LIGHTHOUSE
SWEDISH MARITIME COMPETENCE CENTRE

HÅLLBAR
SJÖFART

ReliS – Reliable Sprinkler

Förstudie som samlar in kunskap gällande tillförlitlighet av drenchersystem i rorolastutrymme.

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I samarbete med
En referensgrupp som bestod av representanter från:
Stena Teknik, ForSea Ferries, Destination Gotland, Transportstyrelsen, Novenco Fire, Johnson Controls, Albacon, DNV, MacGregor och RISE.

Detta projekt har genomförts inom Trafikverkets branschprogram Hållbar sjöfart, som drivs av Lighthouse.

Summary

ReliS – Reliable Sprinkler, is a pre-study investigating open water deluge sprinkler systems in ro-ro spaces on ro-ro ships, also known as drencher systems. The overall goal of the project is to develop proposals for technical and operational improvements, in order to avoid malfunctions and make the systems more reliable.

The principal function of a drencher system is the same as an open water deluge system: when a deluge section is activated, water shall be discharged from all the open nozzles in the deluge (“drencher”) section.

These four approaches to collect knowledge and experience regarding the drencher systems were used in this study:

- A desk study to examine regulations and other guidance documents for the drencher system.
- Interview study to get an understanding of e.g., good examples, issues and ship specific applications.
- Field study to examine the system installation together with crew representatives onboard and to participate in drencher system flow tests.
- System group workshops following a structured method for finding innovative solutions.

The developed proposals for improvements to the drencher systems technical and operational design was developed during Workshop #3 by the system group. The ideas *Piping material* and *Avoid Sea water when testing* was chosen to be further developed.

The use of sea water increases the corrosion rate in steel pipe systems. The salinity of the water also has an effect on corrosion rate. For the ships included in this pre-study, there was a difference among the crews’ experience of clogged nozzles and corrosion whether the ship operated the Swedish west coast or the east coast. The crew at ships operating the east coast, which has lower salinity in the water, did not seem to have experience with clogged nozzles and corrosion to the same extent as the ships on the west coast. Crews at ships operating the east coast was more concerned about fulfilling the requirements and actual suppressing a fire, which was also an expressed concern by the interviewed inspectors.

Problems with internal corrosion in pipes is not unique for deluge system at ships, it also exists for land-based applications, such as in road tunnels and buildings.

The results of the project are communicated directly to the shipping industry via the reference group and system group established for the project, and to the Swedish Transport Agency for further notification to the International Maritime Organization (IMO) development of safety rules for ships.

Sammanfattning

ReliS – Reliable Sprinkler, är en förstudie som undersökt sprinklersystem (gruppaktiveringssystem) i rorolastutrymmen på rorofartyg, även kallade drenchersystem. Det övergripande målet med projektet var att ta fram förslag på tekniska och operativa förbättringar, för att undvika felfunktion och göra systemen mer tillförlitliga.

Den huvudsakliga funktionen för ett drenchersystem är densamma som för ett delugesystem: när en deluge sektion är aktiverad ska vatten tömmas ut från alla öppna munstycken i deluge ("drencher") sektionen.

Dessa fyra tillvägagångssätt för att samla in kunskap och erfarenhet om drenchersystemen användes i studien:

- Litteraturstudie för att granska föreskrifter och andra vägledande dokument för drenchersystemet.
- Intervjustudie för att få förståelse för goda exempel, frågeställningar, skeppsspecifika applikationer m.m.
- Fältstudie för att undersöka systeminstallationen tillsammans med besättningsrepresentanter ombord och för att delta i flödestester av drenchersystem.
- Systemgruppsworkshops efter en strukturerad metod för att hitta innovativa lösningar.

De framtagna förslagen till förbättringar av drenchersystemens tekniska och operativa design utvecklades under Workshop #3 av Systemgruppen. Idéerna Rörmaterial och Undvik havsvatten vid testning valdes för att vidareutveckla.

Användningen av havsvatten ökar korrosionshastigheten i stålrörssystem. Vattnets salthalt har också en effekt på korrosionshastigheten. För de fartyg som ingick i denna förstudie var det skillnad mellan besättningarnas upplevelse av igensatta munstycken och korrosion om fartyget trafikerade den svenska västkusten eller östkusten. Besättningsmedlemmar på fartyg som trafikerar östkusten, som har lägre salthalt i vattnet, verkade inte ha erfarenhet av igensatta munstycken och korrosion i samma utsträckning som de på fartygen som trafikerar västkusten. Besättningsmedlemmar på fartyg som trafikerade östkusten var mer oroade över att uppfylla kraven och att faktiskt dämpa en brand, vilket också var en uttryckt oro från de intervjuade inspektörerna.

Problem med intern korrosion i rör är inte unikt för drenchersystem på fartyg, det är även problematiskt för landbaserade applikationer, som i vägtunnlar och i byggnader.

Resultatet av projektet kommuniceras direkt till sjöfartsnäringen via de referens- och systemgrupper som upprättats för projektet samt till Transportstyrelsen för vidare anmälan till IMO för utveckling av säkerhetsregler för fartyg.

Content

1. Introduction

This report is documenting the pre-study ReliS – Reliable Sprinkler, which will study open water deluge sprinkler systems in ro-ro spaces on ro-ro ships. The systems are also called drencher system, and the principal function is the same, when a deluge section is activated, water shall be discharged from all the open nozzles in the deluge ("drencher") section.

The study is part of the Swedish Transport Administration's Sustainable Shipping program, which is run by Lighthouse (Swedish Maritime Competence Centre) and the work is carried out by RISE (Research Institutes of Sweden) in cooperation with Chalmers University of Technology. The work has been led by RISE.

1.1 Background

In the year 2012 the International Maritime Organization Subcommittee FSI (Flag State Implementation) concluded that there is a need for improvements of fire extinguishing system for ro-ro ships [1]. To further put light on the problem a seminar was hosted by European Maritime Safety Agency (EMSA) in year 2015 with participants from European flag states and investigation bodies, and the focus was on fires in ro-ro spaces. From discussions in this seminar, it was established that malfunctions of the fire extinguishing system were one of the two largest risk contributions to fires in ro-ro spaces (the second one was electrical caused fires) [2]. Hereafter, EMSA funded a project called FIRESAFE [3], in which malfunctions of the fire extinguishing system (mainly drencher systems) were analysed and suggestions for improvement measures were evaluated by SP (now RISE) in collaboration with the classification society Bureau Veritas and the ship operator Stena Line AB.

One insight from the FIRESAFE project [3] was that there is knowledge, experience and "best practices" regarding the reliability of drencher systems in ro-ro spaces left to gather, from the operators and other actors. Moreover, the vast majority of the drencher systems on the world's ro-ro ships of today are subject to the regulation IMO Resolution A.123 (V) [4], which was adopted in year 1967. There has been a modernization of the regulation which are included in MSC.1/1430/Rev2 [5] applicable for ships built on or after 1 July 2014. However, Resolution A.123 (V) still applies to the drencher systems in Special category spaces on ro-ro ships built as long as they are maintainable.

1.2 Scope of the project

The scope of this pre-study ReliS is to collect knowledge and experience regarding the drencher systems which are subject to IMO Resolution A.123 (V) [4]. The focus of the project is on the parts that affect the reliability of the drencher systems, from the time the system (pump) is activated until the nozzle discharge water with the intended pressure and flow. Aspects included are system design, inspections, testing and maintenance. For example, the study will examine the following aspects:

- Design factors that affect reliability

- Design factors that affect sustainability

- Need and possibility of more frequent control of function (testing)

1.3 Outcome

The overall goal of the project is to develop proposals for technical and operational improvements for drencher systems in ro-ro spaces on ro-ro ships, in order to avoid malfunctions and make the systems more reliable.

The proposals will be on a conceptual level and should be practical and useful for the shipping industry. The proposals could have an impact on regulations, standards, and guidance documents, as well as on design changes and work procedures.

The results of the project are communicated directly to the shipping industry via the reference group and system group established for the project, and to the Swedish Transport Agency for further notification to the International Maritime Organization (IMO) development of safety rules for ships.

1.4 Delimitations

The system in focus in this project is the drencher system, from the sea water connections to the open water spray nozzle. For the project it is assumed that 1) the crew correctly activates the drencher system and 2) disposal of water from ro-ro space is done successfully. Design issues related to the activation of the system has been eliminated. Drainage of water from the deck is not included in this study.

The drencher systems of interest are the systems which are subjects to the Resolution A.123 (V) [4].

2. Methodology

This pre-study used four approaches to collect knowledge and experience regarding the drencher systems.

- A desk study to examine regulations and other guidance documents for the drencher system.
- Interview study to get an understanding of e.g., good examples, issues and ship specific applications.
- Field study to examine the system layout together with crew representatives onboard and to participate in drencher system flow tests.
- System group workshops following a structured method for finding innovative solutions.

In the following sections each approach is described more in detail.

2.1 Desk study

The desk study was a review of drencher-related information available before and after the interviews, field studies and workshops were held. The purpose was to get a better understanding of requirements, system layouts and functions of the system. The desk study included for instance previous research/studies, regulations and documents from other applications where open water spray systems are used.

2.2 Interview study

An interview study was carried out to 1) gain understanding of the problems existing with the drencher system of today, both technical and operational. 2) identify good examples of ship-specific solutions and alternative solutions.

The selection of interviewees was made with the aim to represent several perspectives of the actors of the drencher system, see Figure 1.

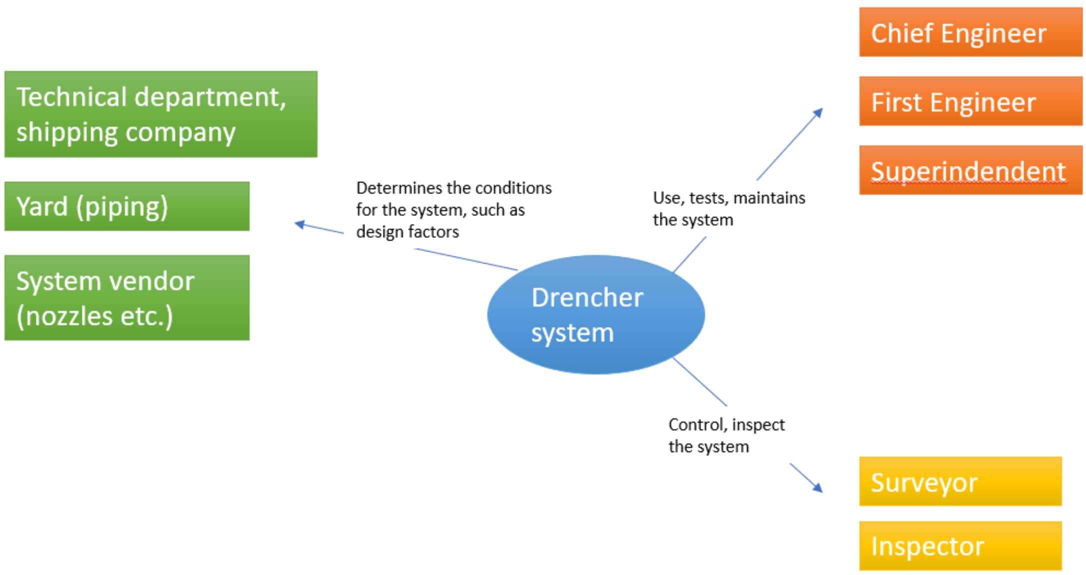

Figure 1. Selection of interviewees

Additionally, interviews were carried out with representatives from other industries (offshore and road tunnels) since the operational environments were considered similar to ro-ro ships.

An interview guideline was used during the interviews, but supplementary questions were asked when it was deemed necessary to gain a better understanding. The majority of the interviews were conducted in digital meetings or during the field studies, and the length of the interviews was 1-1.5 hours. One interview, were for practical reasons, carried out through e-mail communication. A list of interview participations is presented below:

- Principal surveyor, classification society
- Inspectors, flag state
- Chief Engineer
- First Engineer
- Naval architect
- Superintendent
- System vendor
- Operational manager (former), Oil rigg
- Sprinkler expert, road tunnels

Project information was administered before the interviews and consent according to GDPR was sought using a consent form. Notes were taken during the interview. After the interview, the notes were sent to the interviewee for referral. Any comments were corrected in the notes.

2.3 Field study

Due to the pandemic situation the possibilities for carrying out field studies onboard ships were limited. The limited amount of field visits was compensated with more videocall-interviews.

Two field studies on ships from different ship owners were carried out. One on the west side of Sweden, and one on the east side of Sweden. The aim with the field studies was to gain a better understanding of design and operational factors, to study the drencher system installation and to identify possible alternative solutions, issues, and good examples of ship-specific solutions. The field studies included a guided tour made by the chief engineer and first engineer and were combined with a semi-structured interview.

A field study guideline was used during the ship visits, but supplementary observations were studied when it was deemed necessary to gain a better understanding.

2.4 Workshops with the system group

For the work with idea generation and concept development, workshops were carried out with a system group. The system group was led by a change agent from RISE, working as a moderator and structuring the workshops. The work procedure for the workshops was inspired by the workflow described in the book "*Systemgrupper och innovativ problemlösning*" (translated into English: "System groups and innovative problem solving") [6]. The system group was constituted by actors representing as many perspectives of the (drencher) system as possible, participant roles are shown in Table 1. From operation and maintenance to management; from suppliers to owners and so on; in order to take advantage of experiences from all parts of the system and to get a holistic view of the problem and possible solutions. By having this broad representation in the system group, the authors Rollenhagen and Andersson [6] argue that there will be a reduced risk for suboptimized solutions and that the probability for a successful change process will be increased.

The work with the system group was divided into 3 workshops:

Workshop #1: Problem definition, vision, and idea generation
Workshop #2: Idea selection
Workshop #3: Idea development

Depending on the ideas generated, the composition of the system group can be changed to better suit the work ahead. To avoid unnecessary limitation of thoughts in the creative work, the system group members were told to be open minded during the workshops. Moreover, the system group members were requested to collect feedback on workshop results from their own organizations, thus promoting employee attitudes for the solutions.

The participation in the system group was made by in-kind contribution of partners supporting the project. The participant invited and participations at the different workshops are listed in Table 1.

Table 1 Participation in system groups. An X equals one person.

Invited	WS #1	WS #2	WS #3
Principal surveyor, Classification society		x	x
Inspector, Transport Agency			
Expert fire regulations, Swedish Transport Agency	x	x	x
Chief Engineer	xx	xx	x
Naval architect, focus Fire Safety, at shipping company	x	x	x
System vendor	xxx	xxx	xx
Project Manager Fire Safety, at shipping company		x	
Sprinkler expert	x	x	x
Sprinkler expert, land-based applications	x	x	x
Fire expert, Maritime applications		x	
Number of attendees	**9**	**12**	**8**

**Inspectors from the Swedish Transport Agency were invited to the workshops but due to high workload they could unfortunately not participate on any occasion.*

According to Andersson and Rollenhagen [6] it is always possible for the system group to go back and revise the results from previous workshops, as long as all members are agreeing upon the change. The idea behind the iterative work process is that the members of the system group will gain more and more insights as the work proceeds.

Due to the present pandemic situation (autumn, year 2021), these workshops were held online via Microsoft TEAMS. The online collaborative whiteboard platform Mural [MURAL is a digital-first visual collaboration platform | MURAL] was used to facilitate the interactive work.

Each workshop occasion is described in the following sub sections.

2.4.1 Workshop #1: Problem definition, vision, and idea generation

Firstly, the system group had to agree upon the actual problem. *Why is change necessary*? This is important for the idea generation; everybody needs to have a common ground for a fruitful discussion and the work ahead. The change agent had identified the problem picture in advance and presented it to the system group during the workshop. The problem picture was examined through desk study (see section 2.1), interviews (see section 2.2) and field studies (see section 2.3). The system group was given the opportunity to revise the problem description in any way they found suitable. However, as mentioned earlier, the final description needed to be accepted by everyone in the system group to continue to the next step.

Secondly, the system group had to agree upon the vison, i.e. *What should be achieved with the change*? This is also important for work later on; the vision affects preferred solutions. When the first and second agreements were in place, a brainstorming session was initiated. The participants were asked to generate as many ideas as possible. Crazy and unrealistic ideas were encouraged, since these ideas can generate new thinking which can lead to "never before thought of"-solutions. No selection of the ideas was made in this phase of the work.

The rules for the brainstorming session were:

A. Negative criticism is not welcome. Better to have a cheering attitude.
B. As many ideas as possible
C. Wild ideas are encouraged
D. Feel free to combine two or more ideas into new ones
E. Seek improvements in ideas from others
F. Think aloud, openly present all associations

The aim with the first workshop was to release associations and thoughts from different perspectives of the chosen system, (drencher system: from sea water to nozzle) and thereby create a collective compilation of ideas.

All presented ideas were documented and numbered.

2.4.2 Workshop #2: Idea selection

The aim with this workshop was to select ideas that everyone in the system group saw potential in, and hence are ideas worth developing further.

In preparation to this workshop the attendees were asked to go through all the ideas generated in Workshop #1 and choose the ones which they found most appealing from their individual perspective and experience. The ideas which all, or at least the majority, had chosen were further discussed during this workshop. Last, participants in the system group were asked to start creating a concept of the chosen ideas to present in the third workshop.

2.4.3 Workshop #3: Idea development

In this third, and final, workshop the chosen ideas from Workshop #2 were developed into concepts (note: in this project the aim is to develop concept solutions at an overall level). As a preparation, the system group members had been asked to refine the ideas as far as possible with help from their colleagues and partner networks.

The members were divided into two groups to further develop and document the chosen ideas. The groups were also asked to describe requirements, associated risks, examples etc. for the specific solution. Table 2 presented below, was provided as guidance and as a documentation template for the development work.

Table 2. Guidance and documentation template for the development of the chosen solution(s).

What is the solution trying to solve?	*Describe the need e.g., "Avoid salt water when testing"*
This is what the regulations allow today	*Refer to codes, laws, explicit the paragraph/reference and interpretations of the codes, legal text from approved authorities*
Solution proposals from the ReliS project	*Use the term from the solution-list (Excel) or use other words. e.g., "Use fresh water"*
Options for implementation	*There can be several ways to implement the solution. Explain relevant concept(s)*
Associated risks	*List any risks that the solution entails / needs to address*
Associated requirements	*List and/or explain associated requirements that may become relevant during implementation*
Examples from other systems	*Give examples of other systems that have implemented the solution, if any.*
Examples from other/similar industries	*Give examples of other/similar industries that have implemented the solution, if any.*
Stakeholders who may benefit from the solution	*Indicate which stakeholders may be interested in taking part in the solution, e.g., IMO, other shipping companies, fire system manufacturers*

What is the solution trying to solve?	*Describe the need e.g., "Avoid salt water when testing"*
Further or additional information	*E.g., if further studies are needed*

2.4.4 Seminar with corrosion expert

After Workshop #3 a need for more knowledge regarding pipe material in correlation to corrosion was expressed by one of the system group members, and this person helped organize a seminar with a corrosion expert from the industry.

All members of the system group (and colleagues) were invited to a seminar with Jeff Kochelek from Engineered Corrosion Solutions (ECS). The aim with the seminar was to gain an enhanced knowledge of the origin of corrosion and what can be done to prevent it. The title of the seminar was "Corrosion in Dry Pipe (Open Head Deluge) - Fire Sprinkler Systems".

3. Result - Desk study

In this chapter the result from the desk study is presented.

3.1 Rules and regulations

This chapter aims at giving an overview of the requirements applicable in ro-ro spaces regarding drencher system, i.e., "open deluge water spray systems", designed and installed in accordance with Resolution A.123(V) [4]. Resolution A.123 are recommendation on fixed fire extinguishing systems for special category spaces. Special category spaces are defined in SOLAS as "*those enclosed spaces above or below the bulkhead deck intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion, into and from which such vehicles can be driven and to which passengers have access.*"

3.1.1 Applicable regulations

A summary of the main regulations related to drencher system in ro-ro spaces is provided in Table 3:

Table 3. List of main regulations related to drencher system in ro-ro spaces.

Regulation	Application date	Applicable to	Summary
SOLAS 74	1980	Continuously updated with amendments	Overall safety regulation for merchant ships

Regulation	Application date	Applicable to	Summary
Resolution A.123 (V)	1967-10-25	Applicable to 2021-01-01 for systems based on these Recommendations. For systems installed from 2021-01-01, see MSC.1/Circ.1430/Rev. 2*	Recommendation on fixed fire extinguishing systems for special category spaces
MSC/Circ.914	1999	Superseded by MSC.1/Circ.1272 on 2008-06-04	Guidelines for the approval of alternative fixed water-based fire-fighting systems for special category spaces
MSC.1/Circ.1272	2008-06-04	Superseded first time by MSC.1/Circ.1430 on 2012-05-31. However, applicable to 2021-01-01 for systems based on these guidelines. For systems installed from 2021-01-01, se MSC.1/Circ.1430/Rev.2 of 2020-12-08*.	Guidelines for the approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces equivalent to that referred to in resolution A.123(V)
MSC.1/Circ.1430	2012-05-31	Applicable for systems installed to 2021-01-01. For systems installed from 2021-01-01, see MSC.1/Circ.1430/Rev. 2	Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces
MSC.1/Circ.1430/Rev1	2021-01-01	See MSC.1/Circ.1430/Rev. 2	Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces

Regulation	Application date	Applicable to	Summary
MSC.1/Circ.1430/Rev2	2021-01-01		Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces
MSC.1/Circ.1432	2013-05-31		Revised guidelines for the maintenance and inspection of fire protection systems and appliances
International Code for Fire Safety Systems (FSS Code)	December 2000		The purpose of FSS Code is to provide international standards of specific engineering specifications for fire safety systems required by chapter II-2 of SOLAS

** For systems installed to 2021-01-01, the following applies: Rev.2 of the guidelines superseded MSC.1/Circ.1272, MSC.1/Circ.1430 and MSC.1/Circ.1430/Rev.1, except that fire and component tests previously conducted in accordance with MSC.1/Circ.1272 or MSC.1/Circ.1430 or MSC.1/Circ.1430/Rev.1 remain valid for the approval of new systems. Existing fixed fire-extinguishing systems for special category spaces approved and installed based on this pertinent resolution, MSC.1/Circ.1272, MSC.1/Circ.1430 and MSC.1/Circ.1430/Rev.1 installed before 2021-01-01 should be permitted to remain in service as long as they are serviceable.*

3.1.2 SOLAS 74

The requirement for a ro-ro space on a ro-ro ship to be equipped with a fixed fire extinguishing system is found in SOLAS [7] Chapter II, Regulation 20 *Protection of vehicle, special category, and ro-ro spaces.*

For ships constructed <u>on or after 1 July 2014</u> the following applies:

(SOLAS II-2/20.6.1.2) *"Vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces shall be fitted with a fixed water-based fire-fighting system for ro-ro spaces and special category spaces complying with the provisions of the Fire Safety Systems Code which shall protect all parts of any deck and vehicle platform in such spaces. Such a water-based fire-fighting system shall have:*

.1 *a pressure gauge on the valve manifold;*

.2 *clear marking on each manifold valve indicating the spaces served;*

.3 instructions for maintenance and operation located in the valve room; and

.4 a sufficient number of drainage valves to ensure complete drainage of the system."

Ships constructed before 1 July 2014 shall comply with the previously applicable requirements of paragraphs 6.1.2 which had the following wording:

(SOLAS II-2/20.6.1.2) "*Ro-ro and vehicle spaces not capable of being sealed and special category spaces shall be fitted with an approved fixed pressure water spraying system* for manual operation which shall protect all parts of any deck and vehicle platform in such spaces. Such water spray systems shall have:*

** Refer to the Recommendation on fixed fire-extinguishing systems for special category spaces adopted by the Organization by resolution A.123(V).*

.1 a pressure gauge on the valve manifold;

.2 clear marking on each manifold valve indicating the spaces served;

.3 instructions for maintenance and operation located in the valve room; and

.4 a sufficient number of drainage valves."

For the "newer" systems, they shall comply with the Fire Safety Systems (FSS) Code [8] while the "older" systems are referred to fulfil Resolution A.123 (V) *Recommendation on fixed fire-extinguishing systems for special category spaces* [4].

In Regulation 10 in SOLAS [7] Chapter II-2 it is stated that a purpose of the regulation (Suppression of fire) is to suppress and swiftly extinguish a fire in the space of origin.

Regulation 21 *Casualty threshold, safe return to port and safe areas* in SOLAS [7] Chapter II-2 defines thresholds, and how long the ship should remain safe for evacuation. When fire damage does not exceed the casualty threshold indicated in the regulation, the ship shall be capable of returning to port while providing a safe area. This regulation is for passenger ships constructed from 2010-07-01, having length of 120 m or more or having three or more main vertical zones.

3.1.3 Resolution A.123(V)

Resolution A.123(V) published in 1967 [4] is meant for special category spaces, which are those spaces to which passengers have access and intended for the carriage of motor vehicles with fuel in their tanks for their own propulsion. Resolution A.123(V) does only permit the use of manually activated (i.e., not automatic activation) deluge water spray systems.

The Resolution A.123(V) is two pages and leaves the reader with a list of a) to g) that the system should comply with, the list is shown in Figure 2.

A fixed fire extinguishing system for special category spaces should be at least as effective in controlling a flowing petrol fire as a fixed pressure water-spraying system complying with the following:

(a) The nozzles should be of an approved full bore type. They should be arranged so as to secure an effective distribution of water in the spaces which are to be protected. For this purpose, the system should be such as will provide water application at a rate of at least 3.5 litres per square metre per minute (0.07 gallons per square foot per minute) for spaces with a deck height not exceeding 2.5 metres (8.2 feet) and a capacity of at least 5 litres per square metre per minute (0.1 gallons per square foot per minute) for spaces with a deck height of 2.5 metres (8.2 feet) or more.

(b) The water pressure should be sufficient to secure an even distribution of water.

(c) The system should normally cover the full breadth of the vehicle deck and may be divided into sections provided they are of at least 20 metres (66 feet) in length, except that in ships where the vehicle deck space is subdivided with longitudinal "A" Class divisions forming boundaries of staircases, etc., the breadth of the sections may be reduced accordingly.

(d) The distribution valves for the system should be situated in an easily accessibly position adjacent to but outside the space to be protected which will not readily be cut off by a fire within the space. Direct access to the distribution valves from the vehicle deck space and from outside that space should be provided. Adequate ventilation should be fitted in the space containing the distribution valves.

(e) The water supply to the system should be provided by a pump or pumps other than the ship's required fire pumps which should additionally be connected to the system by a lockable non-return valve which will prevent a back-flow from the system into the fire main.

(f) The principal pump or pumps should be capable of providing simultaneously at all times a sufficient supply of water at the required pressure to all nozzles in the vehicle deck or in at least two sections thereof.

(g) The principal pump or pumps should be capable of being brought into operation by remote control (which may be manually actuated) from the position at which the distribution valves are situated.

Figure 2 Aspects that fixed fire extinguishing systems for special category spaces designed in accordance with IMO Resolution A.123(V) should comply with.

For the purpose of this pre-study, the following requirements are worth highlighting:

- The water discharge density shall be 3.5 (l/m^2)/min for deck height up to 2.5 m, and 5.0 (l/m^2)/min for deck height 2.5 m or more.
- The water pressure should be enough to secure an even distribution of water.
- The water supply should be provided by pump(s) other than the required fire pumps (which are used for e.g., fire hoses).
- The drencher pump(s) shall be able to supply with water for at least two sections of the deck, at all times.

It can be noted that the Resolution A.123 (V) [4] is referring to a design fire of flowing petrol.

3.1.4 MSC/Circ.914, MSC.1/Circ.1272 and MSC.1/Circ.1430 with revisions

Around 30 years after the introduction of Resolution A.123(V), MSC/Circ.914 *Guidelines for the approval of alternative fixed water-based fire-fighting systems for special category spaces* [9] were adopted, which permitted alternative fixed water-based fire-fighting systems. However, according to Arvidson in 2010 ("Large scale ro-ro deck fire suppression tests") [10] there were at that time no systems in the market that fulfilled the requirements of MSC/Circ.914.

MSC.1/Circ.1272 *Guidelines for the approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces equivalent to that referred to in resolution A.123(V)* [11], outdated MSC/Circ.914. With the introduction of MSC.1/Circ.1272 in 2008, alternative (to systems designed in accordance with IMO Resolution A.123(V)) systems were allowed to be automatically activated.

MSC.1/Circ.1430 *Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces* [12] allow for manual deluge systems as well as automatic deluge and pre-action systems and this circular provides the guidelines that are valid for ships built on or after 1 July 2014.

MSC.1/Circ.1430/Rev.2 [5], which is the latest amendment of the circular, is much more detailed than Resolution A.123(V) [4]. The circular provides principal requirements and additional requirements both for prescriptive-based system design and for performance-based system design.

The minimum water discharge density varies from 5 to 20 mm/min and depends on the free height of the deck. Lower free height requires lower discharge density.

For the purpose of this pre-study, the following requirements are worth highlighting in MSC.1/Circ.1430/Rev2:

"*3.3 The design of the system should ensure that full system pressure is available at the most remote sprinkler or nozzle in each section within 60 s of activation".*

"3.8 The system should be provided with a redundant means of pumping or otherwise supplying a water-based extinguishing medium to the system."

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

"3.10 The system and its components should be designed to withstand ambient temperatures, vibration, humidity, shock, impact, clogging and corrosion normally encountered. Piping, pipe fittings and related components except gaskets inside the protected spaces should be designed to withstand 925°C. Distribution piping should be constructed of galvanized steel, stainless steel, or equivalent."

"3.20 Means for flushing of systems with fresh water should be provided."

"4.2 Deluge systems should be designed for the simultaneous activation of the two adjacent deluge sections with the greatest hydraulic demand at the minimum water discharge density given in tables 4-1 to 4-3."

Noteworthy is that systems in service (designed in accordance with IMO Resolution A.123(V)) does not need to comply to MSC.1/Circ.1430/Rev2, nevertheless the requirement regarding corrosion/clogging could also be seen as important for these systems.

3.1.5 MSC.1/Circ.1432

MSC.1/Circ.1432 R*evised guidelines for the maintenance and inspection of fire protection systems and appliances* [13] applies to all ships and provide the minimum recommended level of maintenance and inspections for fire protection systems and appliances.

The maintenance is divided into weekly, monthly, quarterly, annual, two-year, five-year, and ten-year actions. For deluge water spray systems, the following maintenance schedule applies:

Interval	**Inspections should be carried out to ensure that the indicated actions are taken for the specified equipment**
Weekly	**4.7 Water mist, water spray and sprinkler systems** .1 verify all control panel indicators and alarms are functional; .2 visually inspect pump unit and its fittings; and .3 check the pump unit valve positions, if valves are not locked, as applicable.
Monthly	**5.1 Fire mains, fire pumps, hydrants, hoses, and nozzles** .1 verify all fire hydrants, hose and nozzles are in place, properly arranged, and are in serviceable condition; .2 operate all fire pumps to confirm that they continue to supply adequate pressure; and .3 emergency fire pump fuel supply adequate, and heating system in satisfactory condition, if applicable. **5.4 Water mist, water spray and sprinkler systems** .1 verify all control, pump unit and section valves are in the proper open or closed position; .2 verify sprinkler pressure tanks or other means have correct levels of water; .3 test automatic starting arrangements on all system pumps so designed; .4 verify all standby pressure and air/gas pressure gauges are within the proper pressure ranges; and .5 test a selected sample of system section valves for flow and proper initiation of alarms. (**Note** – The valves selected for testing should be chosen to ensure that all valves are tested within a one-year period.)
Quarterly	**6.1 Fire mains, fire pumps, hydrants, hoses, and nozzles** Verify international shore connection(s) is in serviceable condition. **6.5 Water mist, water spray and sprinkler systems** Assess system water quality in the header tank and pump unit against the manufacturer's water quality guidelines.
Annual	**7.1 Fire mains, fire pumps, hydrants, hoses, and nozzles** .1 visually inspect all accessible components for proper condition; .2 flow test all fire pumps for proper pressure and capacity. Test emergency fire pump with isolation valves closed;

Interval	Inspections should be carried out to ensure that the indicated actions are taken for the specified equipment
	.3 test all hydrant valves for proper operation; .4 pressure test a sample of fire hoses at the maximum fire main pressure, so that all fire hoses are tested within five years; .5 verify all fire pump relief valves, if provided, are properly set; .6 examine all filters/strainers to verify they are free of debris and contamination; and .7 nozzle size/type correct, maintained and working. **7.5 Water mist, water spray and sprinkler systems** .1 verify proper operation of all water mist, water-spray and sprinkler systems using the test valves for each section; .2 visually inspect all accessible components for proper condition; .3 externally examine all high-pressure cylinders for evidence of damage or corrosion; .4 check the hydrostatic test date of all high-pressure cylinders; .5 functionally test all fixed system audible and visual alarms; .6 flow test all pumps for proper pressure and capacity; .7 test all antifreeze systems for adequate freeze protection; .8 test all system cross connections to other sources of water supply for proper operation; .9 verify all pump relief valves, if provided, are properly set; .10 examine all filters/strainers to verify they are free of debris and contamination; .11 verify all control/section valves are in the correct position; .12 blow dry compressed air or nitrogen through the discharge piping of dry pipe systems, or otherwise confirm the pipework and nozzles are clear of any obstructions. This may require the removal of nozzles, if applicable; .13 test emergency power supply switchover, where applicable; .14 visually inspect all sprinklers focusing in areas where sprinklers are subject to aggressive atmosphere (like saunas, spas, kitchen areas) and subject to physical damage (like luggage handling areas, gyms, playrooms, etc.) so that all sprinklers are inspected within one year. Sprinklers with obvious external damage, including paint, should be replaced, and not included in the number of sprinklers tested in subparagraph .17; .15 check for any changes that may affect the system such as obstructions by ventilation ducts, pipes, etc.; .16 test a minimum of one section in each open head water mist system by flowing water through the nozzles. The sections tested should be chosen so that all sections are tested within a five-year period; .17 test automatic sprinklers and automatic water mist nozzles in accordance with the following flow chart:
Two-year	N/A
Five-year	**9.3 Water mist, water spray and sprinkler systems** .1 flush all ro-ro deck deluge system piping with water, drain and purge with air; .2 perform internal inspection of all control/section valves; water quality testing should be conducted in all corresponding piping sections, if not previously tested as outlined in paragraph 7.5.18 within the last five years; .3 check condition of any batteries, or renew in accordance with manufacturer's recommendations; and .4 for each section where the water is refilled after being drained or flushed, water quality should meet manufacturer's guidelines. Testing of the renewed water quality should be conducted and recorded as a new baseline reference to assist future water quality monitoring for each corresponding section.
Ten-year	**10.2 Water mist, water spray and sprinkler systems** Perform a hydrostatic test and internal examination for gas and water pressure cylinders according to flag Administration guidelines or, where these do not exist, EN 1968:2002 + A1.

3.1.6 National Fire Protection Association (NFPA)

The National Fire Protection Association (NFPA) is a global non-profit organization dedicated to eliminating death, injury, property, and economic loss due to fire, electrical and related hazards. This is for example made by codes and standards for fire protection [14]. NFPA is a worldwide association and American-owned companies, and American insurance companies often require that the sprinkler system be designed and installed in accordance with NFPA standards even if the property is in Sweden [15]. Some of the standards for automatic sprinkler and water spray systems are:

NFPA 13 – Standard for the Installation of Sprinkler Systems

NFPA 15 – Standard for Water Spray Fixed Systems for Fire Protection

NFPA 25 – Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection System

3.2 Research in the area

Besides the FIRESAFE study [3] (which is mentioned in section 1.1 Background of this report), some previous and ongoing research results has been studied for a broader understanding of any problems and good examples of practices, both technical and operational.

3.2.1 IMPRO - Towards new recommendations

In 2010, SP Swedish Technical Research Institute (now RISE) in Borås conducted extensive research and was involved in developing the recommendations that in 2012 resulted in the current guidelines for water sprinkler systems in ro-ro spaces, MSC.1/Circ.1430 [12]. SP carried out several large-scale fire tests and published several reports during the work, as part of the IMPRO-project, "Improved water-based fire suppression and drainage systems for ro-ro vehicle decks". One report from IMPRO is "*A survey of sprinkler design recommendations relevant for ro-ro decks*" [16]. The report gives a good summary of sprinkler technology, sprinkler standards and updates of the relevant IMO circulars for water spray systems in ro-ro spaces.

Magnus Arvidson, the author of the report [16] describes a raised concern regarding circular MSC.1/Circ.1272 that "*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).*" Continuously, Arvidson document and discuss the land-based recommendations in NFPA 13 and NFPA 15 and draw parallel to how a ro-ro space would be protected using those standards.

One chapter in Arvidson's report [16] describes and discusses the overall performance of a sprinkler system. The overall performance is defined as "*system* *activation reliability* × *system performance effectiveness".* Where the system activation reliability is described relying on factors like:

- the quality of the system components,
- the design of the system (redundancy), and
- the quality and frequency of supervision, control, testing, inspections, and maintenance.

The system performance effectiveness is described relying on factors like:

- proper design for the specific fire hazard,
- proper design densities, and
- area of operation, correct location of sprinklers, etc.

Four types of sprinkler systems are discussed: wet pipe, dry pipe, pre-action, and deluge. All of them may be used in ro-ro spaces, relevant for the ReliS project is the deluge system since this type of system is covered in Resolution A.123(V) [4]. The first comment on this type of system and its performance is that 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. For a manual only system, this delay is expected to be longer than for an automatic deluge system and therefore the performance effectiveness can be judged to be higher for an automatic system than for a manual system. Arvidson has made an estimation of the overall performance of a deluge system in ro-ro space based on two scenarios and statistics discussed in the report [16]. A severe fire is, exemplified as involving a complete bus or a complete freight truck or trailer with a highly combustible cargo (such as unexpanded or expanded plastics, food products, tissue products and rubber products). For this fire, the estimated overall performance for a deluge system, designed according to Resolution A.123(V), is 67.5 %, which is the lowest estimation compared to the other three system types included in the discussion. For a small fire, however, the overall performance is estimated to 90.0 % comparable with a dry pipe system. A small fire was exemplified as a tire of a vehicle or refrigeration unit but could also be a complete car or freight truck with non-combustible cargo. Arvidson highlights the importance of proper supervision and maintenance.

A note is that the report includes statistics from National Fire Incident Reporting System, NFIRS, in USA, data between 2003 and 2007:

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%)*

In 2010, also as part of the IMPRO project mentioned earlier, the student report "*An analysis of fixed water sprinkler systems on ro-ro decks*" [17] was also published. The purpose of that report was to develop a cost benefit analysis for the proposal of new sprinkler installation guidelines in ro-ro spaces. In the literature study of this thesis, it is mentioned that The UK Maritime and Coastguard Agency (in 2006) ordered an assessment from the consultancy company BRE Fire and Security to identify whether or not the drencher system is providing an adequate level of safety on board the ro-ro ship. The conclusion from BRE indicated that "*the requirements in Resolution A.123(V) is not enough to provide an acceptable level of safety*". The original report from BRE have not been found during this literature study.

3.2.2 Conducted fire tests

"*Large-scale ro-ro deck fire suppression tests*" [10] includes a series of large-scale fire suppression tests that were conducted in the IMPRO-project. Both deluge water spray and deluge high pressure water mist systems were tested. The fires were made to simulate fire in a ro-ro space with heavy goods freight trucks and trailers. Tests were made when the fires were fully exposed to the water from the nozzles; and when the fires were shielded from the water.

The main results from the fire tests with fire fully exposed to the water shows that a deluge water spray system discharging of 5 mm/min provided fire control, while 10 mm/min provided fire suppression and 15 mm/min provided immediate fire suppression. The high-pressure deluge system provided fire control at a discharge density of 5.8 mm/min, lower densities (3.75 and 4.6 mm/min) provided no fire control.

The tests had no intention to examine the reliability of the deluge system in a ro-ro space. However, it can be noted that a system designed and installed according to Resolution A.123(V) [4] will in most cases not provide fire suppression in case of a fire. The report summarises some practical consequences from the results, for example that increasing the water discharge density to 10 mm/min would radically improve the system performance [10].

3.2.3 Fires on ro-ro decks

The classification society DNV summarized fires in ro-ro cargo spaces from 2005 to 2016 in their paper no. *2016-P012 – April 2016* [18]. The paper includes fires in ro-ro passenger (ro-pax) vessels, vehicle carriers and in general ro-ro cargo vessels. Ro-pax vessels shall have deluge system protecting a closed ro-ro space, CO2 is not an option for those. Ro-ro cargo vessels and vehicle carriers shall have deluge systems in ro-ro spaces that cannot be sealed, CO2 is used in closed ro-ro spaces even though deluge system is an alternative.

During the period 2005 to 2016 a number of 35 fires in ro-ro spaces was found. One of the seven main findings reported in the paper is associated with the fire extinguishing system, and that is that the system plays an important role in fires causing major damages [18].

In two cases of ro-pax vessels, the water was not discharged onto the deck on fire (Norman Atlantic and Lisco Gloria), and in the successful cases the deluge system was quickly activated and with full discharge of water [18].

Regarding the performance of deluge systems, the report from DNV [18] states that it is very important for the outcome of the fire that the extinguishing system is released swiftly and works as intended. There is a correlation of the operation of the deluge system and the size of damages to the ship. Three out of three cases where the deluge system was not functional (did not operate) became total losses.

3.2.4 Human factors perspective

From the user-centred study *"Systemperspektiv på brandsäkerhet till sjöss - en studie av organisering och användbarhet i brandskyddet på RoPax-fartyg"* [19] (free translation "System perspective on fire safety at sea - a study of the organization and usability of fire protection on Ro-Pax vessels") it is stated that the means for activation of the drencher system can be different on different ships, from remote controlled activation to manual activation from the drencher station. Activation of the drencher system is normally needed to be a functional teamwork between the crew at the fire site, at the bridge and in the drencher room. From the interviews made in the study, it is shown that the crew can feel unsecure to activate the drencher system, this due to design issues, confidence about mandate to activate the system and lack of training [19].

3.2.5 Corrosion in sprinkler piping

FM Global data sheet 2-1 [20] has the title *Corrosion in automatic sprinkler systems*. This data sheet provides recommendations that are intended to address the prevention and control of corrosion in automatic sprinkler system piping. This datasheet is from 2016 with a revision in 2018. The identified hazard "internal corrosion in a sprinkler system" can result in partial or full blockage, reducing water flow capacity and severely undermining the system's ability to provide reliable fire protection. Corrosion can also result in pinhole leaks, creating impairments to fire protection systems and damage to equipment and contents beneath the piping.

The datasheet was a result from the FM Global research project on corrosion in sprinkler systems and how it can be prevented (by recommended corrosion mitigation strategies and directions for further studies) [21]. One conclusion from the project is that *"corrosion occurs in all sprinkler systems and is one of the major issues for maintenance and operation for Fire Protection Systems such as wet pipe, dry pipe, and pre-action systems."*

Recommendations include orienting pipe weld seam upward, methods to fill the dry pipe or pre-action systems with nitrogen, vent out trapped air in wet pipe systems, and improve water chemistry, along with potential applications of biocide and corrosion inhibitors. It is also mentioned that "*repairs of corrosion damage due to mechanical failure or water damage adds significantly to the lifecycle cost of sprinkler protection systems in buildings.*" [21].

3.2.6 Webinar about sprinkler piping

RISE participated in a webinar organized by The Swedish Fire Protection Association, on 19 April 2021. The webinar was about the sprinkler system itself (piping, maintenance etc.), and not about the extinguishing capacity. Seven presentations were given and are briefly noted below:

1. Explosion in sprinkler control room in Norway

Flushing in progress in the water and sewer network. Noise was observed from inside the sprinkler control room, something seemed wrong, and the service company was called in. The pressure manometer in the sprinkler room exceeded 25 bar while normal pressure is 8 bar. The system piping was dimensioned up to 12 bars. The system was emptied in the sprinkler control room, the water drained out and the manometer needed to be changed…Then there was an explosion.

Zinc + water + air = corrosion + hydrogen. Hydrogen in combination with no venting was playing a role for the explosion in this case. It is uncertain what was the ignition source.

The system was installed in 2014, using thin-walled galvanized pipes according to European standard EN 12845, no notes on deviations were made. BUT there were no valves for venting or flushing and the system had been untouched since installation. After the accident a finding was that inspections were done by the same company every year, and no deviations had been recorded.

2. Explosion in sprinkler control room in Finland

Similar as what happened in Norway. Explosion caused by hydrogen formed in a wet pipe system. The serviceman drained the system, the door was closed when performing the work. Injuries to one person and damage to the building.

After this accident the European standard EN 12845 has added one appendix regarding this subject and the Finnish Safety and Chemicals Agency (Tukes) has prohibited use of zinc coated pipes.

3. Long-term exposure of pipes, galvanized and untreated pipes in Sweden

Today there are wet pipe systems (filled with water), dry pipe systems (filled with compressed air) and deluge systems (open systems with atmospheric pressure). We want to create an atmosphere where corrosion does not occur. Transition from compressed air to nitrogen in dry pipe systems is judged to reduce the risk for corrosion. Problems can arise in dry pipe systems as these are tested with water and water residues remain, the same can be a problem for deluge systems.

A study was presented where pipes from two suppliers was exposed to water internally for about 2 years at room temperature. The pipes were of two different types; pure steel pipes and galvanized steel pipes. The water sources were from three different tap water locations: Stockholm, Muskö and Gothenburg. The pipes have been laying horizontal and exposed to the tap water from the different sources. The pipes were tested with air and with nitrogen gas to investigate how much nitrogen gas reduces the corrosion rate.

All steel pipes filled with nitrogen gas appear to be easily affected by general corrosion. For the galvanized steel pipes, nitrogen gas seems to reduce the corrosion.

The basis is that we should not change water in the pipe work, then we add oxygen and add problems.

4. Corrosion-resistant steel pipes

Are polymer-coated steel pipes a sustainable solution and what about testing and approval? Surface corrosion and pit corrosion gives higher friction, clogging and leakage. Clogging leads to non-functioning fire protection systems which leads to risk to property and people.

In dry pipe systems, galvanized pipes are generally used. In the presentation it was stated that more than 75% of (dry pipe) installations have medium to large corrosion problems after 12.5 years. In wet pipes systems, more than 25% of the installations have medium to large corrosion problems after 25 years. The problems are not detected in time, hence high costs. The presented challenges with galvanized pipes were the corroding, dissipation of zinc and risk of hydrogen formation.

Fendium (trademark) is a polymer-treated steel pipe. Independent tests and an external corrosion laboratory show good corrosion resistance after 6 months exposure.

5. Replace air with nitrogen gas

Corrosion in sprinkler systems is nothing new but a hot topic. No maintenance until now and then it is realised as a problem, perhaps.

Dry pipe system piping has an average lifespan of 12 years and the pipe controls have been changed to 12 years. Thin and thick pipes, on thick-walled pipes we have more material and accumulate more slag in the pipe. Thinner pipes might have been punctured.

Corrosion requires three things: metal, acid, and water in liquid form, which is normally found in sprinkler pipes. Impossible to drain all the water out, so we will have corrosion.

Venting should take place automatically; over time it will remove 50% of the air. Can also fill pipes with nitrogen gas, stops corrosion and prevents corrosion in new systems. Both dry and wet.

6. The challenges of an industrial operation to ensure the operability of piping systems

No notes.

7. Different methods for carrying out internal pipe inspections and what can be detected during these

Internal pipe control is covered by SBF 120:8, §20.5.7.

Care and maintenance according to SBF: the system owner must have a plan so that the system's efficiency is always maintained. The controls and care must be followed. The manufacturer's measures must be followed. Weekly, monthly, quarterly, annual, audit inspection, three years, ten years, 25 years.

25 annual inspections of pipes: 1 m pipe length/100 sprinklers at least 2 pipe lengths per pipe dimension. Internal and external control. Perform a flush and a pressure test by verified company.

A video was shown from the inside of pipe work. Other methods mentioned was X-ray (looks inside the pipes), disassemble pipes (dismantle pipes - look - measure wall thickness).

How often internal pipe control? Performed by an inspector only 1-2 times per year. Why not more often? It is a cost item?

3.2.7 Cost effective measures for reducing the risk from fires on ro-ro passenger ships (FIRESAFE)

The EMSA-funded study FIRESAFE [3] consists of two parts; the first part considers risk control options (RCOs) in relation to Electrical Fire as ignition risk and the second part considers RCOs to mitigate the risk of Fire Extinguishing Failure (with focus on drencher systems). The study is using the Formal Safety Assessment (FSA) using a risk model to investigate cost effective measures for reducing the risk from fires, the FSA method is described in Guidelines of IMO [22].

In the second part, the risk of unsuccessful or partially successful distribution of drencher systems was investigated. As a result, from many discussions in the project, six RCOs were chosen and analysed in the risk model. The RCO listed for drencher systems which also has a bearing on the reliability was freshwater activation/flushing. Freshwater activation/flushing was shown to be cost effective both for new built ships and for existing ships [3].

The highest life risk reduction was achieved by efficient activation routines [3].

4. Result and discussion

In this chapter the project results are presented together with a discussion.

The main results from the ReliS pre-study are the developed concept solutions formed through the system group, which are presented in section 4.4. Before presenting the suggested solutions, results from the previous steps of the system group are presented together with comments from conducted interviews and the desk study.

Identified practical solutions existing today have been included in the idea generation in section 4.3.

4.1 Problem description

From the interviews, two different perspectives emerged regarding the description of the problem. On one hand, there is no existing reliability problem. The crew has detailed maintenance programs, and all requirements of the drencher system are fulfilled. In the vast majority of inspections and surveys, the drencher system is approved, sometimes with minor adjustments, which is often about blowing one or a couple of nozzles clean from debris.

Additionally, there is an uncertainty of the actual reliability of the drencher system. An issue raised by the interviewees was *"are the existing regulations sufficient to secure a reliable drencher system?"* The same issue was raised during the IMPRO project, for example in the report "Large-scale ro-ro deck fire suppression tests" [10].

The uncertainty regarding actual performance and the reliability can be broken down into four different aspects:

1) Potential obstacles in system
2) Difficulty to test in a realistic setup
3) Dimensioning
4) Activation

The focus of the work in this pre-study has been on the two first aspects.

The uncertainty regarding potential obstacles in the system: Obstacles in the system that could clog a nozzle when water is pushed through the system is the elaborated issue. This is broken down into more details in a tree diagram in Figure 3 in section 4.1.1.

The difficulty to test the system in a realistic setup: As the tests during inspections/surveys are performed today, the focus is on functionality, i.e., to visually observe that water is discharging from the nozzles with desired spread and flow rate. It was questioned whether all safety aspects can be verified during such a standard test procedure, for example the fact that tests are not designed to run the drencher system during a longer period of time. Factors affecting the possibility to test the drencher system in a realistic setup are illustrated in a tree diagram, see Figure 5 in section 4.1.2.

Dimensioning and **Activation**, are outside the scope of this study. However, both aspects are important and are briefly described in the end of this chapter, see sections 4.1.3 and 4.1.4 and are included as a suggestion for "next step" described in chapter 6.

The problem description related to the first two aspects was presented during the Workshop #1 with the system group. After some minor changes (incorporated in the figures) everybody in the system group agreed upon the problem description.

4.1.1 Uncertainty regarding potential obstacles in the system

According to comments from the interviews and the system group experience, it is common that one or a couple of nozzles are clogged during each inspection/survey. This is also in line with what is stated in FIRESAFE [3]. The interviewed crew at ships (included in this pre-study) which operated The Kattegat Sea (Kattegat), all had experiences of clogged nozzles and corrosion of pipes. The crew at ships operating The Baltic Sea (Östersjön) did not have experience with clogged nozzles and corrosion to the same extent as the ships on the west coast. A possible explanation for this could be that the Baltic Sea has a lower salt concentration than the Kattegat Sea, also that some ships is at the quay very close to estuary where the fresh water from a river is mixed with the salt water in the sea, hence less salty. From the seminar with corrosion expert (see section 2.4), it was learnt that using sea water speeds up corrosion rate compared to using fresh water. This is primarily due to two reasons: 1) The conductivity is higher for sea water, which reduces the resistance to corrosion, and 2) The sea water has a higher chloride ion concentration.

Through-wall corrosion pinhole leakage could occur in a new dry pre-action system piping after only 2-3 years after installation due to residual water in the system [20].

Different aspects of uncertainty regarding potential obstacles, which has emerged as a result of the study, are illustrated in the tree-diagram in Figure 3.

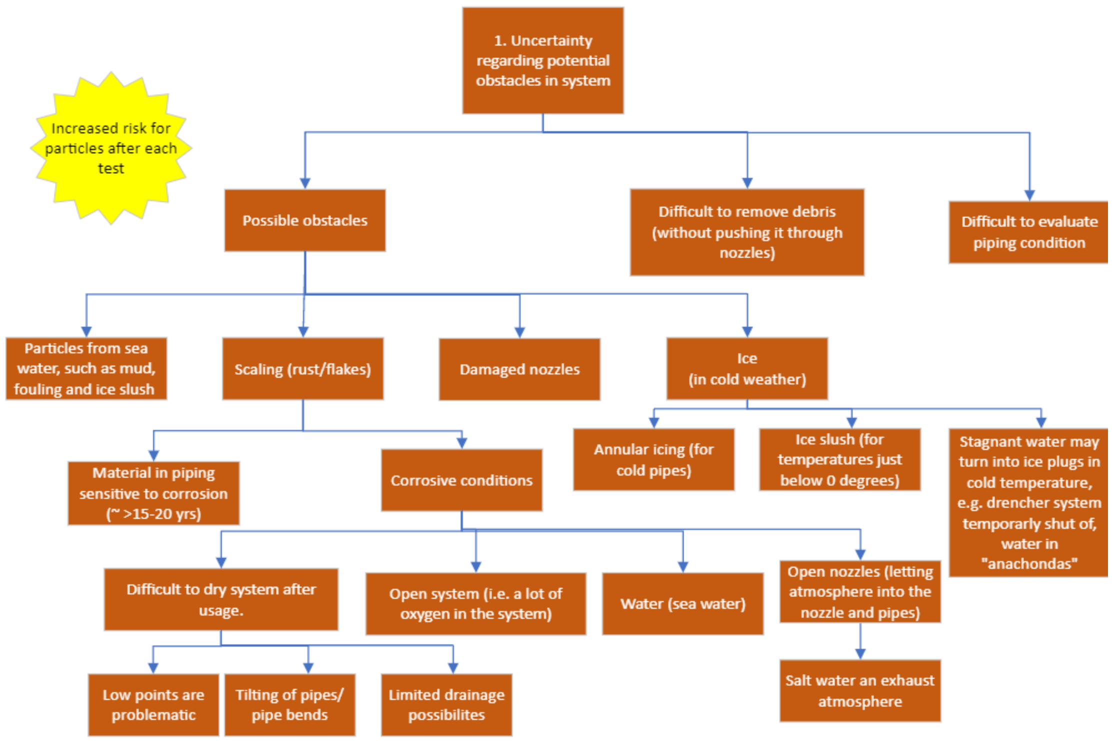

Figure 3. A tree diagram illustrating different aspects of uncertainty regarding potential obstacles in system

The obstacles in the system can be caused by particles or other debris from the sea water, from scaling (i.e., scaling made by corrosion), damaged nozzles or from ice slurry. Moreover, it was made clear from the interviews that the risk for debris in the system increased after every time the system was filled with water, especially sea water. In other words, there is an increased risk of adding particles/debris in the system after each test and this is a conflict with the need to test the system in accordance with MSC.1/Circ.1432 [13]. Also, it was desirable to test the system as used, i.e., with (sea)water.

One testing procedure using air is commercially available on the market, Dry-flo ® (Dry-Flo® – Paradigm Group) and had been considered by one ship operator but rejected due to the high cost, the larger number of installations required for the whole fleet, and due to the fact that it is very new on the market. A comment from the system group was that it is important to emphasise the importance of testing to ensure safety. The ideal concept would be to have a drencher system that could be tested as much as needed without risking decreased performance.

Clogged nozzles

To correct a clogged nozzle, it was very clear from the interviews that the nozzle is removed and cleaned (or replaced if clog could not be removed). It is considered to be an easy measure which causes almost no delays, and the test could be successfully fulfilled. Even if the crew had knowledge about debris in the system, there is usually no way to flush out the debris except through the nozzles, causing a clog. For one of the ships, drainage valves had been installed at the end of the branch pipes, making it possible to flush out debris (from the pipes) instead of it being clogged in the nozzles. From one interview an inspector said that a good thing that works is to flush the piping from the sea chest, i.e., before the drencher piping.

One could argue that cleaning/replacing the clogged nozzles only treats the symptoms, not the actual root cause. This was confirmed by the system group and to understand the cause of the clogged nozzle, the question "What is causing the clogging?" needs to be asked. The inspection and survey test procedures of today do not cover the "what", only the function that water is discharging. There was no existing praxis among the ship operators on how to evaluate the internal condition of the pipes. Hence the actual internal condition was normally not evaluated by the ships, and the crew was uncertain regarding the actual conditions of the pipes. It also emerged that that it is difficult to evaluate the internal piping conditions. Only one of the crews mentioned that scanning with ultrasound technology was used as a method for examining the thickness of the pipes (i.e., ultrasonic thickness inspection) and for this they used the same tool as when they inspected the thickness of the hull. In the maintenance program this was documented as "unplanned maintenance" or "condition-based maintenance". Decisions regarding replacement of pipes were, in this case, based upon the results of the ultrasound scanning, and this procedure was considered successful by the interviewees of that specific ship. Other possibilities to evaluate the piping conditions that was mentioned was with pipe (video) inspection, which is used in land-based systems, also mention in webinar (see section 3.2.6). NFPA 25 requires an internal inspection of land-based sprinkler system piping every five years. This is to be conducted to inspect for the existence of foreign organic and inorganic material.

Corrosion and rust

Corrosion was emphasized as a problem in the interviews and have been a familiar problem in the industry for many years, stated the system group and previous research [20] [21] (see also section 3.2.5). Problems with both debris clogging the nozzles, and with rust holes in the pipes. In the system group, the corrosion problem was often combined with discussions regarding the material of the pipes. A common piping material used in drencher systems in ro-ro spaces is galvanized steel, also mentioned in MSC.1/Circ.1430/3.10 "Distribution piping should be constructed of galvanized steel, stainless steel, or equivalent." [12]. Galvanized steel is a metal, and it is clear that metal corrode when exposed to water in combination with oxygen. Since the drencher system is an empty (open) system the amount of oxygen is high (unlimited), and if water is present in the piping the corrosion process will start. As from the webinar (see section 3.2.6), corrosion requires three things: metal, acid, and water in liquid form. And in FM DS 2-1 [20] it is stated that oxygen is the main cause of corrosion in open steel sprinkler piping, in land-based applications. Water could be made present in the system due to the initial hydrostatic test, condensate moisture from ambient air, and from periodic system flow testing with water/sea water. It is practically impossible to remove all the water in the drencher system pipes. However, one comment from the interviews was that corrosion becomes a problem after about 15-20 years. After this period of time, it is common that parts of the piping need to be replaced with new pipes and it is common that parts of the drencher pipe work need to be changed every other year when docking. For fire sprinkler systems in buildings, it is stated in FM Global data sheet 2-1 [20] that repairs due to corrosion damages significantly adds to the lifecycle cost.

In general, the standard procedure seems to be to choose the same material for the new pipes as for the old pipes. One reason for this, which was mentioned in the interviews, was that a one-to-one change does not require any additional analysis for guaranteeing regulation fulfilment. Another reason was avoiding the risk for galvanic corrosion which can arise when different materials are combined. For one of the ships, pipes made of stainless steel had been used for replacing parts of the piping system. The interviewed crew at this ship expressed that they had a good experience from that change of material.

To avoid corrosion in existing drencher systems, it is utterly important that the system is completely dry after usage. An aggravating fact for this is that the drencher system has limited water drainage possibilities, and therefore it is very difficult to drain out accumulated water in the system. Low points in the system were mentioned as particularly vulnerable for water accumulation and corrosion from the system group and in field studies.

Other strategies can be applied in order to prevent/mitigate corrosion. That is removal/limitation of oxygen (such as using nitrogen rather than compressed air in dry pipe systems) or choosing a more corrosion resistant material. Similar challenges, with sea water in combination with open deluge systems, are found in the offshore industry. Regarding choice of piping material, the interview and system group experience in offshore industry shows that titanium is used to a wider extent compared to galvanized steel and for those the problem with corrosion is not as prevalent.

Water in the pipes

Adding drainage possibilities (valves) and pitching of the pipes, has been highlighted as important features in the interviews to be able to remove the residual water. Drainage should however be added with care since it can change the flow dynamics and affect the capacity of the system. It could need a new hydraulic calculation and dimensioning of the system pipe work. A comment is that the natural tilting of ships could be strategically used as enabler of drainage of pipes, but also very hard to achieve since a ship is rolling on the sea.

Blowing compressed air into the system pipe work is one possible solution for drying the inside of the pipes. Even though it is difficult to dry out all of the residual water from the piping this solution is used by the ship operators and is also included in the guidelines for the newer drencher systems, according to MSC.1/Circ.1430/Rev.2 [5].

Finally, ice blocking the pipes could be a problem associated with low ambient temperatures. This can be caused by annular build-up of ice (for cold pipes), ice slurry from the sea in the pipes (for temperatures just below 0°C) or ice plugs. The latter can, for example, be caused by frozen water accumulated in the steel hose used for hoistable decks (also called "anacondas" by some crews), see Figure 4, or in situations when the drencher system is temporarily shut off (could for instance be a strategic choice for facilitating a manual fire response by the fire team).

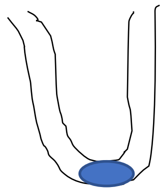

Figure 4. There is a risk that water accumulation in "anacondas" freezes during low temperatures conditions.

One experience mentioned in the interviews was handling a fire in ro-ro space when the temperature was around -15 °C. The drencher system was running for about 2 hours, and during the final part of the operation it was virtually snowing out of the nozzles. The crew made the decision not to stop the drencher system, which normally could be a part of the fire response strategy. The crew realized that if they stopped the system the probability of a successful restart would have been low, since the pipes probably would have been blocked with ice. When reaching the port, the system was shut off, and the whole ro-ro space was covered with ice. It took two days with the aid of powerful diesel heaters for the system piping to be defrosted.

4.1.2 Difficulty to test in a realistic set up

Firstly, a brief description of how tests, inspections and surveys are carried out in Sweden today is given, followed by a description of factors affecting how tests/inspections can be carried out.

Test/inspections/surveys

According to the regulations [13] at least one drencher section must be flow tested annually and the whole drencher system (all sections) must have been tested within a period of five years. The pump must be tested monthly, and the valves need to be exercised every year. It is the Chief Engineer and the technical team of the ship who are responsible for carrying out the tests.

The classification society carries out a survey for certification each year, in association with the ship's "birthday" (date for first time in traffic). Time window of annual survey is +/- 3 months from birthday. The certification task is sometimes delegated to the classification society from the flag state, which is the case in Sweden. Surveys are ordered from the company. The attending surveyor has the liberty to expand the scope of the intended survey based on test results and previous experiences with the vessel.

The focus of the survey of the drencher system is to verify the functionality of the system, by controlling the discharge of water from the nozzles. The condition of other parts of the drencher system are verified through a review of the documentation in the maintenance program (the maintenance program is described further below). Normally, at least two adjacent drencher sections are tested during each survey. If the result from the test with the selected sections is unsatisfactory, additional sections can be tested. It is the surveyor who decides which and how many drencher sections to be tested. However, this is usually coordinated with the ship's test plan. If the test reveals major issues with the drencher system, the surveyor can demand an internal inspection of the pipes. Though, a comment from the interviews was that internal pipe inspections is rarely (never) used for Swedish ships. As mentioned before, the main finding at an inspection is clogged nozzles and that is fixed by cleaning the nozzle and putting it back again. The drencher systems are tested and maintained continuously, which ensures a certain level of functioning. In addition to visual control of the discharge of water from the nozzles, it is also visually verified that drainage points are free from hindrance.

An inspection called Port state Control is carried out for foreign ships in national ports. The aim with that inspection is to verify that requirements of international regulations are fulfilled, both regarding equipment but also regarding aspects such as manning and operation [23]. Port state Control inspections are based on the regulations contained in the Conventions from the International Maritime Organization (IMO) and International Labour Organization (ILO) [24]. According to comments from the interviews with Swedish inspectors carry out port state controls, testing of one or two drencher sections, pumps and valves are usually included in the port state control. Moreover, the inspection also includes a review of the existing documentation in accordance with Annex 10 of the Paris MOU Memorandum (for the region "European and the north Atlantic") [25].

The inspections which include testing of the drencher system are announced in advanced.

During a test/survey/inspection of the drencher system's functionality the discharge of water is judged visually by the persons performing the test. If the water from a nozzle has a deviating spray pattern/do not discharge, then this nozzle is reported to be malfunctioning. The action is to clean the nozzle from debris or, if it for example has been mechanically damaged, to replace it. Usually this is done by the crew immediately after the test, making it possible for the test result to be approved during the ongoing survey/inspection. If the malfunction of the system only involves a few individual nozzles, the deadline for the ship to correct the malfunction is normally set to a week. If the malfunction involves more than a few nozzles, the flag state can decide to ban the ship for use until the malfunction is corrected.

During one field study a flow test was carried out and to verify that correct volume of water a tub was placed, under the drencher section to be tested, on the ro-ro deck before the drencher started. Discharged water was collected during a 2-minute period and the collected water was then measured and compared to the expected amount of water compared to the requirement (5 mm/min). However, this test method is optional, and not a standard procedure during surveys or inspections.

Maintenance

In the ship's maintenance program, it is described how and when maintenance tasks are to be carried out. The input to the program comes from requirements from regulations, from requirements and recommendations from suppliers and internally which is manually inserted into the system. All maintenance activities carried out are documented in the maintenance program, making it possible to follow up what has been done and when. Tasks, not included in the maintenance program, can also be documented, and will often be marked as unplanned maintenance or condition-based maintenance. It is the Chief Engineer of the ship that is responsible for the maintenance to be undertaken. As mentioned above, reviewing, and updating the documentation made in the maintenance program is part of the survey/inspection. From interviews it was mentioned that having a good arrangement and clearly described tasks in the maintenance system and a crew that enjoys maintenance work was key for successful execution of maintenance.

Factors affecting the test procedure

From the interviews, it emerged that there is an uncertainty associated with the test procedure, both in terms of method and scope. Are all safety aspects of the drencher system considered by the way tests/inspections/surveys are carried out today? The design of the test procedures is affected by the conditions on the test day, such as available time and weather conditions. Factors affecting the possibilities to test the drencher system are illustrated in Figure 5.

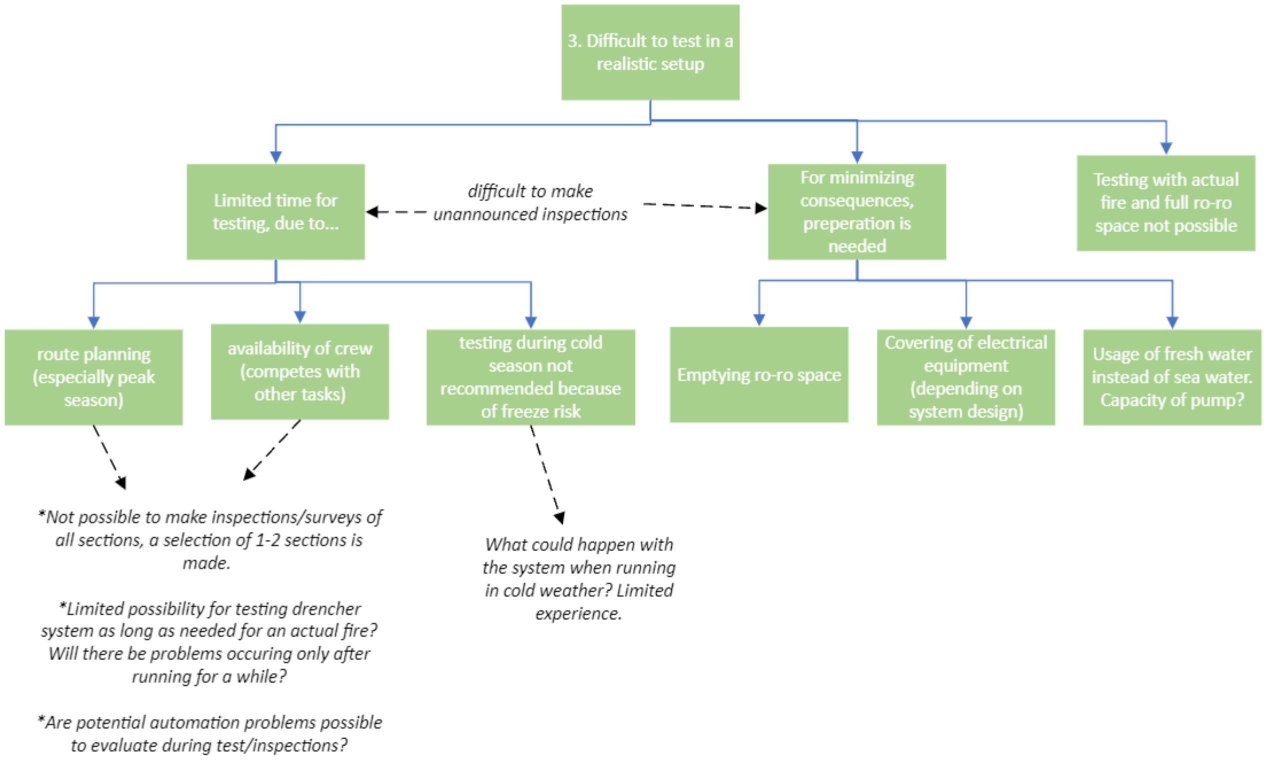

Figure 5. Tree diagram illustrating different factors affecting the test procedure

Test opportunities

Possible test opportunities depend on available time, based on route schedule, availability of crew members and also on climate conditions. During the high seasons, there are few opportunities to carry out tests without having a major impact on route planning. In Sweden, the high season usually coincides with summertime. During wintertime tests are avoided due to the risk for freezing. If the system never is tested during cold weather, is it then possible to predict how the system will perform in case of a fire during low ambient temperatures conditions? As mentioned earlier, one insight the crew had from running the drencher system in -15 °C was that the system should not be temporarily shut off, due to the freezing risk with stagnant water in the system. Questions which arise from the interviews were: *Is this a well-known experience within the shipping industry? What can be done to avoid freezing risk of piping?*

Before tests are carried out, the ro-ro space is usually emptied of vehicles and electrical equipment sensitive to water is protected. The time needed for preparation work in combination with time limitations for the actual tests restrain the window of test opportunities. Inspections and surveys are therefore normally announced in advanced, to limit the influence on the normal operation of the ship. For one of the ships included in the interview study, electrical equipment had been placed at a safe distance from the nozzles and thus no protection was needed during test. A comment from the crew at this specific ship was that this allowed more frequent testing, as fewer man-hours were needed for each test. For another ship in the interview study, the crew had chosen not to cover any sensitive equipment, since they wanted to test the real outcome from running the drencher system, while another ship covered their equipment before testing.

Scope of test

The functional tests carried out during inspections/surveys of today run for a couple of minutes (i.e., time needed to verify the function) and normally two drencher sections, or when needed additional sections, are tested. However, in case of an actual fire, the drencher system will probably be running for a couple of hours (depending on the fire), and it is not unlikely that different sections will be started/shut off based on the development of fire and smoke. Questions which arise from the interviews were: *Are there any safety issues related to a long discharge duration which are not covered by the tests today? Are there any safety issues related to alternating between sections which are not covered by the tests today? How is the performance of the system's software controlled, such as signals from sensors and performance of automation?*

Using fresh water when testing

Using fresh water during flow testing could be used as a mitigation action for decreasing the rate of corrosion (compared to using sea water), and also for eliminating the risk for debris from sea water entering the system. From the interviews an uncertainty was raised regarding the capacity of the fresh water-pump. Normally, the capacity of this pump is lower compared to the capacity for the pump used for pumping sea water. How does this affect the result of the test? Is equal capacity needed for the two pumps? According to Flag administration - it is considered acceptable to use fresh water during a flow test even if the fresh water-pump has lower capacity (as long as the functionality of the sea water pump also was tested). On the other hand, a comment from the interviews was that it was recommended to have redundant pumps, which enables the same conditions for a test with sea water as with fresh water.

Test frequency

Another aspect of testing is the frequency of tests. As mentioned previously, at least one drencher section must be flow tested each year and all sections in the whole drencher system must be tested within a five-year period [13]. In reality, tests are carried out more frequent. According to comments from the interviews it is common that flow tests are carried out three to four times each year; in surveys, port states controls, during fire drills and also tests performed by the crew themselves. The advantage of frequent testing is that the function of the system is verified and that the crew is trained in operating the system. A drawback is that stagnant water after testing increases the risk of corrosion. From the discussion in the system group the following questions were raised "*Due to the risk of corrosion, is the number of tests carried out today motivated or should the test frequency be limited to what is required in circular 1432?". Could for instance a test occasion be documented in such a way that other actors only would have to see the documented test and not having to carry out a real test?*

4.1.3 Uncertainty regarding activation

The reliability issue related to the activation is whether the drencher system can be activated fast enough when manual activation is the only alternative. Some interviewees explain that on specific ships they have set a time for how long it shall take to activate the drencher system. However, it is the situation and the fire chief's decision (the Chief Engineer) to activate the drencher. But there may be different things that need to be taken into account before making that decision. It can, for example, be chemicals in the cargo that can aggravate the situation, the cargo's configuration, evacuation control etc. A comment from the interviews is that decision making is getting more complex as more sensors and automation are added to the systems onboard. Additionally, the crew size has decreased, and the number of safety critical tasks have increased on ships with hybrid/alternative fuel. The decision and workload aspects can theoretically affect the activation time.

In Bram et al [19], uncertainties among the crew regarding drencher activation are raised. These uncertainties depend on design issues, unconfident of mandate of activation of the system and lack of training. If the crew hesitates to activate the drencher system, this will also have a negative effect on the activation time, and the outcome of the fire [18].

Another aspect is the opening of drencher valves. Can anyone, regardless of muscle strength, handle the valves needed to activate the drencher system? If a crew member struggles with turning the valves to the open position, this will extend the activation time. Also, electrical problems during activation of remote-controlled valves were noted in this aspect.

In the IMPRO-project [10] [26] [16], it is stated that the performance effectiveness of an automatic drencher system is higher with regards to activation time, compared to a manual system. However, in reality there could be a need for strategic operation of the drencher system, i.e., altering the activation of drencher sections depending on the development of the fire and smoke. An automated activation may hinder the possibility for the crew to control the choice of sections being activated, although deluge valves should always be possible to operate manually.

4.1.4 Uncertainty regarding dimensioning

The reliability issue regarding dimensioning is the uncertainty related to if the capacity of the drencher systems is sufficient for the fire challenges of today (and tomorrow). The drencher system which is subject to Resolution A.123 (V) [4] is based on regulations from 1967 and much has happened since then. The amount of plastic in vehicles has increased and vehicles have generally become larger and heavier, i.e., there has been an increased fire load for each vehicle. Moreover, the fleet of today (and tomorrow) consists of a mix of power supply, for example, electric cars, gas and hydrogen vehicles and trucks. There has also been a change in shipping needs since the 1960s, with the consequence that there is a higher uncertainty regarding cargo content. Given these changes in vehicle technology and shipping, there is an uncertainty among the interviewees whether a drencher system in accordance with Resolution A.123 (V) [4] have the capacity to supress a fire in a ro-ro space, and if the capacity of the drencher system of today is enough for fulfilling the SOLAS requirement of "safe return to port" (SOLAS II-2/21) [7].

In the report "*Sprinkler design recommendations relevant for ro-ro decks on ships*" [26] it is also stated that the sprinkler technology has evolved since the 1960s and that "*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.*". The report summarises the outcome of a literature review and the intention of new installation guidelines was to support the use of modern sprinkler technology in recognition of changed fire risks onboard. Already then (in 2010) it was questioned whether drencher systems, designed and installed in accordance with Resolution A.123 (V) manages to control a fire on a ro-ro deck with modern cars, tourist buses and heavy trucks. Since 2010 the evolution of modern cars, buses, and trucks has further evolved and so has the numbers of them.

4.2 The agreed vision

During the Workshop #1 with the system group the members where asked: *What should be achieved with the change*? The answer to this question is the vison of the developed conceptual solution(s). The system group members agreed upon the following vision (here translated into English)

- Avoid malfunction and make the system more reliable
- Visualise the actual reliability and the shortcomings of the system

The first part of the vision is that suggested solutions should have a positive impact on the reliability of the system. The second part of the vision addresses the uncertainty of the actual reliability (which is described in section 4.1 Problem description). The solutions should aim at decreasing the uncertainty by illuminating the actual reliability of the system. Aspects mentioned that can complicate the visualisation is for example:

- actual reporting of clogged nozzles
    - o surveyors only make notes on the general system and not on individual components. Can also be hard to get access to classification statistics.
- Ability/willingness to extract statistic
    - o available from the ships
    - o access from service by system suppliers

4.3 Idea generation and selection

During the first workshop, the system group had a brainstorming session where members came up with ideas of solutions related to the agreed problem definition, i.e., **potential obstacles in the system** and **difficulties to test in a realistic setup**. The feasibility of the ideas was not considered at this point in the project. The intention was to allow the members to be as creative as possible. Ideas identified during the interviews and field studies were also presented during the workshop (by the project team from RISE and Chalmers). If deemed appropriate, some of the ideas were merged into one idea.

As a preparation work to Workshop #2, the system group members were asked to vote on the ideas that appealed to their perspective the most, regardless of feasibility level. Each member could give one vote to each and every idea that he/she saw potential in.

The complete list of ideas is presented in Appendix A.

The idea which received a voting score higher than 5 are presented in Table 4.

Table 4. Ideas with voting score higher than 5.

Ideas (idea id) see more in Appendix A	**Voting score**
Piping material (1.3.1 + 1.3.2)	1.3.1: **11** 1.3.2: **6**
Use of nozzles with higher K-factor (large openings) (1.4.1)	**6**
Avoid sea water when testing (1.5.1+2.2.7+3.2.1)	1.5.1: **7** 2.2.7: **7** 3.2.1: **9**
Test valve that enables testing of the pump (in winter) by discharging water into the bilge pit engine room / deck (4.1.1)	**6**
Use heating cables in parts that are exposed to the risk of freezing (4.1.2)	**6**
Systematic exchange of experience between sea and land (7.1.2)	**6**

The two ideas which received the highest scores in the voting session, *Piping material* and *Avoid Sea water when testing,* were chosen to be develop further within the system group and are described in section 4.4.

The idea *Use of nozzles with higher K-factor (large openings)* addresses the risk with clogged nozzles. It was seen as a possible solution for making the system less sensitive to debris, i.e., facilitating removal of debris by using larger nozzle openings.

The idea *Use heating cables in parts that are exposed to the risk of freezing* addresses the risk of ice blocking the pipes during low ambient temperatures.

The idea *Systematic exchange of experience between sea and land*, was a suggestion for visualisation and improving the exchange of experiences with operation of open deluge water spray systems used in different applications onshore and on ships.

4.4 Suggested solutions

The developed proposals for improvements to the drencher systems technical and operational design was developed during Workshop #3. The ideas *Piping material* and *Avoid Sea water when testing* was chosen ideas to be further developed. In this pre-study the goal was to develop ideas in conceptual stage (see 2.4.3). Each concept is presented in more detail in section 4.4.1 and 4.4.2.

After Workshop #3, Jeff Kochelek at ECS was invited as a lecturer, and a seminar was held via TEAMS on the 27th of October 2021. The results presented in this report has been updated with information from this seminar, which is in line with the methodology of the system group, i.e., having an iterative working procedure in order to make changes as knowledge increases.

4.4.1 Piping material

This proposed idea is about investigating pipe material and possible change from galvanized steel, which mainly is used today, to a more corrosion resistant material. In particular, black steel and stainless steel were discussed as alternatives. Pipes made of Glass Reinforced Epoxy (GRE), Bronze and Titanium was also mentioned as potential alternatives. Also, components in the system should comply with the piping material, valves, couplings, nozzles. It was also highlighted that material have to be compared in the right context, the salinity of the environment can, for example, play a role in what material is more corrosion resistant for one ship but not for another. The proposed solution is documented in Table 5.

Table 5. Change of piping material developed as concept solution(s)

What is the solution trying to solve?	- Avoid internal pipe corrosion and debris blocking piping and nozzles. - Facilitate maintenance, testing and repair work. - Secure function during fires (and testing).
This is what the regulations allow today	SOLAS regulation II-2/20.6.1.1.3, incorporated into Swedish law by TSFS 2009:98 appendix 1 [rule 20.6.1.1.3], states that a fixed water spray system for ro-ro spaces and special category spaces shall meet the requirements of the FSS Code. The FSS Code in turn states through rule 7.2.4, incorporated into Swedish law by TSFS 2009:98 appendix 2 [rule 7.2.4], that fixed water-based fire extinguishing systems for ro-ro spaces, vehicle spaces and special category spaces shall meet the requirements of the MSC.1/Circ.1430. MSC.1/Circ.1430/Rev.2 paragraph 3.10 states that: The system and its components should be designed to withstand ambient temperatures, vibration, humidity, shock, impact, clogging and corrosion normally

	encountered. Piping, pipe fittings and related components except gaskets inside the protected spaces should be designed to withstand 925 °C. Distribution piping should be constructed of galvanized steel, stainless steel, or equivalent. Sprinklers and nozzles should comply with paragraph 3.11. TSFS 2009: 98 Section 11, which corresponds to SOLAS rule I/5(a) on equivalence states that: Where these regulations require certain accessories, materials, devices or equipment, the Swedish Transport Agency may allow other accessories, materials, devices, or equipment if they provide an equivalent level of safety. In cases where the Swedish Transport Agency allows the use of plastic pipes on board ships, the requirements of Resolution A.753 (18), as amended by Resolution MSC.313 (88), shall apply. (TSFS 2011: 88) Thus, according to the first paragraph, there is room here for equivalent solutions through alternative design of fire protection according to SOLAS II-2/17 which has been incorporated into Swedish law through TSFS 2009: 98 appendix 1 rule 17. One of the performance criteria set out in an alternative design of fire protection according to rule 17, it should then be reasonable for the system to withstand a temperature of 925 °C. Since the circular also states that the material must be galvanized steel, stainless steel or equivalent, another performance criterion should be that the system must be made of steel or equivalent material defined as in the regulation and SOLAS II-2/3.43, i.e.: "non-combustible materials which, by themselves or through their insulation, exhibit strength and integrity properties equivalent to those of steel after being subjected to appropriate exposure according to the standard fire test (for example, aluminium alloys suitably insulated)" *Definitions:* *33 Non-combustible material is a material which neither burns nor gives off flammable vapours in sufficient quantity for self-ignition when heated to approximately 750 °C, this being determined in accordance with the Fire Test Procedures Code.*
Solution proposals from the ReliS project	Solutions are described per material 1-4. And within each material, for existing vessels, we need to consider the material if it is going to be *a) repair/partial changes/gradual changes* or *b) full replacement of the piping system.* *Solution 1. Stainless steel a) or b)* *Solution 2. GRE b)* *Solution 3. Black steel a) or b)* *Solution 4. Titanium a) or b)*
Options for implementation	*Solution 1. Stainless steel* *a) Replace pipe when needed, though welding or with groove coupling (mechanical coupling) in service. The use of mechanical couplings involves no hot work and is easier to do in service but require some equipment available.* *b) Change full system at yard during docking.* *Solution 2. GRE* *a) Partial change not applicable*

	b) Change full system at a yard during docking. Not allowed material unless material is proven non-combustible according to definition 33 above. Temperature could likely meet requirements. Regulation 17 analysis (SOLAS II-2/17) for alternative solutions needs to be carried out for each ship prior to implementation. This is time consuming and costly. *Solution 3. Black steel* *a) Same as for stainless steel,* *b) Same as for stainless steel* *Solution 4. Titanium* *a) Replace pipe when needed, through mechanical coupling in service. The use of mechanical couplings involves no hot work and is easier to do in service but require some equipment available. Long lead times for acquiring material some could be stored onboard for this purpose. High cost expected. Low weight, approximately 0,6*steel. No corrosion issues.* *b) Change full system at yard during docking*
Associated risks	*Solution 1. Stainless steel: may also corrode* *a) Hot work if welded method is chosen. Mixed materials galvanic corrosion is not believed to be a general problem in open systems but in locations where water is standing still over periods of time, mixed materials could cause intensified corrosion. Risk for similar corrosion problems at some point.* *b) More expensive than galvanized or black steel. Risk for similar corrosion problems at some point* *Solution 2. GRE* *a) Partial change not applicable* *b) Risk analysis through regulation 17 is time consuming and costly, material needs to be proven non-combustible according to definition 33 above. Temperatures likely ok but may need further verification. Repairs onboard may be challenging, no GRE workshop onboard. Uncertain about instant onboard repair methods and pipes needs to be ordered for replacement. Availability is unknown.* *Solution 3. Black steel. Need protection from outside corrosion to hold over time. Will also corrodes. Heavier due to thicker dimensions.* *a) Same as for stainless steel, risk for similar corrosion problems at some point.* *b) Risk for similar corrosion problems at some point.* *c) Risk for corrosion when pipes are being stored waiting for installation. External piping corrosion protection is needed.* *Solution 4. Titanium* *a) Long lead times for acquiring material. High cost expected. Only mechanical couplings, not suitable for welding. Uncertainties about bending of pipes with onboard tools.* *b) Long lead times for acquiring material. High cost expected. Only mechanical couplings.*
Associated requirements	*Requirements on Solutions 1-4:* **Repair in service must be possible to do with normal onboard skills and material;* **Material needs to be available onboard for direct use;* **Material needs to be available for ordering within reasonable time for larger repairs and available worldwide; and* **Reasonable cost in relation to expected lifetime of the vessel.*

	Note: Solution 1 and 3 will still give corrosion. If the full system is replaced it can be seen as a reset of the system. Meaning we will still have corrosion issues but perhaps not in the nearest future. How long time it takes until we get problems is hard to say but would be interesting to find out. Also, there are different grades of example stainless steel, and the solution needs to be refined with proper grades. *Experience from onboard: stainless steel 316L and flushing the system with fresh water should be ok for these open nozzle systems that do not contain water. Molybdenum content for the 316L can vary and one should choose a quality with at least about 2.5%.* *If the material is used where sea water is stagnant inside the pipe and where it is rather warm (could be warm in ro-ro spaces), 316L will not be enough. One would have to go with super duplex or a different material.*
Examples from other systems	*Solution 1 and 3: Fairly conventional* *Solution 2: Available systems exist in offshore* *Solution 4: Is used offshore. In pipes and for nozzles.*
Examples from other/similar industries	*See above*
Stakeholders who may benefit from the solution	*Solution 1 and 3: Ship owners* *Solution 2: GRE pipe makers, IMO and national authorities, research institutes, providers of regulation 17 analysis.* *Solution 4: Industry, suppliers*
Further or additional information	**Corrosion institute could provide material info and research for various metallic materials.* **Combined effects; Fresh water flushing, and black steel pipes may perhaps be the reasonable option here. Black steel is easy to weld etc but needs protection from the outside, thicker pipes.* **Investigate corrosive protection of black steel and the technical development.* **Black steel corrodes evenly over time and several participants mentioned this as favourable over galvanised steel.*

Regarding the selection of material for sea water sprinkler systems, more corrosion resistant materials are sought after, although care should be taken when selecting the specific material or metal alloy due to risks of chloride stress corrosion cracking for example. Titanium alloys are sometimes selected for sea water handling systems, but the high material cost often limits the application of such alloys. Galvanized steel is found in sea water sprinkler systems but is known to corrode initially at the zinc coating and subsequently on the underlying steel. Low-alloyed carbon or black steel is also highly at risk to corrosion in sea water systems. Regarding the possible application of Glass Reinforced Epoxy (GRE) pipes in these kinds of systems the system group have experience that GRE pipes are used in the offshore industry today, and they can withstand high temperatures from a fire. This was not further examined in ReliS.

From recommendations given in FM datasheet 2-1 [20] it can be observed that black steel piping is acceptable in dry-pipe and pre-action sprinkler systems if pipes are filled with nitrogen. If compressed air is used, then galvanized steel pipe is recommended. However, it is a conditional recommendation, requiring a system free of water and in practice it is difficult to maintain existing drencher systems completely dry.

When comparing galvanized steel with black steel for drencher system pipework, it is according to Jeff Kochelek at ECS more advantageous to use black steel. Under identical operating conditions (such as temperature, pressure, trapped water volume, gas composition, etc.) galvanized steel corrodes 3-4 times faster than black steel piping. Moreover, when oxygen corrosion occurs in galvanized drencher pipes the zinc layer is penetrated and the ability of the galvanization to provide cathodic protection to the underlying black steel is lost, hence local pitting attacks are caused. Oxygen corrosion in black steel pipes will not penetrate the pipe as quickly as galvanized steel, according to Jeff Kochelek. However, both systems will produce corrosion debris.

Some of the ship operators are using stainless steel in drencher pipes, which is also likely to corrode less than galvanized steel. However, more knowledge of the cost-benefit for stainless steel is needed and to be compared to black steel.

According to Jeff Kochelek, the galvanized steel could be approximately 30 % more expensive than black steel. A benefit mentioned in interviews was that the crew can modify black steel pipes themselves (not having to send the pipes for galvanization), which facilitates repair work onboard. One disadvantage of black steel in comparison to galvanized steel is that pipes made of black steel are more sensitive to external corrosion, which could be a problem when pipes are stored onboard. External pipe coating or similar protection will then be needed as protection.

Both black steel and stainless steel are interpreted as better alternatives compared to galvanized steel in deluge systems, when gathering the knowledge and experiences in this pre-study. However, these materials can also corrode, although with a lower rate and this study has not investigated the actual effect on the amount of internal corrosion debris if changing pipe material into black steel or stainless steel (from galvanized), which should of course be further examined if regulatory changes should be made.

Finally, it should be remembered that this report does not have all results of the best recommended piping material for drencher pipes. More studies and assessments are needed to draw conclusions about advantages, disadvantages, cost effectiveness etc. regarding piping material.

4.4.2 Avoiding sea water when testing

This proposed idea is to avoid sea water during flow testing. Avoiding sea water when testing slows down the corrosion rate in existing pipes but does not completely eliminate the corrosion problem. The fresh water-solution also reduces the risk of introducing debris from the sea into the system. The proposed solution is documented in Table 6.

Table 6. Flush the system with fresh water developed as a concept solution

What is the solution trying to solve?	*Flush the system with freshwater (FW) after sea water testing or use only fresh water when testing.*
This is what the regulations allow today	*IMO Resolution A.123 and supervision manual (STA Tillsynshandboken) chapter 6.07. Minimum water spray 5 litres each m^2/minute if deck height is above 2.5 meters. Water pressure must be enough to make an equal spray in all nozzles. And must be enough for two sections at the same time. Test interval according to flag, all sections every 5th year. At least one section every year.*
Solution proposals from the ReliS project	*Existing FW make up tank could be used as holding tank. However, the makeup water pump needs larger capacity comparable to Drencher pump to be able to achieve authentic test result. Drencher pump capacity 285m^3/h, Make-up water pump capacity 5,5 m^3/h. Optimal solution would be a fixed pipeline from FW tank connected to Drencher pump suction. Indication of valve position in automation system.*
Options for implementation	*Upgrade FW pump capacity, increase nominal diameter of FW supply piping connected to existing Drencher system.* *New pipelines from FW tank direct to drencher pump with double non return valves.*
Associated risks	*Function of non-return valves when mixing systems.* *Risk of running out of water when system connected to FW line.*
Associated requirements	*It is predicted that this solution can be introduced without the need for major modifications to existing systems onboard ships. Retrofit is possible. However, pump and pipe need modifications and Drencher pump to be tested regularly with closed valve to the outer system drencher system.* *Flag/Class to accept longer intervals between testing, i.e., 5 years. (Not acceptable today)* *In between testing: air flow could be tested and accepted yearly. This can possible be done with swirls.*
Examples from other systems	-
Examples from other/similar industries	*Fresh water testing is used on some ships today in various settings. It is also included in guidelines for newer ships to have means for flushing of drencher systems with fresh water (MSC.1/Circ.1430 section 3.20).*

Stakeholders who may benefit from the solution	*Ship operators*
Further or additional information	*Adding detergent into water can facilitate removing debris in pipework if combined with flushing the system with fresh water, preferably backwards so debris is not pushed deeper into the system ending up in the nozzles. This was noted from seminar with Jeff Kochelek and has not been evaluated by operators in the ReliS study.*

The focus during the development of this idea was to develop a guidance for how to retrofit freshwater flushing into existing systems. The solution of freshwater flushing for reducing the amount of debris in the drencher system was calculated as cost effective both for new building ships and for existing ships in the FIRESAFE study in 2016 [3]. Also, means for flushing of systems with fresh water should be provided on ships complying to MSC.1/Circ.143/Rev.2 [5]. Fresh water testing is also used on ships with drencher systems complying with Resolution A.123 (V), in various settings but is not a requirement.

Freshwater flushing is also stated by FM Global [20] [21] as an alternative strategy for better water quality and less corrosion in sprinkler pipes (besides the alternative of using compressed nitrogen as the supervisory gas in dry pipe systems). The strategy can reduce corrosion of galvanized steel pipe containing trapped water.

5. Conclusion

The suggested solutions are described in section 5.1.

General conclusions are presented in section 5.2.

5.1 Conclusions regarding suggested solutions

Both the proposed solutions address the risk of corrosion in the drencher system pipes; In the first solution, by **replacing existing galvanized steel pipes with pipes made of a more corrosion resistant material**. This has the potential to eliminate or mitigate the risk of corrosion, depending on the choice of material. However, there are several associated requirements which limit possible choices in practice, such as economy, fire resistance, and compatibility with existing piping material in cases were the pipes in the systems are partly replaced.

The other solution, **using fresh water when testing**, aims to reduce corrosion rate, compared to using sea water. Another advantage of using fresh water during tests is the reduced risk of debris from sea water entering the pipework of the drencher system. Here, a requirement of retrofit the freshwater flushing could be made in the existing regulations. Either as an update of Resolution A.123 or as a retroactive requirement for all ships in MSC.1/Circ.143/Rev.2.

Important aspects for the solutions were that they should **be possible to retrofit** into the existing systems. Both in terms of what is **technically feasible**, but also **economically reasonable**.

The **development of the ideas is at a conceptual state** and need further development by innovation, research, and testing.

It can be concluded that these two solutions **partly cover the agreed vision in the system group**. The risk of clogged nozzles is reduced by eliminating/mitigating corrosion debris, and hence the solutions have the potential to increase the reliability of the drencher system. The second aspect of the vision, i.e., visualise the actual reliability and the shortcomings of the system, is not covered by these solutions. However, there are ideas presented in Appendix A, which relates to this part of the vision, such as testing aspects and evaluation of pipe conditions.

5.2 General conclusion

It can be concluded that the problem description which emerged in this study was twofold. On one hand, there is no existing reliability problem since in most cases the drencher system is approved during tests, sometimes with minor adjustments, which is often associated with cleaning of nozzles from debris. On the other hand, maintenance and testing activities are needed for removing debris in the system and thereby avoiding and at the same time increasing the risk of clogged nozzles. Also, there is a conflict between frequent testing (with sea water) and reliability, where the risk for corrosion debris is increased after each test because of residual water in the pipes. This is due to the fact that it is practically impossible to remove all of the trapped water from the systems, and accumulated water in the system triggers the corrosion process. These traits of the system indicates that the system is not designed for withstanding the amount of corrosion and clogging normally encountered.

Additionally, it can be concluded that there is an uncertainty of the actual reliability of the drencher system in a ro-ro space and if the capacity of the system is sufficient for achieving the SOLAS requirement to suppress and swiftly extinguish a fire in the space of origin.

The uncertainties were divided into four groups 1) Potential obstacles in system, 2) Difficulties to test in a realistic setup, 3) Dimensioning and 4) Activation. The two latter issues were not handled further in this pre-study but are recommended areas for future research.

One aspect regarding uncertainties with potential obstacles in system was corrosion debris causing clogging of nozzles during the flow test. To eliminate or mitigate internal corrosion in drencher systems different strategies could be applied 1) removal of the water in the systems 2) removal/limitation of the oxygen (for instance nitrogen inerting, but not for deluge systems) 3) Change material to a more corrosion resistance material.

The use of sea water increases the corrosion rate in steel pipe systems. The salinity of the water also has an effect on corrosion rate. For the ships included in this pre-study, there was a difference among the crews' experience of clogged nozzles and corrosion whether the ship operated the Swedish west coast or the east coast. The crew at ships operating the east coast, which has lower salinity in the water, did not seem to have experience with clogged nozzles and corrosion to the same extent as the ships on the west coast. Crews at ships operating the east coast was more concerned about fulfilling the requirements and actually suppressing a fire, which was also an expressed concern by the interviewed inspectors.

Problem with internal corrosion in pipes is not unique for deluge system at ships, it also exists for land-based applications, such as in road tunnels and buildings.

Another aspect of testing was an uncertainty regarding if all safety aspects (e.g., fire suppression and duration) were covered by the testing procedures used today.

Finally, it can be stated the focus of work in the system group has been on solutions that were deemed possible to implement into existing systems. Some of the ideas generated during the brainstorming session addressed removal of water and oxygen and also testing procedures. These ideas did not receive enough votes for being selected for further development by the system group. Nevertheless, these ideas could still have the potential of increasing and illustrating the reliability of drencher systems in ro-ro spaces. Some of the ideas were of a more visionary nature (i.e., not considered possible for retrofit) and could be of interest for future research. Please see Appendix A for all ideas generated during this pre-study.

6. Recommendations for next step

The results in this pre-study have in some parts highlighted the need for further development and studies of drencher systems used in ro-ro space. The system in focus of this pre-study have been on existing systems installed according to IMO Resolution A.123 (V) [4], and solutions discussed during this work has been focused on what can be retrofitted to these systems. As a next step, focus could be on drencher systems of the future, not being limited by existing design and regulations. A next step would also be to use the concept ideas and investigate more practical integration for existing systems since these can be used as long as maintainable.

6.1 Future system

A research question could be "*how should future drencher systems be design for increased sustainability*?". A holistic approached should be used and include at least piping material, system design, testing procedures, user perspective, and costs. Moreover, operational aspects of activation of the drencher system should be a part of the scope, as well as requirements regarding dimensioning of the system to be able to handle a fire with the vehicle fleet of the future. Regulation amendment for the "next generation" suppression system in ro-ro spaces could be a possible outcome from this work.

An additional direction for the next step is to further study how the existing drencher systems handle fires in the modern vehicle fleet carried on board ships today, this includes, for example, electric cars, gas and hydrogen vehicles and trucks. Ensuring that the existing drencher systems have sufficient capacity to handle a fire as required by regulation is a major safety issue for the shipping companies and also for flag states and system manufacturers.

6.2 Existing system

In order to proceed with the reliability and design of drencher systems, a next step is to carry out a cost-benefit analysis based on, for example, the proposed solutions from this pre-study. Further research should be carried out regarding suitable piping materials and assessment for changing drencher piping material on vessel sailing today. Focus of this research should be on enhancing the knowledge of possible piping materials and their advantages/disadvantages. Aspects such as material, quality, weight, maintenance, and thickness as well as the cost should be included in the scope. Another activity could be to carry out fire tests in order to examine the fire resistance for non-metallic materials, such as GRE, when used in these kinds of systems.

A next step could also be to develop a methodology for estimating the time for manual activation of the drencher system. Challenges from the real work context should be included as parameters in the estimated time, such as decision making and crew availability. This estimation time is used to motivate if automatic activation of the drencher system is needed or not. Advantages and disadvantages regarding an automated activation versus manually activation could also be considered in this next step. For instance, how could an automated solution be implemented without hinder the crew from using the drencher system tactically.

The frequency of testing of the existing systems and how to improve test, inspection, and survey for optimal reduction for possibility of corrosion. For example, investigating methods for sharing data between actors executing port state control and regularly surveys. Also, the relevant safety aspects of the drencher system, e.g., water discharge from nozzles and sensors should be addressed to find a way forward on how test/inspection/survey be carried out in order to cover relevant safety aspects of the drencher system. How frequently should the system be tested with water? Are there alternative ways (i.e., not using water) of verifying the function of the drencher system and how should test procedures include these kinds of alternatives? Dry-flo has been mentioned as new on the market for this purpose and can be further investigated.

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8. Appendices

All ideas from Workshop #1, translated to English and with an ID number, are listed in Table 7.

Table 7. Ideas generated in brainstorming session of Workshop #1 together with comments from system group discussions.

ID	Ideas	Votes	Comment
1	**Changes in the system design to reduce risk of particles/dirt/ice in the system**		
1.1	**Protection against pollution in the sea chest**		
1.1.1	When using sea water, filter systems capable of filtering the water while not getting clogged, shall be installed. Filtering from sea chest.	5	* What does this mean with regards to pressure/suction ability? Could this be handled in 1.1.4?
1.1.2	Make use of the sea chest in other applications as well (i.e., frequent use)	1	
1.1.3	Copper anodes that prevent mussel growth	0	
1.1.4	Use parallel system-filters after the sea chest	3	
1.1.5	Self-cleaning valves for the ejector	2	
1.1.6	Improved filter and maintenance of filter around the sea water intake before it enters the drencher system	4	* Unsure of how the filter side looks like today
1.2	**Protection against pollution in the atmosphere**		
1.2.1	Closed pipes and nozzles (which open at a certain water pressure) with nitrogen-filled pipes.	4	* Maybe this only works for new systems
1.2.2	Closed pipes with circulating temperate water, e.g., cooling water	0	
1.2.3	Closed pipes with stationary liquid containing some type of antifreeze	2	* There is an ultrasound-listed antifreeze on the market
1.2.4	Close pipes/nozzles, i.e., not having an open system, not letting the external environment affect over time	3	* Close the pipes in some way, that needs to be looked upon in the future
1.2.5	Use 'blow-off caps' on nozzles	1	

1.3	**Material pipes (that can withstand the corrosive environment)**		
1.3.1	- The utopia are pipes that do not rust or burn up, and that are easy to maintain/replace, but what? - "Better" materials in piping systems. E.g., corrosion resistant material with sufficient resistance to salt corrosion. - Use pipes that are adapted to extinguishing water, i.e., no galvanized pipes for saltwater. - Matching of materials in the piping system in order to reduce the corrosion - Other materials, e.g., Coated pipes, GRE-pipes, Titanium, Stainless, Fendium, Composite.	11	* For new vessels. This would solve many problems and is highly recommended for new vessels. Though we have the old vessels with galvanized systems left, and the question is how to handle them in a smart way. This is actually two separate questions: How would we like it to look on new vessels, and how do we best handle old ships with galvanized pipes? * Pipe material with better resistance I think is the best solution to prevent or limit the extent of inside and outside corrosion. The pipes are more expensive in the investment-phase, but here it is necessary to show that it can cost less in a longer time perspective. Many of the pipes that are mentioned has lower internal flow resistance which is an advantage for the hydraulic dimensioning. * Many problems would be solved if we have better pipes. GRE is compatible with black and galvanized. Part of seawater is GRE. * Is a fire classification needed for pipes? What does SOLAS say? Pipes shall be of steel. * Changing to corrosion-proof/stainless on some vessels today. It is available instantly, just a matter of time. The pipes are replaced when they brake, then time is an important factor. * Service on different vessels - often problem in the pipes from corrosion new built. * Corrosion and pipes, black steel, galvanized and stainless and install valves. Harmonization of the piping systems so that the materials work together; from sea chest to nozzle. On land many components are in black steel and that is the same material. At sea, it can be different materials and the classification society doesn’t review this. Filters into the piping system. * temp 925 Celsius, piping systems should be in galvanized, stainless, or similar. Swedish regulations: in cases where we allow it refers to ResA753(18) (right now up for revision)

			* same formulations as on land (non-combustible, metal etc), plastic is used today, the pipes cannot burn up before the system has fulfilled its purpose. I.e., fast enough function, connected to risk class (a risk like this on a ro-ro deck would not be allowed to have plastic pipes according to land based standards). Difficult to introduce something new, supplier market is affected. Offices, schools are allowed to have plastic pipes, not warehouse, production. * Black pipes on land, corrosion proof/ stainless pipes cost twice as much to install (on land). Mixing pipes is not ok, galvanic corrosion (physical). Galvanized pipes are being phased out now on land. * different metals have good resistance for different things. Titanium is the material that copes with everything the best. * Trelleborg has an approval for the offshore industry for a plastic pipe type. * GRE, has it followed in the regulations? Maybe there is an opening here, see Res.A753 * black pipes better than galvanized, less rust. * price should also be included in the discussion. Approved pipes for offshore are expensive. * "Novel design", if you can show that it is as at least as good. Then it should also be cheaper than stainless. * operationally * dept. piping can handle fire endurance test for 60 minutes dry condition * Regulations

1.3.2	Use sprinkler pipes in glass fibre reinforced epoxy	6	* Glass Reinforced Epoxy (GRE) * How can GRE pipes be replaced on board, e.g., if there is a damage? Bend and fix. * Ice breaker fleet has changed to GRE for sea water. Has long lifetime. * How does GRE get affected of warm temperatures? * is there plastic pipes that can handle 925 Celsius? * pipes shall also manage the fire endurance test for 60 minutes dry condition (class society) * Some type of fire classification would be necessary though.
1.4	**Nozzle design**		
1.4.1	Use nozzles with high K-factor (large opening in the nozzle)	6	* K-factor is of course adjusted, so that the pressure at the nozzle is not lower than the normally recommended nozzle pressure. * purpose with a high K-factor - to have less risk of clogging while maintaining performance. Higher k-factor gives greater opening. Higher K-factor gives less risk of clogging. The pressure in the nozzle may drop, then it must be compensated. * make a hydraulic calculation to see if it is possible to change nozzles. Probably no need to rebuild piping systems. * K-factor today is about 80, sometimes up to 160. There are up to 800 on the market. But then maybe it falls on the market and cost. * there are approved systems the tested. Problems become more installation technical. * balance between pressure and covered area. * optimizations go in opposite directions. K-factor 115 is something that has been a balance. * stability must not be forgotten. The rules and regulations agree that you should be able to drain the water you add, 125%.
1.5	**Avoid salt water**		
1.5.1	Avoid salt water in testing	7	* Is done on many vessels today and is fairly easy to solve
1.5.2	Can seawater be desalinated before it is introduced in the system? E.g., on Gotland desalinated seawater can be drunk	0	* Deionized water is one of the most aggressive known solvents available - it "breaks with" metals including copper. So, it is not obvious that this is a good solution.

1.5.3	Avoid getting salt water into the system from day 1 of the usage of the system	2	* Hard for existing vessel
Added after voting	Secure that pipes and systems are clean from the start		* Experience is that the systems are often very contaminated from construction with gravel, metal shavings, plastic.
Added after voting	Use settling-principle in the piping systems (heavy particles sink), "sedimentation chamber"		* Sprinkler on incoming water from pools, for example when fetching sprinkler water to pools. Also used in the fuel system on board
2	**Changes in the testing procedure to reduce the risk of contamination/corrosion**		
2.1	**Design for alternative test procedure**		
2.1.1	Create smart design solutions, with valves for tests with/without salt water, with/without system filling etc.	4	* Increase the complexity of the system and worsen the reliability in the event of fire.
2.1.2	The same capacity for the two pumps (Sea and FV)	2	* Could be possible already, should be investigated on board first.
2.1.3	Separate tank for FV flushing coupled via 3-way valve directly on the drencher pump	5	* Thoughts exist on board
2.1.4	Pipe connection to land to test with freshwater	0	* Think that there must be enough fresh water on board, but such an opportunity would probably also be good… but as said, I think it would be good with a requirement to be able to run on fresh water, so to be able to connect to portside/land I think should not be a requirement.
2.3	**Test procedure**		
2.2.1	More research-testing of real systems to provide recommendations for testing and maintenance	4	* Linked to frequency and sweet spot to get a guide to what is a good level
2.2.2	Guideline on whether it is possible to increase the reliability through sub testing of nozzles, pipes, or filters	1	
2.2.3	There are approved air testing systems, how can they be used for sub testing and to provide an overview of the condition of the pipes?	2	* Adds additional complexity to the system (which, however, does not impair its reliability). Sophisticated testing with compressed air can probably identify if the nozzles are clogged but not if the diffuser plate is deformed (this requires testing with water and a visual inspection of the dispersion) or that each individual nozzle is visually inspected. move to 5.2?

2.2.4	Clarify what you want to test. There is no need to fill the piping system with water, or risk clogging of nozzles if you want to test the pumps, activation impulses etc.	3	* It is probably important to try that the section valves open and close as they should. Testing of these without water flowing through the entire piping system requires a return line downstream of the section valve to the drain and a shut-off valve downstream of the return line. This means increased system complexity and reduced reliability in the event of a fire. * Frequency is defined for every type of test, not necessarily with water every time.
2.2.5	Is it possible to run the drencher with anything else than water in exercise/training?	0	
2.2.6	- Test with other media than water, e.g., air, theatrical smoke - Test without water	1	
2.2.7	Test with freshwater	7	* Retrofit, is often very simple. There are freshwater tanks on the vessels. The problems are that they are different, and the solution needs to be developed individually. That's a good effect. Filters and strainer collect a lot of dirt, so if you clean them after / during the test you will find a lot. Could collect different solutions. * if problems already have occurred, then the pipes are probably bad. Fresh water is good to avoid clogging in the future, but probably does not solve the problem if you already have it. * When you start to see problems, we who perform inspections have a poor chance of noticing it. We test the function. Over time, the systems do not get less rust. It is a matter of keeping track of the status of the pipes and introducing fresh water. * you are not allowed to connect drinking water to other systems, so how do you solve it? a connection must not be permanent, so you connect it when running. You can run from the rinsing water system, washing water, then it is ok to have a permanent connection. * should be approved to run with fresh water. There is also a requirement from DNV to initially run with fresh water. * pumps etc. should have the same capacity but does not have to be infinite, can be down to a few minutes.

			* if you run from a tank, you must be careful that the water does not run out in a live situation. * to set the valve position should be included in the routine. An indicator on the bridge could alert if there are problems. * testing different functions should be a way to go, the pump can be tested separately, the dispersion can be tested separately, thus everything does not have to be run with water. * the electrical part is not as developed on the vessels as it is for the land systems * SS-EN TS 14816. * Explore opportunities on board. * Time required to start and stop valves, muscle strength when activated. Regulations. Land: emergency solution to go down to the sprinkler control.
2.3	**Test frequency**		
2.3.1	Develop the basis for "correct" frequency of testing	4	
2.3.2	Develop a guideline on how often it is good to test. Activation is needed on board at regular intervals for realistic exercises	4	
2.3.3	Restrict/Limit testing - creates problems	1	* If system failure, it is a system failure in a double sense
2.3.4	Document tests (including filming etc.) to avoid unnecessary iterations	5	
3	**Possibilities to clean the system after testing**		
3.1	**Drainage**		
3.1.1	- Drainage at all low points = obvious - Drainages at all low points (automatic)	4	
3.1.2	Design the system with few low points and with inclination, avoid bends and low points	5	
3.1.3	Strategic location of the drainage	4	

3.1.4	As short deaeration pipes as possible from sea chests, avoid horizontal pipes from sea chests	4	Unsure if this is in the right group. Moved to area Sea chest.
3.2	**Cleaning with freshwater**		
3.2.1	Clean with freshwater after running with salt water	9	* Cic1430 / rev2 has a note that flushing with fresh water should be available. * false alarm to manned location - on land if it is in the wrong position. * even for a new installation, ensure that dirt is not left in the system from the construction phase (metal shavings, plastic, etc.) * Should always be done but difficult to get all the salt water out. Concentrations of salt and crystal formation are still a risk
3.3	**Cleaning with air (after test/prevention)**		
3.3.1	Dry with air, does not entirely avoid corrosion but helps remaining drops etc. that is inconvenient when testing	5	* Know that it is difficult to get it completely dry * Condensation will still create a moist piping system
3.3.2	Use the same air cleaning method that is available on almost all aspirating smoke detector systems	2	What does it mean? * Condensation will still create a moist piping system
3.3.3	Permanent connections and fixed air compressor installation for air cleaning of pipes	3	* Condensation will still create a moist piping system
4	**Reduce freezing risk**		
4.1.1	Test valve that enables pump testing during winter by releasing water into bilge well engine room	6	* Is also included in cleaning of the sea chest
4.1.2	Use heating cables in parts that are exposed to freezing risk	6	* On strategic locations
4.1.3	Do not turn off the drencher when running in winter conditions. Way of working?	1	
4.1.4	Pre-action system with nitrogen, similar to FM design for cold storage	3	* This means that the system is rebuilt into an automatic system with automatic sprinklers. Filling with nitrogen gas is preferable to compressed air to reduce the risk of internal corrosion. Move to another chapter
4.1.5	Drainage of water + refrigerant in "anaconda"	3	

5	**Increase preventive maintenance opportunities**		
5.1	**Preventive cleaning**		
5.1.1	Easily dismountable nozzles for faster/easier air cleaning/can be done mor often than larger testing	4	
5.1.2	Pipe ends on each section which can be opened and flushed for dirt before it reaches the nozzles	4	* The drain valves need to be located upstream of manifolds with nozzles. See also comment below. * E.g., "bottom plug" in riser.
5.1.3	Do not flush the system without being sure that all the particles large enough to block the nozzles will be removed	4	
5.1.4	Vibrations or other methods to loosen rust flakes that would come off during activation of the system. Loosen them before and flush them occasionally.	1	* Will create more corrosion
5.1.5	Strategic "cleaning" e.g., drain valves at the end of the manifolds	5	* Since these drainage valves, according to the proposal, are located downstream of the nozzles, most of the water will still make its way out through the nozzles. * Low pressure flushing
5.1.6	Redundancy of outlets, nozzles.	3	* Means double drencher capacity
5.1.7	Deaeration to the sea chest needs to be cleaned in certain intervals.	5	* Relevant for other systems as well
5.1.8	Possibilities to discharge water from the sea chest without letting it pass through the system	1	
5.1.9	Easy to access, easy to clean filters situated directly before the respective nozzle. That means that the test run also is a flushing.	0	* Nozzles with a low K-factor (nozzle opening) are often equipped with a filter ('nozzle strainer'), but these filters are also available for nozzles with a larger K-factor. Note that the filter increases the flow resistance through the nozzle and the hydraulic dimensioning of the system. * Filters tend to clog faster than nozzles
5.1.10	Magnets or filtering systems that attracts the rust flakes somewhere in the piping system, fairly close to the nozzles in order to avoid blocking of the nozzles.	3	* Interesting but there is a risk that there will be a giant plug when many flakes drop at the same time when the power of the water overcomes the magnet's ability to hold the flakes.

5.2	**Evaluation of pipe condition**		
5.2.1	Measure the amount of water at the test (to get a picture of the pipe condition)	2	* Measurement of water flow through the system at a given pump pressure. Over time, one could identify changes in the piping system's hydraulics, for example due to internal sediments or clogging of nozzles.
5.2.2	Analysis of liquids in the pipes to assess the pipe condition	2	* More relevant for wet piping systems that always contains water.
5.2.3	Ultrasound-measurement of the wall thickness of the pipes	4	* Measurements with ultrasound * Sample for example every 10 years at inspection
5.2.4	Send pipe samples every 10 years to a laboratory for quality evaluation	2	* RISE performs such inspections of pipes from time to time. The pipes are sawn apart in the longitudinal direction. Can measure the depth of pitting with a microscope but not say anything about the remaining life of the piping system. * Maybe even of sprinkler heads - 10-year inspection?
5.2.5	Examine the inside of the pipe with a camera (when they are disassembled)	3	* This is normally done without disassembling the system, which means that all parts of a system can be inspected. See also 5.2.7 and 5.2.8.
5.2.6	Use sensors to control the status/function etc.	1	Unsure if this is in the right group. Should be moved to testing. * Basic idea is to find functions which means that you do not have to do a full-scale test
5.2.7	Inside control of the pipes with a camera, on site, for installed systems - this is already being done today for land-based systems.	4	
5.2.8	The piping system shall be examined with a camera at least once a year.	5	* 5 years is generally a better frequency. Can be lowered to 2,5 for ships older than 15 years
	Cleaning with air (preventive) - see 3.3		
6	**Protect sensitive auxiliary equipment**		
6.1.1	Fibre optic cable for fire detection	3	* This technology is much more robust than point detectors and does not need to be protected from water during testing. Can also provide earlier fire alarms.
6.1.2	Place equipment without the risk of water	2	

6.1.3	Change to detectors that can handle water splashes instead of covering the detectors during testing	4	
6.1.4	Cylinders as nozzles to limit the dispersion (more time-efficient to use) compared to covering during testing	1	* The disadvantage is that the dispersion from the nozzles cannot be examined. On the other hand, an ocular inspection that the diffuser plate is deformed can be made when these cylinders are suspended.
6.1.6	Secure that electric monitor and control systems are "fail-safe" and/or with circuit monitoring. Otherwise control acc. To MSC 1430 rev.1	1	
6.1.5	Place detectors above the drencher nozzles - or choose detection that can be placed on the sides	4	* May not help for everything
7	**Exchange of experiences**		
7.1	**Marine/Land**		
7.1.1	Re-use all relevant parts in land-based standards, frequencies, methods etc.	4	
7.1.2	Systematic exchange of experiences between marine and land	6	
7.2	**Visualize/Quantify the problem**		
7.2.2	Create a database where all detected errors/failures within this area is registered for a period, in order to verify perceived problems	3	* CINE? * Perhaps rather a long-term research project
7.2.3	Could the vessels open up their maintenance systems in order to create a database for failures with old drenchers?	1	* Perhaps rather a long-term research project
7.2.4	Examine how many that has a system according to ResA123 to get clarification of how large the problem could be	3	
7.3	**Experiences of different system solutions**		
7.3.1	Separate between water mist and deluge system, different nozzle openings etc. Water mist = extremely small nozzle openings = large risk of clogging. Deluge = larger openings, less sensitive.	2	

	Different types of systems, different requirements of water quality		
8	**System change**		
8.1.1	Upgrade to automatic sprinkler systems	1	* This probably refers to upgrading to wet pipe system (which have minor problems with internal corrosion) or to dry pipe or pre action systems that are filled with nitrogen gas.
8.1.2	Change to high pressure systems (protects against contamination/rust, changes the testing and activation)	0	* These systems are even more sensitive to clogging of nozzles, which means that water quality is even more important. * High pressure systems have had bigger problems with clogging than Deluge