Horizon 2020

Project acronym: **LASH FIRE**

Project full title: **Legislative Assessment for Safety Hazard of Fire and Innovations in Ro-ro ship Environment**

Grant Agreement No: **814975**

Coordinator: **RISE Research Institutes of Sweden**

Deliverable D07.9

Development and implementation of design guidelines and procedures for extinguishing system activation

March 2023

Dissemination level: **Public**

Call identifier: H2020-MG-2018-Two-Stages Starting date: 2019-09-01 Duration: 48 months
MG-2.2-2018: Marine Accident Response, Subtopic C

Abstract

The initial phase of a fire on ro-ro ships is critical. Fixed fire extinguishing system activation (drencher and CO_2) often takes long time, typically 20 minutes or more, from fire detection until extinguishing system is activated. This allows fires to escalate and spread before extinguishing starts. Thus, reducing the time spent before drenchers or CO_2 systems are activated will contribute significantly to reducing the consequences of a fire. The objective of the work described in this report is to develop improved procedures and design for more efficient fixed fire extinguishing system activation.

The development of solutions is based on studies of research literature and governing documentation, interviews with crew from ro-ro, ro-pax and vehicle carriers, remote ethnography studies, and field studies on ro-ro ships. The demonstration of the two developed solutions were performed in a relevant environment, the Jovellanos Maritime Safety Training Centre in Gijon, Spain and on board a ro-ro vessel while docked in port.

To meet the objective of improved procedures and design for more efficient fixed fire extinguishing system activation, a *reflection, evaluation and change (REC) process* has been developed for ship-specific adaptation of procedures and design. The REC process is developed to function as an internal crew process, to be implemented in connection with, and as an extension of, ordinary fire drills. In the REC process, the crew collectively reflect on and evaluate activation procedures and material/design conditions before, during and after drills, with the aim of producing and implementing recommendations for changes in procedures and design that will increase the efficiency of the extinguishing system activation process. A user guide for the REC process is available (included) as a brief guideline, see Section 9.4.

In addition, a training course for activation of fixed fire extinguishing systems has been developed based on the acknowledgement of a current lack of training and familiarization among ro-ro and ro-pax crew members, with realistic hands-on activation of fixed firefighting systems (drencher and CO_2). Evaluations from participants at the course show that hands-on experience with activation of fixed extinguishing systems is experienced as useful and may improve fire safety at sea. Drencher activation can be trained and performed on board, but the intense daily operative of the vessel makes it difficult to incorporate the drencher activation to the mandatory and regular fire drills due to, among other reasons, that cargo space needs to be empty of cargo for the real discharge of water. LASH FIRE recommends the incorporation of drencher activation to the on-board training routines. CO_2 presents different issues due to the inherent dangers of the gas (asphyxiant even lethal at high concentrations), so the only way to train the real activation will be under a controlled scenario ashore. The recommendation is to include the competence of the real activation of firefighting systems to the column 3 (Knowledge, understanding and proficiency) of the table A-II/2 of the STCW Code as the specification of minimum standard of competence for masters and chief mates of ships of 500 gross tonnage or more.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814975

Document data

Document Title:	D07.9 – Development and implementation of design guidelines and procedures for extinguishing system activation		
Work Package:	WP07 – Design		
Related Task(s):	T07.6, T07.7, T07.8		
Dissemination level:	Public		
Deliverable type:	Report		
Lead beneficiary:	19 - NSR		
Responsible author:	Torgeir Kolstø Haavik		
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Date of delivery:	2023-03-28		
References:			
Approved by	Jaime Bleye on 2023-01-25	Staffan Bram on 2023-02-10	Maria Hjohlman on 2023-02-16

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Document history

Version	Date	Prepared by	Description
01	2022-03-01	Torgeir K. Haavik	Draft of structure
02	2023-01-12	Torgeir K. Haavik	Draft of final report, circulated to reviewers
03	2023-02-28	Torgeir K. Haavik	Final report
04	2023-03-28	Torgeir K. Haavik	Final report

Content

1 Executive summary

1.1 Problem definition

The initial phase of a fire on ro-ro ships is critical. Fixed fire extinguishing system activation (drencher and CO_2) often takes long time, typically 20 minutes or more, from fire detection until extinguishing system is activated. This allows fires to escalate and spread before extinguishing starts, thus reducing the time spent before drenchers or CO_2 systems are activated will contribute significantly to reducing the consequences of a fire. Procedures, practices and design solutions vary between ships and are not always optimised, and there are few occasions for gaining hands-on experience with realistic operation of the extinguishing systems.

This report describes the studies performed within the LASH FIRE project to map the challenges related to extinguishing system activation, and outlines the development of solutions that aim to contribute to improved efficiency of fixed extinguishing system activation.

1.2 Method

The report is based on studies of research literature and governing documentation, interviews with crew from ro-ro, ro-pax and vehicle carriers, remote ethnography studies, and field studies on ro-ro ships. In addition to the interviews, informants have provided us with supplementary materials such as photos and written procedures.

The solutions have been developed in close collaboration with stakeholders and end-users. Early developments have been presented to them, and feedback has been taken into account.

The demonstration of the two solutions were performed in a relevant environment, the Jovellanos Maritime Safety Training Centre in Gijon, Spain and onboard a ro-ro vessel while docked in port.

The deliverable is the main deliverable of LASH FIRE Action 7-B.

1.3 Results and achievements

The work has resulted in two Risk Control Options (RCOs):

RCO6: The *reflection, evaluation and change (REC) process* is a crew internal process intended to develop better procedures and better designed environment for working effectively with extinguishing system activation. The output from this process will be procedures and design that are adapted to actual working context, experiences and practices of the actual crew in the actual vessel. Hence, the final implementation of recommendations will imply context-specific adoption of faster, better and safer activation processes, with operator company and their crews in particular being the target group.

RCO7: Training programme for activation of extinguishing systems. The training course is first and foremost a *practical* course, intended to improve the participants' competences related to activation of drenchers and CO_2 extinguishing systems. The theoretical part of the course aims to encourage the participants' own reflexivity and inspire them to use their own experience and contextual knowledge from their own workplace to take ownership of the working principles introduced in the training and adapt them to their own respective working contexts.

Through these developments, that has been demonstrated in operative environments and labs and given that the solutions are implemented by shipping companies, the objective of facilitating improved procedures and design solutions has been achieved.

1.4 Contribution to LASH FIRE objectives

This report is contributing to LASH FIRE Objective 1, the objective of WP07 and specifically Action 7-B.

Objective 1: LASH FIRE will strengthen the independent fire protection of ro-ro ships by developing and validating effective operative and design solutions addressing current and future challenges in all stages of a fire.

WP07 Inherently Safe Design: Reduced potential for human error, accelerating time sensitive tasks and providing more comprehensive and effective decision support, by increased uptake of human centred design and improved design of tools, environments, methods and processes for critical operations in case of fire.

Action 7-B: Develop guidelines for efficient extinguishing system activation and inherently safe design.

1.5 Exploitation

The reflection, evaluation and change (REC) process (RCO6) is designed to adapt and improve existing procedures and design relating to fixed fire extinguishing systems management. The process should be carried out at the level of individual ships, preferably in collaboration with the onshore organisation – e.g., with participation from the so called "Designated Person Ashore" (DPA). This to ensure continuity across the process, from discovering improvement potentials during a drill, to implementing suggested changes in design or procedures.

The complete developed training course (RCO7) can be used by maritime onshore training organisations, while the theoretical principles can also be applied for drills organised by crew on board individual ships. It is recommended to include the competence of the real activation of firefighting systems to the column 3 (Knowledge, understanding and proficiency) of the table A-II/2 of the STCW Code as the specification of minimum standard of competence for masters and chief mates of ships of 500 gross tonnage or more.

2 List of symbols and abbreviations

AB	Able seaman
APV	Alternatively powered vehicle
CCTV	Closed-Circuit Television (surveillance camera)
CO_2	Carbon dioxide
DPA	Designated person ashore
ECR	Engine Control Room
FRMC	Firefighting Resource Management Centre
FSS	Fire Safety Systems Code
HF	Human Factors
IACS	International Association of Classification Societies
IMO	International Maritime Organization
IMDG	International Maritime Dangerous Goods (Code)
MSC	Maritime Safety Committee
OOW	Officer on watch
PPE	Personal Protective Equipment
RCO	Risk Control Option
REC	Reflection, evaluation and change
Ro-pax	Vessel type with both roll-on roll-off cargo and passengers
Ro-ro	Vessel type with cargo type roll-on roll-off
SOLAS	IMO International Convention for the Safety of Life at Sea
STCW	IMO International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
VHF	Very High Frequency Radio

3 Introduction

Main author of the chapter: Brit-Eli Danielsen, NSR

This report concerns the work in the LASH FIRE project that focuses on the extinguishing system activation process. Fire extinguishing system activation (drencher and CO_2) often takes long time, typically 20 minutes or more, from fire detection until extinguishing system is activated. This allows fires to escalate and spread before extinguishing starts. The initial phase of a fire on ro-ro ships is critical, and reducing the time spent before drenchers or CO_2 systems are activated will contribute significantly to reducing the consequences of a fire. Successful management of fixed fire extinguishing systems in fire situations in ro-ro ships requires both efficiency and thoroughness from the crew involved in the firefighting. Efficiency relates to the swiftness of the activation process, and thoroughness relates to getting it right – particularly activating the extinguishing system in the right section of the ship. The current work has aimed at developing improved training and procedures for that will contribute to both efficient and thorough fixed fire extinguishing system activation.

To provide a background for the developed solutions, this report first outlines the current status and context in which activation of fixed fire extinguishing systems occurs. The regulations and legal requirements for fixed fire extinguishing systems are presented, followed by the state-of-the-art from to two other sectors – the offshore oil and gas sector and the nuclear sector – that are known for their high safety standards, including fire safety. Thereafter, the status and challenges as described by ship operators are presented before the central challenges for an efficient activation processes identified through empirical research performed in this project is discussed. The rest of the report describes the developed solutions, and demonstration of their applicability.

The LASH FIRE research to develop improved training and procedures for fixed fire extinguishing system activation follows an *action research* approach. Action research entails not only studying a system but also active collaboration with its members. Both the research performed leading up to the developed solutions, and the solutions in themselves, follow this principle in order to produce results and changes that are anchored in the organisations and among the people that are going to make use of it. *Reflective practise* is a central topic and method in the action research literature. Reflective practice as an approach to learning and development means stepping back to think about and reflect over experiences, to be able to develop an understanding of the experiences that may be overlooked in practice, providing a basis for future action.

It has been considered important to develop solutions that are 'living' and that capture and address the dynamics – changes and adaptations in the social and material environment that occur in a living work environment. Thus, the solutions need to be process oriented, i.e., should not be a 'once-and-for-all-implementation'. The solutions must also be 'self-sustainable' with available resources (time and personnel) in the operative ship environment. This has pointed towards a process solution fitted into the regular activities of the crew, and administered by the crew themselves (if necessary, in collaboration with DPA).

The solutions described in this report include a training module and tools for improvement of work procedures and design related to extinguishing system activation. The tools are outlined as internal *reflection-, evaluation- and change processes* where the output will be procedures and design that are adapted to actual context, experiences and practices of the actual crew in the actual vessel. Hence, the final implementation of recommendations will imply context-specific adoption of faster, better and safer activation processes, with operator company and their crews in particular being the target group. Regarding the training module, the recommendation is to include the competence of the real activation of firefighting systems to the column 3 (Knowledge, understanding and proficiency) of the table A-II/2 of the STCW Code as the specification of minimum standard of competence for masters and chief mates of ships of 500 gross tonnage or more.

4 Methods

Main author of the chapter: Brit-Eli Danielsen, NSR

This report builds on research that has been undertaken to understand current praxis and needs for modification of extinguishing system activation design and procedures. The report describes the two developed solutions aimed to improve extinguishing system activation design and procedures, the reflection, evaluation and change process (RCO 6) and the training programme (RCO 7), as well as the demonstration and evaluation of these.

The LASH FIRE research to develop improved training and procedures for fixed fire extinguishing system activation follows an *action research* approach. Known also by other names such as participatory research and collaborative inquire, a brief but concise definition of action research is learning by doing, where people "identify a problem, do something to resolve it, see how successful their efforts were, and if not satisfied, try again" (O'Brien, 1998, p. 3). A dual commitment of action research is to, concurrently, study a system and collaborate with its members to improve develop it in a desired direction (Gilmore et al., 1986). Both the research leading up to the developed solutions, and the solutions in themselves, follow this principle in order to produce results and changes that are anchored in the organisation and its end user. To that end, the seafarers involved are during the process turned into researchers, too. The research is done in the midst of real-world situations – actual fire drills – and it is aimed at solving real problems, and leans on the maxim that "people learn best, and are more willingly apply what they have learned, when they do it themselves" (O'Brien, 1998).

The data collection started in 2019 by visiting two ships where interviews and a tour of the bridge and fire related environments and equipment was included. One fire drill was observed on board a ship in 2020. The onset of the Covid-19 pandemic limited further possibilities for being physically present on ships, thus further interviews were conducted via the video-conferencing tool Microsoft Teams. In-depth, targeted interviews with 16 officers with roles and tasks in the firefighting organisation, mainly on the bridge and in the engine control room on ro-ro, ro-pax and vehicle carriers was performed. In addition, interviews from LASH FIRE WP06 helped to shed light on the extended firefighting organisation on the vessels, making the number of interview informants close to 30.

Practices and challenges identified from the interview study was supplemented with and nuanced by results from remote ethnography studies. The adapted ethnography methods named "remote ethnography" and "virtual walkthrough" (described in LASH FIRE reports D07.2 and D07.4) were employed during 2021, using on-ship facilitators and wearable action cameras. These methods generated rich data and descriptions of the firefighting context and practices on four different ships.

The remote ethnography studies have contributed with important insights into the relationship between work-as-imagined and work-as-done (Hollnagel, 2015). While descriptions of work based on interviews tend to emphasize the 'correct' way to carry out procedures (work-as-imagined), the remote ethnography studies have produced work descriptions as they play out in practice, with contextual adaptation of written procedures. While this represents an important methodical strength, there is yet another layer of work-as-imagined and work-as-done that has not lent itself to inspection – when we have studied work related to safety-critical situations (simulated activation of extinguishing systems) we have done so during drills. The realism of drills is debatable; drills are planned, they have a set scenario (which to a large degree excludes unforeseen events), they are performed during daytime. Thus, although drills exhibit practices, they exhibit a kind of idealised practices that may not be confronted with the situational surprises that reality tend to produce in real crisis situations.

Thus, the assumption that drills let the crew train on realistic scenarios is only partly true, and this is a limitation also to our studies. Our opportunity to understand the dynamics between procedures and practices is limited by the lack of opportunities to study real fires and the crew's response as they play out. We do, however, find important resources in historic investigation reports from real fires, and the study of such should also be mentioned as an important part of the methodical repertoire.

4.1 Demonstration of solutions

The testing and demonstration of RCO6, the reflection, evaluation and change process, was performed on board a ro-ro vessel while docked at port. The demonstration was planned in collaboration between the ship's crew, the shipping company's project manager and the research group. The demonstration was incorporated into a customized fire drill that involved activation of the drencher system. Participating in the demonstration were crew from deck/bridge, engine and three researchers. Before the drill started the researcher team with support from the shipping company's project manager, held an introduction explaining about the LASH FIRE project and the background for the demonstration. This introduction also included the premises for the participation of the crew, their contributions and their rights with respect to the GDPR regulative. All participants signed consent forms. The researcher team split up and were allocated to each their locations/team: one researcher stayed at the bridge, one researcher was to follow the first engineer to the safety control room, and the last researcher would follow the fire team to the location of the fire at the deck. The researchers documented the drill by taking notes, pictures and video, as well as conversating with the crew when the situation allowed for that. After the drill was finished, the crew, the shipping company project leader and the researcher team gathered on the bridge for a debrief with evaluation. After about half an hour of collective evaluations, the discussions continued as separate researcher-crew discussions for a while longer. A detailed description of the drill as well as the evaluation is provided in Chapter 9.

The testing and demonstration of and RCO7, the training programme, was performed at the Jovellanos Maritime Safety Training Centre (SASEMAR, Spain), an onshore centre providing maritime fire training facilities. A total number of 10 participants from three shipping companies attended the course. The course consisted of a theoretical module (a lecture given by NSR) and a practical module (fire simulation, administered by SASEMAR). For the practical part two of the participants acted as captain and first officer on the bridge, while the rest of the participants formed a firefighting group to approach the fire on deck (see Figure 28). The bridge was simulated in a dedicated room in the Jovellanos facilities. This room was equipped with radios for communication with the fire team. In addition, on a screen on the bridge simulator the officers could watch the fire team, as live video was streamed from the fire location. This was to simulate the CCTV on a real ship. The deck was simulated by aid of a container and another separate 'cargo hold' in the outside area of the Jovellanos facilities. Researchers/training instructors from Jovellanos were present at both locations to guide the participants through the exercise. In addition, five researchers observed the participants – two were located in the bridge simulator and three were located in the field, taking notes, pictures and video in order to document the event for evaluation and further research. The course was evaluated through debrief and survey. A detailed description of the course as well as the evaluation is provided in Chapter 10.

5 Regulations and legal requirements for fixed fire extinguishing systems

Main authors of the chapter: Blandine Vicard and Eric de Carvalho, BV

This chapter aims at giving an overview of the requirements applicable in ro-ro spaces regarding LASH FIRE Action 7-B, i.e., "efficient extinguishing system activation and inherently safe design". Several kinds of fixed fire-extinguishing systems may be installed in vehicle and ro-ro spaces, depending on the type of ship and type of space concerned, with different requirements associated to their activation. A significant focus is put here on the water-based fixed fire-extinguishing systems because they are the most common, and, for practical purposes, the only allowed solution on passenger ships. The design of the fixed fire detection and fire alarm system as a support for decision-making is not covered in detail here.

5.1 General

5.1.1 Applicable regulations

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

Table 1: List of documents used for the review of regulations for activation of fixed fire extinguishing systems

IMO Documents	SOLAS Convention, as amended (IMO, 2020c)
	MSC.1/Circ.1615, Interim Guidelines for minimizing the incidence and consequences of fires in ro-ro spaces and special category spaces of new and existing ro-ro passenger ships
	MSC.1/Circ.1430/Rev.1, Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces (IMO, 2020d)
	IMO FSS Code, as amended (IMO, 2020b)
IACS & Class Rules	IACS Blue book dated January 2019
	BV Rules for Steel Ships (NR467), as amended in July 2020
Flag Administration Rules	Chinese rules for domestic passenger ships, as indicated in IMO SSE5/INF6

5.1.2 Definitions

5.1.2.1 Ro-ro space, vehicle space and special category space

As per SOLAS II-2/3 [5]:

- "Vehicle spaces are cargo spaces intended for carriage of motor vehicles with fuel in their tanks for their own propulsion."
- "Ro-ro spaces are spaces not normally subdivided in any way and normally extending to either a substantial length or the entire length of the ship in which motor vehicles with fuel in their tanks for their own propulsion and/or goods (packaged or in bulk, in or on rail or road cars, vehicles (including road or rail tankers), trailers, containers, pallets, demountable tanks or in

or on similar stowage units or other receptacles) can be loaded and unloaded normally in a horizontal direction."[1]

- "Special category spaces are those enclosed vehicle spaces above and below the bulkhead deck, into and from which vehicles can be driven and to which passengers have access. Special category spaces may be accommodated on more than one deck provided that the total overall clear height for vehicles does not exceed 10 m."
  Special category spaces are ro-ro spaces to which passengers have access, possibly during the voyage. Special category spaces are the most frequent type of closed ro-ro spaces on ro-ro passenger ships. It is to be noted that open ro-ro spaces are not considered as special category spaces.

5.1.2.2 Closed, open and weather deck

As per SOLAS II-2/3 [3]:

- A "weather deck is a deck which is completely exposed to the weather from above and from at least two sides."
  IACS UI SC 86 [7] additionally details that: "For the purposes of Reg. II-2/19 a ro-ro space fully open above and with full openings in both ends may be treated as a weather deck."
  For practical purposes, drencher fire-extinguishing system cannot be fitted on weather decks due to the absence of deckhead. This criterion is often used for a practical definition of weather decks.
- An open vehicle or ro-ro space is "either open at both ends or [has] an opening at one end and [is] provided with adequate natural ventilation effective over [its] entire length through permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10% of the total area of the space sides."
- A closed vehicle or ro-ro space is any vehicle or ro-ro space which is neither open nor a weather deck.
  As a reference criterion, it can be considered that a vehicle space that needs mechanical ventilation is a closed vehicle space.

5.2 Requirements

5.2.1 General

SOLAS II-2/20.6.1 [5] requires a fixed fire-extinguishing system to be provided in every vehicle or ro-ro space. It is to be noted that this requirement does not apply to weather decks intended for the carriage of vehicles, because weather decks are not "spaces".

Pure cargo vehicle or ro-ro spaces capable of being sealed from outside may be provided with:

- Fixed gas fire-extinguishing system – typically CO_2; or
- Fixed high expansion foam fire-extinguishing system; or
- Fixed water-based fire-extinguishing system – "drencher" type or equivalent.

[1] In other words, ro-ro spaces are vehicle spaces into which vehicles can be driven. It is to be noted however that, for the purpose of the application of SOLAS II-2/19 [5], the following interpretation can be found in MSC.1/Circ.1120 [6] and IACS UI SC 85 [5]: "Ro-ro spaces include special category spaces and vehicle spaces".

In the case of special category spaces (i.e., passengers have access to the garage) or if the space cannot be sealed, only the fixed water-based fire-extinguishing system is allowed.

[SOLAS II-2/20.6.1.1 and II-2/20.6.1.2]

It can be noted that China requires CO_2 fixed fire extinguishing system in ro-ro spaces of domestic ferries, whereas such systems are usually avoided in spaces where passengers can have access.

[IMO SSE 5/INF.6]

[IMO FSS Code Ch 5 §2.2.1.2]

5.2.2 CO_2 systems

A CO_2 fixed fire-extinguishing system, if installed for the protection of a ro-ro or vehicle space, is to comply with the requirements of IMO FSS Code Ch.5 [9]. Basically, these rules are aimed at ensuring both the efficiency of the system for fire-extinguishing (i.e., effectively inerting the volume to be protected) and avoiding the risk of asphyxiation.

5.2.2.1 Requirements for controls and system activation

Especially, precautions are taken in order to avoid inadvertent release into the space:

- Two separate controls are required for releasing the CO_2, meaning two successive deliberate actions;
- It should not be possible to operate the controls in the wrong order;
- Operation of these controls is to activate an audible and visual alarm in the space, which will signal to anybody remaining in the space that CO_2 will be released and that they should leave immediately. The alarm is to remain active for a period long enough to allow evacuation of the space prior to CO_2 discharge; and
- Both controls are to be enclosed in a box in order to avoid unintended operation.

[IMO FSS Code Ch 5 §2.2.2 & §2.1.3.3]

As a note, automatic release of CO_2 systems is normally not allowed – again in order to avoid asphyxiating people.

[IMO FSS Code Ch 5 §2.1.3.4]

The manual controls for the release of the CO_2 into the protected space are to "be readily accessible, simple to operate and shall be grouped together in as few locations as possible at positions not likely to be cut off by a fire in a protected space. At each location there shall be clear instructions relating to the operation of the system having regard to the safety of personnel."

[IMO FSS Code Ch 5 §2.1.3.3]

5.2.2.2 History

IMO FSS Code Ch 5 has been fully revised by IMO Resolution MSC.206(81) which entered into force on 01/07/2010. However, the requirements related to the release of CO_2 systems have been quite consistent over time – with two continued concerns: efficient release and avoiding asphyxiating people. One major evolution with MSC.206(81) was the introduction of the requirement for two separate controls, meaning two effective actions for releasing the CO_2.

5.2.3 High expansion foam systems

A high expansion foam fixed fire-extinguishing system, if installed for the protection of a ro-ro or vehicle space, is to comply with the requirements of IMO FSS Code Ch.6 [9].

5.2.3.1 *Requirements for controls and system activation*

Here again, it is taken into account that high expansion foam flooding can be very hazardous if people are trapped in the space and an automatic pre-discharge alarm is required prior to foam release.

[IMO FSS Code Ch 6 §3.1.20]

In addition, breathing apparatuses are foreseen for fire-fighters who would need to enter the space after foam release.

[IMO FSS Code Ch 6 §3.1.15]

The requirements for the release controls aim at ensuring efficient and quick release of the system:

- Means of controls are to be "readily accessible and simple to operate, and […] arranged at positions outside the protected space not likely to be cut off by a fire in the protected space"; and

[IMO FSS Code Ch 6 §3.1.12]

- Operating instructions and plans showing the sections covered by the system are required close to the operating positions.

[IMO FSS Code Ch 6 §3.1.8 & 3.1.16]

Manual release of high expansion foam systems is required. Most are capable of manual release only. But automatic release may however be allowed, without further requirement for ro-ro and vehicle spaces.

[IMO FSS Code Ch 6 §3.1.1]

5.2.3.2 *History*

IMO FSS Code Ch 6 has been fully revised by IMO Resolution MSC.327(90) which entered into force on 01/01/2014. Prior to this date the requirements related to the controls and activation of high expansion foam systems were very scarce and for practical purposes limited to:

"The […] means of controlling the system shall be readily accessible and simple to operate and shall be grouped in as few locations as possible at positions not likely to be cut off by a fire in the protected space."

5.2.4 Water-based systems

Water-based fixed fire-extinguishing systems installed for the protection of ro-ro, vehicle or special category spaces are to comply with the requirements of IMO MSC.1/Circ.1430 rev.1 [10]. This guideline contains a number of requirements regarding the dimensioning and design of the system and also covers its controls, with a view to ensure efficient and easy operation of the system.

5.2.4.1 *Requirements for controls and system activation – Section valves*

Water-based fixed fire-extinguishing systems installed for the protection of ro-ro, vehicle or special category spaces are divided into sections, i.e. the activation of the system will not lead to releasing water over the whole space, only over a section of the space. A section physically corresponds to a grouping of pipes and nozzles covering a given area of the space and that can be isolated from the rest of the system by a section valve.

[MSC.1/Circ.1430 rev.1 §3.2]

Operation of the section valves may be local or remote and "means should be provided to prevent the operation of the section control valves by an unauthorized person".

[MSC.1/Circ.1430 rev.1 §3.2.1]

The section valves are to be easily accessible, outside of the protected space and their location is to be "clearly and permanently indicated". In addition, ventilation is required at the section valve locations in order to avoid smoke accumulation.

[MSC.1/Circ.1430 rev.1 §3.2 and §3.2.1]

It is to be noted that there is no requirement to gather all section valves at the same location – as was initially the case in traditional drencher systems covered by IMO Resolution A.123(V). However, for deluge systems, i.e. systems for which effective activation requires opening the section valves, the controls of the section valves, together with an indication of their position and the controls for the pump, are to be grouped in a continuously manned control station[2].

[MSC.1/Circ.1430 rev.1 §3.2.2]

5.2.4.2 Requirements for proper system operation

As a complement, a number of requirements cares for the easy and informed operation of the system:

- Operating instructions are to be displayed at operating positions, in the working language of the ship; and

[MSC.1/Circ.1430 rev.1 §3.14 & §3.18]

- A list or plan showing the areas covered by each section is to be displayed on board.

[MSC.1/Circ.1430 rev.1 §3.15]

For passenger ships, IMO Interim guidelines for minimizing the incidence and consequences of fires in ro-ro spaces and special category spaces of new and existing ro-ro passenger ships [11] focusses on the easy identification of the section to be activated, recommending:

- That the sections of the water-based fixed-fire extinguishing system correspond with the sections of the fixed fire detection and alarm system in order to ease decision making and to avoid erroneous activation; and

[MSC.1/Circ.1615 §2.1.2 and 2.1.3]

- Visual marking of the sections in the ro-ro, vehicle or special category space.

[MSC.1/Circ.1615 §2.6]

5.2.4.3 Requirements for automatic activation

IMO MSC.1/Circ.1430 rev.1 [10] allows and provides requirements for automatic activation of the system. This is a recent evolution which was introduced in IMO MSC.1/Circ.1430 – only manual activation was allowed before.

[MSC.1/Circ.1430 rev.1 §3.1]

In case of automatic activation:

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[2] SOLAS II-2/3.17 and II-2/3.18 [5]: "Continuously manned central control station" is a central control station which is continuously manned by a responsible member of the crew and "Control stations" are those spaces in which the ship's radio or main navigating equipment or the emergency source of power is located or where the fire recording or fire control equipment is centralized. Spaces where the fire recording or fire control equipment is centralized are also considered to be a "fire control station".

- A warning notice is to be displayed at the accesses to the space, mentioning the possibility of automatic water release; and

[MSC.1/Circ.1430 rev.1 §3.17]

- A visual and audible alarm is to be triggered at a continuously manned control station, indicating the activated section.

[MSC.1/Circ.1430 rev.1 §3.5]

There are two technical options for automatic activation:

- Automatic sprinkler nozzles with normally wet pipes and thermosensitive bulbs that will break open in case of high temperature detection; or
- Open nozzles with normally dry pipes, controlled by section valves that will open automatically upon fire detection by the fixed fire alarm and fire detection system. In this case:
    - The fixed fire detection and fire alarm system is to involve two types of fire detectors (heat/flame/smoke). TV monitoring of the space is also required for performance-based systems, i.e. systems that have been approved based on a fire test rather than on a standard flow-rate;

[MSC.1/Circ.1430 rev.1 §4.8.2, §5.6.1 and §5.6.2]

- An alarm is required in case of activation of any single fire detector and the system is to discharge water in case of activation of two or more detectors. For performance-based systems, release upon activation of one detector may be accepted;

[MSC.1/Circ.1430 rev.1 §4.8.3 and §5.6.3]

- Means for manual release and stop of the system are also required. Automatic release may be disconnected during on- and off-loading operations, then automatically reconnected; and

[MSC.1/Circ.1430 rev.1 §4.8.4 and §5.6.3]

- Simultaneous release of multiple sections is to be avoided (explicitly required for prescriptive-based systems, i.e. systems with standard flowrate, as opposed to performance-based systems).

[MSC.1/Circ.1430 rev.1 §4.8.4]

5.2.4.4 History

Requirements for water-based fixed fire-extinguishing systems installed in ro-ro, vehicle or special category spaces have evolved a lot over time. Table 2 gives a short summary of the applicable IMO regulations in this respect. Key evolutions with respect to activation and control of the systems are:

- MSC.1/Circ.914 allows automatic release; and
- MSC.1/Circ.1430 also allows automatic release and includes clear requirements for grouped, remote control of the system from a central control station / wheelhouse rather than direct, mechanical control from the “drencher room” as required by IMO Resolution A.123(V) for traditional drencher systems.

Table 2. Summary of regulation changes

Regulation change	Date	Title	Summary
Resolution A.123(V)	25/10/1967	Recommendation on fixed fire extinguishing systems for special category spaces	Covers the traditional “drencher” systems Superseded by MSC.1/Circ.1430
MSC/Circ.914	04/06/1999	Guidelines for the approval of alternative fixed water-based fire-fighting systems for special category spaces	Allows alternative water-mist systems and an option for automatic release. Superseded by MSC.1/Circ.1272
MSC.1/Circ.1272	04/06/2008	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)	Supersedes MSC/Circ.914 Superseded by MSC.1/Circ.1430
MSC.1/Circ.1430	31/05/2012	Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces	Supersedes MSC.1/Circ.1272 and A.123(V) Amended by MSC.1/Circ.1430/Rev.1
MSC.1/Circ.1430/Rev.1	07/12/2018	Revised guidelines for the design and approval of fixed water-based fire-fighting systems for ro-ro spaces and special category spaces	Amends MSC.1/Circ.1430

6 State-of-the-art in other safety-critical domains

Main authors of the chapter: Torgeir K. Haavik and Martin Rasmussen Skogstad, NSR

In this section we look to two other sectors – the offshore oil and gas sector and the nuclear sector – that are known for their high safety standard, including fire safety. The brief reviews of these sectors focus on the areas of challenge on ro-ro ships elaborated on above and how these are dealt with in the oil & gas and nuclear sectors respectively, to inspire the search both for causes of the challenges and possible solutions.

6.1 Offshore oil & gas installations

The offshore oil and gas domain is known for its high level of safety in general, including fire safety. As is the case with ro-ro ships, there are large differences between the individual offshore installations, so it is not possible to present a review that is generic and detailed at the same time; every description rises from experiences with particular installations and ships, from which general considerations and statements may rise – but with the important reservation that these may not be relevant/correct for all installations/ships.

The reviews are based on informal conversations with emergency/fire system professionals from the oil and gas domain in combination with review of a selection of safety strategy documents from oil and gas installations. As these documents are internal to particular oil and gas installations, they are not referenced here.

6.1.1 Method of fixed fire extinguishing system activation

The fixed activation systems are predominantly configured with automatic activation mechanisms. This goes for CO_2 as well as drencher systems (which in the oil and gas sector are called deluge systems). When one fire detector is activated, the alarm goes, and the firewater pumps are started. If two or more detectors go off, this is considered as confirmed fire and the drencher system is automatically activated in the actual sector.

It is underscored that very reliable and advanced detection systems with sophisticated hardware and software are needed for automatic activation to function well. This is reportedly the case in this sector; there are few false alarms. But it does happen, and sometimes is a recurring problem relating to gases on the deck. On one particular installation mentioned, this is considered as a design flaw.

Manual release of drencher is an option in case automatic activation is not working. This can be done either from the central control room, or from local deluge-skids in the 'field'.

6.1.2 Design issues relating to system usability

Fire alarm panels in the control room are reported to be very clear and readable, with large interfaces. The issues on ro-ro ships relating to fire location information being distributed over different digital and analogue media and the lack of correspondence between detector references, installation sections and drencher sections are known in the oil and gas sector, but are not characteristic for the installations. For the supply ships going between the installations, however, the situation is much the same as described for ro-ro ships. According to our informants, this difference between ships and oil and gas installations is due to different standards applying for ship building and oil and gas installation building; the requirements for offshore installations are much higher – corresponding to amounts of tens of millions Euros – and the resulting standard and usability is thus much higher. For example, the requirements for segregation and redundancy of safety functions, so that for example errors and fires does not take down the system, are much better. Compared to ships, the requirements are also higher for emergency preparedness and operation.

There is a movement towards more use of industry standards in the oil and gas sector, meaning less tailor-made solutions as those dominating today, but in that movement offshore personnel are concerned with preserving particular safety systems.

There are particular arrangements for logging functions and alarms that are deactivated. These logs are part of the agenda for the control room operators' handover between shifts – which is every 14. day.

6.1.3 Operational issues

On the offshore installations, there are ARL teams (alarm reaction teams) that act on single detector fire alarms through a *check and report* procedure. The check and report action can be compared with the function 'localization and confirmation' that the runners on ro-ro ships execute, although 'check and report' has a more active (verb) formulation that suggestively points more actively towards what is to be done.

False alarms occur very seldom. According to our informants, the automatic systems are so well instrumented that they seldom go off except for when they are supposed to. If a fire detector is falsely activated, the operator will either 1) reset the detector, or 2) 'bridge over' the other detectors that might lead to activation of the drencher. In the latter case, detection is still active, but the action is paused until the faulty detector – or the reason for it being activated – is fixed.

The crew is thoroughly drilled on mustering. Every 14th day – once per shift – there is a drill. Over the course of one year, each of the defined hazards and accidents events, for example gas in a process area, fire in a process area, fire in the living quarter) will be subject to a drill. The drills are described as realistic; the general alarm is activated, the check and report function is executed, the emergency teams muster according to procedures – some in the field, some in the control room, some in the emergency room. Every person has his or her responsibility and function, but the offshore installation manager (OIM) – who is also the emergency manager – has the overall responsibility, and also delegates tasks, such as search for any 'missing person' who has not met at the mustering station. Those without any assigned emergency tasks are to muster in the liferafts, where they are accounted for and from where reports are sent to the onshore emergency central. The mustering and counting take only a few minutes – usually less than the formal requirement, which is twelve minutes. Its portrayed as highly effective.

In case of missing persons, the personnel lists are checked against work orders. The work orders are accessible from the control room, and will indicate the whereabouts of any personnel according to work plans. The work orders used to be paper based, but today they are digital and allow for quick access, not only from the control room but also from iPads in the field. In the field the personnel also carry UHF radios that enables communication most of the time. Radio shadow is rare, but the increased use of iPads and other items that use Wi-Fi make the issue of Wi-Fi signal coverage relevant. There are also a number of 'emergency buttons' distributed over the installation, that personnel in need of assistance may push. A push on any of these buttons will activate a flashing light on a display in the central control room.

Following a positive 'check and report', the OIM has the final decision on the response – on offshore installations the most dramatic response is shutdown and evacuation. However, if the control room operator gets a confirmation of fire in the equipment room, for example, he or she will activate the drencher without conferring with the OIM first in case that will save time. In a more serious situation that may require shutdown and evacuation, the OIM will have to make that decision.

Since drenchers are in general and most often activated automatically on offshore installations, the issue of hesitation and fear of blame does not appear as frequently in the offshore sector as it does in connection with ro-ro ships. However, there are other fire-related systems offshore apart from the drencher systems, for example *deck integrated firefighting systems*, that are activated manually, and in those situations hesitation reportedly may occur. We do not have thorough information on the acuteness of this issue, however, and the fear of blame, but our investigations so far only indicate that such hesitation will anyway only last for a minute or two, before the alarm has been checked, and also that no-one will be blamed for acting *too safely*. It is important to note, however, that this viewpoint is also represented in the domain of ro-ro ships, but only as one perspective among others; there are divided opinions on this from ship to ship, and, not the least, between the positions in different levels in the hierarchy.

6.2 Nuclear industry

Main authors of the chapter: Martin Rasmussen Skogstad, NSR

This review is based on informal conversations with an industry risk and safety expert and relevant documentation and procedures from the Nuclear Regulatory Commission (NRC) for commercial nuclear power plants (NPPs) in the US (U.S. NRC., 2007, 2012, 2015, 2018).

This report addresses efficient extinguishing system activation, the activation time and activation procedures – and their context – after localization and confirmation, including issues causing delayed activation. However, as the time shortly before and after is also of relevance here it will also be discussed.

There are differences in how fires are handled in different NPPs, including which criteria set off automatic suppression systems. Every NPP in the US has their own Fire Protection Program which must be reviewed and approved by the U.S. NRC for a plant to operate (U.S. NRC., 2015). NRC guidelines state that automatic suppression systems should be installed as determined by the fire hazards analysis and as necessary to protect redundant systems or components necessary for safe shutdown and structures, systems and components important to safety (U.S. NRC., 2018).

6.2.1 Fire suppression activation

Depending on the part of the plant, there will be features that can be activated from the control room (isolation, safety injection, sprinkler systems, halon gas systems). There are field operators who can jump in quickly and control other suppression systems if central activation from the control room isn't possible. However, activation of extinguishing systems is generally done automatically either through the fire monitoring system (fire alarm), through the automatic reactor trip system (a reactor trip, or scram, is defined as the sudden shutting down of a nuclear reactor, usually by rapid insertion of control rods) or through the plant reactor protection system in response to off-normal conditions (such as a fire affecting certain plant equipment and/or circuits). While automatic activation would often occur in a fire scenario, having the option to manually activate it from the control room and outside of the control room is seen as important, even if it is only used when the automatic activation fails. Once activated (whether automatically or manually), the system should perform its design function with little or no manual intervention. A big difference between a ro-ro vessel and a NPP is that NPPs have many areas that people should not be in while the NPP is running in normal conditions. This allows for an increased use of automatic suppression systems that would be harmful to humans (e.g. gas systems).

6.2.2 Operational issues and human resources

The second part of fire extinguishing is manual firefighting. Plants includes lots of defence in depth for fire, but if those fail to fully deal with the situation, the fire brigade can be brought in. To reduce both the likelihood and severity of consequences from a fire in a NPP, all plants are required to have their own dedicated fire brigade (at least in the US). For accidents, then local and regional emergency response can also be brought in.

In a fire situation one crew member can be delegated to the fire brigade. Most plants can be operated from the control room with two or three operators as the minimum, but a crew may consist of four or five licensed operators. Therefore, assigning one to the fire brigade does not diminish the control room capability below what is required.

All the systems are described as being very reliable, activation generally being automatic, the fire brigade being specially trained for fires at a NPP, and there are many layers of barriers between a fire starting and an accident occurring. However, there are some events that show how multiple things can fail at once.

In the 2010 H.B. Robinson Fire Event, an electrical fault caused a fire. The fire occurred in an area without automatic fire suppression, and the crew chose to put it out manually with fire extinguishers. Unknown to the crew, the system that was supposed to isolate the initial fire failed, leading to other fires. The event was further complicated by equipment malfunctioning and the crew failing both to diagnose the plant conditions and properly control the plant.

At some point after the location of the fire had been identified the fire alarms in the area had been shut off. After the first fire was put out the fire alarms where not reset, leading to a delayed identification of the subsequent fires that had started due to failing isolation. The event did not lead to any catastrophic consequence, but is seen an example of how the several layers of safety barriers can fail.

The main potential issues in a fire are pointed towards as:

- A fire damaging wiring and sensors, which would reduce situational awareness in the control room.
- Fires are uncommon, which means that the procedures are rarely used (even if they are trained on).
- Controlling the plant, and possibly shutting down, is something that still has to be done in a fire.

6.2.3 Training

NRC guidelines include that there should be at least one fire drill including the fire brigade per quarter, with every member participating at least twice per year, and the local fire department included at least once per year. The drills are unannounced with the fire brigade not knowing about the drill until it has started. In these drills it is assumed that automatic suppression systems are not functioning (U.S. NRC., 2018).

6.2.4 Requirements

The amount of time would be very dependent on both the size and position of the fire. When risk analysis of NPPs is performed it is assumed that the crew is aware of the location of the fire within the first 10 minutes of a significant indication of non-normal condition through fire alarms or an automatic trip (U.S. NRC., 2012).

7 Status and challenges as described by ship operators

Main authors of the chapter: Sif Lundsvig and Lena Brandt, DFDS

This chapter is written from an operator perspective of Ro-ro and Ro-pax vessels and describes the current practice on board and what issues this practice brings. The chapter also highlights future ideas and areas for improvements. The chapter is based on interviews and ship visits performed by Lena Brandt as well as maritime incident reports.

7.1 Current practice

Three main types of fixed fire extinguishing systems exist on board vessels. These three are typically drenchers, foam and inert gas systems. On DFDS vessels are used drencher systems and inert gas systems. Activating a fixed fire extinguishing system is the captain's decision. In this chapter the term 'system' will be used in short for "fire extinguishing system". This term refers to the fixed fire extinguishers located on board a vessel.

7.1.1 Inert gas systems

Typically, this system is used in the engine room and engine control room as these rooms are packed with electrical devices and other equipment that will be destroyed by use of water. For the inert gas systems to work efficiently the room needs to be locked airtight. For safety reasons a room must be vacated before inert gasses are released, as the oxygen is repressed from the room. These two important factors often slow down the speed and/or efficiency with which the system can be activated. However, since LASH FIRE mainly focuses on the cargo holds, the description of how inert gasses are used on board will be kept brief.

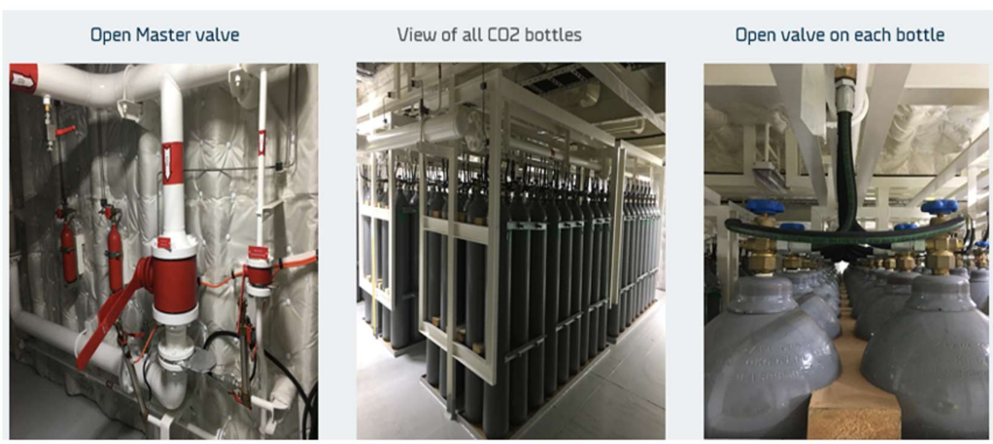


Figure 1. Inert gas system.

7.1.2 Foam system

Fixed foam systems are not installed in the DFDS fleet. Foam is only used on board as manually handled extinguishers in case of oil fires.

7.1.3 Drencher system

This system uses water to extinguish a fire or limits the spreading of a fire by cooling down surroundings. Less precautions needs to be taken to activate this system than the inert gasses. This does however not imply that activation is not a serious matter, as the ship's stability can be affected if things go wrong, and cargo can be damaged or destroyed.

Figure 2. Active drencher system on a car deck.

The drencher systems are typically activated at one of the fire detection-panels, these panels can be found in many different designs by different producers. In the DFDS fleet several different systems can be found on board the vessels, to mention some: Tyco Minerva, Consilium, Autronica Automaster and Salwico.

When activating the drencher system, the following should be considered:

- Which sections should be activated?
- Do the cargo types in the section allow for water extinguishing? Or is there some type of IMDG good that hinders this action? Reefers?
- Starting the bilge pumps to make sure to avoid water on deck creating free liquid surfaces and thereby bad stability of the vessel.

7.1.3.1 System activation

Can it be confirmed that the system is activated and working as intended? The section that needs to be activated is determined by feedback from the fire detectors and the person sent to verify the outbreak of fire. Sometimes CCTV can be used as well. On some vessels the section of the detectors registering smoke/flames can be seen directly on the fire panel at the SCS. On other vessels the number of the fire detector can be looked up and the section then found on a drawing showing the sections and numbers of fire detectors, see Figure 3 below. The crew prefers to be able to identify the section that needs activation directly at the fire panel as it saves valuable time.

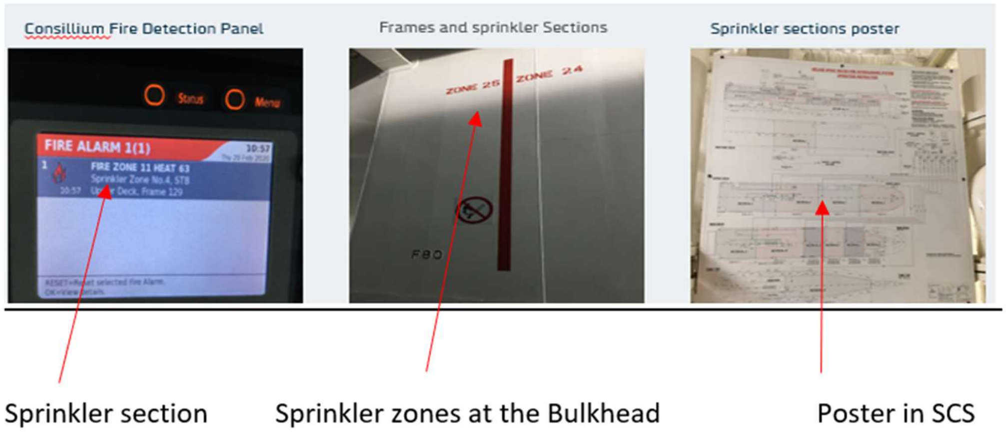


Figure 3. Drencher system- Control panel and markings.

7.1.3.2 IMDG

Location of IMDG goods can be found by looking at the cargo stowage plan. This is accessible at the bridge.

7.1.3.3 Bilge pumps

Pumps needs to be started as soon as the drencher system starts pouring water over the deck, this responsibility falls to the engine department, often the chief engineer or the 1st engineer. This is often done from the engine control room or manually. Knowledge of the specific pumps are often needed to perform this task well, as the pumps often are of the type that cannot run dry without breaking down[3]. This means that the rolling movement of the ship poses a challenge to the pumps. Some vessels try to mitigate this, by leading the water from deck into tanks before pumping it overboard. At some vessels, the volume of water that the pump can remove is not well proportioned to the system though. Minimum demands are of course fulfilled, but in some cases the pumps are so powerful that they empty the water reservoirs too quickly risking running dry and then breaking down. Clogging of scuppers or pumps are also a known problem as every smaller loose object on deck will wash to the scuppers when the fire extinguishing system starts.

[3] Pumps of this type are typically centrifugal pumps.

7.1.4 Main contributors to a quick activation of the fire extinguishing systems

- Quick confirmation and overview:
  - Fast manual identification of the fire or with the use of CCTV
  - More than one detector is activated gives an identification of a larger area effected as two detectors are not likely to fault at the same time.
  - Good knowledge of the vessel and how to get around from deck to deck/engine room
  - Quick assessment of IMDG goods at the relevant section
- Clear roles:
  - No doubt of line of command, or how to execute the tasks that needs to be carried out
  - No doubt of alarm signals or mustering station
  - Culture, some officers will wait for the captain's approval and not start action immediately. A remedy for this is to make sure captains standing orders should address especially for night duties regarding first action to extinguish. E.g. if fire is seen please start extinguishing immediately with local equipment or sound out the alarm.
- Fast activation:
  - Trained crew who knows how to activate the drencher system
  - Drencher/CO_2 can be started remotely from the bridge
- Timing:
  - During night, the engine room is unmanned, and all crew except night watch are sleeping, therefore it will take longer for the crew to muster

7.1.5 Disadvantages

Drawbacks of the three types of fixed fire-fighting systems are as follows:

- Cargo and equipment are damaged or destroyed (foam and water)
- Dangerous to human life (Inert gasses)
- Operation demands continuous training of the crew
- Stability of vessel can be influenced if water (or foam) is not pumped overboard
- Storage of extinguishing agents (foam and inert gasses)
- System can run short of extinguishing medium (foam and inert gasses)
- Nozzles get clogged with rust flakes if not rinsed frequently (water)
- Wet pipe systems can get frost damages (water)
- Heavy cleaning after use (foam)
- Works only if rooms are sealed air-tight (inert gasses)
- Can be blocked by watertight trailer covers and the like (water and foam)
- Environment and health issues (foam)
- Installation and maintenance costs (all)
- Manual release is often time consuming and demands specialist knowledge (all)

There are always unexpected problems developing when first a critical situation is escalating. The above is therefore the general disadvantages. However, two examples of unexpected problems are given by the fires of *Brittania Seaways* (2013) and *Lisco Gloria* (2010).

On *Brittania Seaways* the Lyngsø fire panel broke down during the fire in 2013, and the crew needed to locate and operate valves etc. to get the fire extinguishing system running. It is important that the crew has knowledge of how to operate the system - but also that there is back-up not relying on electronics. Even though a system operated from the SCS saves a lot of time, it is an advantage to be able to operate the system manually without a huge delay (see Danish Maritime Investigation Board, 2014).

On *Lisco Gloria* as the cargo started burning the cargo debris were flushed down the scuppers clogging the system draining system. This most likely caused the list of the vessel since the water used for fire extinguishing could not be pumped overboard quickly enough (Bundestelle für Seeunfalluntersuchung and Lithuainian Maritime Safety Administration, 2012).

7.2 Design and production aspects

A safe design of a fire extinguishing system should in the best imagined case:

- Be simple to operate
- Start extinguishing immediately after activation
- Be extremely efficient in extinguishing a fire - no matter the size
- Not be possible to release by mistake
- Be able to handle different types of fires (electrical, oil, IMDG goods etc.)
- Be class approved and live up to IMO standards
- Take up little space on the vessel
- Preferable not have the option of running out of extinguishing medium
- Safe for humans and marine environment
- Preserve vessel, cargo, and equipment as much as possible
- Able to reach the fire without delay when activated
- Possible to activate remotely
- Possible to activate if electricity fails
- Not endanger vessel stability
- Easy to maintain or even better - maintenance free
- Easy to include full scale in fire-drills
- Be reliable and not cause faults and/or delays in activation
- Be easy to clean up after when the fire is extinguished
- Not limit crew access to the section where the system is activated
- Provide easy overview of where the system is activated
- Be easy to shut down again
- Work on weather decks as well as below decks
- Be able to handle ship movements and rough environments

Neither the inert gas system, the foam or the water drenchers does fulfil these requirements - this list represents requirements to the ideal system.

7.2.1 Environmental aspects

The medium used to extinguish fire should not be harmful to human or marine life. The latter is especially important if the medium is pumped overboard.

7.2.2 Proposal for development and restrictions

Preferably a new fire extinguishing system - fixed or not - can be used on the complete vessel. The more different systems that needs to be integrated and maintained the bigger the chance of failure, be it due to human errors, mechanical or other. Also, the more systems there are on a vessel, the more systems the crew needs to familiarize them self with - and already there are many systems with different interfaces. A new system would therefore preferably integrate with the existing ones, or an integrated solution would otherwise be included, at least over time.

It is important that the crew has the control over the activation, so that no unintended activation is done. This is a safety issue both for vessel, cargo and humans on board.

The complete fire extinguishing system must be designed so that it includes both the “active part” being the means of fire extinguishing and the “post treatment” such as pumping water overboard. The system should be designed so that it is intuitive enough that a lot of training and special know-how of the system and vessel is not needed to handle it. Often bilge pumps arrangements needs a lot of familiarisation before they can be handled correctly without a pump running dry or pumping from a wrong localization. Capacity and technical demands to the systems are covered by SOLAS, but nowhere are softer values of ease of operation and intuitive systems a demand.

8 Status and challenges identified through empirical research

Main author of the chapter: Brit-Eli Danielsen and Torgeir K. Haavik, NSR

This chapter describes the extinguishing system activation challenges identified through empirical research performed in WP7.

8.1 Identified extinguishing system activation challenges

Studies of procedures for drencher and CO_2 system activation have documented a number of practice related issues where efficiency can be improved, uncertainties be lowered, and time spent can be reduced. In Table 3 below, a summary of those issues is provided:

Table 3. Practice related issues with efficiency improvement potential.

No	Short description	Extinguishing system	Explanation
1	Confirmation of fire	Drencher CO_2	It is critical to have confirmation before deciding to activate the extinguish system. E.g., there is limited amount of CO_2 available, it cannot be used unnecessary. Cameras are often not covering the entire area and are often not useful when area is filled with smoke. The practice of sending runners is covered in WP6 but still mentioned here as it is an important first step in the firefighting practice that adds time.
2	Location from where drenchers are activated differs between ships	Drencher	On some ships, the drencher pump must be activated from drencher room or engine control room (ECR), while on other ships the drencher pump can also be activated from the bridge. Preferences are also different; while some say that drencher activation from the bridge is preferred, other say that it is better to have drenchers activated from ECR. This issue could also be seen in relation to the manning of the ECR at night.
3	Localization from which CO_2 is activated	CO_2	CO_2 can in general be activated from two locations, the fire control station or the CO_2-room. The fire leader decides which location will be used. The Chief will often be the person to do the actual activation, but the Captain and the Chief officer will also be trained to do it. The main difference in activation between the two locations is that in the fire control station everything is remotely monitored and controlled while in the CO_2room the process can be seen and heard directly. In the CO_2-room valves can also be opened manually if necessary. The preferred location for activation varies between ships.
4	Responsibility for drencher activation differs between ships	Drencher	Mustering routines differ between ships, as does the division of labour. It is particularly the role of the chief engineer (CE) that differs; on some ships CE musters to the bridge and has the role of fire leader, on other ships CE will muster to the engine control room and have a more decentralised role. None of these variables seem to be decisive for drencher activation responsibility, though. In cases where drencher activation *decision* and *execution* take place in different locations (e.g. the bridge and the ECR, respectively), extra communication is

			needed, with the potential downside of extra time spent, and potential upside of improved shared situational awareness.
5	Drencher zone communication	Drencher	In cases where the correct drencher zone is subject to oral communication between a decision maker and an executor (who cannot confirm this in local information systems), sometimes under noisy and stressing circumstances, this is an occasion where inaccurate actions may occur or propagate.
6	Head count	CO_2	Account for all crew – must know where everybody are located (usually 17-19 persons), including the runners. A factor that adds time and stress to the activation process.
7	Dangerous goods	Drencher	While dangerous goods that might react with water should in general be stored in secure locations, practice studies show that it is not unusual that dangerous goods are stored in locations with drencher systems installed. If a fire starts in a vehicle with such dangerous goods, readily available information on dangerous goods and clear procedures for how to handle the drenchers and the IMDG cargo will be important. That is not the case on all ships today.
8	Alternative fuel vehicle (AFV)	Drencher CO_2	Electric cars are a concern for crews, and there is uncertainty about how to act in the case of a fire in an electric car. There are no procedures especially for these cases. Crews find that the design of the car decks is not fitted for the new situation with increasing amount of alternatively powered vehicles.
9	Drencher de-activation	Drencher	De-activation of drenchers represents an important phase of the firefighting. De-activation can be done at the tail of the extinguishing process in order to visually check that the fire is out. It is important to make the time period between de-activation and potential re-activation as short as possible, and to that ends continuous communication between the fire management/drencher operator and the runner is of high importance. That is not always the case today.
10	Confirmation that fire is extinguished before ventilating	CO_2	After release of CO_2, it is important to wait long enough (usually several hours) to make sure the fire is extinguished before ventilating the CO_2due to the finite amount of CO_2available. The CCTVs are most likely not appropriate for this as there can be a lot of smoke hampering visibility. It is possible to monitor the temperature readings from fire detectors nearby the affected area. Other possibilities are using IR camera or to send in smoke divers to check.
11	Operating instructions	Drencher CO_2	In safety-critical situations, it is always a great advantage if the operation of equipment is intuitive and simple, and that operating instructions are short and unambiguous. This is not always the case, for example in connection with activation of drenchers, activation of CO_2 system and the management of bilge pumps.

12	Manual/electric/ automatic solutions	Drencher CO_2	On many ships there is a combination of automatic, electrical and mechanical solutions for operating fire-related equipment. For example, on many ships the closing of fire dampers is done through a combination of electrical/remote and manual/mechanical procedures. To close all dampers manually can take as much as 20-30 minutes for two persons. Considerations regarding configuration of manual vs electrical/remote solutions are also relevant for drencher pumps and section valves.
13	Radio communication	Drencher CO_2	Since much of the communication during a fire operation goes over radio, efficient communication is important to avoid misunderstandings and to speed up actions. There exist standards/protocols for two-way radio communication, that ensure efficient communication, and from our studies of fire drills we see that these protocols are not always adopted.
14	Communication content and feedback loops related to extinguishing activation	Drencher CO_2	Effective drencher activation requires collaboration and coordination between people in different locations. To achieve this, mutual references must be continuously maintained. For example, what is the drencher pump mode, which drencher pump source is connected, which section valve has been opened, what is the temperature? Different communication practices for this reference maintenance exist on different ships.
15	Fire in harbour	Drencher CO_2	In harbour, crew may not be available on the bridge or other locations where they normally are at sea. When the ship is docked there are additional people on board, doors are open, access ramps are out. The sections normally closed at sea are open. Land-based fire departments will be involved, and they are not familiar with the ship. This adds additional and other challenges than fire at sea.

8.2 Discussion of drencher system activation challenges

8.2.1 Location from where drenchers are activated

On different ships, there are different setups regarding possible locations for drencher activation. No standards apply, so different ships offer different possibilities both with respect to drencher pumps activation and section valves management.

A key question relating to the efficiency of drencher activation is whether the activation process is most effectively managed from the bridge, or locally from the drencher room or the engine control room. Both these setups and practices are found in our studies, as are different meanings among crews on what is more effective. The question is not one that can be answered generically. Although there is a general drive in the maritime field of research and development both towards more centralisation of functions and more automatic solutions, studies of practice also show that locally developed work practices where practical functions (such as the physical activation of drencher system) are decentralised in order to offload the fire management on the bridge, may serve a well-functioning division of labour, and overall coordination of the firefighting resource management.

Management of drencher system from the bridge (both pumps and section valves) reduces the need for radio communication, which may reduce the risk of misunderstanding and errors. On the other hand, radio communication where situation assessment and decisions are communicated evidently contribute to building and maintaining a shared situation awareness, and also provide opportunities for challenging others' interpretations and decisions. Additionally, a central finding from the FIRESAFE II studies is the need to reduce the cognitive and practical workload of the fire management, something that can be done by distributing certain tasks to others and leaving the fire management with more coordination tasks. Yet another aspect that might count in favour for a decentralised management of the drencher activation function is that one thus is closer to the physical systems and hence have a better chance of confirming and following up actions by visual/auditive inspection.

Current practices on ships may result from a combination of *constraints* by the current technical setup (for example, if there is no *possibility* for remote activation from the bridge one may not consider advantages of centralising this task), *opportunities* of the technical setup (if remote activation from bridge is possible, it may feel odd not to make use of this in the fire management and reflection on practice may thus be limited), and accumulated experience and practice among competent crews which have produced and refined existing practices to function optimally in the particular context of the ship.

To optimise the organisation of the activation process and support this with a technical set-up that facilitate such organisation, reflections on pros et cons of current organisation of the activation task, and pros et cons by alternative arrangements should be undertaken. These reflections should not be restricted by current technological constraints and opportunities.

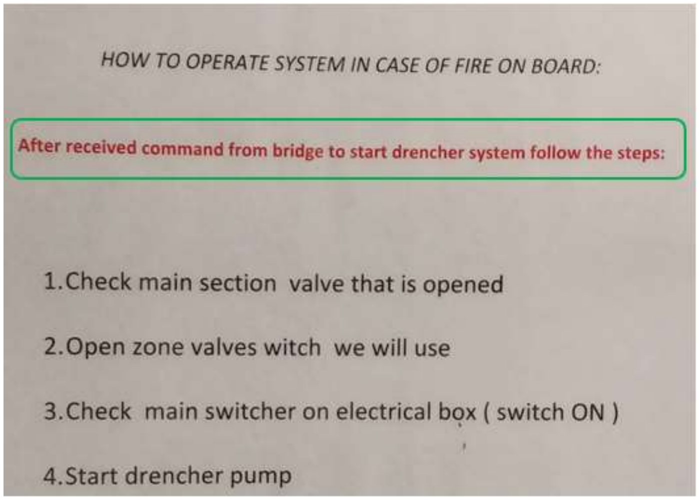
8.2.2 Responsibility for drencher activation (decision and execution)

On most ships in our study, the crews report that anyone is allowed and urged to make the decision and to start the drenchers if they notice a fire, be they officers or ABs. However, neither formal procedures nor drills that we have observed reflect this.

First, in the drills we have observed, the practice seems to be that decision about drencher activation is taken by the formal fire leader on the bridge. It will often be the chief engineer that has the role of fire leader, and the coordination of fire management and the decision to activate drenchers tend to be the chief engineer's responsibility. On ships where the chief engineer musters to the engine control room, decisions of drencher activation are still made on the bridge, and orders are given from there to the chief engineer in the control room, if drenchers cannot be activated directly from the bridge.

Second, formal procedures for drencher activation may actually counter the statements that anyone are allowed and urged to make the decision and to start the drenchers. The facsimile below (Figure 4) clearly states that the decision and the command to start the drencher system must come from the bridge.

While the two conflicting 'stories' of who may make the decision and activate the drencher system may live well side by side under normal conditions, in an emergency situation there may be ambiguity associated with which rule to follow. Operating instructions for ro-pax drencher activation similar to the one in Figure 4 may cause confusion if the initiative to activate the drenchers is coming from other crew members than the fire commander on the bridge.



HOW TO OPERATE SYSTEM IN CASE OF FIRE ON BOARD:

After received command from bridge to start drencher system follow the steps:

1.Check main section valve that is opened

2.Open zone valves witch we will use

3.Check main switcher on electrical box (switch ON)

4.Start drencher pump

Figure 4. Facsimile of operating instructions for drencher system. Green square added by authors.

8.2.3 Drencher zone communication

Whether drencher section valves are operated locally from the drencher room, or remotely from the engine control station or the bridge, communication will take place between a person who operates the section valves, a decision maker located on the bridge, and a runner communicating the drencher section in connection with manual confirmation. Regardless of the circumstances, the communication of which drencher section to open (or close) is critical and represents an instance in fire-related communication where misunderstandings may have serious consequences. Examples exist from near maritime history, where knowledge about the right drencher section existed at one location, and a different drencher section was opened from another location, after communication between the two. Regardless of the cause of the misunderstanding in that specific case, there are several potential communication risks: conditions may be noisy; different words like sections and zones may be used ('drencher section' and 'drencher zone'); both sections and zones are terms that are used together with referents other than drenchers (for example, section may also refer to 'main section valve', and zone may also refer to 'fire zone').

To reduce the risk of misunderstandings and erroneous actions due to unclear communication on activation of the right drencher section, vocabulary and expressions relating to drencher zones should be explicitly considered, perhaps standardised, and it should be harmonized with the operating instructions for the drencher system. Existing vocabulary for other systems than the drencher system should be taken into consideration when considering a practical and unambiguous language for drencher zone communication.

8.2.4 Dangerous goods

Dangerous goods that may react with water should not be subjected to drenchers systems, and although special locations usually exist for such goods it still occurs that dangerous goods are placed in ro-ro spaces where drenchers are installed. Our research shows that the crew does not always have a clear idea on how to immediately handle a fire situation involving dangerous goods in drencher areas. If no formal procedures exist and such situations are not subjected to practice, one can assume that valuable time may pass before an approach is decided. A central consideration that the crew will face and spend time to conclude on is whether or not there is any dangerous goods that should not be exposed to water in the actual drencher zone.

While these questions *may* be addressed on the fly, and while clear procedures for how to approach them may support the decision-making process, these questions would have the same answer before and after a fire has been detected and could therefore more effectively and safely be asked in advance. We have found that there are no standards for this; while some ships rely on the crew keeping any dangerous goods in drencher areas in mind without any formal system for managing this, other ships have systems invented and developed locally where dangerous goods are visualised by magnetic stickers on a panel (general arrangement) next to the fire panel Figure 5. This latter solution will inform the person responsible for activating the drenchers if activation in the actual drencher zone is ok.

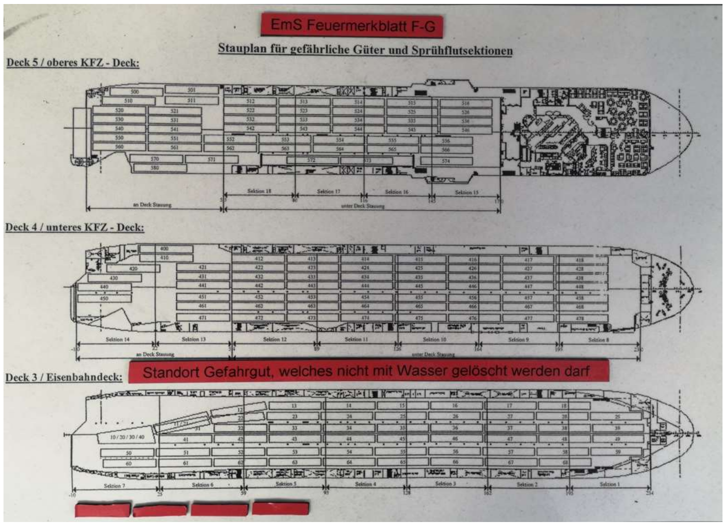


Figure 5. Red, magnetic stickers used for 'no water' units.

The different solutions for taking dangerous goods into account when activating drencher systems reflect among other aspects different deck arrangements and different loading practices on different ships, and it may therefore be challenging to advice standard solutions for managing dangerous goods in drencher activation processes. We therefore outline an internal (facilitated) process run on every vessel with the aim of producing a vessel-specific procedure for saving time in the managing of issues related to dangerous goods in connection with drencher system activation, with a particular focus on conducting as many as possible of the time-spending actions *in advance*. The procedure items should include: an investigation of the existence of formal procedures or informal practices of *not* allowing DG on decks with drenchers, including means for formalising informal practices; an investigation of the existence of formal or informal practices of allowing DG on decks with drenchers[4]; an agreed, transparent and invariable practice for the allowance of DG on decks with drenchers; a simple and user-friendly system for keeping track of location and type of dangerous goods specifically for decks with drenchers; an agreed, transparent and sufficiently flexible practice for handling of DG when the preferred extinguishing method is the drencher system.

8.2.5 Drencher de-activation

An activated drencher system will at some point in time have to be de-activated. While attention in earlier research (e.g., Firesafe II) has been directed towards activation, the phase of de-activation has received less focus. For example, while activation is explicated in the fire plan, and assigned a specific role, de-activation is generally not.

[4] Only if there do exist such formal and/or informal practices needs the rest of the process be run.

In our research, we have seen that decisions regarding de-activation are sometimes based more on gut feeling than on sensor-based, confirmed temperature observations that are systematically observed and evaluated. For example, reference temperature curves for fires under cooling could provide useful comparisons for evaluation of temperature reductions; which temperature drop could be considered significant, and what happens to the temperature curve at the time when the fire is completely extinguished? Answers to such questions are today based on manual control, feeling for warmth rather than measured 'evidence'. The focus on temperature developments and the means to do so can be improved. Reference curves as a means should be accompanied with defined work processes to document actual temperature development, for example by plotting the temperature for all relevant sensors at a certain time interval. This could give a more accurate indications on the fire development and could support the decisions on when it is timely and safe to stop the drenchers.

Also, the decision to stop drenchers is a critical and one that should be accompanied by an intensified focus on the temperatures and the reference curves. Since fire *may* take up again after the drenchers have been stopped, procedures for reading and communicating temperatures should be intensified in the first time period.

8.3 Discussion of CO_2 system activation challenges

Carbon dioxide (CO_2) is an effective fire extinguish medium as it has a high rate of expansion, enabling large areas to be flooded quickly. CO_2 must be released in a confined space, and a concentration of 20% or more is sufficient to smother a fire. However, it provides almost no cooling effect and there is a risk of re-ignition if the space is subsequently vented before it has had sufficient time to cool. The main drawback of using CO_2 as a fire-extinguishing medium is that the amount required to suppress a fire is higher than the amount required to cause harm to human beings (Marine Accident Investigation Branch, 2018). At concentrations of 17% and above, survival time is less than a minute. This has consequences for the processes regarding handling of CO_2. Measures must be taken to ensure the safety of people and it may be a cause for hesitation of activation. Safer alternatives to CO_2 do exist and land-based systems move away from using CO_2. However, the marine industry's seem to be reluctant to adopt a similar approach (Marine Accident Investigation Branch, 2018).

From the alarm is received at the bridge until CO_2 release is activated it may take up to 35 minutes (National Transportation Safety Board, 2017a, 2017b).

The areas on board where CO_2 is used as fire extinguish system differ between ro-ro/ro-pax and vehicle carriers. For ro-ro and ro-pax ships the drencher system is the fixed firefighting system for the cargo holds and CO_2 will mainly be available in the engine room. Using CO_2 requires an enclosed space. Other common areas for use of CO_2 can be pump rooms, paint stores and galley exhaust ventilation ducts. For vehicle carriers CO_2 is the main firefighting system for the cargo holds.

8.3.1 Location from which CO_2 is activated

CO_2 can generally be activated from two locations – the fire control station or the CO_2-room. The fire leader decides which location will be used. The Chief will often be the person to do the actual activation, but the captain will also be trained to do it. The main difference in activation between the two locations is that in the fire control station everything is remotely monitored and controlled while in the CO_2 room the process can be seen and heard directly. In the CO_2 room valves can also be opened manually if necessary. There are differences between crew as to where they prefer to activate CO_2. Some of our informants preferred the CO_2 room as the process can be physically seen and heard there and they have access to the valves in case they must be opened manually.

The fire control station and the CO_2-room may both be located on upper deck, but on older ships the CO_2 room might be located down by the engine room which could add an estimated 6-8 minutes of transport time. The choice of room will be affected by this.

Other informants prefer the safety control centre as it is perceived as safer in case of leaking bottles. This is a justified concern as the unintended release of carbon dioxide from fire-extinguishing systems has resulted in a number of deaths and injuries in the marine industry (Marine Accident Investigation Branch, 2018). As an example, in September 2004 an unintended release of CO_2 in the CO_2 room on board the Hong Kong registered container ship "YM PEOPLE" killed the Master, the Chief Engineer, the Chief Officer and the Third Engineer (Marine Department The Government of Hong Kong Special Administrative Region, 2004). Unintended release has been connected to procedures during maintenance and testing of equipment.

8.3.2 Head count

To account for all personnel is extremely important before activating CO_2. In the case of Pyxis, a vehicle carrier that experienced fire on its car decks in 2008, the chief engineer died as a result of misunderstandings during head count. From the information the master received he assumed the chief engineer was in the engine control room when he activated the CO_2 release. The chief engineer had entered the car deck without carrying a receiver and was exposed to the released CO_2 (Japan Transport Safety Board, 2011).

Ensuring that all persons on board are accounted for is a factor adding time and stress to the activation process. In addition, two persons are sent in in the direction of the fire and they must be back before action is taken to activate.

Our informants described head count being performed twice before the release of CO_2, the last time as part of the actual activation steps.

The procedure and practice for localizing crew on board can differ between different companies and ships. It is suggested that the procedure for head count is evaluated by crew in each ship, in order to find the most effective and efficient procedure that first and foremost ensure that all crew are accounted for, and if possible, reduce time spent on this task.

8.3.3 Unclear procedures for fire in AFV

Electric cars are one major concern for crew, they refer to it as a horror scenario. Part of this may be due to the uncertainty about how to act in the case of a fire in an electric car. There are no procedures especially for these cases. Crew also express that the design of the car decks is not fitted for the new situation with increasing amount of alternatively powered vehicles.

8.3.4 Confirmation that fire is extinguished before ventilating

After release of CO_2, it is important to wait sufficiently long before ventilating the area due to the risk of re-ignition if the space is vented before it has had sufficient time to cool. There may not be enough CO_2 to extinguish the fire a second time. The CCTVs are most likely not appropriate for this as there can be a lot of smoke hampering visibility. It is possible to monitor the temperature readings from fire detectors nearby the affected area. Other possibilities are using IR camera or to send in smoke divers to check the status of the fire. It may be difficult to assess when ventilation can be performed. In 2012, after extinguishing a fire on board the *M/V Alliance Norfolk*, 2 days later while in port, the fire re-ignited when the damaged cargo deck was ventilated (National Transportation Safety Board, 2013).

The procedure for deciding when an area can be ventilated after CO_2 exposure should be supporting crew in a clear manner. It is suggested that the procedure for this is evaluated by crew in each ship, in cooperation with technical support to make sure the most effective and efficient procedure and supporting equipment is available. Things to consider would be what kind of temperature readings should be made and in what temperature range is it safe to ventilate.

8.4 System activation challenges for both drencher and CO_2

8.4.1 Confirmation of fire

In order to have confirmation of localisation and amount of fire/smoke runners are sent to the location from where alarm has been triggered. There is a limited amount of CO_2 onboard, there is not enough to release in all zones. Hence it is crucial to have confirmation of fire before activating CO_2. Our informants report they will always send out runners for certain confirmation of fire as the available CCTV system is not suitable for that. Cameras are not covering the entire area and nevertheless not useful when area is filled with smoke.

When the fire alarm is released on the bridge the search group, consisting of one or two runners will immediately be sent out to confirm whether there is smoke or fire. They are only to confirm, they don't wear any gear and are not supposed to do any firefighting. The two persons designated as runners must have some experience and know the ship well. The informants estimate that the search group will confirm whether it is a real fire within a few (2-4) minutes. The runners must also be accounted for before activating CO_2. The procedures and practices regarding runners are covered in WP6 but are still mentioned here as it is a crucial part of the process and a part that adds minutes before activation.

Our informants would like to have more support from CCTV in the form of quick video overview of the affected area. As described in other LASH FIRE WP7 reports there are not cameras covering the entire cargo hold, there is often cargo blocking the cameras, smoke will disturb visibility and it takes time to manually find the right camera to show on the displays on the bridge. Connecting camera to detection system so an automatic view from appropriate cameras shows up or having cameras in the detectors are measures suggested from crew. In addition, the ability to rewind video from the CCTV system has been mentioned.

8.4.2 Manual closing of dampers

For CO_2 firefighting to be effective the affected area must be sealed so dampers must be closed. For certain areas in the cargo hold the electricity to the fans will be cut when the alarm sounds, hence the dampers will close automatically. This is confirmed by checking displays remotely. Dampers connected to fans can be monitored and controlled from the bridge, the engine control room and the Chief's office.

There are also many manually controlled dampers with no electronic surveillance. The manual dampers are often in smaller areas like the engine room and outside the cargo holds. Sending a person to manually close or to confirm dampers are closed adds minutes to the time it takes before CO_2 can be released.

The mix of manual and automatic fans and dampers makes the overall system complicated. There may be checklists available to keep an overview of location, number and color-codes of dampers and fans.

The system of dampers and fans and how to manage them in an efficient way should ideally be part of the overall ship design process. In order to handle the system as it is, an evaluation of procedures and practices in each ship is recommended. The evaluation can include developing checklist or reviewing existing checklist, making sure there is a complete overview of all dampers, whether they are manual or not, and if maps/displays reflect the actual situation in the ship. Dampers should be part of familiarization/training.

8.4.3 Outline of operating instructions

Usually operating instructions for extinguishing systems are pinned to the wall in the immediate vicinity to the system to operate. Clarity of operating instructions is particularly crucial in emergencies, and not-so-well and ill-formulated instructions that one find understandable under normal circumstances may cause uncertainty and hesitation in the heat of the moment.

We have seen several examples on ambiguous operating instructions both in the history of marine accidents and in our LASH FIRE research. Examples include multiple and incompatible instructions for CO_2 system activation, imprecisely formulated instructions for drencher activation and overly complex instructions (and actual system configuration) for bilge pump management.

> One example is the fire on board *Mignon* in 2018, where the Chief tried to follow the instructions from the manufacturer which turned out to be so unclear that the Chief's confusion added an extra five minutes before CO_2 was released (Swedish Accident Investigation Authority, 2019).

Another example is a particular operating instruction for drencher activation in a ro-pax from our data collection. The first step of action is to verify that the main valve is open. This valve shall always be open, but it should still be checked before drencher activation. The way this is explained in the otherwise brief and relatively concise instruction (apart from spelling error and mediocre language) is as follows: "Check main section valve that is opened". Among the things that could be commented here are that

- It is unclear what exactly to check
- The valve in the drencher room is labelled "main valve", not "main section valve"
- The word "section" may be confused with having something to do with drencher sections, which it has not

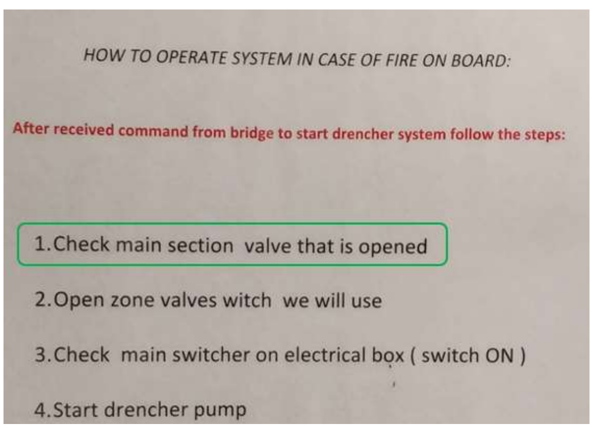


Figure 6. Operating instructions for drencher system. Green square added by authors.

> Although the steps for the actual activation of CO_2 are rather simple, the crew expressed they need the support from the instruction in a stressful situation as a confirmation that they remember correctly and are performing the steps correctly.

We suggest that all written operating instructions associated with drencher and CO_2 activation are scrutinized and corrected, preferably in a collaboration between those who operate them and an external expert on language and communication.

8.4.4 Fire in harbour

In order to use CO_2 in ro-ro spaces they must be closed off. When the ship is docked there are additional people on board, doors are open, access ramps are out. The sections normally closed at sea are open. To close off everything and activate CO_2 in harbour would take more time than at sea, as well as head count.

8.4.5 Radio communication - form

Communication related to fire extinguishing system activation takes place either face-to-face, through phone or over radio (UHF or walkie-talkie), the latter being a central communication mode. Radio communication has drawbacks that may hamper effective communication, but it also offers opportunities for highly effective communication. We have observed significant variation in the radio communication practices among different crews. It should be an explicit target to reduce the effect of the downside as much as possible, while at the same time exploiting the opportunities in order to optimize communication and its role in the activation process.

One *downside* of radio communication is the low-quality sound that may occur, depending on the quality of the radio signal in different parts of the ship, in turn depending on the range of the antennas and the degree amplification in the system. In addition, the transition between speakers may produce extra noise that may hamper sound quality at the first second of each speech sequence. In the literature on two-way radio protocols there are some recurring advice meant to heighten the quality of communication, and to avoid misunderstandings. Here we will highlight the following:

- Only use one language on radio, English may be preferred as standard, there are often multicultural crews on board.
- Avoid using personal names as call-signs. Establish unambiguous call-signs for the main positions during fire management to avoid misunderstanding regarding who is called/are talking on the radio. E.g. “fire leader”.
- Clarity: for the sake of clarity, speak a little slower than normal, and strive for clear pronunciation.
- Simplicity: keep messages simple enough for listeners to understand.
- Brevity: Be precise and to the point
- Recommend using procedure words to help in clear and consistent communication. Example of procedure words from the ISS (International Space Station) communication, used also by NSRs space research projects:
    - Acknowledge – Let me know you have received and understood my message
    - Advise Intentions – Tell me what you plan to do
    - Affirmative – Yes!
    - Break break – I wish to interrupt a transmission already in progress
    - Copy – I have received your transmission
    - Concur – I agree with your statement
    - Correction – An error has been made in the transmission and the correct version follows
    - Disregard – Cancel my transmission in progress or cancel my last transmission
    - Go Ahead – Proceed with your transmission
    - Immediately – Used when such action is required to avoid an imminent situation
    - Negative - No
    - Out – The conversation has ended, and no response is expected
    - Over – My transmission has ended, and I expect a response
    - Read back – Repeat all or the specified portion of my last transmission

   - Report – Advise when a specified event occurs
   - Say again – Repeat all or the specified portion of you last transmission
- Turn-taking: when pushing the push-to-talk button, wait two seconds before starting speaking, to avoid the chopping off of first words.
- Addressing and self-presentation:
   - Starting the conversation: [recipient's call sign] “this is” [your call sign] “over”
   - Response: [recipient's call sign] “this is” [your call sign] “go ahead”
   - Rest of conversation: [recipient's call sign] “this is” [your call sign] [the message] “over”.

While the last point may seem a bit cumbersome and seemingly being more time consuming than a less formal way of addressing recipients and conveying messages, it builds a structure into the conversation that reduces probabilities for misunderstandings. In addition, it helps the participants in the conversation to keep track of who is talking and who the message is meant for – parameters that may actually be of great importance for how messages are understood.

Among the *opportunities* offered by radio communication is the listening-in function; several people located different places can listen to the same conversation, and also join in on any occasion, without invite. This allows for the establishment and maintenance of shared situation awareness, even in an effortless manner since it may occur as a side-effect of dialogue. To that end, adhering to the above rules is not only a way to mitigate the downsides of radio communication, it is also a way of amplifying the benefits; to draw on the listening-in function and make it a collective resource, radio practise should be optimized and consistent.

8.4.6 Communication content and feedback loops

The coordination of people, information and tasks in the process of efficiently activating the drencher system requires a certain degree of standardised, structured procedures. This relates in particular to the physical activation process and the sequences of activating drencher pump, ensuring that the pump’s water source is correct, opening of section valves, handling of bilge pumps, closing of dampers and more. Clear and unambiguous procedures for these actions are important prerequisites for correct and fast activation, but it is not enough. Extinguishing system activation is not a mere technical process, it is also (and even more so) a social, collaborative process.

Communication in different forms involves and coordinates the relevant actors in the activation process. A well-coordinated response requires a shared situation awareness, and the process of establishing and maintaining a shared situation awareness is organised by communication. Every situation is unique and depending on the particular circumstances of each situation adaptations will be necessary to make the response fit to the circumstances. This kind of situational adaptation, in the literature often referred to as articulation work (Haavik, 2010; Schmidt & Bannon, 1992), is fuelled by communication between crews who have different formal positions and competences, different individual situation awareness, are in different locations and have different situation development expectations or projections.

Communication fills the purpose not only of negotiation – establishing agreement on the course of action – it also contributes to making work visible/tractable. We have seen quite different practices of communication during our field work, and the differences are reported by our informants to stem from personal preferences rather than any standardised communication protocols. The differences we have observed are in particular related to the quantity and form of communication; among some crews there is much more frequent radio communication than among others, and often involving questions whose answers are either already known or are readily available to the one posing them. We have observed extinguishing system activation processes (during fire drills) where there is an almost constantly ongoing conversation over radio, and this is contrasted by other drills where silence is the dominating modus, interrupted by short conversations only when particular actions are undertaken, messages/orders given, or questions asked.

From past fire incidents on ro-ro ships, we have learned that unsuccessful or suboptimal activation processes can follow from several conditions relating to communication;

- Critical knowledge of a system's state existed, but was not being communicated to those who needed to act upon it
- A system's state not being communicated/rendered visible by the system (design related)
- Messages being transmitted from a sender not being made subject to confirmation, allowing misunderstandings to propagate through the sociotechnical system

There is no guarantee that *more* communication will be of such a quality that such issues are being solved, but it is true that frequent communication, even on known issues, provides a high potential for building a shared situational awareness, while little communication does not provide that potential. Communication should therefore not be held to a minimum to give orders or to ask questions about things one do not know. We suggest that communication should be considered as means for actively building a shared situation awareness and should be trained and practiced thereafter. To that ends (the list is not exhaustive),

- Communication practices should include feedback loops: receivers of information should repeat the message so that both parts know that the message is understood correctly; if orders are given, those executing the order should always give feedback when it is done, and if any unforeseen challenges occurred.
- The fire leader has a responsibility to construct and maintain not only his/her own situation awareness, but a *shared* situation awareness. To that ends, it may be necessary to frequently provide information or ask questions that has no direct news value for the sender but may have for others.
- Should longer periods of silence occur, people will normally start wondering what is going on. In such situations, both the crew and the fire leader have a responsibility to break silence and inform about what is going on at their location – or ask others.

9 Reflection, evaluation and change: improved procedures and design for efficient extinguishing system activation (RCO6)

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"I don't have time to think!" (Raelin, 2002)

This chapter describes the solution the *Reflection, evaluation and change (REC) process* (RCO6), including its development and the demonstration and evaluation.

9.1 Assumptions, preconditions

The Reflection, evaluation and change (REC) process is a crew internal process intended to develop better procedures and better designed environment for working effectively with extinguishing system activation.

The process – a framework for improvement – is developed to meet not only the specific challenges and improvement potentials identified in section 7 and 8. While these point to opportunities discovered through expertise statements and fieldwork covering a limited part of the ro-ro fleet, the *REC process* is generic and developed to discover the situated opportunities wherever it is applied – regardless of shipping company, ship type, organisational or national culture or geographic sailing area. The rationale behind such a process-oriented solution is that both the present situation and the desired future situation might differ significantly between ships; therefore one size does not fit all, and the solution should be context-sensitive.

Our experiences show that seafarers are in general very good at what they do. This is also what the literature on seafarers and seamanship reports – they have capabilities to adapt and develop local practices and solutions to cope with the circumstances (Danielsen et al., 2022; Danielsen et al., 2021).

However, local knowledge and experience – indeed the seamanship – tend to be largely tacit, meaning that the practices and solutions are often not made subject to discussion and explicit evaluation. While debrief sessions after fire drills have the obvious potential to serve as occasions for explication, critical reflection, and change, these occasions are often underexploited. Typical scope for drills, lasting between two and fifteen minutes, can be

- What went well and what could have been done better?
- Did the applied tactics work?
- Were any problems encountered?
- Did equipment work as expected?
- How did the communication work?
- Round the room experience in general

This will vary between companies, ships and individual preferences, but the overall trend is that discussions are short and generic. The quote from Raelin (2002) in the beginning of this section reflects this situation.

This enables suboptimal conditions to last and evolve without correction, a result of which is documented in section 7 and 8.

9.2 Theoretical approach

Many qualities of work performance are never brought to the scene and made subject to explicit evaluation (Star & Strauss, 1999), and actually it is often so that only those who actually perform the work are aware of how it is done (Suchman, 1995). Hence, procedures that are developed at a distance from where the work is carried out, both spatially and temporally, are always at risk of not reflecting well both the challenges and opportunities of how work is – or could be – carried out in the actual, operative context. There are therefore pitfalls associated with the design of procedures by departments and managers detached from the operative context, and also with research resources that are brought into the work process design. Even procedures developed by users themselves may lose relevance and accuracy as contextual parameters change; technology, equipment and design may change, the nature of the work activities may change, organisations may change, personnel composition may change, roles and responsibilities may change – all with implications for how well the procedures function.

Procedures may be both material and immaterial. Material procedures are those that are put down in writing and appear on laminated papers, stickers and other surfaces either readily available to the crew in the operating environment, or they can be found in folders and binders on a shelf. By immaterial procedures we mean those procedures that are acted out in practise, but not necessarily written down anywhere.

There is a tendency that procedures are examined and adapted only when incidents and accidents occur. The conditions are therefore not favourable for improvement and change: we focus mostly on what does *not* work, and even though we may try to learn from that which goes well, much such work is not easily available for inspection by ordinary means. As Amulya (2004) frames it, "In the world of work, there are enormous opportunities to learn, yet relatively few structures that support learning from experience" (Amulya, 2004, p. 4)

The paradigmatic reference to action research stated in the introduction, that "people learn best, and more willingly apply what they have learned, when they do it themselves" (O'Brien, 1998), thus underscores the relevance of *reflective practise* as the approach to learning and development. By reflective practise, we mean the method or mode of learning that Schön (2017) advocates through his writings, based on substantial empirical case studies. Reflective practise is

> *"(…) the practice of periodically stepping back to ponder the meaning of what has recently transpired to ourselves and to others in our immediate environment. It illuminates what the self and others have experienced, providing a basis for future action. In particular, it privileges the process of inquiry, leading to an understanding of experiences that may have been overlooked in practice." (Raelin, 2002, p. 1)*

Importantly, the subjects of this quotation are the practitioners. The practitioners are considered competent individuals that should not be *instructed* on how to do their work, only be guided on how they themselves can use the resources of their own reflexivity and practical experiences to improve their work practices and their procedures, both individually and collectively. It is to that end, inspired by the theoretical framework for reflective practise as developed by Schön (2017), we have developed the LASH FIRE *Reflection, evaluation and change process* (REC).

Numerous arguments point towards the type of practise-anchored, process-oriented solution that we have chosen:

- In LASH FIRE we are doing action research, and reflective practise is a central topic and method in the action research literature (McIntosh, 2010)

- There is a need to develop solutions that are ‘living’ and that capture and address the dynamics – changes and adaptations in the social and material environment that occur in a living work environment – thus solutions need to be process oriented, i.e. should not be a ‘once-and-for-all-implementation’
- Solutions must also be ‘self-sustainable’ with available resources (time and personnel) in the operative ship environment
- ➢ This points towards a process solution fitted into the regular activities of the crew, and administered by the crew themselves (if necessary, in collaboration with DPA)
- The approach of reflective practise is also transferable to the context of RCO7, training programme for more efficient activation of fixed fire extinguishing systems – see Section 10.

The developed *Reflection, evaluation and change process* is presented in the following.

9.3 Solution: A structured process for reflection, evaluation and change

A structured process is developed that can be run in conjunction with existing fire drills. The process consists of three-stages: (i) knowing-in-action: explication of tacit knowledge (competence) that supports intuitive performance under ‘normal conditions’, (ii) reflection-in-action: explication of tacit knowledge (competence) that supports adaptive improvisations in the course of disruptions (surprises, incidents, crises), and (iii) reflection-on-action: critical reflection on explicated practices and design during post-event (drill, real situations) de-briefing processes Figure 7.

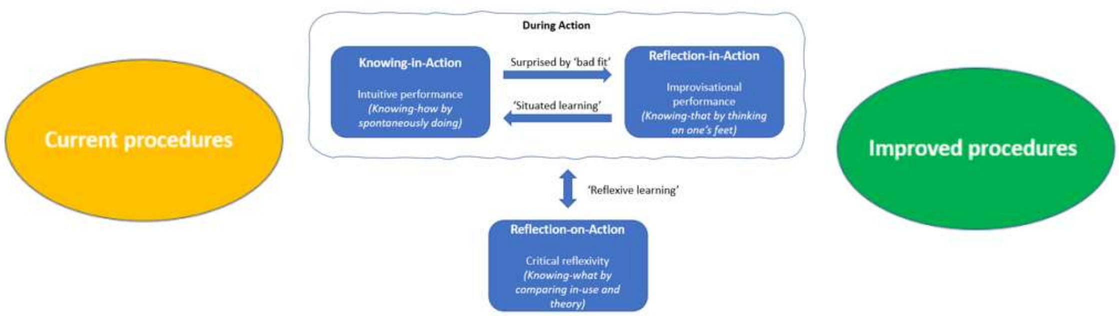


Figure 7. Schematic description of Reflection, evaluation and change process.

The first phase (reflection) is undertaken as a pre-brief, before the actual fire drill is initiated. It can be done just before the drill, leading up to the drill, or, alternatively, it can be done longer time before the drill, so that the drill can be initiated without the crew knowing about it in advance.

During this pre-brief, which could be scheduled for 30 minutes or more, the crew will reflect upon their unspoken, tacit practices and the designed environment, guided by a set of leading questions (Textbox 1). This will prime them for the next phases.

After the pre-brief, the planned fire drill will be carried out. The crew will use the output from the pre-brief as a basis for what to focus on, and are primed to make note (in memory) of how the practices and design function under the circumstances of the drill, faced with a specific work context including surprise elements. This can be considered as a continuation of the reflection phase. The REC process does not presuppose any adaptation of the ordinary drills apart from the dedication to in-action reflection.

The second phase of the REC process (evaluation) is dedicated to discussing how well the existing procedures and designed environment functions during the course of the drill, given the premise that modifications are possible. This debrief will be guided by leading questions (Textbox 2 and Textbox 3), and will last as long as it takes to bring up all relevant impressions and critical reflections from the drill. In the generic process template, 1 hour is set aside for this phase. If necessary, changes that would require permissions or support from DPA or other relevant onshore representatives or departments will have to be forwarded for discussion in the relevant fora.

The third and last phase of the REC process (change) involves deciding and implementing the suggested changes. Some changes can be implemented right away in a seamless continuation of the evaluation, while others might be implemented later, as involvement of shore organisation and physical implementation might take some time. Yet other changes might be rejected by the land organisation. Those should nevertheless be documented so that they might be brought up again, in conjunction with other changes that may be initiated at a later stage.

As an extension of the standard drill, the REC process thus provides a structured approach for converting tacit knowledge into explicit knowledge, for identifying procedure and design candidates for change, in order to increase efficiency in the activation process. Elements included in this structure are, as elaborated above:

- Reflection phase: Pre-brief before drill (1/2h) – priming participants to raised awareness of both “autopilot actions” and improvised actions during the drill.
- Evaluation phase: De-brief after drill (1h) – structured discussion supported by leading questions, to identify improvement potentials for procedures and design.
- Change phase: Concluding decisions and implementation of changes in procedures and design.

9.4 Reflection, evaluation and change: Guidelines for improving procedures and design for extinguishing system activation

9.4.1 Introduction

(e.g. purpose, intending recipients, acknowledgement as per above, etc.)

Successful management of fixed fire extinguishing systems in fire situations in ro-ro ships requires both efficiency and thoroughness from the crew involved in the firefighting. Efficiency relates to the swiftness of the activation process, and thoroughness relates to doing things in a right and safe way – e.g. following the established procedures and activating the extinguishing system in the right location of the ship.

9.4.1.1 Purpose

This guideline presents a *Reflection, evaluation and change (REC) process* designed to adapt and improve existing procedures and design relating to fixed fire extinguishing systems management. The process should be carried out at the level of individual ships, preferably in collaboration with the onshore organisation – e.g. with participation from the DPA. This to ensure continuity across the process, from discovering improvement potentials during a drill, to implementing suggested changes in design or procedures.

A premise for the REC process is that there exists substantial tacit knowledge in the ship organisation, through which ship crews shoulder risks associated with suboptimal designs and procedures. Such tacit knowledge is instrumental in coping with both routine work and for improvisation when faced with surprises. The purpose of the REC process is to make such tacit knowledge explicit through reflection, to evaluate needs for change, and to implement suggested/necessary changes (see Figure 8).

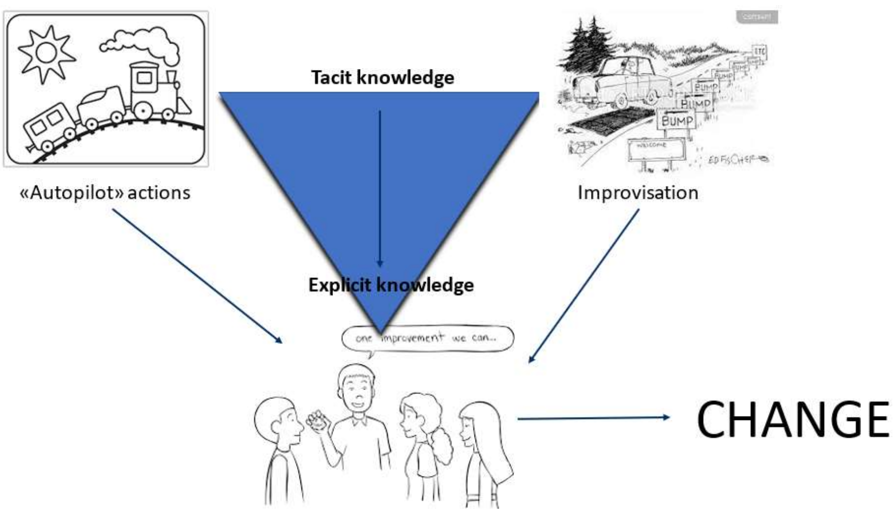


Figure 8. REC process.

The REC process should be run with a particular focus relating to fire extinguishing activation, that should alternate from each time. Examples of foci could be decision making and activation; communication; design of instructions materials; roles and responsibilities (coordination).

9.4.1.2 Intended recipients

The intended recipients of this guideline are

- those onboard the ship involved in fire management, the captain and the fire commander typically being 'super users'[5].
- the DPA, or other similar roles that can connect the crew with onshore organisational environments that can support with implementing changes.

This guideline is developed in the project LASH FIRE.

The project has received founding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 81497.

[5] While a many of the ship's crew will be involved and engaged in the process, 'super user' such as the captain and the fire commander should own the process, introduce it, and lead it.

9.4.2 Application

The REC process should be carried out in connection with ordinary fire drills, although not all of them. It can be seen as an extended fire drill that is devoted not to rehearsing existing procedures and systems, but to identify improvement potentials for the same procedures and systems. There is no requirement with respect to the frequency of implementation, but since work practices and material environments on a ship is subject to continuous adaptation, it is recommended to implement the REC process no less than four times per year.

The REC process is estimated to extend a regular fire drill with approximately 1 ½ hours, in addition to time necessary for planning the extended drill (scenario).

9.4.3 How to conduct the Reflection, evaluation and change process

9.4.3.1 Pre-brief

A meeting is held before the drill, with everybody participating in the drill. The intention with this meeting is to prime everybody with a 'critical' mindset and to reflect collectively on their existing practices and experiences, searching for improvement potentials.

The pre-brief is focused on reflecting on and discussing a series of questions. The focus of the questions will change with the focus of the planned scenario (see 9.4.1.1). The common denominator is the heading, the context for the questions: "Based on your experience, and during the drill, try to notice…". The framing of the pre-brief thus involves both looking back and looking forward. An example of questions that could be asked in a pre-brief when focus is on decision making and activation are provided in Textbox 1. For other foci, e.g. communication; design of instructions materials; roles and responsibilities (coordination), questions should be tailor made.

Based on your experience, and during the drill, try to notice…

- Do you experience any difficulties or dilemmas?
- What could make this specific task difficult in a real emergency (dilemma/challenge), e.g.
  - Making sense of the alarm (sensemaking)
  - Identifying correct drencher zone (sensemaking)
  - Looking up dangerous goods manifest (sensemaking)
  - Choice of extinguishing strategy (decision making)
  - Drencher activation steps (communication, know-how)
  - Activation instructions 'poster' (design)
  - Effect of water on dangerous goods (sensemaking)
  - Other …
- Are there things you would have to do differently in a *real* fire emergency?

Textbox 1. Leading questions for REC pre-brief. Questions may be adapted by users.

The intention is to bring up experiences and knowledge that is seldom discussed explicitly, but merely coped with.

9.4.3.2 REC adapted drill

After the pre-brief, the drill is run as planned. The crew should during the drill bear in mind the questions and discussions from the pre-brief. If useful, the questions could be printed and brought during the drill. Notes can also be taken during the drill, although this is often not convenient for all participants.

9.4.3.3 De-brief

The debrief should start with discussing open question about learning points from the drill (Textbox 2):

- What worked well?
  - How can we maintain and strengthen what went well?
- What did not work so well?
  - Is there anything we should have done differently?
  - If yes, which changes do that require in procedures and design?

Textbox 2. Open questions for debrief.

After the open questions session, proceed with more detailed questions (Textbox 3). The questions in this section should be related to the drill scenario and the activities undertaken during the drill. Hence, although many of the leading questions in Textbox 3 would be relevant in most drills, the questions must be adapted to the context.

Localisation of fire

1. Was it easy to make sense of the alarm?
2. Was the information from alarm panel and other systems (e.g. CCTV) clear? What would be different in a real situation due to e.g. smoke?
3. Was the runner sent in the right direction? How precise information was the runner able to gather?

Dangerous goods, information and handling

4. How was the process of looking up necessary information on dangerous goods? Easy? Cumbersome?
5. Are there routines for checking dangerous goods when an alarm goes off? How efficient are they?
6. Does the presence of dangerous goods cause any hesitation?
7. Is the information about how to handle different types of dangerous goods clear and unambiguous?
8. Do you plan so that unpleasant surprises with respect to dangerous goods cannot appear?

Drencher activation

9. What did you have to do to identify the correct drencher zone? Is it cumbersome?
10. Are markings and numbering of drencher zones and pumps clear and unambiguous?
11. Was the communication about drencher zone and pumps clear and unambiguous?
12. Are there different locations from where drenchers could have been activated in this situation?
13. Did you have any choice with respect to location from where you activate drenchers? (Are there organisational habits or actual/potential technical systems setup restricting the use of other locations)
14. Was it obvious who should do the activation? Could there be alternatives regarding who undertakes the activation?
15. Did you have any doubts at the moment of activation? Would you have any doubts if it was a real situation?
16. Did you have the necessary information when activating the drenchers? (Both the person ordering it and the person performing the actual procedure
17. Are there any hands-on instructions for the drenchers? Did you make use of them?
18. Are they well formulated? Unambiguous? Is there anything with the wording in the instruction that may lead to hesitation in a stressing situation?
19. Are activation instructions available in all relevant locations from where activation is possible?
20. Do the instructions say anything about who are allowed to activate the system, and in case, is it in line with the standing order or the general perception?
21. Did the management of other fire-related equipment (e.g.fire dampers) cause any problems, delays, hesitation?
22. How could we arrange for earlier activation the next time, or during a real fire?

Textbox 3. Detailed questions for debrief. Note: these are only examples.

A designated facilitator of the debrief session should be responsible for having the discussions and noting suggested changes, and bring this forward to the last stage (Section 9.4.3.4)

9.4.3.4 Change

To close the loop of the REC process, a change initiative must be implemented. The authority required to implement a design or procedural change will vary from case to case and from company to company. Some changes will be possible for the crew to implement without conference with the onshore organisation, while others may necessitate involvement from the DPA or other onshore resources. This will typically also depend on the magnitude of the change, such as the costs and time needed, whether they are small (S), medium (M) or large (L). As part of the debrief documentation, this should be described, e.g. using a table like the one in Figure 9.

Change	Description	S M L	Responsible	Done
Technical system		☐☐☐		☐
		☐☐☐		☐
		☐☐☐		☐
Procedures		☐☐☐		☐
		☐☐☐		☐
		☐☐☐		☐
Design		☐☐☐		☐
		☐☐☐		☐
		☐☐☐		☐

Figure 9. Description of change suggestion, magnitude and responsible.

This documentation should be kept for reference until a change has been implemented. It can also be useful as a reference in case a DPA or other relevant onshore representatives wish to explore transfer value of change suggestion to other ships.

9.5 Results from demonstration

The REC development process has taken place through a series of iterations through which the current framework has been shaped. This includes the early definition of conditions, the description of challenges as seen from the shipping companies, through observations, interviews and discussions with seafarers, discussions with LASH FIRE advisory groups (including representatives from authorities). Hence, although the present outline of the REC process as such is a *product* of this development, and despite concrete guidelines for implementation are defined, it is still a *process*. One should expect that as soon as the REC process is adopted on a ship, it will take on its own trajectory of development and use, following the culture of adaptations in the maritime industry (Danielsen et al., 2022; Lützhöft, 2004).

9.5.1 First pilot test in operative environment

As a part if the development, an early prototype of the REC process was tested out on potential future user. As a limited, but generic intervention and test scope, the debrief framework was tested in a staged debrief with a selection of guiding questions relating to an extract of the challenges described in section 8. The guiding questions included the following:

1. Decision making and activation
    - What were the decisive information on which you were basing the final decision to activate drencher system?
    - Did you activate the drenchers from the location nearest to the person making the decision?
    - Why did you not activate drenchers earlier?
    - What would be required in order to activate drenchers earlier?
    - How could you arrange for earlier activation the next time, or during a real fire?
2. Communication
    - Is everybody deploying standard ways of addressing the recipient, and presenting oneself, during radio communication?
    - Is everybody using the same language throughout the whole drill?
    - Do you always get the information with respect to situational status and decisions, necessary for you to fulfil your tasks?
    - What could be done to ensure better sharing of important information during a drill or a real fire?
3. Design of instructions material
    - Are the hands-on instructions for activation of drencher/CO_2 system clear and unambiguous?
    - Is there anything with the wording in the instruction that may lead to hesitation in a stressing situation?
    - Are activation instructions available in all relevant places (from where activation is possible)?
    - Do the instructions say anything about who are allowed to activate the system, and in case, is it in line with the standing order or the general perception?
4. Roles and responsibilities
    - When an order is given, will the person giving the order always get feedback that the order is effectuated?
    - Does it happen that there are ambiguities with respect to who is responsible for a certain action related to fire management?
5. Activation errors/mistakes
    - What could be a typical reason for activating wrong drencher zone?

- In case of communication problems (e.g. due to noise, language, wording, other issues), what can you do to avoid this?
- In case of poor/ambiguous markings of section valves, what could be done to improve this?
- Do you always seek for confirmation that the right zone has been activated, after activation?
- Is the selected water source for the drencher pump always obvious and unambiguous to the one operating the pump?

A number of the questions that were posed in the debrief were found very relevant and useful by the crew. This was conveyed both orally in connection with the debrief session, and it was also reflected by written comments to the questions. Here, we will particularly highlight the discussions relating to point #3 Design of instructions material.

As it became evident that it was always the engineer with the responsibility for the drencher system according to the muster plan who was expected to manage the drencher system, among the deck officers there was a lack of familiarity and experience with the drencher system. Not everybody would know how to activate the system, and in addition, there were significant lack of information in the form of instruction posters for handling the drencher system.

As a result, an internal process was initiated on the ship, with the aim of improving the written instructions material for drencher activation, and to take other necessary measures to make sure that everybody working on the car deck, and that all deck and engine officers know how to release the drencher system. This would make a significant different to fire management and effective activation of systems in a situation where the engineer who usually does this, is injured or otherwise unavailable.

9.5.2 Demonstration and evaluation

The final demonstration of the REC process took place on a ro-ro vessel on the 5th December 2022, during port stay at Gothenburg.

9.5.2.1 Planning and script

The demonstration was planned in collaboration between the ship crew, the shipping company project manager and the research group. The point of departure for the planning was that the demonstration would be incorporated into a customized fire drill. The drill should involve activation of the drencher system, and should also contain some elements that would complicate the decision making and execution.

The final scenario was settled in agreement with the captain, and with respect to the preparations and actions necessary from the crew side, the fire drill was prepared as illustrated in Figure 10:

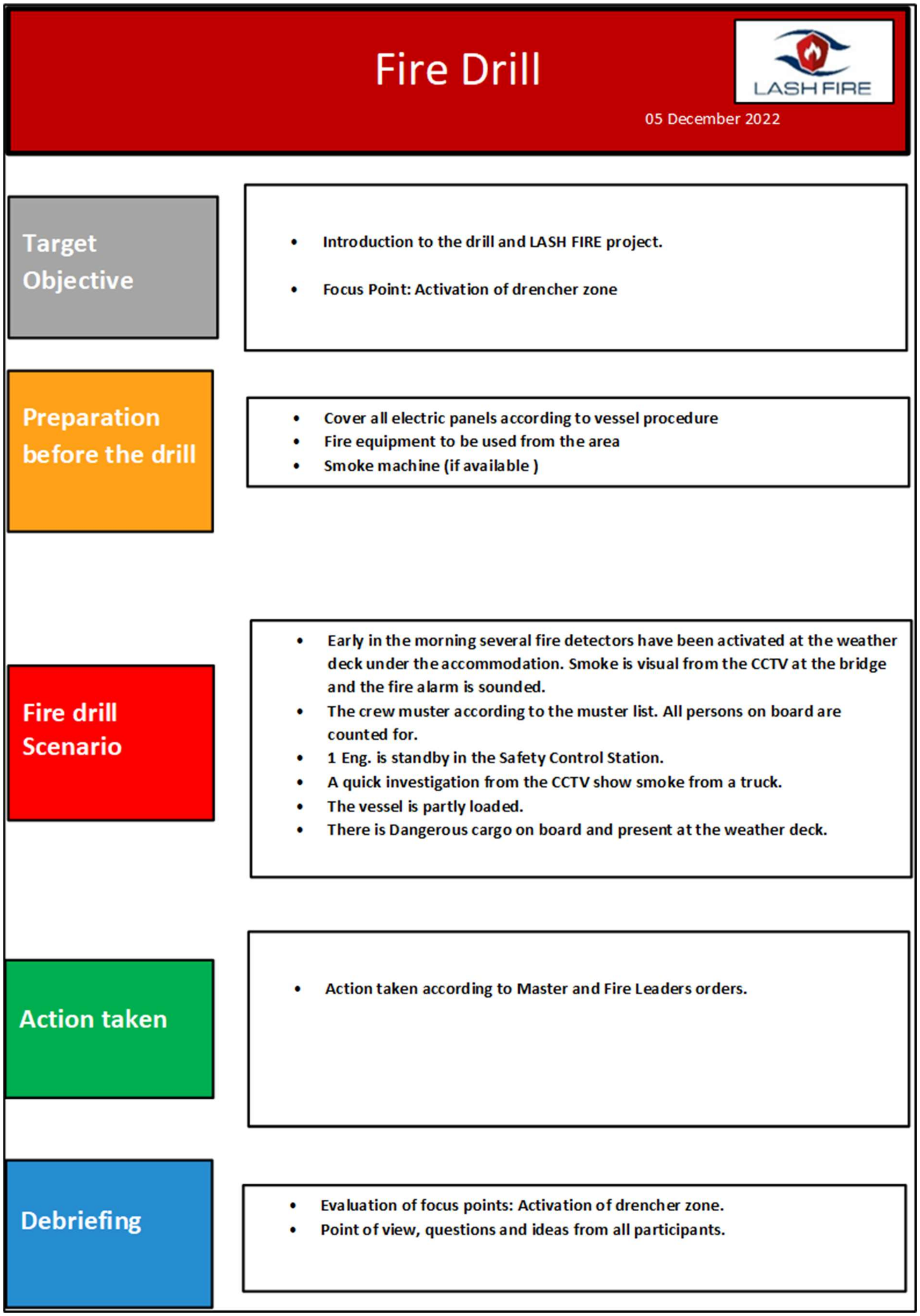


Figure 10. Outline of fire drill scenario for REC demonstration.

Participating in the demonstration were crew from deck/bridge and engine. Only the captain was fully informed about the details of the script, so that surprise elements would appear as realistic as possible to the crew.

The researcher team consisted of three researchers. The researchers met up with the shipping company's project manager and the captain early in the morning, allowing for some last on-site preparations before the demonstration would start at 09h. This included a brief round of familiarisation in the safety control room, which in addition to the bridge is an important location of action in the fire drill.

The researcher team and the shipping company's project manager then met the ship crew at the bridge. After a brief introduction by the captain, the researcher team with support from the shipping company's project manager also held an introduction explaining about the LASH FIRE project and the background for the demonstration. This introduction also included the premises for the participation of the crew, their contributions and their rights with respect to the GDPR regulative. Consent forms that had been distributed and signed were thereafter collected by the researcher team.

The researcher team split up and were allocated to each their locations/team: one researcher stayed at the bridge, one researcher was to follow the first engineer to the safety control room, and the last researcher would follow the fire team to the location of the fire at the deck.

Following this, the demonstration started. The steps of reflection, evaluation and change are described in the following sections.

9.5.2.2 Reflection

A brief explanation of the concepts of tacit knowledge and explicit knowledge was provided by the research team, and the crew was encouraged to reflect upon their own automatised practices both at the spot, and during the fire drill – an example being the sequence of actions involved with drencher activation. Still, the participants were urged to act as they usually do, and not to adapt their patterns of action due to the presence of observing researchers.

9.5.2.3 The drill

The drill was initiated by a sounding alarm, whereby mustering and fire management took place according to normal procedures and practices. The researchers followed their designated teams.

The drill followed the planned sequence. It was simulated that a truck on the weather deck had caught fire, under roof with installed drencher system. Some meters away from the truck, another truck with dangerous goods (simulated) was placed in order to put some restrictions to the use of water.

Order was given from the bridge to try putting out the fire with manual means first. Thereafter, order was given to activate the drenchers, which was done (not simulated) from the safety control room. Drenchers poured water for several minutes until the fire was (simulated) put out.

The following deviation occurred in the context and course of action, compared to the script:

- Smoke machine was not implemented, due to practical considerations

9.5.2.4 Evaluation

After the drill was finished, the crew, shipping company's project manager and the researcher team gathered on the bridge for a debrief with evaluation. After about half an hour of collective evaluations, the discussions continued as separate researcher-crew discussions for a while longer, with the first engineer and the first officer respectively.

The evaluation from the crew resulted in concrete suggestions for improvement of design solutions:

- The ‘home-made’ written procedure for drencher activation in the safety control station (Figure 11) was considered ambiguous. As it is advised to always activate a minimum of two zones, the written procedure formulates that two section valves should be opened in the “Sections “2-5) or (6-11)”. This is ambiguous because it may be read as if the two sections must be either within 2-5 OR 6-11, which is not the case. For example, section valves 4 and 6 could be opened, if needed. The engineer is well aware of this, but that might not be the case with others that would have to stand in for him under specific circumstances.
- The formal laminated fire plan showing the drencher system instructions and zones (Figure 12) is difficult to read due to small scale, both in fonts and drawings. As it hangs a bit high on the wall, somebody with reduces sight could have serious problems interpreting it.
- The formal laminated fire plan showing the drencher system instructions and zones (Figure 12) is difficult to read due to worn plastic lamination, which reduces transparency.

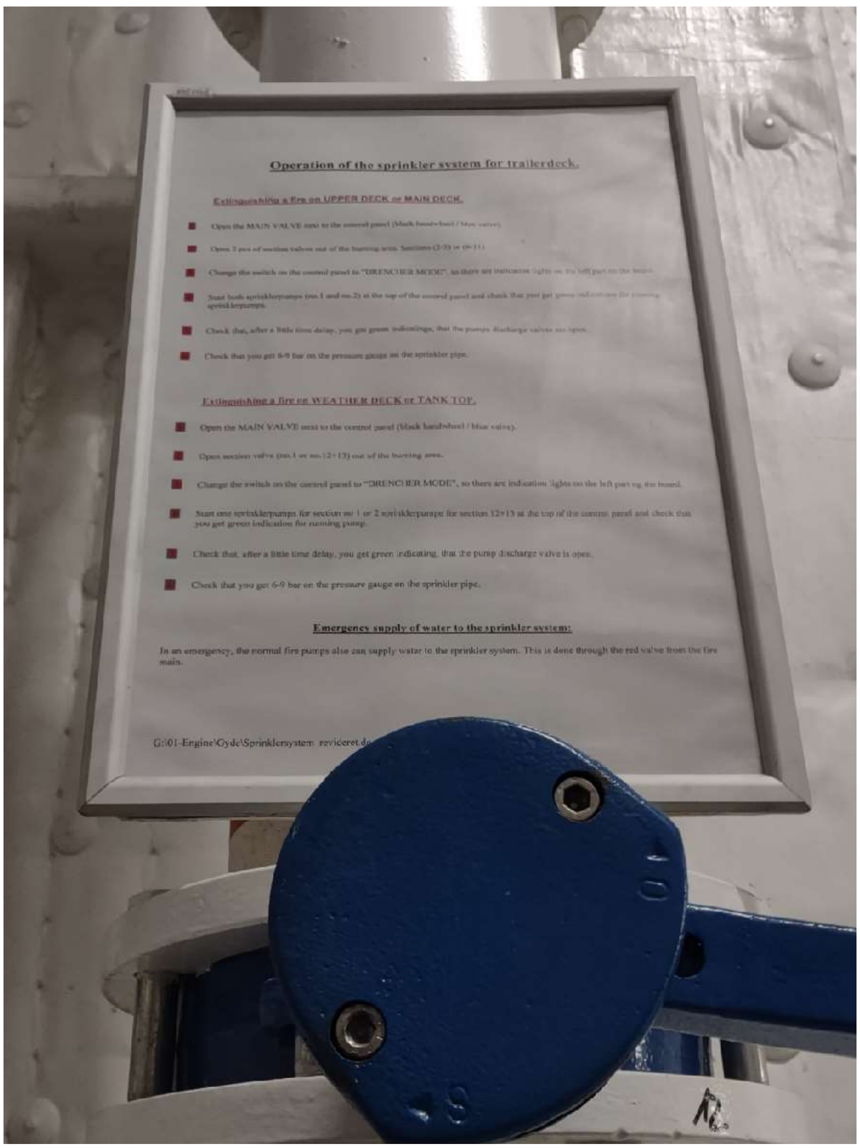


Figure 11. 'Home-made' operating instructions for drencher system.

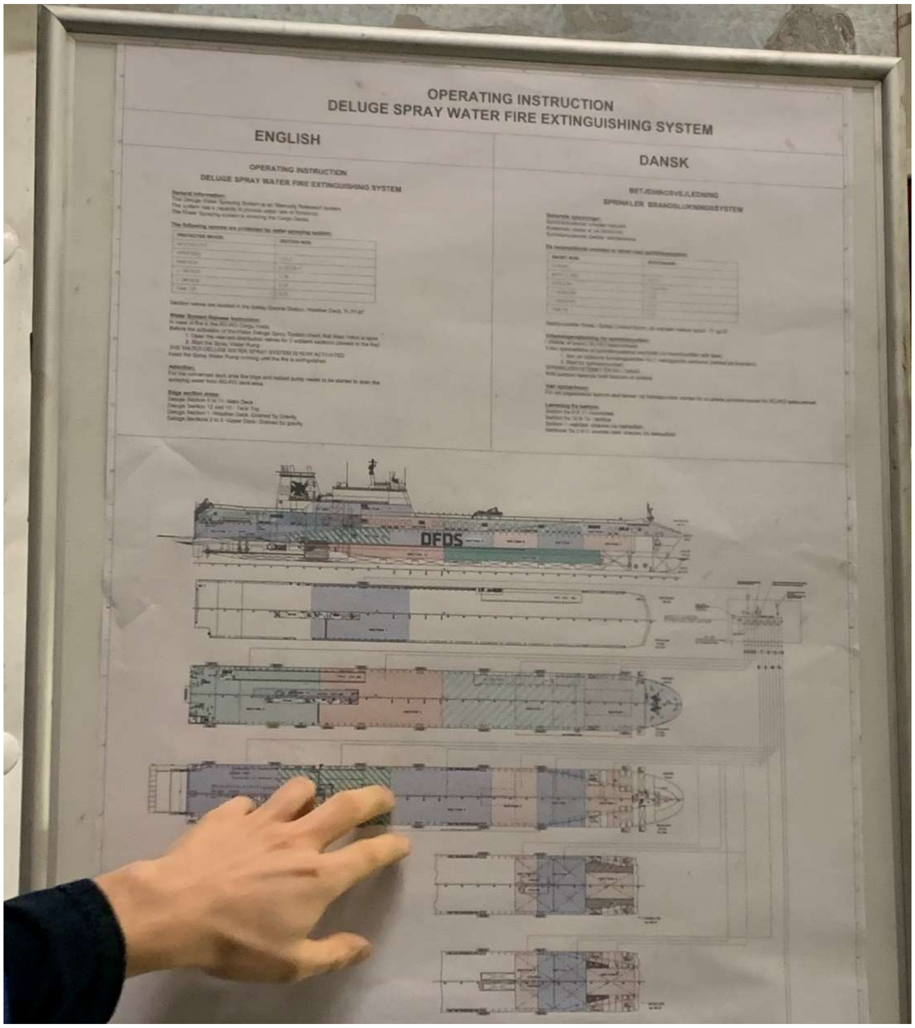


Figure 12. Formal drencher system instructions.

Although the REC process is meant to be administered by the crew, and the change requests are meant to come from them, during this demonstration the research team also made notice of improvement potentials. These findings by 'outsiders' illustrate the potential value of inviting e.g. a DPA into the REC process to identify issues that paradoxically might be so obvious to the crew that it evades their attention. One such identified issues was:

- The existence of two separate and different instructions for drencher activation can be a source of confusion in a critical situation, and particularly in a situation where the engineer usually managing the drencher system is unavailable. Learnings from the *Mignon* fire (see Section 10.3.3) show that this is unfortunate.

9.5.2.5 Change

To make actual changes in procedures and design is the last stage in the REC, and one that might require longer time than what is available during the part of the REC that ends with the debrief session.

Surely, certain changes could be decided and implemented locally more or less immediately, without conference with onshore organisation, but that is not always the case. And in fact, sometimes it is exactly the local solutions that are implemented without anchoring from higher up in the organisation that over time contribute to cluttering and ambiguity.

With respect to the current demonstration, no decisions were made on the spot. This makes even more sense owing to the fact that this was a *demonstration*, initiated and 'owned' by the LASH FIRE project. Potential developments that were discussed and that were found potentially valuable, did not find their addressees during the demonstration. Neither was it definitely decided by the crew that they would be pursued in the near future. Here again, the question of ownership to the process and the change requests is influenced by the fact that this demonstration session is brought about from the *outside*. There is thus a chance that the identified improvement potential this time will not result in any concrete changes in the shorter time perspective. However, the research team at the time of writing continues the investigation of chances to close the loop of reflection, evaluation *and change* to gain more learning about possibilities and obstacles outside the 'sharp end' of the ship. Indeed, although change of suboptimal design in the maritime domain has been acknowledged by many others to be cumbersome (Danielsen, 2022; Danielsen et al., 2022; Gernez, 2019; Lützhöft, 2004; Petersen et al., 2015), the REC process should be seen as adding structure to the will to improvement both in the sharp and the blunt end of the organisation.

9.5.3 Potentials for future improvement of REC method

From the demonstration in an operative environment, improvement potentials relating to the process facilitation were noted, that can impact the efficiency of the REC process. We would advise that both the pre-brief and the debrief is held in a meeting room instead of on the bridge. Although the bridge is a natural assembly point and the crew is acquainted with briefings taking place on the bridge, these are often expected to be brief meetings, highly integrated with the daily operatives. This invites to short meetings, something that could be witnessed during the demonstration, where the participants were standing and showing signs of impatience as the time exceeded the regular time for drill debriefs. In a process like the REC process, it is an objective in itself to take a step back from the daily operative and reflect 'at distance' on own practices. To provide a suitable time and context for that, it is advised that both pre-brief and debrief sessions are arranged in a room with a round-table around which everyone can sit down and take part in brainstorms and discussions that can last for as long as an hour.

10 Training programme for activation of extinguishing systems (RCO7)

Main author of the chapter: Jaime Bleye, SAS and Torgeir Kolstø Haavik, NSR.

This chapter describes the developed training course (RCO7), including the demonstration and evaluation of the course.

10.1 Introduction

This work aims to set a realistic training module for efficient fixed firefighting activation that LASH FIRE has identified as the most common type (water based-drencher and gas type- CO_2) in the generic ships in the ro-ro fleet. Efficient activation processes for fixed fire extinguishing systems (drencher systems and CO_2 systems) are crucial for successful management of fire situations in ro-ro ships. Historic maritime accidents show that time is an extremely important factor, as are working practices and system design that minimise risk of misunderstandings and erroneous actions in the extinguishing system activation process. Training on the activation of fixed systems on board is not always possible. Hands-on training will ensure that crew members are competent in managing high-risk systems in a safe environment without interrupting on the daily operative.

10.2 Challenges relating to activation of fixed fire extinguishing systems

It is commonly known that the initial phase of a fire on ro-ro ships is critical, and reducing the time spent before drenchers or CO_2 systems are activated will contribute significantly to reducing the consequences of the fire. Studies within the LASH FIRE project have mapped challenges related to extinguishing system activation, and how these can result in late activation. The most central of these challenges have been presented in Table 3. The majority of these challenges are relevant for the scenario of the training, exceptions being fire in APVs and fire in harbour, which the scenario is not designed to address.

10.3 Some examples where activation challenges contributed to slow delayed firefighting

In the training course, relevant context is presented to the course participants through brief reviews of historic cases with fires on ro-ro ships. These are presented below.

10.3.1 *Norman Atlantic* – activation of wrong drencher zone

On some ships, the drencher section valves must be opened from the drencher room. Since the drencher room is normally not manned, one person will be sent from the engine control room to open the correct valves. If so, the information flow can be such that a fire has been confirmed visually by a runner, who has called the bridge and informed about the fire situation and possibly in which fire detection section. If it is not possible for the runner to confirm the fire detection section due to for example smoke or cargo hiding the painting on the bulkhead, the fire leader on the bridge will have had to look up information about drencher sections and find the section that corresponds with the location of the fire by other means. This is done by combining information on detector number, frame number and starboard/port side with the general arrangement map showing drencher sections. This information would thereafter have to be communicated on phone or radio to the chief engineer in the engine control room – who in turn inform the person sent to the drencher room to open section valves. With such communication between people in potentially three different locations – in a situation where many things are going on at the same time, and the personnel may be stressed – there are opportunities for miscommunication. Such miscommunication happened at the *Norman Atlantic* accident (Ministry of infrastructure and transport, 2014), where the wrong drencher section was activated, despite the captain and the deck officer communicating about this was actually co-located on the bridge (from where the drenchers were activated).

In the case of *Norman Atlantic*, a breach occurred somewhere along this line of communication, resulting in the opening of the wrong drencher section (valves on deck 3) valve from the engine control room although the right section (valves on deck 4) was reportedly identified by the command group on the bridge. The exact circumstances for the valve opening action are not known, but clearly fewer sequences of actions would reduce the number of points in which errors could be introduced.

10.3.2 *Lisco Gloria* – deactivated remote drencher pump

When remote drencher pump activation is possible, there is usually a switch locally on the pump where possibility for remote activation can be switched on or off. When maintenance on the pump is to take place, the normal procedure is to turn off the possibility for remote activation, to prevent pump start-up during the maintenance work. This represents a risk; in the fire on the ro-pax ship *Lisco Gloria* in 2010, the master started the drencher system from the bridge, but the system did not deliver any water. This led to a rapid spread of the fire, and the ship had to be evacuated. While the master probably suspected malfunction of the system, this was not the case. As elaborated in the investigation report (Bundestelle für Seeunfalluntersuchung and Lithuainian Maritime Safety Administration, 2012) the most probable reason for the lack of response from the drencher system was that the valve for water supply to the drencher pump was set to manual mode on the main switchboard in the engine control room.

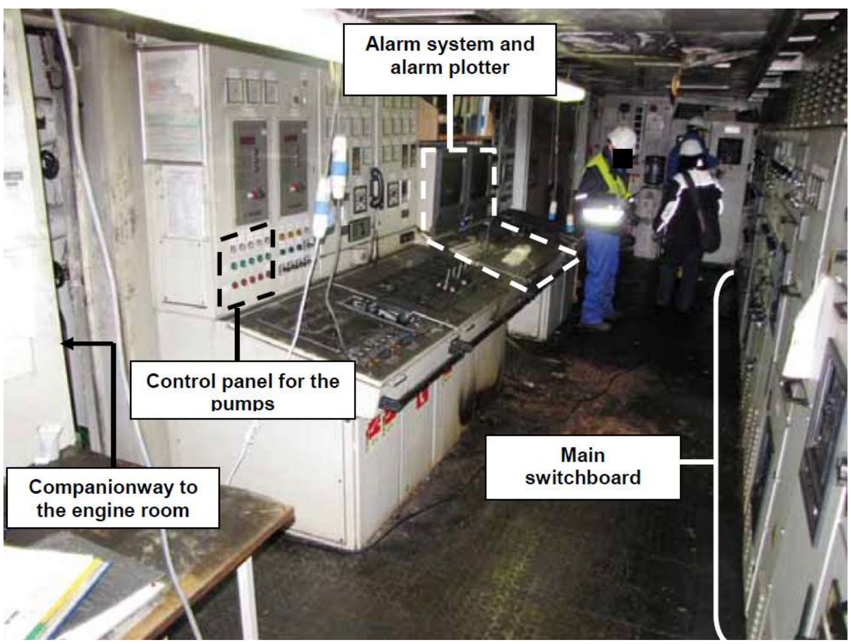


Figure 13. The engine control room of Lisco Gloria.

With this setting, pressing the button to activate the drencher pump will have no effect. Information about valve setting and pump activation possibilities existed in the engine room, but at the bridge there were no information about the valve settings for the pump. Had there been, the message could have been conveyed to personnel in the engine room and drenchers could have been started by simply changing the valve setting on the main switchboard to ‘automatic’.

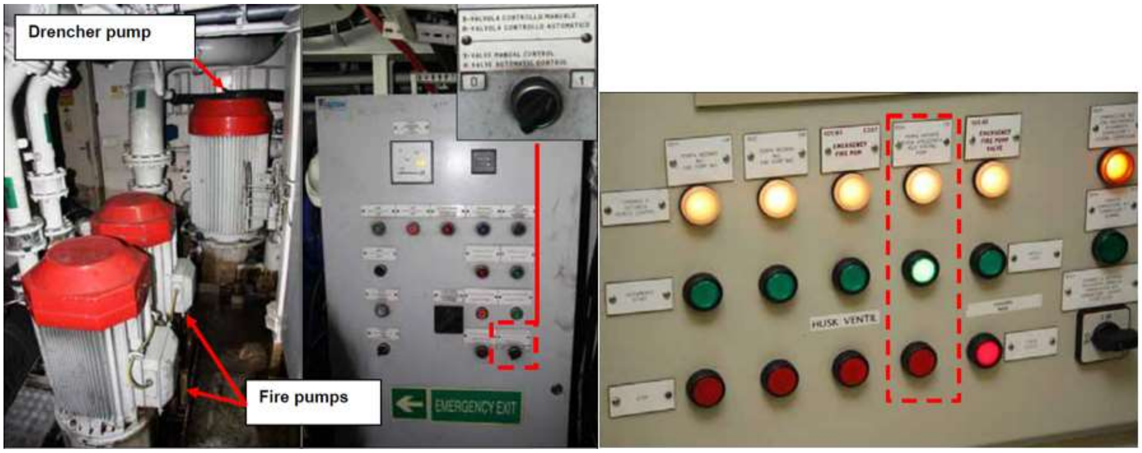


Figure 14. Valve setting (left picture) and control panel for drencher pumps (right) on Dana Sirena.

10.3.3 Mignon – unclear instructions

4th April 2018 there was a fire in the cargo room in the vehicle carrier *Mignon* (Swedish Accident Investigation Authority, 2019). The fire was caused by a short circuit in the start motor of one of the (used) cars. After the chief engineer decided that CO_2 was to be released, a five-minute delay was caused by unclear manufacturer's instructions for the use of the CO_2 system. In the CO_2 room there were two instructions for activating the system, one from the manufacturer and one from the ship operator. The chief engineer chose to use the manufacturer's instruction, which was unclear and caused the chief engineer to wait several minutes too long before the full activation procedure was completed and CO_2 was released.

Figure 15. Image of two different operating instructions for the same CO_2 system that caused confusion in the 2018 Mignon fire.

This was the first time during *Mignon*'s 18 years' lifetime that CO_2 had been used to tackle a fire. Training experience among personnel is also generally low, and very few officers have practical experiences of using CO_2 in realistic situations.

In the aftermath, critics was raised both towards the unclear instructions, and to the training regime which does not provide ship personnel with experience of activating CO_2 systems under realistic conditions.

10.4 The regulatory context

The realistic training module for efficient extinguishing system activation is designed to address the following challenges/situations:

- Hands-on activation of the fire extinguishing systems is not part of the Table A-VI/3 of the STCW Course "*Advanced firefighting*". Model course 2.03 (IMO, 2020a);
- SOLAS II-2/19.3.2 (IMO, 2020c) requires at least one fire drill on board every month. The shipping company Safety Management System (SMS) will specify clear instructions and guidelines about how fire drills shall be safely and efficiently carried out. However, in reality and due to the daily operative on board the real activation of the firefighting systems is not part of the compulsory fire drills;
- According to MSC.1/Circ.1430/Rev.2 (IMO, 2020d) the manual activation of the deluge (or so-called drencher) systems is allowed, and every crew member should be aware of the procedure. There is sometimes a "blame culture" for activation and due to the lack of training and familiarity ; and
- According to Chapter 5 "Fixed gas fire-extinguishing systems" of the International Code for Fire Safety Systems (FSS Code) Point 2.2.2. (IMO, 2020b) set that "*Controls of the Carbon Dioxide Systems shall be located inside a release box clearly identified for the particular space. The box containing the control is to be locked and a key to the box shall be in a break-glass-type enclosure conspicuously located adjacent to the box*". Reality shows that crew members don´t have access to the CO_2 control room Figure 16 which is considered as a protected space with locked access. They are not familiar with activation and the efficacy of the carbon dioxide as firefighting agent.

Figure 16. Release box for control of activation of the CO_2 system. BALEARIA ro-pax vessel.

10.5 Jovellanos training facilities

The venue of the training course is the Jovellanos Maritime Safety Training Centre[6] Located at Gijón (North coast of Spain) that belongs to the Spanish Maritime Search and Rescue Agency (SAS) Salvamento Marítimo (salvamentomaritimo.es).

Jovellanos has been delivering safety maritime courses since 1993 to crew members in different training areas like firefighting, sea survival, pollution combat or vessel traffic systems.

Figure 17. Overview of Jovellanos Training Centre.

10.6 Course format

Date for the training: 22nd November 2022

Theoretical module: 2h

Practical hands-on module: 4h

Debriefing session: 1h

Target group: Crew members (Deck officers and AB) sailing on board ro-ro, ro-pax vessels.

Goal of the training: To train a methodology and a procedure for the effective activation of the fixed firefighting systems. Different rounds of activation both drencher and CO_2 will be possible

[6] https://www.centrojovellanos.es/

TRAINING PROGRAMME	
Training topics	hours
THEORY	
- Procedures for extinguishing systems activation (Theoretical part)	2
- End of the course. Q&A. Debriefing session	1
PRACTICAL	
- Drencher fire extinguishing system activation procedure and instructions	1
- CO_2 fire extinguishing system activation procedure and instructions	1
- Actions to be taken in case of fixed firefighting system failure	2
TOTAL	

SCHEDULE	
08:00-08:10	Safety introduction, introduction of LASH FIRE project, team, course and participants
08:10-08:15	Background – rationale and objective of the course
08:15-08:45	Fixed fire extinguishing systems – some challenges and historic events
08:45-09:00	Coffee break
09:00-09:30	Discussions in groups and plenum
09:30-10:00	Reflective practice and learning: introduction to the learning framework of Schön
10:00-10:15	Coffee break. Donning of PPE
10:15-11:15	Drencher fire extinguishing system activation procedure and instructions
11:15-12:15	CO_2 fire extinguishing system activation procedure and instructions
12:15-13:00	Lunch on fireground
13:00-15:00	Actions to be taken in case of fixed firefighting system failure
15:00-16:00	End of the course. Q&A. Debriefing session

Definitions of conditions for the training module drill are provided in ANNEX A Definitions of conditions for training module drill

10.7 Description of training course

10.7.1 Theoretical framing: methodology for improved learning from training and drills

The training course is first and foremost a *practical* course, intended to improve the participants competences related to activation of drenchers and CO_2 extinguishing systems. However, the course will also draw on the participants' own reflexivity and encourage them to use their own experience and contextual knowledge from their own workplace to take ownership to the working principles introduced in the training and adapt them to their own respective working contexts.

Although the training is provided by experts in their fields, the course participants are also considered expert practitioners. Whereas t*raining* has connotations to a linear process where skills are transferred from the teacher to the student, *learning* has connotations to more of a two-way interactive process, and although this is a *training programme*, the ambition is that it will in practice and effect be a *learning programme*. The objective of the course is not to *provide* training, but to *develop* competence. In other words, this is not another mandatory course in need of a 'check', but an opportunity to develop competences that are substantially anchored in the crew's own experiences and reflexive evaluations.

A much-used definition of learning is that learning is a relatively permanent change in behaviour due to education and training, practice, and experience.

Further, a fundamental assumption, or working principle, in the learning framework and methodology of Schön has perhaps best been formulated by Rogers: *"[the] only learning which significantly influences behaviour is self-discovered, self-appropriated learning"* (Rogers, 1961) [5] That implies that the opportunity and the environment for learning can be provided by others, but the learning itself belongs to the learner.

10.7.1.1 Knowledge in Action – tacit knowledge

Schön (2017) acknowledged that among skilled practitioners, much of the knowledge base is tacit knowledge. Thus, many of the things done – the actions taken – when practitioners act, is done on 'autopilot'. The practitioner is acting without thinking about it, or without consciously considering the various steps and actions necessary to fulfil the task. To understand what this means, think about the act of riding a bicycle. Once you know how to do it, you can do it without thinking about what you actually need to ride the bike – how much power you supply to the pedals, what you're doing when you're taking a turn, how you activate the different muscles to keep the balance. In the context of activating extinguishing systems in case of a fire, there may also be considerable tacit knowledge involved; which path is chosen for the runner in order to localise and confirm the fire; what kind of information is sought regarding dangerous goods; what kind of information is exchanged with the engine control room before the fire is actually confirmed; how do you confirm that the correct drencher zone has actually been activated?

10.7.1.2 Reflection in Action

A second central term from Schön, and an important approach to learning and improvement, is *Reflection in action*. Reflection in action involves active reflection on behaviour as it is undertaken. Reflection in action is a way to make the implicit explicit, to turn tacit knowledge into explicit knowledge. By doing that, one is also able to adjust on practices that one believes can be done more effectively. For example, could one think of a quicker way for the runner, or could another runner be sent that would speed up the confirmation given the circumstances of the specific situation? Or could one rethink the traditional pattern of communication to for example ask some additional questions – or fewer ones – or talk aloud in the room in order to include others in the process of creating awareness and making decisions? What is written on the whiteboard and what is not written - is there something during the course of action that could be improved with respect to logging practices?

10.7.1.3 Reflection on action

Lastly, Schön introduced the principle of *Reflection on action*. While Reflection *in* action represents a learning potential that is explored during activities, Reflection *on* action is done after the activity (training, drill, other) has taken place. Reflection on action refers to reviewing, analysing and evaluating the actions that were taken, and how effective they were in achieving the objective or the desired outcome. In practise, this involves reflecting on what was done, what worked well and what did not work so well, what could be done differently the next time, and what would need to be changed in the environment (material, procedures etc) in order to support the change.

As this is done after action, there is better time for reflection, reflection may be done collectively, and reflections and decisions may be documented more thoroughly in order to support future change processes.

10.7.1.4 Implications for practice

A consequence of working in the Knowledge-in-action-mode is that opportunities for identifying suboptimal practices, and to improve, may be lost. Explicating the knowledge in action is necessary to support Reflecting in action, testing out adaptations to achieve more effective individual and group processes/practices. Further, reflecting after action provides opportunities to identify the actions and resources that need to be designed into future behaviours and procedures.

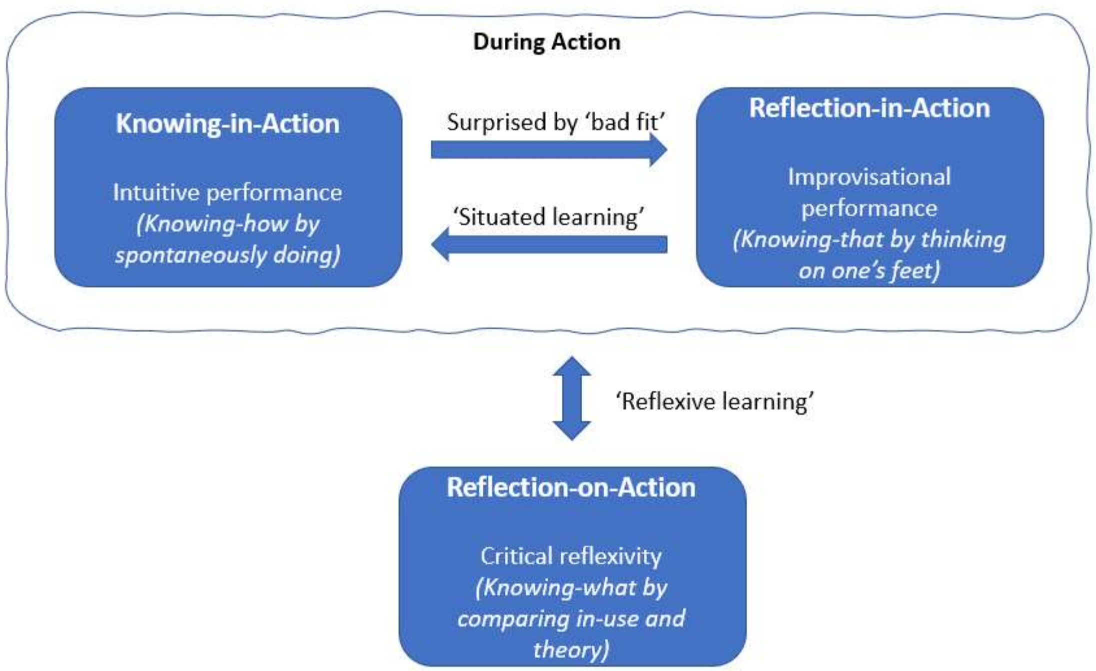


Figure 18. Learning dimensions (adapted from Schön (1987)).

10.7.1.5 How can these principles be applied in training and drills?

After participants have been introduced to the theory/concept of Schön's learning philosophy, we will adopt this learning framework in practise. A brief group exercise will be done on point 1. below. Thereafter, the practical training session starts, where the participants are asked to consciously think about how the tacit knowledge plays out in practise (point 2). At last, during the final debrief after the practical training session, participants will have some time to collectively review their experiences and their learnings in terms of needs for changing of established practices.

1. Before training/drill:
    - describe/explicate tacit knowledge – collective task, write down bullet points
2. During training/drills:
    - reflect actively on actions applying the tacit/explicated knowledge, and consider continuously possible adaptations
3. After training/drill:

- o debrief with collective reflection on how procedures and adaptations worked – what worked well, what did not work? Which embodied skills are functional, which are not? Summarise points to feed back to next comparable event, and for possible changes of procedures and other frameworks for action.

10.7.2 Presentation material for theoretical introduction

The theoretical introduction took place in a classroom (Figure 20). Slides for the lecture are presented in Figure 19:

Figure 19. Slides for theoretical lecture.

Figure 20. From the classroom presentation of theoretical learning module.

10.7.3 Practical introduction (SAS)

The practical module will be mainly hands-on training where trainees will have the opportunity to train the real activation of systems and check the efficacy of the different firefighting media affecting class A fires (Solids) and Class B (flammable solids)

Dangerous Goods (class 4) according to IMDG Code will take part of the training, adding **substances** which are liable to spontaneous combustion and goods that emit flammable gases when they come into contact with water to the drills.

The Safety induction will consist of an explication about the correct use of the Personal Protective Equipment (PPE) that includes:

- Fire gear and firefighting suit
- Fire helmet
- Safety boots
- Safety gloves
- Flash hood
- Breathing Apparatus
- Gas detector
- Safety torch

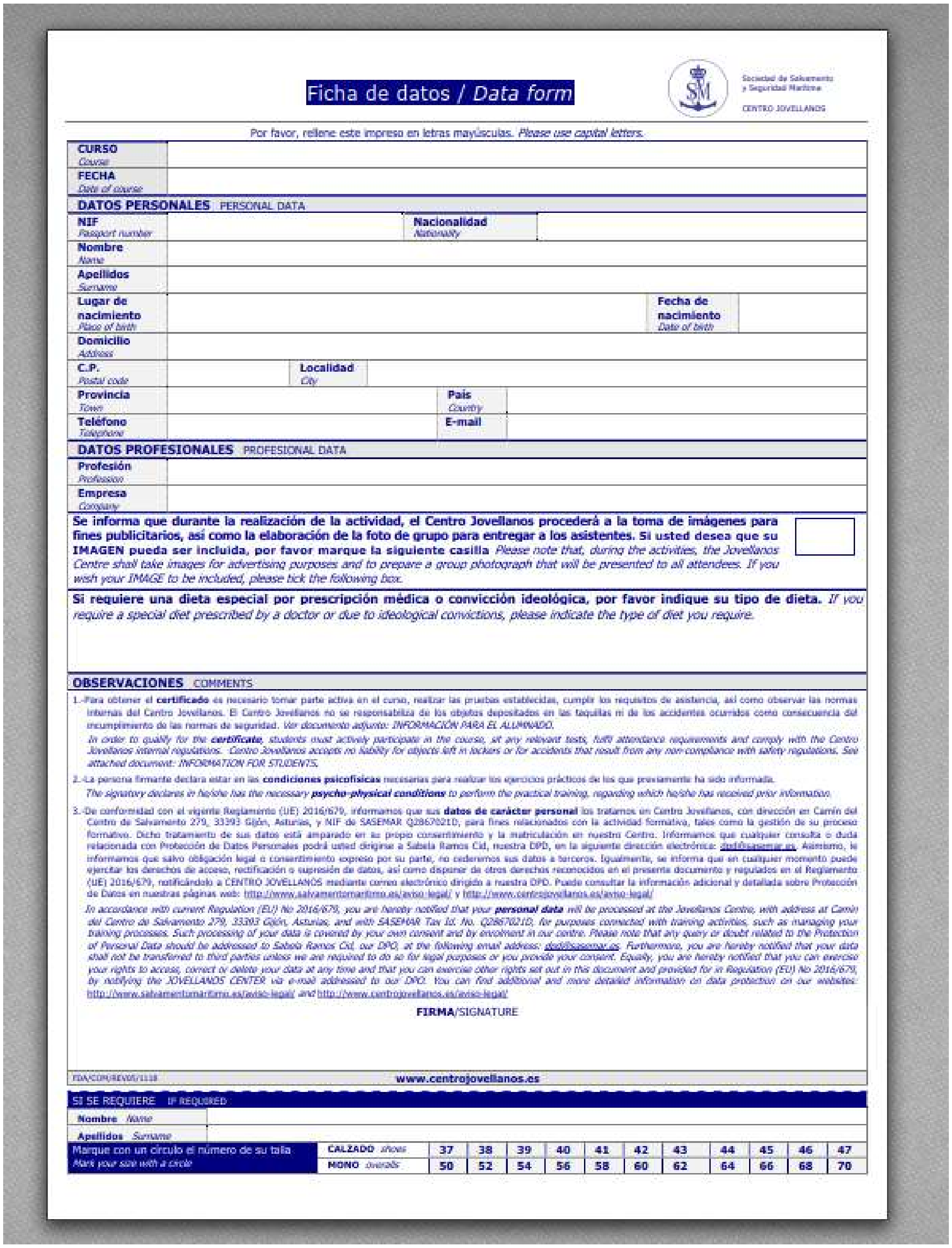
The familiarization with the fire equipment will consist of:

- 45 mm and 25 mm fire hoses
- Fire pump (Hydrant) 7 bar working pressure
- Water nozzles with flow rate selectors
- Portable foam equipment
- Infra-red camera

Fuel needs are:

- 100 litres of diesel
- 8 wooden pallets
- 50 litres of polar solvent

Trainees will be covered by a medical insurance by filling their personal in the following date sheet.



Ficha de datos / *Data form*

Sociedad de Salvamento y Seguridad Marítima
CENTRO JOVELLANOS

Por favor, rellene este impreso en letras mayúsculas. *Please use capital letters.*

CURSO *Course*			
FECHA *Date of course*			
DATOS PERSONALES PERSONAL DATA			
NIF *Passport number*		**Nacionalidad** *Nationality*	
Nombre *Name*			
Apellidos *Surname*			
Lugar de nacimiento *Place of birth*		**Fecha de nacimiento** *Date of birth*	
Domicilio *Address*			
C.P. *Postal code*		**Localidad** *City*	
Provincia *Town*		**País** *Country*	
Teléfono *Telephone*		**E-mail**	
DATOS PROFESIONALES PROFESIONAL DATA			
Profesión *Profession*			
Empresa *Company*			

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Si requiere una dieta especial por prescripción médica o convicción ideológica, por favor indique su tipo de dieta. *If you require a special diet prescribed by a doctor or due to ideological convictions, please indicate the type of diet you require.*

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1.-Para obtener el **certificado** es necesario tomar parte activa en el curso, realizar las pruebas establecidas, cumplir los requisitos de asistencia, así como observar las normas internas del Centro Jovellanos. El Centro Jovellanos no se responsabiliza de los objetos depositados en las taquillas ni de los accidentes ocurridos como consecuencia del incumplimiento de las normas de seguridad. *Ver documento adjunto: INFORMACIÓN PARA EL ALUMNADO.*

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2.-La persona firmante declara estar en las **condiciones psicofísicas** necesarias para realizar los ejercicios prácticos de los que previamente ha sido informada.

The signatory declares in he/she has the necessary ***psycho-physical conditions*** *to perform the practical training, regarding which he/she has received prior information.*

3.-De conformidad con el vigente Reglamento (UE) 2016/679, informamos que sus **datos de carácter personal** los tratamos en Centro Jovellanos, con dirección en Camín del Centro de Salvamento 279, 33393 Gijón, Asturias, y NIF de SASEMAR Q2867021D, para fines relacionados con la actividad formativa, tales como la gestión de su proceso formativo. Dicho tratamiento de sus datos está amparado en su propio consentimiento y la matriculación en nuestro Centro. Informamos que cualquier consulta o duda relacionada con Protección de Datos Personales podrá usted dirigirse a Sabela Ramos Cid, nuestra DPD, en la siguiente dirección electrónica: dpd@sasemar.es. Asimismo, le informamos que salvo obligación legal o consentimiento expreso por su parte, no cederemos sus datos a terceros. Igualmente, se informa que en cualquier momento puede ejercitar los derechos de acceso, rectificación o supresión de datos, así como disponer de otros derechos reconocidos en el presente documento y regulados en el Reglamento (UE) 2016/679, notificándolo a CENTRO JOVELLANOS mediante correo electrónico dirigido a nuestra DPD. Puede consultar la información adicional y detallada sobre Protección de Datos en nuestras páginas web: http://www.salvamentomaritimo.es/aviso-legal/ y http://www.centrojovellanos.es/aviso-legal/

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SI SE REQUIERE IF REQUIRED

Nombre *Name*												
Apellidos *Surname*												
Marque con un círculo el número de su talla *Mark your size with a circle*	**CALZADO** *shoes*	37	38	39	40	41	42	43	44	45	46	47
	MONO *overalls*	50	52	54	56	58	60	62	64	66	68	70

Figure 21. Data sheet filling form for Jovellanos training.

10.7.4 Practice module

Activation of fixed extinguishing systems both drencher and CO_2 will be developed in a close to realistic environment producing real pool fires.

Figure 22. Container prepared to simulate the procedure on the efficient activation of the system.

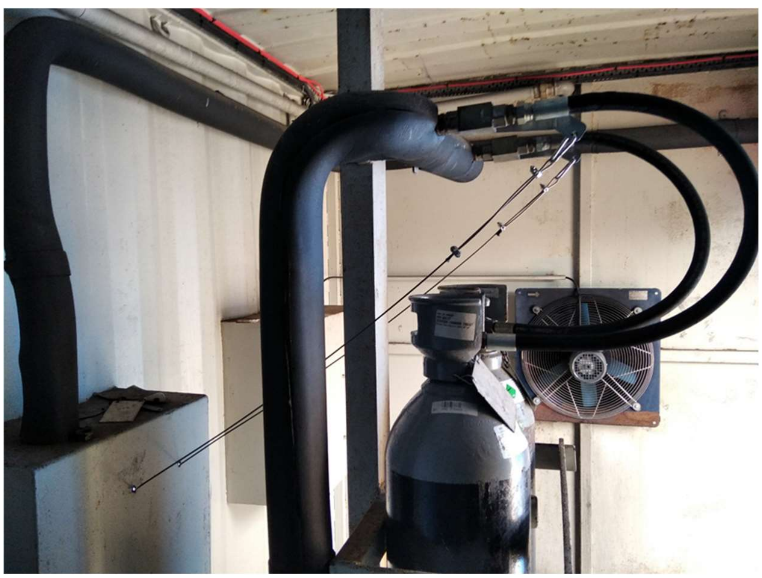

Figure 23. CO_2 cylinders and ventilation

Figure 24. Drencher activation

Post-extinguishing actions like monitoring the development of the fire and checking the efficacy of the system will be incorporated to the training, proceeding in line with the manual firefighting guidelines developed through WP06. The aim of the course is going beyond the simple activation of the system following the procedures implemented on board and the philosophy of the LASH FIRE project about the efficacy of the crew fighting against fires without external intervention.

10.8 Implementation of training course: Practical exercise of CO_2 & drencher activation system

Test the operational effectiveness of fixed fire extinguishing systems, in accordance with applicable performance specifications and legislative requirements.

10.8.1 Script for the demonstration of the training exercise

10.8.1.1 Model course reference

STCW CODE TABLE A- VI/3 KNOWLEDGE, UNDERSTANDING AND PROFICIENCY

3.1 Fire detection systems; fixed fire-extinguishing systems; portable and mobile fire extinguishing equipment, including appliances, pumps and rescue, salvage, life- support, personal protective and communication equipment.

3.1.2 Fire detection equipment

3.1.3 Fixed fire-extinguishing equipment

10.8.1.2 Learning objective

At the end of the exercise each trainee team should be able to efficiently activate the fixed fire-extinguishing system (CO_2 & drencher) on board

10.8.1.3 Safety briefing

Safety briefing by chief trainer of the dos and don'ts during the practical task demonstration. Correct use of PPE.

10.8.1.4 Sequence/script for both CO_2 & drencher

- 6 Hands on Trainees on site (container) (Figure 25)
- 2 OOW/Captains trainees on emergency simulator (Figure 26). They will be communicated with training ground by means of UHF radio. Visual CCTV system
- Ensure that the system has electrical connection
- A car will be placed inside the container with a fire inside the cabin
- DG Magnesium (Mg). CLASS 4.3 IMDG "***Substances which, in contact with water, emit flammable gases*"** will be placed inside the vehicle. No information in the cargo manifest
- Forced ventilation should be stopped
- Head counter
- Check section/zone affected (Figure 27) for CO_2
- Activation of fire pump (water pressure)
- Selection of valves
- Trigger fixed system
- Confirmation with OOW/captain
- Monitoring temperature
- Has system been effective? If not consider manual firefighting (see manual firefighting practical exercise) NOTE: it will be considered that drencher will be not effective due to presence of DG

Figure 25. Container for fixed FF systems activation.

Figure 26. Jovellanos Emergency simulator.

Figure 27. CO_2 cylinders.

10.8.1.5 Assessment

Discusses the below listed checks of the Fixed fire-extinguishing system.

	Practical task - assessment	PERFORMED	NOT PERFORMED
1	Trainee has received the confirmation/presence of a fire		
2	Trainee has checked that first response has not been successful or possible		
3	Presence of personnel in the area. Head count		
4	Trainee confirms the areas where the system has to be discharged		
5	Controls and distribution valves are checked before discharge		
6	Warning alarms (audible/visual)		
7	Forced ventilation is stopped		
8	All doors and openings are locked		
9	Identification of DGs		
10	Release the system		
11	Confirmation that the system has been triggered		
12	Temperature check		

13	Confirmation that the system has been effective		

10.8.1.6 Debriefing

The trainer then debriefs the trainee on the discussed checks made by the trainee (positives and negatives)

10.8.2 Implementation of the training exercise

A total number of 10 participants from three shipping companies attended the course. Two of the participants volunteered to act as captain and first officer on the bridge, while the rest of the participants formed a firefighting group to approach the fire on deck.

The bridge was simulated in a dedicated room in the Jovellanos facilities. This room was equipped with radios, for communication with the fire team. In addition, on a screen on the bridge simulator the officers could watch the fire team, as live video was streamed from the fire location. This was to simulate the CCTV on a real ship. See Figure 28 and Figure 29.

Researchers/training instructors from Jovellanos were present at both locations to guide the participants through the exercise. In addition, five researchers observed the participants – two were located in the bridge simulator and three were located in the field, taking notes, pictures and video in order to document the event for evaluation and further research.

Figure 28. View of the fire scene from the bridge.

Figure 29. Manual firefighting after drencher deployment (view from the bridge).

The deck was simulated by aid of a container and another separate ‘cargo hold’ in the outside area of the Jovellanos facilities.

Figure 30. Training instructor explaining the situation to the course participants.

Figure 31. Car with dangerous goods. Type of dangerous goods indicated by the orange sticker.

Figure 32. At this stage, the CO2 has been activated inside the container.

10.9 Results and evaluation of training course

The evaluation of the training course is comprised by a combination of course participant evaluation and researcher evaluation. As an overall conclusion, the training course was considered as both successful in terms of implementation, and useful in terms of takeaways for the participants. In the following we will provide more details about the results and evaluation, and also reflect on improvement potential for future development of the course.

As the last activity of the course, a collective debrief session was organised, where participants and researchers were asked to reflect on the training course, and to comment on positive aspects and aspects for improvement.

The feedback was framed with respect to how the activities would relate to a real situation, thus point directly to learning points from the course that are applicable both to their daily work and to fire emergency situations.

10.9.1 Evaluation through debrief

Aspects to consider in a real situation (+ represent positives, ÷ represents improvement potential)

- \+ During the exercise, the crew did not take headcount before the activation of CO_2 as a priority. In the debrief session, awareness was established about this. As important as this is in a real situation, it is just as important to include it as part of drills. This is an important learning point to bring back and implement in drills.
- \+ During the training scenario, an injured person was introduced in the midst of the firefighting scenario. This resulted in significant hesitation, and no immediate and quick life-saving actions were taken. During the debrief, awareness was raised about the importance of dealing with such instances, both in real situations and during drills.
- \+ In the training scenario, a noise fan feeding the fire with oxygen was constantly running, making communication and firefighting more difficult. None of the participants took initiatives to ease the conditions by turning off the fan. Discussions in the debrief raised awareness of the importance of acting tactically on such conditions both in real situations and during drills.
- ÷ During debrief, course participants expressed that they found it very useful to train on actual release of fixed firefighting systems in a training scenario, since this increases the realism of the training. One aspect to consider for future improvement of the course is how to meet the challenge that CO_2 system release steps may be different from ship to ship, and so even the realistic training on shore may not be identical to release on each and every ship.

10.9.2 Evaluation through survey

In addition to this researcher/participant co-evaluation of learning outcomes from the course, a survey was distributed to the course participants where they were asked to rate the course with respect to different factors. The result from this survey is presented in the following:

1. The course content was relevant for my job

   All course participants agreed (22%) or strongly agreed (78%) to this statement

2. I would feel more confident on activating extinguishing systems if I had more practical, hands-on training

   All participants agreed (70%) or strongly agreed (30%) to this statement.

3. The course provided more comprehensive training on activation of fixed fire extinguishing systems than other courses I have participated to

67% of the participants agreed or strongly agreed to this statement. 33% of the participants were neutral or disagreed.

4. The theoretical part of the course provided knowledge that makes me better prepared for fire management

   68% of the participants agreed or strongly agreed. 33% of the participants were neutral or disagreed.

5. The practical training on activation of fixed fire extinguish system provided knowledge that makes me better prepared for fire management

   77% of the participants agreed or strongly agreed. 23% of the participants were neutral or disagreed.

6. The theoretical and practical part of the course complemented each other

   88% of the participants agreed or strongly agreed. 22% of the participants were neutral or disagreed.

7. The course gave me an improved understanding of factors that may influence effective activation of fire extinguish systems

   All the participants agreed (89%) or strongly agreed (11%).

Figure 33 shows participants, trainers and researchers taking part in the course.

Figure 33. Training on activation of fixed firefighting systems.

11 Conclusion

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To meet the objective of improved procedures and design for more efficient fixed fire extinguishing system activation, a *reflection, evaluation and change (REC) process* has been developed for ship-specific adaptation of procedures and design. The REC process is developed to be an internal crew process, to be implemented in connection with, and as an extension of, ordinary drills. In the REC process, the crew collectively reflect on and evaluate activation procedures and material/design conditions before, during and after drills, with the aim of producing and implementing recommendations for changes in procedures and design that will increase the efficiency of the extinguishing system activation process.

During on-board demonstration of the REC process, several issues with improvement potential were identified and brought up by the crews, several of which would require small efforts – both in terms of work and financial resources – to implement. The demonstration did not follow up how the improvement suggestions were administered after the demonstration, and whether actual change was implemented. A user guide for the REC process is available as a brief guideline version, see section 9.4.

In addition, a training course for activation of fixed fire extinguishing systems has been developed and demonstrated at the training facilities of Jovellanos training centre. The background for developing this course is the acknowledgement of a current lack of training and familiarization among ro-ro and ro-pax crew members with the realistic activation of fixed firefighting systems (drencher and CO_2).

Drencher activation can be trained and performed on board providing a good knowledge of the drencher system of the specific vessel rather than a general view of the training centre facilities, but on the other hand the intense daily operative of the vessel makes it difficult to incorporate the drencher activation to the mandatory and regular fire drills due to, among other reasons, that cargo space needs to be empty of cargo for the real discharge of water. LASH FIRE recommends the incorporation of the drencher activation to the on-board routines. This can be certified by ship's Captain by filling and signing an Annex of participation on the activation of the drencher system.

CO_2 presents different issues due to the inherent dangers of the gas (asphyxiant even lethal at high concentrations), so the only way to train the real activation will be under a controlled scenario ashore.

The recommendation will be to include the competence of the real activation of firefighting systems to the column 3 (Knowledge, understanding and proficiency) of the table A-II/2 of the STCW Code as the specification of minimum standard of competence for masters and chief mates of ships of 500 gross tonnage or more.

Evaluations from participants at the course show that this or similar courses that let the crew gain hands-on experience with activation of fixed extinguishing systems is experienced as useful and may improve fire safety at sea.

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13.4 ANNEXES

13.5 ANNEX A Definitions of conditions for training module drill

Sociedad de Salvamento y Seguridad Marítima
CENTRO JOVELLANOS

DEFINITIONS OF CONDITIONS FOR THE DRILL OF ACTIVATION OF FIXED SYSTEMS (CO_2 & DRENCHER) AND MANUAL FIREFIGHTING

You will oversee the decision-making process during a land-based fire drill in a simulated scenario (quite different that the conditions that you might find on-board).
Yes, we know this is quite challenging... We will try to assist you giving some few information.
You will be connected with your team on site via UHF radio, besides, you will receive images through a simulated CCTV
We will simulate that the activation of the fixed system in the container (first CO_2, then drencher)

We will simulate that the system has not been effective. Now we must change the scenario. So that the exercise will continue in the hold of our ship simulator, and you will have to control a ***manual firefighting operation***

CO2 & DRENCHER

Fire in the boot of a vehicle

Presence of dangerous goods in the boot of the vehicle. Magnesium powder IMDG Class 4.3 Substance which, in contact with water, emit flammable gases.

Casualty: There is a casualty located close to the car

Drencher pump is ON

Fire detectors Smoke and temperature

Sections One single section for the whole container

Warning alarms: Audible and visual

Doors and opening Can be locked

Mechanical ventilation: Can be started or stopped.

Monitoring of temperature: Can be done by IR camera

MANUAL FIREFIGHTING

Equipment: The team will be equipped with full PPE and SCBA (remember to check the duration of breathable air) HEAD- CUONT , fire hoses, nozzles, IR camera, lifeline, torches, radios, fire blanket to cover the vehicle (dimension 6 x 8 meters), 2 units of dry-powder hand held extinguishers for metals (class D)

Drencher: Should you let the drencher running while the team is inside the space? It is better to stop it?

Casualty: Where is located?

High expansion foam There is a generator to fill the space with foam if needed

Noise The annoying noise is produced by a forced ventilation

Ventilation of smoke the vertical hatch of the hold can be hydraulically opened