternative systems tested to MSC.1/Circ. 1272

2 Design guidelines given by NFPA 13

2.1 Guidelines for Light, Ordinary and Extra Hazard occupancies

NFPA 13, "The Standard for the installation of sprinkler systems" [8] uses the following classification of occupancies:

- Light Hazard
- Ordinary Hazard (Group 1)
- Ordinary Hazard (Group 2)
- Extra Hazard (Group 1)
- Extra Hazard (Group 2)

The classification is based on the quantity and combustibility of contents, the expected heat release rates, the total potential for energy release, the height of any stockpiles and the presence of flammable and combustible liquids within the occupancy. Table 1 shows examples of occupancies that could be considered to have similarities with the fire hazard present on ro-ro decks, and the sprinkler protection criteria in terms of minimum water discharge densities and area of sprinkler operation.

Table 1 The classification of occupancies used in NFPA 13 together with occupancy examples, characterization of the hazard and the sprinkler protection criteria.

		NFPA 13 characterization of hazard			
Hazard class	**Occupancy examples for comparison with ro-ro decks**	**Fuel quantity**	**Fuel combustibility**	**Heat Release rate**	**Sprinkler protection criteria**
Light Hazard	Offices, residential	Low	Low	Low	4,1 mm/min over 139 m^2 or 2,8 mm/min over 279 m^2
Ordinary Hazard (OH1)	Automobile parking, automobile showrooms	Moderate, stockpiles <2,4 m	Low	Moderate	6,1 mm/min over 139 m^2 or 4,1 mm/min over 372 m^2
Ordinary Hazard (OH2)	Mercantile, repair garages, exterior loading decks, tire manufacturing	Moderate to high	Moderate to high	Moderate for stockpiles <3,7 m, high for stockpiles <2,4 m	8,2 mm/min over 139 m^2 or 6,1 mm/min over 372 m^2
Extra Hazard (EH1)	Aircraft hangars, upholstering with plastic foams	Very high, dust, lint or other similar materials present	Very high	High, but no combustible or flammable liquids	12,2 mm/min over 232 m^2 or 8,2 mm/min over 465 m^2
Extra Hazard (EH2)	Manufactured homes, modular building assembly, "miscellaneous" palletized, shelf or rack storage of plastics	Moderate to substantial amounts of flammable or combustible liquids present, or where shielding of combustibles is extensive			16,3 mm/min over 232 m^2 or 12,2 mm/min over 465 m^2

The recommended water discharge densities and sprinkler operating areas vary from 4,1 mm/min over 139 m^2 to 16,3 mm/min over 232 m^2 for the different occupancies. It is, however, allowed to decrease the water discharge densities if the area of operation is increased, as indicated in the table.

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

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

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

2.2 Guidelines for storage of plastic commodities

Chapter 15 of NFPA 13 (2010) contains design guidelines for the protection of storage of "plastic and rubber commodities" that are either palletized, solid piled, stored in bin boxes or on shelf storage.

The guidelines cover "control-mode" sprinkler systems, i.e. systems that would limit the size of a fire by direct distribution of water and pre-wetting of adjacent combustibles. This would also result in a reduction of ceiling gas temperatures such that structural damage could be avoided.

Plastic commodities can be divided into essentially two forms, unexpanded and expanded. In simplistic terms one can say that unexpanded plastics have a high density and expanded plastics have a low density. The heat release rate for expanded plastics is generally greater due to the relatively low density and resulting high burning rate.

A commodity is classified based on the content of unexpanded or expanded plastics as follows:

- If more than 25% by volume is expanded plastic (for example foam packaging), the commodity is considered a plastic commodity
- If more than 15% by weight is unexpanded plastic (for example plastic tote) the commodity is considered a plastic commodity
- If between 5% and 15% by weight is unexpanded plastic the commodity is considered a Class IV commodity
- If greater than 5% but less than 25% by volume is expanded plastic, the commodity is considered a Class IV commodity
- If less than 5% by weight or volume is unexpanded or expanded plastic the commodity is Class I - III

Plastics are generally much more hazardous than ordinary combustibles (class III - IV commodities) for several main reasons:

- The heat of combustion of plastics is two to three times as high as ordinary combustibles such as paper or wood

- Fires in plastics develop very high temperatures, typically over 1100°C
- Plastics exhibit a very high burning rate and the flammability of plastics is generally much higher than that of ordinary combustibles
- Plastic do not absorb the water from sprinklers, as is the case for paper or wood
- Plastics can melt and form pool fires
- A plastics fire can give off particularly thick, dense smoke and toxic combustion gases making it extremely difficult for fire fighters to control the fire with hose streams

The design of a sprinkler system shall be based on the conditions that routinely and periodically exists in buildings and create the greatest water demand. These conditions include the following:

1) Commodity pile height
2) Clearance, i.e. the vertical distance measured between the sprinkler deflector and the top of the storage
3) Pile stability
4) Array

Stable piles are defined as those arrays where collapse, spillage of content, or leaning of stacks across flue spaces is not likely to occur after initial fire development. Unstable piles are defined as those arrays where collapse, spillage of contents, or leaning of stacks across flue spaces occurs soon after initial fire development.

An array consisting of solid-piled and palletized storage with large flue space between stacks will burn more fiercely than an array with narrower flues between stacks because air access in the open array promotes fire growth and heat radiation between stacks. A closed array is defined in NFPA 13 as a storage arrangement where air movement through the pile is restricted because of 6 in. (152 mm) or less vertical flues. An open array is defined as an array where air movement through the pile is enhanced by vertical flues larger than 152 mm.

Table 2 summarises the recommended water discharge densities for plastic commodities that are that are either palletized, solid-piled, stored in bin-boxes or shelf storage. The criteria apply to systems with ceiling sprinklers only.

Table 2 Design densities for palletized, solid-piled, bin-box, or shelf storage of plastic and rubber commodities, as given in Table 15.2.6 (b) of NFPA 13 (2010).

Storage height [m]	**Ceiling height [m]**	**Water discharge density [mm/min]**				
		A	B	C	D	E
>1,5 to ≤3,6	Up to 4,6	8,2	EH2	12,2	EH1	EH2
	>4,6 to 6,1	12,2	24,5	20,4	EH2	EH2
	>6,1 to 9,8	16,3	32,6	24,5	18,4	28,6
4,6	Up to 6,1	12,2	24,5	20,4	16,3	18,4
	>6,1 to 7,6	16,3	32,6	24,5	18,4	28,6
	>7,6 to 10,7	18,4	36,7	28,6	22,4	34,7
6,1	Up to 7,6	16,3	32,6	24,5	18,4	28,6
	>7,6 to 9,1	18,4	36,7	28,6	22,4	34,7
	>9,1 to 10,7	24,5	49,0	34,7	28,6	44,9
7,6	Up to 9,1	18,4	36,7	28,6	22,4	34,7
	>9,1 to 10,7	24,5	49,0	34,7	28,6	44,9

The column designations correspond to the configuration of plastic storage as follows:

A: Unexpanded plastics that are unstable or unexpanded plastics that are stable and designed as a fixed-height solid unit load
B: Exposed, expanded plastics that are stable
C: Exposed, expanded plastics that are unstable or cartoned unexpanded plastics that are stable
D: Cartoned, expanded plastics that are unstable
E: Cartoned, expanded plastics that are stable or exposed unexpanded plastics that are stable.

"EH1" and "EH2" indicate that the sprinkler system should be designed in accordance with the requirements for Extra Hazard Group 1 and Group 2, respectively.

The term "exposed" plastics refers to those plastics not encapsulated in packaging or covering that absorbs water or retards the burning rate.

The design area shall be a minimum of 232 m^2, however, for closed arrays the area is allowed to be reduced to 186 m^2. If standard K=80 or K=115 sprinklers are used, the design is permitted to be reduced by 25%, but not below 186 m^2, where high-temperature sprinklers are used. The use of K=160 (ELO) sprinklers or larger orifices would allow the design area to be reduced by 25%, but not below 186 m^2.

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

For rack storage, the presence of flue spaces and the stability given by the racks to hold the commodity in place will result in a fire hazard more severe than solid-piled and palletized storage. Often, the protection afforded by ceiling sprinklers needs to be supplemented by in-rack sprinklers to assure adequate fire control or fire suppression. The protection of commodities stored on racks is not discussed here as it is not relevant to commodities transported on vehicles.

2.3 Guidelines for deluge systems

NFPA 15, "The Standard for water spray fixed systems for fire protection" [9] contains guidelines for fixed water spray systems.

Systems shall be arranged for automatic operation with supplementary manual tripping means provided. Manual operation shall be permitted where automatic operation of the systems presents a hazard to personnel or where a system is isolated and attended by trained personnel at all times.

System nozzles shall be installed to ensure that the nozzle spray patterns meet or overlap. The nozzle spacing (vertically and horizontally) shall not exceed 3,0 m, unless the nozzles are listed for spacings exceeding 3,0 m.

For "fire extinguishment" a general range of water spray application rates that shall apply to most ordinary or combustible solids or liquids is 6,1 mm/min to 20,4 mm/min across the protected surface. For "control of burning" of flammable and combustible liquid pool spill fires, not less than 12,2 mm/min across the protected area is recommended.

There are no specific requirements for the protection of storage areas of combustible solids that are arranged similar to what would be expected on a ro-ro deck.

2.4 Judgement of sprinkler protection criteria based on NFPA 13

2.4.1 Ro-ro decks less than 2,5 m in height

These decks can only accommodate passenger cars, SUV:s or smaller vans due to the limited height.

A classification in accordance with NFPA 13 would suggest sprinkler protection in accordance with Ordinary Hazard (Group 1), i.e. 6,1 mm/min over 139 m^2 or 4,1 mm/min over 372 m^2 for wet pipe systems. For dry pipe systems, the sprinkler operating area should be increased by 30% without revising the water discharge density.

2.4.2 Ro-ro decks in excess of 2,5 m in height

The decks typically have a free height of approximately 5 m for the carriage of freight trucks, trailers and buses but are sometimes higher.

It is typical that the commodity on a trailer would be solid-piled or palletized and the individual cargo is probably stored in a quite compact manner to optimise transport volumes, i.e. both the longitudinal and transversal flue spaces are narrow. In other words, the commodity on a trailer would be assessed as arranged in a “closed array”, which would allow a reduction of the area of sprinkler operation per NFPA 13.

The cargo on the trailers of freight trucks could contain a nearly unlimited variation of combustible materials and need not be homogenous even on a single, specific trailer. The most conservative approach when applying the recommendations of NFPA 13 would be to assume that exposed, expanded plastics are transported. Another conservative approach would be that the cargo is stable after initial fire development.

Given that the maximum internal height of the cargo hold of a trailer would be of the order of 2,5 m to 3,0 m, the maximum storage height is limited to below 3,0 m.

Classification in accordance with NFPA 13 would suggest sprinkler protection in accordance with Extra Hazard (Group 2), i.e. 16,3 mm/min over 232 m^2 or 12,2 mm/min over 465 m^2 for wet pipe systems. Note that this design is allowed to be used up to a ceiling height of 6,1 m. A reduction of the area of sprinkler operation, without revising the density, to 186 m^2 is allowed with high-temperature sprinklers. For dry pipe systems, the sprinkler operating area should be increased by 30% without revising the water discharge density.

It should also be noted that there are several differences between the conditions on a ro-ro deck as compared to the conditions in a storage facility that may require a higher design flow, for example that:

- The spacing and separation between vehicles is very tight.
- The clearance, i.e. the vertical distance measured between the sprinkler deflector and the top of the vehicles, is limited which could enhance fire spread and would expose the ceiling construction to high temperature levels.
- The shielding afforded by the fact that the vehicles are constructed to resist water, which would prevent water from reaching the seat of the fire.

These differences make the assessment of appropriate sprinkler protection uncertain and are one reason for the test series described within SP Report 2009:29 [7].

3 Design guidelines given by CEN

3.1 Guidelines for Light, Ordinary and High Hazard occupancies

EN 12845:2004, "Fixed firefighting systems – Automatic sprinkler systems - Design, installation and maintenance" [10] uses a classification of occupancies as follows:

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

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

Table 3 shows the design criteria for LH, OH and HHP occupancies.

Table 3 Design criteria for LH, OH and HHP occupancies given in Table 3 of EN 12845:2004.

Hazard class	Design density [mm/min]	Area of operation [m^2]	
		Wet or pre-action systems	Dry or alternate systems
LH	2,25	84	Not allowed. Use OH1
OH1	5,0	72	90
OH2	5,0	144	180
OH3	5,0	216	270
OH4	5,0	360	Not allowed. Use HHP1
HHP1	7,5	260	325
HHP2	10,0	260	325
HHP3	12,5	260	325
HHP4	Deluge		

The recommended water discharge densities and sprinkler operating areas vary from 2,25 mm/min over 84 m^2 to 12,5 mm/min over 260 m^2 for the different occupancies. HHP4 hazards are usually protected with deluge systems, which are not covered within EN 12845:2004.

For dry pipe systems, the sprinkler operating area should be increased by 25% without revising the water discharge density. Quick response sprinklers are not allowed to be used in dry pipe systems.

Fire hazards similar to "Car parks" fall under OH2, and "Depots for buses, unladen lorries and railway carriages" under HHP2. Otherwise, there are no examples cited in EN12845:2004 that are directly comparable for ro-ro decks.

The sprinkler installation standard used in the United Kingdom, "LPC Rules for automatic Sprinkler Installations 2009, Incorporating BS EN 12845" [11] lists "car workshops" as an OH3 hazard.

3.2 Guidelines for storage occupancies

For storage facilities denoted High Hazard Storage (HHS), the guidelines in EN 12845:2004 is based on the storage height, the ceiling height, the commodity classification and the storage arrangement. Design criteria for ceiling sprinklers are given for the protection of Category I to Category IV commodities that are either free standing or stacked in blocks, see Table 4.

Table 4 Design densities for the protection of Category I to Category IV commodities that are either free standing or stacked in blocks according to Table 4 of EN 12845:2004.

Storage configuration	**Maximum permitted storage height [m]**				**Density [mm/min]**	**Area of operation [m^2]**
ST1 Free standing or block stacking	Category I	Category II	Category III	Category IV		
	5,3 6,5 7,6	4,1 5,0 5,9 6,7 7,5	2,9 3,5 4,1 4,7 5,2	1,6 2,0 2,3 2,7 3,0	7,5 10,0 12,5 15,0 17,5	260
			5,7 6,3 6,7 7,2	3,3 3,6 3,8 4,1 4,4	20,0 22,5 25,0 27,5 30,0	300

There are four main commodity categories, Category I, II, III and IV, where Category I represent the least hazardous and Category IV the most hazardous commodity. To categorize the commodity, the method is to first analyze the materials involved, in order to determine a Material Factor, and thereafter to determine its storage configuration.

The Material Factor shall take into account the product, packaging material and the pallet material. The storage configuration takes into account whether the product has exposed plastic surfaces, have a solid or open structure, etc. Examples of commodities under the four different categories are:

Category I: Non-combustible products in combustible packaging and low or medium combustibility products in combustible or non-combustible packaging. The commodity is only allowed to contain modest amounts of plastics. Examples include metal parts with or without cardboard packaging on wood pallets, leather products, wood products and canned food.

Category II: Products with a higher energy content. Examples include wood or metal furniture with plastic seats, electrical equipment with plastic parts or packaging and synthetic fabrics.

Category III: Products containing predominantly unexpanded plastic or materials with higher energy content. Examples include empty car batteries, plastic brief cases, personal computers and unexpanded plastic cups and cutlery.

Category IV: Products containing predominantly expanded plastic (more than 40% by volume) or materials with similar energy content. Examples include foam mattresses, expanded polystyrene packaging and foam upholstery.

The maximum permitted storage height is measured from the floor to the deflectors of the sprinklers, minus 1,0 m.

3.3 Guidelines for deluge systems

CEN/TS 14816:2009, “Fixed firefighting systems – Water spray systems – Design, installation and maintenance” [12] contains guidelines for fixed water spray systems. Design criteria are given for the protection of solid combustibles using deluge systems with open nozzles are summarised in Table 5.

Table 5 Design criteria for the protection of solid combustibles as given in Table 1 of CEN/TS 14816:2009.

	Design density [mm/min]	Duration of operation [minutes]	Area of operation per deluge valve [m^2]
Theatre stage ≤ 10 m ceiling height	5,0	30	Full area
Theatre stage > 10 m ceiling height	7,5	30	Full area
Refuse bunker - Height of waste ≤ 2 m - Height of waste > 2 m ≤ 3 m - Height of waste > 3 m ≤ 5 m - Height of waste > 5 m	 5,0 7,5 12,5 20,0	 60	 400
Expanded plastic - Storage height ≤ 2 m - Storage height > 2 m ≤ 3 m - Storage height > 3 m ≤ 4 m - Storage height > 4 m	 10,0 15,0 22,5 30,0	 60	 150 150 200 200

The information for expanded plastics is most relevant for ordinary combustible material on freight truck trailers.

Additional guidelines for the protection of flammable liquids are given within the document. For hazards involving flammable liquids having a flash point below 66°C, “medium velocity” nozzles are recommended. For flammable liquids having a flash point above 66°C, “high velocity” nozzles should be used.

The terminology “medium velocity” and “high velocity” is, however, not defined within the document but there are nozzles approved by The Loss Prevention Certification Board (LPCB) under these categories [13].

3.4 Judgement of sprinkler protection criteria based on CEN guidelines

3.4.1 Ro-ro decks less than 2,5 m in height

These decks only accommodate passenger cars, SUV:s or smaller vans due to the limited height. Hazards similar to "car parks" are classified as OH2 in the CEN guidelines and the additional requirements used in United Kingdom classify "car workshops" as OH3.

Wet pipe systems for OH2 would be designed for 5 mm/min over 144 m^2. For dry pipe systems, the sprinkler operating area should be increased by 25% without revising the water discharge density.

However, a conservative approach, given that the fuel load is high due to the compact storage of the vehicles would advocate sprinkler protection in accordance with OH3, which would require 5 mm/min over 216 m^2 for wet pipe systems.

3.4.2 Ro-ro decks in excess of 2,5 m in height

The decks typically have a free height of approximately 5 m for the carriage of freight trucks, trailers and buses.

Fire hazards similar to "Depots for buses, unladen lorries and railway carriages" would be defined as HHP2 which would require a wet pipe system design of 10,0 mm/min over 260 m^2 and a dry pipe system design of 10,0 mm/min over 325 m^2.

It is typical that the commodity on a trailer would be solid-piled or palletized and the individual cargo is probably stored in a quite compact manner, i.e. both the longitudinal and transversal flue spaces are narrow.

The cargo on the trailers of freight trucks could contain a nearly unlimited variation of combustible materials and need not be homogenous even on a specific trailer. The most conservative approach when applying the recommendations of CEN would be to assume that a Category IV commodity is transported. Given that the maximum internal height of the cargo hold of a trailer would be of the order of 2,5 m to 3,0 m, the maximum storage height is limited to below 3,0 m.

It is therefore concluded, that a wet pipe system should be designed for 17,5 mm/min over 260 m^2. No reduction of the design area is allowed if high-temperature sprinklers are used, as is the case in NFPA 13. For dry pipe systems, the sprinkler operating area should be increased by 25% without revising the water discharge density.

A deluge system should be designed for 15,0 mm/min over 150 m^2.

4 Positioning of sprinklers relative to obstructions

4.1 Ceiling constructions on ro-ro decks

The ceiling construction of ro-ro decks typically includes deep transverse beams. These beams are usually positioned at every third or fourth frame rib, i.e. the horizontal distance between the beams is either approximately 2400 mm or 3200 mm. The beams are typically approximately 700 mm to 1000 mm in depth.

4.2 Requirements of NFPA 13

For automatic sprinklers, it is essential that the vertical distance from the underside of the deck to the heat-activated element is within certain limits, in order to provide as fast activation of the sprinklers as possible. For unobstructed ceiling constructions, the general recommendation is that the distance between the sprinkler deflector and the ceiling shall be a minimum of 25 mm and a maximum of 305 mm.

Sprinklers at the underside of 'obstructed ceiling constructions'[3] need to be positioned such that the development of the water spray is not obstructed by beams. This requires that the sprinklers are installed with their deflectors a certain distance below the underside of the deck above.

NFPA 13 provides recommendations of the minimum and maximum allowed vertical distances for obstructed ceiling constructions. For obstructed ceiling constructions, which would apply to ro-ro decks on ships, the following recommendations are given:

1) Sprinklers should be installed with the deflectors within the horizontal planes of 25 mm to 152 mm below structural member and a maximum distance of 559 mm below the ceiling deck.
2) Sprinklers should be installed with the deflectors at or above the bottom of the structural members to a maximum of 559 mm below the ceiling deck. Comment: Additional requirements in order avoid obstructions to discharge are discussed below.
3) Sprinklers should be installed in each bay of obstructed constructions, with the deflector located a minimum of 25 mm and a maximum of 305 mm below the ceiling deck.
4) Where sprinklers are listed for use under other ceiling constructions features or for different distances, they shall be permitted to be installed in accordance with their listing.

Sprinklers could be positioned in each bay formed by the beams which would allow that they are positioned closer to the deck, in order to improve the activation time. However, the water spray will therefore be obstructed such that overlap of water sprays from adjacent sprinklers on opposite sides of the beams is prevented. NFPA 13 state that sprinklers installed under obstructed ceiling constructions need to be positioned such that the development of the water spray is not obstructed by the beams that supports the ceiling. This requires that the sprinklers are installed with their deflectors a certain distance below the underside of the deck above. NFPA 13 provides recommendations for

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[3] An obstructed ceiling construction is defined as "Panel construction and other construction where beams, trusses, or other members impede heat flow or water distribution in a manner that materially affects the ability of sprinklers to control or suppress a fire."

standard spray (pendent or upright) sprinklers to avoid obstructions to the sprinkler discharge, see Table 6 and Figure 1.

Table 6 Position of sprinklers in order to avoid obstruction to discharge, as per Table 8.8.5.1.2 of NFPA 13 (2010) but converted to millimetres.

A The horizontal distance from sprinklers to side of obstruction	**B** The maximum allowable vertical distance of deflector above bottom of obstruction
Less than 305 mm	0
305 mm < 457 mm	0
457 mm < 610 mm	25 mm
610 mm < 762 mm	25 mm
762 mm < 914 mm	25 mm
914 mm < 1067 mm	76 mm
1067 mm < 1219 mm	76 mm
1219 mm < 1372 mm	127 mm
1372 mm < 1524 mm	178 mm
1524 mm < 1676 mm	178 mm
1676 mm < 1829mm	178 mm
1829 mm < 1981 mm	229 mm
1981 mm < 2134 mm	279 mm
2134 mm < 2286 mm	356 mm
2286 mm < 2438 mm	356 mm
2438 mm < 2591 mm	381 mm
2591 mm < 2743 mm	432 mm
2743 mm < 2896 mm	483 mm
2896 mm < 3048 mm	533 mm

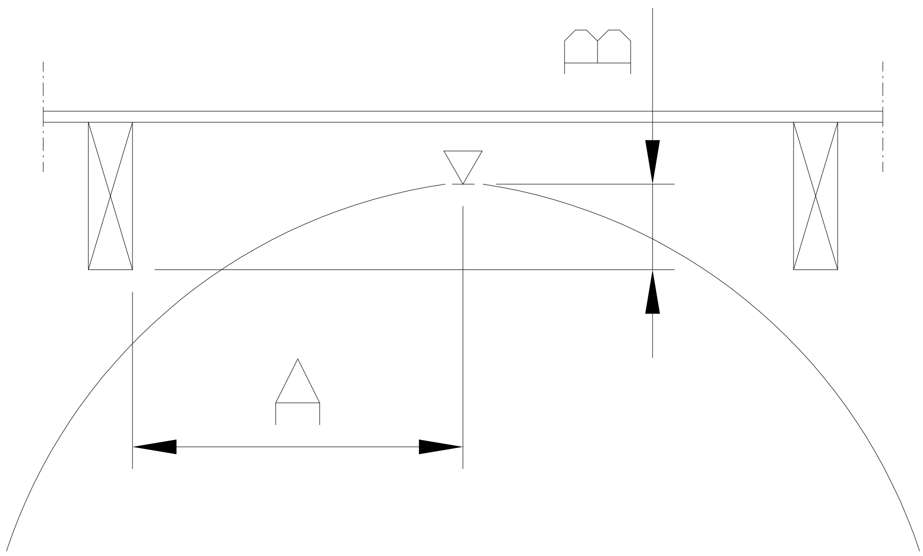

Figure 1 Positioning of sprinklers in order to avoid obstruction to discharge.

Ceilings with beams also need special consideration when designing a fire detection system as the ‘pockets’ formed between the beams can trap smoke. Fire codes such as the NFPA 72, National Fire Alarm Code® that covers the application, installation, testing, and maintenance of fire alarm systems recognize this problem and recommend smoke detectors in every pocket.

5 Overall performance of sprinkler systems

5.1 The definition of overall performance

The overall performance of a sprinkler system can be described as:

Overall performance = system activation reliability × system performance effectiveness.

The system activation reliability relies on factors like: the quality of the system components, the design of the system (redundancy) and the quality and frequency of supervision, control, testing, inspection and maintenance.

The system performance effectiveness or capability of the system relies on: proper design for the specific fire hazard, proper design densities and area of operation, correct location of sprinklers, etc.

This chapter contains a discussion about the overall performance of the following sprinkler system types for fire hazards similar to what could be expected on ro-ro decks:

- Wet pipe systems
- Dry pipe systems
- Preaction systems
- Deluge systems

The four different types of systems are described below.

Wet pipe systems

Wet pipe systems are designed for applications where the temperature is maintained above freezing and employ sprinklers attached to a piping system which contains water under pressure. The water discharges immediately as one or more sprinklers are activated by the heat from a fire. These types of systems are the least complex, least expensive and most reliable of the types of systems discussed here. The main disadvantage of a wet pipe system is concern about freezing and unintentional activation of a sprinkler, due to for example mechanical damage, which implies a risk for water damage. However, the unintentional activation is of lesser concern for cargo consisting of regular vehicles.

Dry pipe systems

Dry pipe systems employ automatic sprinklers attached to a piping system containing air or Nitrogen under pressure. The activation of one or more sprinkler permits the water pressure to open a valve, known as the dry pipe valve. The water then flows into the pipe-work and out of the opened sprinklers. It is essential that the dry pipe valve is installed in an area not subject to freezing. The main disadvantages of using dry pipe fire sprinkler systems compared to wet pipe systems include:

Increased complexity: Dry pipe systems require additional control equipment and air pressure supply components which increase the system complexity. This puts a premium on proper maintenance, as this increase in system complexity results in an inherently less reliable overall system (i.e. more single failure points) as compared to a wet pipe system.

Higher installation and maintenance costs: The added complexity impacts the overall dry pipe installation cost, and increases maintenance expenses primarily due to added service labour costs.

Increased fire response time: Because the piping is empty at the time the sprinkler activates, there is a time delay in delivering water to the sprinklers which have activated. A maximum of 60 seconds is usually allowed by regulatory requirements from the time a sprinkler activates until water is discharged onto the fire. This delay in fire suppression may result in a larger fire prior to control, producing increased fire damage. The sprinkler operating area of dry pipe should typically be increased by 30% compared to wet pipe systems, without revising the water discharge density, in order to compensate for the increased fire response time.

Increased corrosion potential: Following operation or testing, dry pipe sprinkler system piping is drained, but residual water may collect in piping low spots, and moisture is retained in the atmosphere within the piping. This moisture, coupled with the oxygen available in the compressed air in the piping, increases pipe internal wall corrosion rates, potentially leading to leaks.

Preaction systems

Preaction systems use automatic sprinklers attached to a piping system that contains air that may or may not be under pressure, with a supplementary fire detection system installed in the same areas as the sprinklers. Preaction systems are commonly used for areas where there is a danger of serious water damage as a result of damaged automatic sprinklers or broken piping. The two most common types of preaction systems are:

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

2) Double-interlocked systems, which admit water to the sprinkler piping upon operation of both the fire detection system and the automatic sprinklers, i.e. in order to activate, two independents events, caused by a fire condition, must occur. The sprinkler system piping must lose air pressure due to the operation of one or more sprinklers and a solenoid valve must open upon the operation of a fire detection system. If a sprinkler head is intentionally or unintentionally damaged, <u>or</u> if the solenoid valve accidentally opens, this will only cause an alarm and will not trip the system or flood the sprinkler system piping. Double-interlocked systems are therefore safer than single-interlock systems in areas subject to freezing, as the sprinkler piping will not fill up due to a failure of the fire detection system. The time delay, from the activation of the system until full discharge at the sprinkler, requires that this specific type of preaction system is typically designed with a 30% increase in area of operation.

The disadvantages of using preaction sprinkler systems compared to wet pipe systems are similar to those listed for dry pipe systems.

Deluge systems

Deluge systems employ open sprinklers[4] or spray nozzles[5] attached to a piping system. The system is connected to a water supply through a deluge valve. This valve is opened by the operation of a fire detection system installed in the protected area, alternatively, the system may be manually operated. When the valve opens, water flows into the piping system and discharges from all sprinklers or nozzles. The deluge valve needs to be installed in an area that is not subject to freezing. A deluge system has a time delay between detection of a fire and the discharge of water due to the time required to operate the valve and to fill the piping network with water and therefore represents similar disadvantages relative to a wet pipe system as those cited above for a dry pipe system.

5.2 General reliability data for automatic sprinkler systems

5.2.1 Data from National Fire Incident Reporting System (NFIRS)

Based on data from the National Fire Incident Reporting System (NFIRS) in USA, an analysis of automatic sprinkler system reliability has been made by Hall [14]. The analysis is interesting as it is based on up to date data from 2003 – 2007.

The data shows that sprinklers activated in 93% of the fires large enough to activate them. The estimated failure rates for different types of systems were as follows:

- 5% failure rate for wet pipe sprinkler systems.
- 17% failure rate for dry pipe sprinkler systems.

Failures to activate occurred (combined figures for all types of system) because:

- The system was shut off (53%)
- The equipment was inappropriate for the type of fire (20%)
- Lack of maintenance (15%)
- Manual intervention defeated the equipment (9%)
- Component damage (2%)

Sprinkler systems that activated (combined figures for all types of properties) were effective as follows:

- 98% effectiveness for wet pipe sprinkler systems
- 95% effectiveness for dry pipe sprinkler systems

Based on these figures, it can be concluded that wet pipe sprinkler systems are more reliable than dry pipe sprinkler systems (95% vs. 83%) and slightly more effective when they activate (98% vs. 95%). This results in a overall performance, for all type of properties, as follows:

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[4] An open sprinkler is a sprinkler that does not have actuators or heat-responsive elements.

[5] An open spray nozzle is an open water discharge device that will distribute the water in a specific, directional pattern. Spray nozzles are typically used in applications requiring special water discharge patterns, directional spray, or other discharge characteristics.

- 93% for wet pipe sprinkler systems, i.e. 95% system activation reliability × 98% system performance effectiveness.
- 79% for dry pipe systems, i.e. 83% system activation reliability × 95% system performance effectiveness.

Usually, only one or two sprinklers are required to control a fire. When wet pipe sprinkler systems activated, 89% of the reported fires involved one or two sprinklers. When dry pipe sprinkler systems activated, 74% of the reported fires involved one or two sprinklers.

5.2.2 Data from FM Global

FM Global has also recently evaluated sprinkler system reliability [15] and found results that were consistent with the results of Hall. The work of FM Global constitutes a probabilistic reliability analysis to quantify the probability of inadequate or delayed flow to a sprinkler activated by a fire. The analysis concluded that the system activation reliability of wet pipe systems is in the order of 94% to 98%, given that all systems have been adequately designed and manufactured.

5.2.3 Data from additional sources

An analysis of the reliability of sprinkler systems made by Koffel [16] and Budnick [17] based on previous studies of the topic come to essentially the same conclusion as those conducted by Hall and FM Global. However, estimates of reliability indicate significant variation between different studies.

The reported reliability estimates range from 81,3% to 99,5%, see Table 7. These differences may be attributable to any number of variations in the protocols or the databases used for each study and the number of incidents covered by the study.

Table 7 The reliability of automatic sprinkler systems documented in different studies, reproduced from [16].

Study by:	Reliability of success	Comments
Marryat	99,5	Inspection, testing, and maintenance exceeded normal expectations and higher pressures.
Maybee	99,4	Data from Australia and New Zeeland. Inspection, testing, and maintenance exceeded normal expectations.
Powers	98,8	Office buildings only in New York City.
Powers	98,4	Other than office buildings in New York City.
Finuance et al	96,9 – 97,9	
Milne	96,6/97,6/89,2	
NFPA	88,2 – 98,2	Data provided for individual occupancies – total for all occupancies was 96,2%.
Linder	96	
Richardson	96	
Miller	95,8	
Powers	95,8	Low rise buildings in New York City
US Navy	95,7	Data from 1964 – 1977
Smith	95	UK data
Miller	94,8	
Budnick	92,2/94,6/97,1	Values are lower in commercial uses (excludes institutional and residential).
Kook	87,6	Limited data base.
Ramachandran	87	Increases to 94% if estimate number of fires not reported is included and based upon 33% of firs not reported to fire brigade.
Factory Mutual	86,1	1970 – 1978
Oregon State Fire Marshal	85,8	1970 – 1978
Taylor	81,3	Limited data base.

5.3 Data on system performance effectiveness

FM Global Property Loss Data Sheet 8-9 [18], offers several general observations regarding rack storage losses. The loss history is relevant for control mode density area sprinklers. Loss experience shows that, where there are no protection defects, existing storage area protection arrangements provided by FM Global are adequate. Major protection defects include inadequate water supplies, closed or partially closed valves, obstructed sprinkler piping, missing sprinklers, etc. Protection defects were identified in all storage losses where the fire was determined to be uncontrolled.

Table 8 shows the percentage of rack storage fires controlled by a given number of sprinklers. The data covers a recent 18-year period, in which no protection defects were identified. Therefore, the data can be regarded as showing the system performance effectiveness for fire hazards similar to rack storage fires.

Table 8 FM Global data on the percentage of rack storage fires controlled by a given number of sprinklers [18].

Number of activated sprinklers	Percentage of fires controlled
1	14
2 or fewer	32
3 or fewer	41
4 or fewer	49
5 or fewer	54
10 or fewer	77
25 or fewer	98

For ceiling sprinklers only, the average number of sprinklers that activated was eight. For ceiling plus in-rack sprinklers, the average was three ceiling sprinklers and three in-rack sprinklers. It could also be concluded that both damage and the number of activated sprinklers increased with higher storage and building heights.

Another study by FM Global [15] concludes that approximately 87%, by number, of all risk losses (excluding natural catastrophe) are below deductible. Based on the percent of losses reported to FM Global that are below deductible, it is estimated that 83% of all losses are unreported. If it is assumed that 1) this unreported percentage holds for all loss subsets (i.e. fire losses in sprinklered buildings), 2) all of these unreported fires are 'successes' (activated sprinklers that were effective) and 3) the ratio of unreported information in FM Global data is comparable to the ratio of the National Fire Incident Reporting System (NFIRS) unreported, then the calculated activated and effective 90% reported from NFRIS can be adjusted to a 98% overall performance of a sprinkler system. This number is reasonably consistent with statistics from Australia and New Zeeland (overall performance in excess of 99%), the most regulated and consistent data in the world.

5.4 Overall performance for different type systems based on statistics

Wet pipe systems are generally considered the most reliable of the types of systems discussed here. Based on reliability data from several sources it seems that the overall performance of a wet pipe sprinkler system is of the order of 90% to 95% (or even higher, as discussed above). Due to increased complexity and increased fire response time, the overall performance of a dry pipe system is generally considered to be less than that of a wet pipe sprinkler system, typically in the order of 80% to 85%.

Preaction systems rely on a separate fire detection system for their function. No specific reliability data is available for this type system; however, it is judged that the activation reliability would be less compared than that for a dry pipe system. The overall system performance effectiveness is judged to be similar or better than that for a dry pipe system (due to a shorter time from the start of a fire until water is discharged from the sprinklers).

Deluge systems may be either manually or automatically (with provisions for manual activation) activated. The activation reliability of the automatically activated systems (with provisions for manual activation) is deemed to be slightly higher compared to a system that only relies on manual activation. In both cases, however, there is a time delay between detection of a fire and the discharge of water due to the time required to operate the valve and to fill the piping network with water. The time delay from the start of the fire until the activation of the system is expected to be most significant. For a system that is manual only, this time delay is expected to be inherently longer than an automatic system. It is therefore judged that the system performance effectiveness generally is higher for an automatic system compared to a manual only system.

5.5 Judgment of overall performance for ro-ro decks

Presently, only manually activated deluge systems are prescribed in IMO Resolution A.123(V). Four different types of sprinkler systems may be used on ro-ro decks according to the new proposed installation guidelines, wet pipe, dry pipe, preaction and deluge type systems. The deluge type system may either be manual activation only or automatic activation (with provisions for manual activation).

Tables 9 and 10, respectively, show an estimation of the overall performance of the sprinkler system concepts described in the proposed new installation guidelines, for two different fire scenarios.

The first fire scenario can be described as a “small” fire. This fire may be limited to for example a tire of a vehicle or a freezer or refrigeration unit on a trailer. But it may also involve a complete passenger car on a deck intended for the transportation of larger vehicles, or freight trucks or trailers with a cargo consisting of non-combustible products or products with low fire load and combustibility: Examples include metals, glass or cement or non-flammable liquids in glass containers, canned food products, frozen food products, fresh fruit, etc.

The second scenario can be described as a “severe” fire. This fire may involve a complete bus or a complete freight truck or trailer with a highly combustible cargo. Examples include products containing unexpanded or expanded plastics, food products such as margarine, products with wax or paraffin such as candles, tissue products, rubber products, etc.

The estimations are based on an assessment of the system activation reliability (based on the statistics discussed above) and an assessment of the system performance effectiveness. The assessment of the system performance effectiveness is partly based on the statistics discussed above and partly on fire test data conducted for fire hazards equal to the fire hazards present on ro-ro decks [19].

An effective system performance is defined as the performance where a fire is prevented from progressing from a “small” fire to a severe fire or from a “severe” fire to a very severe or catastrophic fire.

The system activation reliability for a deluge sprinkler system installed in accordance with IMO Resolution A.123(V) is judged to be similar to a manually activated deluge system per the new proposed installation guidelines. However, due to the lower discharge density its performance effectiveness is expected to be less.

For the “severe” fire scenario, none of the systems are judged to have a 100% performance effectiveness.

Table 9 Estimated overall performance for the system types according to the new proposed installation guidelines and the deluge system concept of IMO Resolution A.123(V) against "small" fires.

	Wet pipe	Dry pipe	Preaction	Deluge (automatic)	Deluge (manual)	Deluge according to Resolution A.123(V)
System activation reliability [%]	95	90	85	95	90	90
System performance effectiveness [%]	100	100	100	100	100	100
Overall performance [%]	95,0	90,0	85,0	95,0	90,0	90,0

Table 10 Estimated overall performance for the system types according to the new proposed installation guidelines and the deluge system concept of IMO Resolution A.123(V) against "severe" fires.

	Wet pipe	Dry pipe	Preaction	Deluge (automatic)	Deluge (manual)	Deluge according to Resolution A.123(V)
System activation reliability [%]	95	90	85	95	90	90
System performance effectiveness [%]	95	90	95	95	90	75
Overall performance [%]	90,0	81,0	80,0	90,0	81,0	67,5

Although these numbers are estimates and should be treated as such, they provide an understanding on how the system activation reliability and the system performance effectiveness influence the overall performance.

As indicated by the statistics from Hall [14], 53% of all failures to operate due to the fact that the system was shut off and 15% due to lack of maintenance. These figures highlight the importance of proper supervision and maintenance.

The statistics from Hall also includes reliability data for carbon dioxide systems indicating a failure rate of 17% and an effectiveness of 94%, for all types of properties. This results in an overall performance of 78% (i.e. 83% system activation reliability × 94% system performance effectiveness). In other words, a change-over from a protection of ro-ro decks with carbon dioxide systems to efficiently designed and installed sprinkler systems would likely improve long-term fire statistics.

6 Discussion

New types of cargoes on freight trucks, new construction material in vehicles and the increased use of plastics in the interiors and exteriors of vehicles have all contributed to substantial increases in the fire load on ro-ro decks since the 1960s. New alternative fuels such as ethanol, E85 (blend of 85% ethanol 15% gasoline), DME (dimethyl ether), CNG (compressed natural gas), CBG (compressed biogas), LNG[6] (liquefied natural gas), LPG (liquefied petroleum gas), electric and hybrid vehicles and hydrogen powered vehicles have or will change the fire risk and the nature of a vehicle fire. Present ship design is moving towards larger vessels and larger ro-ro spaces. The ro-ro deck fires on-board UND Adriyatik in 2008 [20] and Vincenzo Florio in 2009 [21] further underline the effects of ro-ro deck fires and the problems associated with fighting them.

Since the 1960s, sprinkler technology has evolved. This report summarises the outcome of a literature review focused on establishing input for new design and installation guidelines. The intention of these new installation guidelines is to support the use of modern sprinkler technology on ro-ro decks in recognition of changing fire risks on-board. But modern sprinkler technology may also offer higher overall performance, using less water, potentially at a lower expense.

The survey shows that there are limited guidelines, testing or research data specifically applicable to ro-ro decks. A proper sprinkler system design needs to rely on data for similar applications or testing, a certain degree of judgement and a careful application of safety factors. Indeed, a series of large-scale fire suppression tests with deluge water spray and water mist systems was conducted within the IMPRO project with that objective , see SP Report 2009:29 [**Fel! Bokmärket är inte definierat.**].

Based on the results of these tests and the literature study presented here, sprinkler design recommendations for ro-ro decks are suggested, see Tables 11 to 13. For comparison, the densities given in Resolution A.123(V) are given and a nominal total flow rate has been calculated based on a imaginary deck with a width of 30 m.

It is proposed that the length of the deluge sections are reduced from 20 m, as required by for present days deluge systems, to 15 m. This is an attempt to reduce the required total volume of water, although it will require a greater number of deluge valves (+25%). With the expected improved system performance, however, the reduction in length should not be a concern.

Table 11 The proposed minimum required water discharge density and area of operation for decks having a free height equal to or less than 2,5 m.

Type of system	Minimum water discharge density [mm/min]	Minimum area of operation	Nominal total water flow rate* [L/min]
Wet pipe system	6,5	140 m^2	910
Dry pipe or preaction system	6,5	185 m^2	1200
Deluge system	5	2 × 15 m	4500
Resolution A.123(V)	3,5	2 × 20 m	4200

*) The nominal total water flow rate is based on a deck with a width of 30 m.

[6] LNG, liquefied natural gas is made by refrigerating natural gas to -162°C. There are heavy-duty vehicles on the market that operates on LNG. If a leakage from a tank occurs, LNG in liquid form will spill out. Water from a sprinkler system will increase the vaporization of the liquid and could potentially increase the fire hazard.

Table 12 The proposed minimum required water discharge density and area of operation for decks having a free height in excess of 2,5 m but less than 6,5 m.

Type of system	Minimum water discharge density [mm/min]	Minimum area of operation	Nominal total water flow rate* [L/min]
Wet pipe system	15	280 m^2	4200
Dry pipe or preaction system	15	365 m^2	5475
Deluge system	10	2 × 15 m	9000
Resolution A.123(V)	5	2 × 20 m	6000

*) The nominal total water flow rate is based on a deck with a width of 30 m.

Table 13 The proposed minimum required water discharge density and area of operation for decks having a free height in excess of 6,5 m but less than 9,0 m.

Type of system	Minimum water discharge density [mm/min]	Minimum area of operation	Nominal total water flow rate* [L/min]
Wet pipe system	20	280 m^2	5600
Dry pipe or preaction system	20	365 m^2	7300
Deluge system	15	2 × 15 m	13500
Resolution A.123(V)	5	2 × 20 m	6000

*) The nominal total water flow rate is based on a deck with a width of 30 m.

For dry pipe systems, the sprinkler operating area has been increased by 30% without revising the water discharge density, which is in line with the recommendations of NFPA 13. The use of an automatic sprinkler system (i.e. a wet, dry or preaction system) will typically reduce the total flow rate compared with today's requirements, unless the free height of the deck is in excess of 6,5 m.

For decks with a free height in excess of 2,5 m, the use of high-temperature sprinklers, i.e. sprinklers with a nominal operating temperature of between 121°C to 149°C is proposed. With such sprinklers, the number of sprinklers that activates during a fire will be reduced, especially for fires where flammable or combustible liquids are present or where shielding of combustibles are extensive (as with fires in vehicles).

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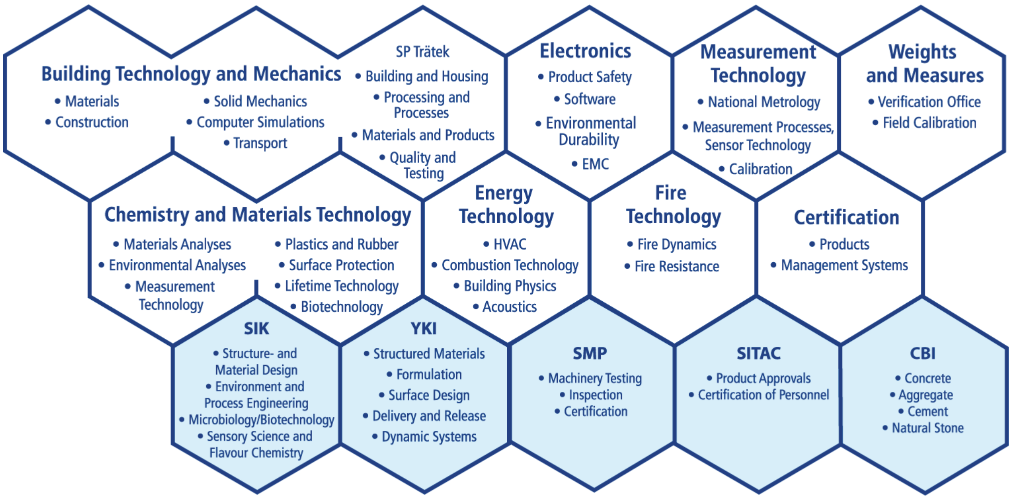

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