White Paper

September 2025

Autonomous Robotic Fire Suppression Systems (ARFSS):
Design, Validation, and Applications in High-Risk Environments

Live-fire validation of the FlameRanger™ Autonomous Robotic Fire Suppression System (ARFSS), conducted by the Research Institutes of Sweden (RI.SE).

UNIFIRE

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I. Executive Summary

The world of fire suppression is on the brink of transformation, led by Autonomous Robotic Fire Suppression Systems (ARFSS). These systems detect fires almost instantly, locate them precisely, and deliver high-volume water or foam streams directly at the source. Unifire's FlameRanger™ is at the forefront of this revolution, establishing itself as the most advanced ARFSS technology on the market. With more than 230 systems operational across six continents, FlameRanger has been saving property and lives every day for years.

The Need for Speed

Fires can double in size every 10 to 60 seconds, depending on factors like fuel type and ventilation. This exponential growth makes immediate suppression essential. Traditional methods—sprinklers, deluge systems, and fire brigades—are often too slow or too indiscriminate. They either respond after minutes have passed or release agent broadly at low density, causing collateral damage while failing to contain the fire at its source.

By contrast, ARFSS deliver fast, targeted suppression right at ignition, shutting off automatically once suppression is complete. This not only reduces damage and downtime but also minimizes water use and environmental runoff. In high-stakes environments, every second truly counts.

Positioning Within the Smart Monitor Spectrum

As outlined in *The Smart Monitor Revolution: From Remote to Autonomous* (see: Appendix 4), smart fire monitor systems exist on a spectrum:

- Remote Operator (RO): controlled in real time by human operators using detectors and live video.
- Automatic Fire Monitors (AFM): detect and discharge automatically but with limited precision and adaptability.
- Autonomous Robotic Fire Suppression Systems (ARFSS): the most advanced, doing everything RO and AFM systems can do and more—combining 3D localization, dynamic targeting, intelligent shutoff, flexible detection integration, networking across multiple units, and remote control from anywhere.

Unifire's FlameRanger is firmly in the ARFSS category, offering the full functionality of RO and AFM systems plus a unique combination of speed, precision, efficiency, and resilience that places it in a class of its own.

Proven Performance

Since 2010, Unifire has continuously refined the FlameRanger, leveraging proprietary electronics and software to stay years ahead of competing solutions. Independent testing by globally respected organizations—including the U.S. Naval Research Laboratory, Jensen

Hughes, the Research Institutes of Sweden (RISE), Thomas Bell Wright, and the EU-funded LASH FIRE project—has consistently validated the system's effectiveness in high-risk scenarios.

Benefits at a Glance

- **Immediate intervention**: typically begins suppression within 15 seconds of ignition.
- **Pinpoint accuracy**: through three-dimensional fire detection and dynamic tracking, robotic nozzles deliver dense, high-volume agent streams directly to the source for maximum effectiveness.
- **Efficiency**: rapid extinguishment minimizes agent use, collateral damage, and runoff.
- **Resilience**: multiple systems can coordinate, providing redundancy and scalability.
- **Flexibility**: integrates with any detection technology and offers remote control via joystick, radio, app, or secure PC (from anywhere in the world).
- **Global support**: Unifire technicians can remotely commission and troubleshoot anywhere in the world.

Industry Need for Autonomous Fire Suppression

In high-risk environments such as waste and recycling facilities, industrial plants, aircraft hangars, storage depots, and large-scale commercial buildings, fire incidents have become increasingly frequent and severe. Facilities with high value assets, high fire-load densities, hazardous materials, and complex operations are especially vulnerable. Lithium-ion batteries, combustible materials, mechanical failures, human error, and environmental conditions all contribute to a growing risk of catastrophic fires.

Because fires grow exponentially, effective suppression demands a rapid, high-volume response targeted at the source. Any delay—or reliance on low-density water discharge—dramatically increases the risk of uncontrollable spread, severe property damage, and loss of life. Traditional fire protection methods cannot consistently deliver this. ARFSS can.

Introduction to the FlameRanger System

The FlameRanger ARFSS is designed specifically to address this critical need. Operating autonomously 24/7, it combines advanced detection technologies with high-flow robotic nozzles to detect and suppress fires—typically in under 15 seconds. Years of testing have optimized its aiming strategy: surrounding and cooling the fire before targeting its core for rapid extinguishment.

The system is flexible: it can integrate with virtually any detection technology, or combine multiple detectors to minimize false alarms. Once activated, FlameRanger's proprietary software directs streams of water or foam with pinpoint accuracy, then shuts off automatically once the fire is out. At any time, operators may take manual control via joystick, radio, or secure digital devices.

With its autonomous precision, adaptability, and round-the-clock coverage, the FlameRanger reduces reliance on human intervention, shortens response time, and dramatically improves outcomes in fire safety.

Purpose of This White Paper

The aim of this White Paper is to equip stakeholders with the knowledge to evaluate advanced fire suppression options and to highlight the speed, precision, reliability, and cost-effectiveness that make the FlameRanger ARFSS the optimal choice for industries facing serious fire risks.

To achieve this, the White Paper demonstrates the critical role of ARFSS in revolutionizing fire protection for high-risk, large-scale environments. By examining the Unifire FlameRanger, it explores how cutting-edge technology, independent validation, and real-world performance have established the system as the leading ARFSS solution worldwide.

II. Overview of the FlameRanger ARFS System

The core technology behind Unifire's FlameRanger and other advanced robotic nozzle systems includes our proprietary components in three key areas, each discussed in more detail below:

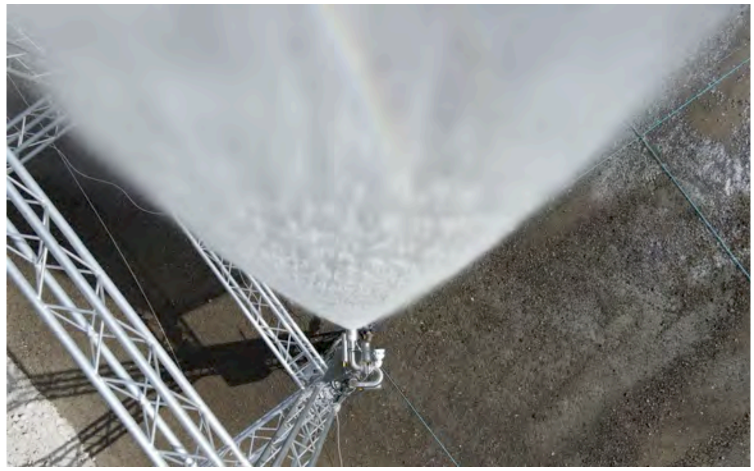
- **Robotic Nozzles**
- **Electronic Hardware**
- **Software**

A. Robotic Nozzles

Unifire's advanced Force™ robotic nozzles are extremely high quality, manufactured in Denmark and are available in two primary models—the Force 50 (2"/50mm) and the Force 80 (3"/80mm). Built from acid-proof, marine grade stainless steel 316L, these nozzles are designed for long-term high performance in the harshest environments, including marine environments. They can be used with fresh water, sea water, foam and additives. They offer a full spherical range of motion. They offer the following flow rates:

- **Force 50:** Up to 2,200 liters per minute (580 GPM) at 12 bars (175 PSI).
- **Force 80:** Up to 5,500 liters per minute (1,453 GPM) at 12 bars (175 PSI).

Ideal for a wide range of applications—including fire protection on- and off-shore, mining, wash-down, cleaning, and fountains—they are powered by precision gearing and industrial robot-type 24V brushless DC (BLDC) motors. Thanks to their extremely high-quality gears, motors, and electronics, the robotic nozzles always stay precisely calibrated, which is critically important for autonomous systems, routine wash-down applications, synchronized fountain systems, etc.

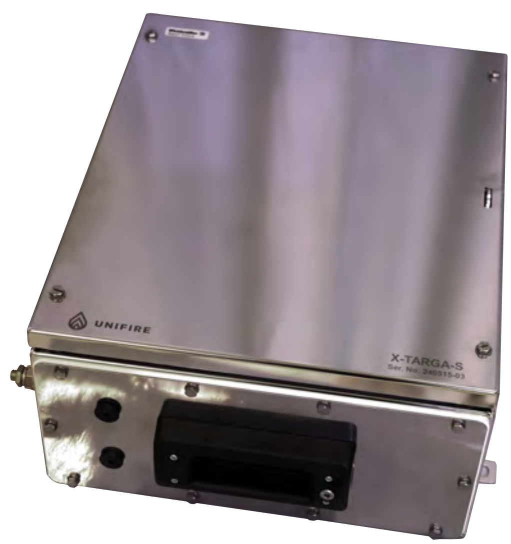


FlameRanger systems typically come with Unifire's Integ adjustable jet/spray nozzle tip. FlameRanger's software can adjust the spray pattern based on the fire's distance—providing a wider cone pattern for fires close up, and a tighter stream for fires farther away to provide greater reach and density.

For much more information about our full robotic nozzle product line, please see our complete Robotic Nozzle Catalog (click here).

B. Unifire's Proprietary Electronic Hardware

Unifire designs its own electronics, manufactured in Sweden, and tailored to provide advanced functionality. Since 2002, Unifire has been continually improving its electronic hardware, offering new features with each generation.



At the heart of every Unifire robotic nozzle system is our TARGA PLC, a 24V DC programmable logic controller that serves as the "brain" of the system, including the

FlameRanger. We also offer the X-TARGA, an IP66/IP67 cabinet version with a built-in power converter.

Key features of the TARGA PLC include:

- A range of communication protocols, including, but not limited to: 2 x CAN 2.0 29-bit header (UniCAN) 125,250,500 kB/s, RS232, RS485 (Modbus, DMX, etc.).
- Physical layer protocols including USB, Ethernet (TCP/IP, web socket), others available per customer requirements.
- Integrated web server and PC connectivity, enabling advanced programming, networking, data exchange, and remote support via any modern browser—no additional software installation required.
- 6 BLDC motor driver slots.
- 4 digital inputs (NPT) + 2 per installed motor driver card, 6 analogue inputs (4-20 mA or 0-5V), expandable with Unifire's 10 digital in expansion box & customizable to customer requirements.
- 8 digital outputs, of which 4 can be set to PWM, expandable to customer requirements.
- Connector types: M12 A/B coded, 4P, 5P, 8P, 12P.

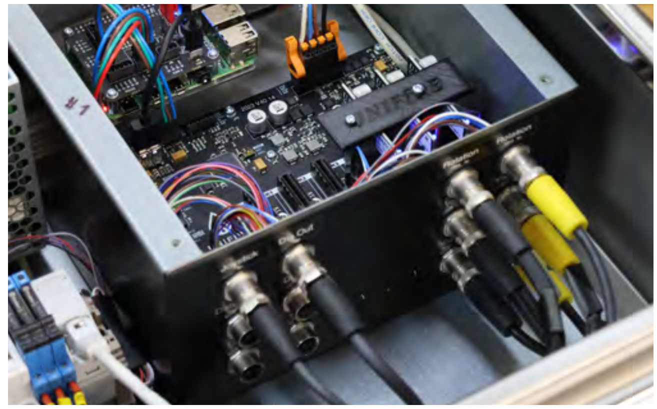
The TARGA is CE Marked, certified to EMCD 2014/30EU, and manufactured in Sweden at ISO-certified facilities.

Unifire TARGA PCB

Unifire CanCape & Raspberry Pi

Unifire BLDC Motor Driver

C. Software



Unifire develops its own proprietary software and firmware, constantly evolving to improve user experience and functionality. Our key software tools include:

FlameRanger™ - Autonomous Robotic Fire Suppression software

Ammolite™ - System setup and monitoring GUI

Spark™ - Data exchange and automation (scripting) servers

ONE App™ - Smartphone or tablet Joystick

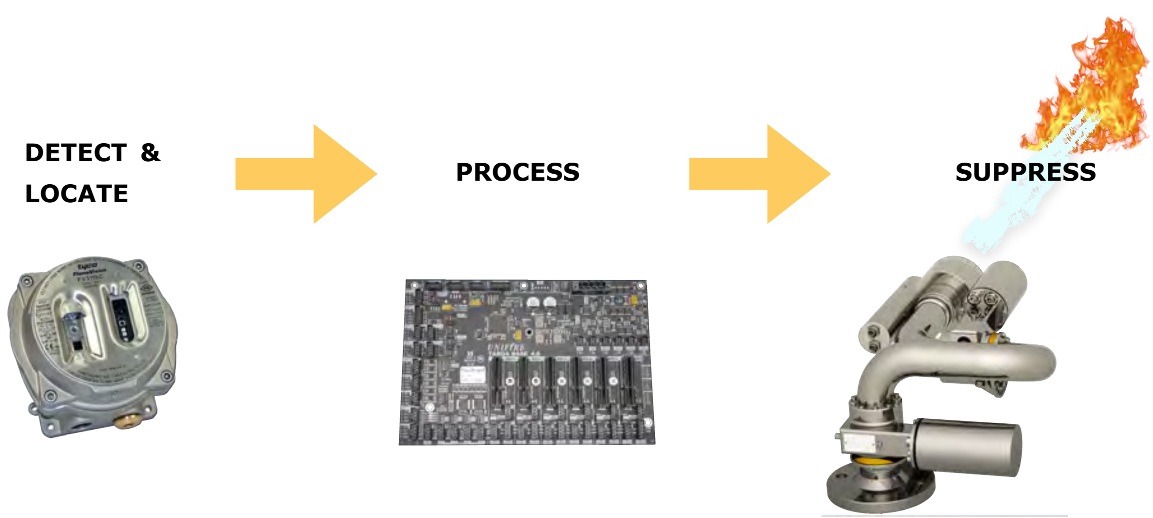
ONE Web™ - Joystick interface for PC

ONE Direct™ - Unique graphical floorpan control for Tablet or PC

FlameRanger

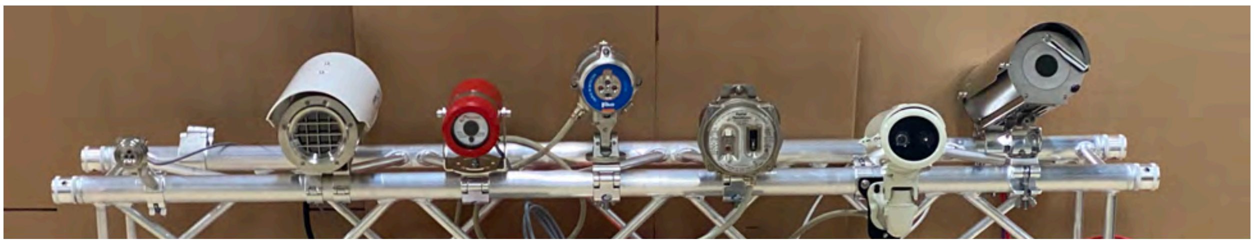
Unifire's FlameRanger system combines fire detection technologies with advanced robotic nozzles to autonomously detect and suppress fires 24/7. The system instantly identifies the presence of flames, calculates their position, and precisely directs water or foam to suppress the fire at its source.

Years of development have refined the system's aiming strategy to first surround and cool the fire, then target the core. This approach ensures efficient containment and extinguishment. Fire suppression begins in as little as 5 seconds and typically within 15 seconds. Once the fire is out, the system automatically shuts off and remains on standby for future incidents.

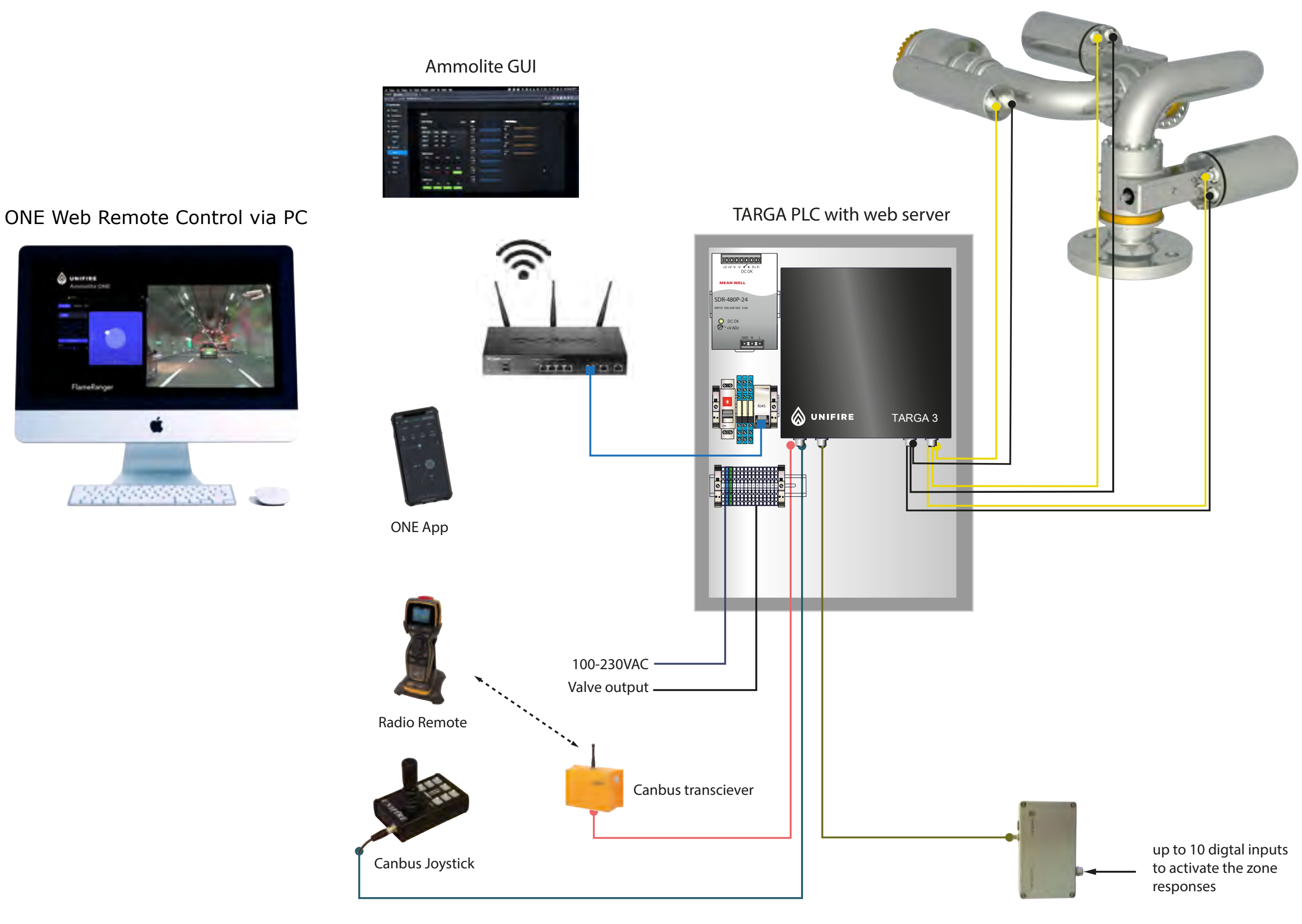


FlameRanger offers clear advantages over other smart fire monitor systems as well as traditional methods like sprinklers or fire brigades. Fires grow exponentially, and every second of delay can mean the difference between quick extinguishment and a devastating fire. Sprinklers and manual response often take 5–20+ minutes, by which time the fire may be uncontrollable. In stark contrast, FlameRanger responds in seconds, using a high volume of water or foam to contain and extinguish the fire directly at is source, minimizing the risk to life, property damage and keeping water usage to an absolute minimum.

FlameRanger is highly flexible, allowing integration with any fire detection system and customization to meet specific customer needs.



In addition to its autonomous function, the system allows manual remote control at any time via a CANbus joystick, radio remote, the ONE app for iOS/Android, and/or ONE Web on any computer connected over a secure network via LAN or WAN.



FlameRanger's Detection and Response Modes

FlameRanger integrates with various fire detection systems and offers multiple response methods based on the detection technology used and project requirements—another unique feature on the market that provides customers the perfect-fit tools for their needs. Response methods include:

1. **3D Location and Dynamic Aiming**: the most accurate method, using pairs of detectors —either Tyco FV311 IR Array flame detectors, IR3-HD flame detectors, or thermal imaging cameras. By triangulating the fire or heat source, the system calculates its precise three-dimensional size and location, then applies dynamic aiming updated 10 times per second to ensure rapid and accurate suppression.

2. **Vector Aiming**: Utilizes one or more IR3-HD detectors placed directly above the nozzle to send vector data for targeting the fire.

3. **Zone Aiming**: Covers pre-defined zones where fires are detected, with the system suppressing the entire zone.

4. **Combined Methods**: Multiple detection techniques can be integrated for optimal coverage and elimination of blind spots.

FlameRanger can handle up to 4 fires simultaneously and integrates with external detectors using various interfaces and protocols (see page 8, above).

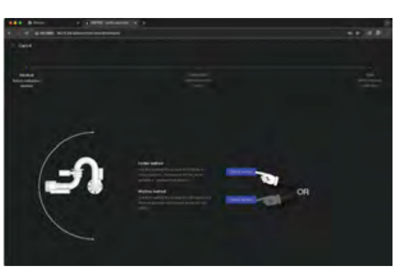
Ammolite™

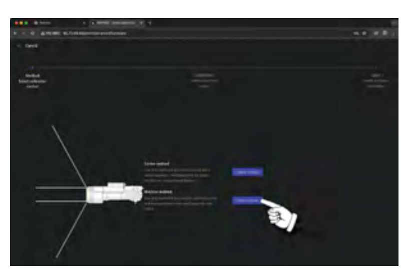
Ammolite is an easy-to-use tool for the setup of all Unifire robotic nozzle systems, including FlameRanger. It comes standard with all Unifire robotic nozzle systems.

Ammolite makes it as easy as possible to configure even the most complex of systems through the intuitive GUI.

Set up through Ammolite is achieved from any computer networked with the TARGA PLC and is performed from any modern web browser, hence requiring no software installation on the computer used.

Below are examples of calibrating the robotic nozzle's horizontal working range (up to 360°), vertical range (up to 180°) and the Integ nozzle tip spray pattern range.





Ammolite is extremely powerful, providing all system data. It features varying access levels, preventing end users from accessing or resetting critical system settings and features, while allowing trained personnel a higher level of access and control, and Unifire technicians full access and control.

Unifire regularly updates Ammolite with improved tools to further simplify the setup of even the most complex systems. For example, Unifire’s FlameRanger 3D Dynamic systems must know the three-dimensional size of the area it protects, and precisely where the fire detectors and robotic nozzle are located spatially within that area. This process previously required entering these data in the coding, yet Ammolite now makes this process simple to enter without any coding whatsoever.

Ammolite instructions can be found in the Force 50 and Force 80 manuals (or, click here).

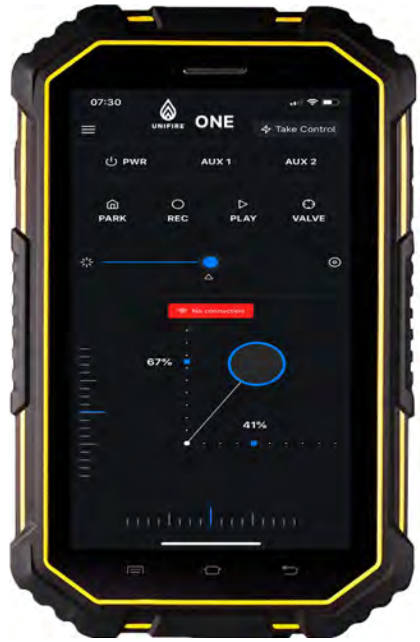
Spark™

The Spark Server software manages the data exchange with external devices, allowing our system to integrate with virtually any external fire detection technology and fire alarm system, utilizing any common industrial protocol over TCP/IP (ModbusTCP, MQTT, REST, Websocket, etc.) and/or local or distributed digital and analogue inputs and outputs.

Moreover, Spark allows us to use Lua Scripts to write advanced automation. One example of a Lua script application is the Unifire wash down GUI, an easy-to-use tool developed for automating repetitive cleaning / wash down sequences. As shown below, all parameters are simply entered with intuitive sliding bars (see our video here).

- **Rotation start and stop point**
- **Rotation speed**
- **Vertical speed**
- **Nozzle spray pattern**
- **Step size**
- **Total number of repetitions**

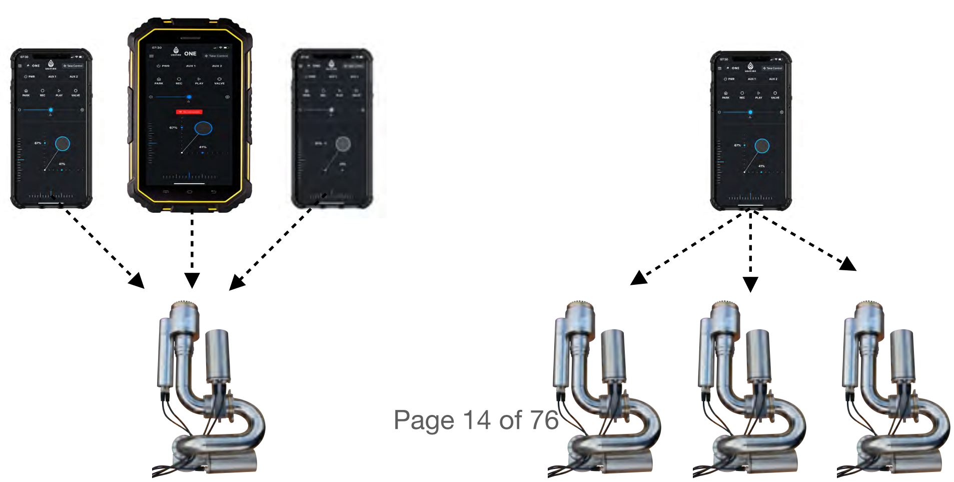
O N E 

App™ 

ONE App is a powerful, full-function and customizable app for iOS/Android devices. It is an optional software license we sell for the same price as our PI CANbus joystick.

ONE App turns any smartphone or tablet into a remote control device with all the functions of Unifire's CANbus and wireless remote control devices. Aiming the robotic nozzle is super easy—just place your finger on the control pad and drag in the direction you want to aim the nozzle. And, the farther you drag, the faster the nozzle moves.

What's more, an unlimited number of authorized devices can control a single system, and a single authorized device can control any number of robotic nozzles.



The ONE App can be offered in any language and customizable logos, colour schemes and functions.

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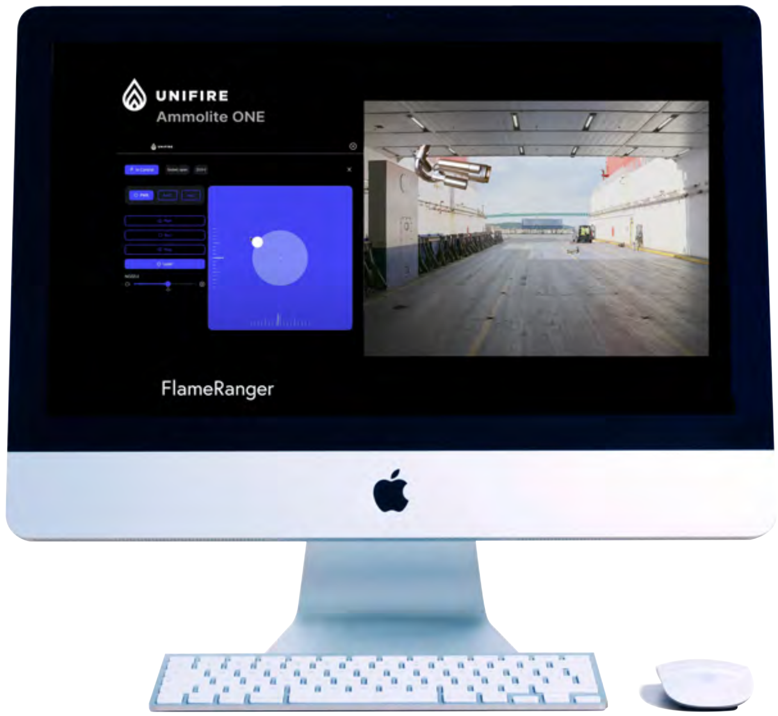
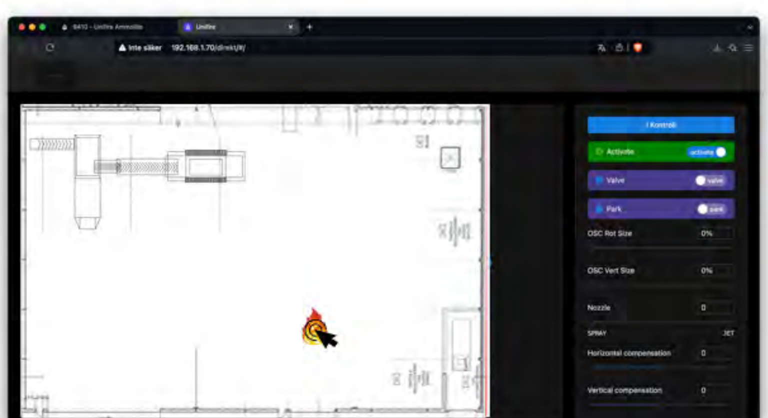
ONE Web™



ONE Web turns any computer with a secure network connection (LAN or WAN) to the TARGA into a full-function remote control. It operates over any modern web browser (Safari, Chrome, FireFox, Edge, etc.). It is an optional software license we sell for the same price as our PI CANbus joystick.

Like the ONE App, ONE Web can control multiple robotic nozzles, and a single robotic nozzle can be controlled from multiple computers with a ONE Web license. And, it also can be customized in terms of language, color scheme, logos, and functions, etc.

ONE Direct™



ONE Direct allows intuitive point-and-click control of FlameRanger and other robotic nozzle systems by using floor plans, images, or live CCTV feeds.

ONE Direct is particularly useful

for ceiling-mounted nozzles, providing ease of control in otherwise challenging configurations.

III. Independent Testing and Validation of the FlameRanger System

Since its introduction in 2010, the FlameRanger system has been rigorously tested year after year to ensure its reliability and effectiveness in high-stakes environments. Unifire has conducted countless tests in its own laboratory as well as in demonstrations for prospective clients and various stakeholders. Testing locations have spanned Sweden, Japan, the United Arab Emirates, Denmark, Norway, Australia, South Korea, and more. Each system—totaling nearly 200 units and growing—undergoes comprehensive testing at Unifire before delivery, followed by an additional round of testing during the commissioning process, to ensure full operational readiness and effectiveness. These extensive testing procedures underscore Unifire’s commitment to quality and confidence in the FlameRanger’s capabilities.

Importantly, in addition to in-house testing, the FlameRanger has undergone rigorous, scientific third-party testing by respected organizations, including the United States Naval Research Laboratory with Jensen Hughes, the Research Institutes of Sweden (RISE) together with Thomas Bell-Wright, as well as numerous tests within the EU-funded LASH FIRE project. These independent evaluations have consistently confirmed the FlameRanger's capability to rapidly detect and precisely locate fires, while accurately directing a high-flow stream to contain and suppress them effectively. Below, we summarize the outcomes of these independent tests, with further detailed reports included in the appendices for reference.

A. Tests Conducted by the U.S. Naval Research Laboratory & Jensen Hughes

The U.S. Navy, faced with the unique challenge of effectively combating fires in Large Volume Spaces (LVS) on naval vessels, approached Unifire in search of an innovative solution. Given the complexities and potential dangers of fires in expansive, confined areas, the Navy required a system that could respond autonomously, precisely, and with minimal human intervention. At the time, Unifire was the only company worldwide to offer an autonomous robotic fire suppression system, making its FlameRanger an ideal candidate for rigorous testing. Conducted jointly by the U.S. Naval Research Laboratory and Jensen Hughes, these tests aimed to evaluate the system's ability to detect, target, and extinguish fires in LVS settings. The FlameRanger met and exceeded the Navy's requirements, with test results demonstrating highly effective performance to the Navy's satisfaction.

The U.S. Naval Research Laboratory (NRL) and Jensen Hughes are among the most respected authorities in scientific research and fire safety engineering. Established in 1923, the NRL is the United States Navy's premier research facility, dedicated to advancing scientific knowledge in support of national defense and security. Renowned for developing advanced technologies, the NRL's expertise and rigorous testing standards make it a credible authority for evaluating fire suppression systems and other critical safety technologies.

Jensen Hughes, a global leader in fire protection engineering, is recognized for its technical excellence and over 80 years of experience in safety, security, and risk-based engineering. The company collaborates frequently with government agencies, regulatory bodies, and private industries to set fire safety standards, conduct thorough fire testing, and develop cutting-edge fire protection technologies. This extensive background solidifies Jensen Hughes' reputation as a trusted and impartial evaluator of fire safety systems.

Together, the U.S. Naval Research Laboratory and Jensen Hughes bring a combined expertise and reliability that make their joint evaluation of the Unifire FlameRanger a definitive measure of its performance, effectiveness, and adherence to the highest standards of safety.

The following is a summary of the tests conducted in a report entitled SUPPRESSION OF SHIPBOARD FIRES IN LARGE VOLUME SPACES USiNG MONITORS - FINAL REPORT December 20, 2015. The report authors are Gerard G. Back and Ryan Grantham of Jensen Hughes, Baltimore, MD, and Hung V. Pham, Lt. Timothy Polyard and John P. Frley, Navy Technology Center for Safety and Survivability, Washington, DC.

The full report is set out in Appendix 1.

I. Table of Primary Results:

Table 3: Large Fire Suppression Test Results

Four large fire suppression tests were conducted to assess the ability of the monitor system to suppress/extinguish large Class A fires for a range of operating conditions.

The large fires consisted of two stacks of 16 standard size oak pallets placed side-by-side. The pallets were elevated 20.3 cm (8.0 in) above the deck to allow for ignition by heptane pan fire located under each pallet stack.

The results of the large fire suppression tests are summarized in Table 3. A series of video snapshots showing the suppression sequence for each test are provided as Figures 21-24.

In short, **all of the fires were quickly suppressed and controlled within a few seconds** of the stream reaching the fire/fuel package. A short time later (seconds), both stacks of wood pallets were completely extinguished. In a few tests, this occurred before the heptane pan fires used to ignite the pallet stacks self-extinguished (i.e., burned out of fuel). A detailed description of each test is provided in the following sections.

Table 3 – Large Fire Suppression Test Results

Test #	Description	Activation Time	Control min:sec	Extinguishment min:sec	Total Water (gal)
FS-7	Large Fire Suppression (Manual Control)	3:00 pre-burn	0:10	0:20	<100
FS-8	Large Fire Suppression (Pre-programmed Targeting)	3:00 pre-burn	0:15	0:30	125
FS-9	Large Fire Prevention (Automatic Activation and Targeting)	0:10 act.	instant	instant	<25
FS-10	Large Fire Suppression (Delayed Automatic Activation and Targeting)	3:00 pre-burn	0:10	0:15 wood 1:00 pans	~65 wood 250 pans

II. Test Results:

7.3.2.1 Test FS-7: Large Fire Suppression (Manual Control)

The first large fire suppression test assessed the ability of a novice operator to combat a large Class A fire. After the three minute preburn, the monitor was manually activated using the joystick (by a novice) and the fire was extinguished. The novice operator was able to apply water to the fire within a few seconds of system activation. Within seconds, the fire was quickly suppressed with the residual burning located low, on the backside of the two stacks. By 20 seconds into the discharge, there was no visible flaming inside of the stack of pallets and the fire was determined to be extinguished.

7.3.2.2 Test FS-8: Large Fire Suppression (Pre-programmed Targeting)

The second large fire suppression test assessed the ability of a preprogrammed manually operated monitor to suppress/extinguish a large Class A fire.

During the test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time). After the three minute preburn, the monitor was manually activated using the “Play Back” function to allow the monitor to automatically suppress/extinguish the fire.

The monitor was able to apply water to the fire within a few seconds of system activation. By 10-15 seconds into the discharge, the bottom of the array had been extinguished with only a limited amount of burning observed near the top of the two stacks. By 30 seconds into the discharge, there was no visible flaming inside of the stack of pallets and the fire was determined to be extinguished.

7.3.2.3 Test FS-9: Large Fire Prevention (Automatic Activation and Targeting)

The third large fire suppression test assessed the ability of a fully automatic system (detection and automatic targeting) to detect and suppress/extinguish a fire in a large stack of Class A materials.

The system detected the fire so quickly, that the firefighting party igniting the heptane pan fires below the stacks of pallets, had to run out of the hangar after ignition. The system applied water to the fuel package within 5 seconds of ignition. The applied water prevented the pallets from igniting but the heptane pans located below the stacks continued to burn until all of the fuel (heptane) in the pan had been consumed. The continued burning of the pans was expected since the monitor was discharging water during this test. If the monitor had been discharging AFFF, the heptane pans would have been immediately extinguished.

7.3.2.4 Test FS10: Large Fire Suppression (Delayed Automatic Activation and Targeting)

During this test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time).

The system detected and aimed the monitor at the fire within five seconds of ignition but the water supply was not activated until three minutes later. Within seconds of water application, the fire was quickly suppressed with the residual burning located low, on the backside of the two stacks. By 15 seconds into the discharge, there was no visible flaming inside of the stack of pallets.

7.3.3 Multiple Small Fires

[A] test was conducted at the end of the test series to assess the systems' capabilities against multiple fires. The cribs were ignited (using small pans of heptane) and allowed to burn for one minute prior to activating the monitor system.

According to the manufacturer, the detection system records the location of the three fires and attacked the fires in the order in which they were detected. The system initially applied water to the fire located in Grid Sector 2. Within a few seconds of water application, the fire was completely extinguished.

The system then applied water to the fire located in Grid Sector 7. Within a few seconds of water application, the fire at this location was also completely extinguished.

The system then applied water to the remaining fire located in Grid Sector 5. Within a few seconds of water application, the fire at this location was also completely extinguished.

III. Report Conclusion:

The results of this investigation demonstrate the potential for using automated monitors for protecting LVS on USN Ships/Platforms. Additional testing is recommended to assess the capabilities of this technology in fully loaded, highly clutter spaces representative of actual LVS.

B. Tests Conducted by RISE and Thomas Bell-Wright

RI. SE | Research Institutes of Sweden

THOMAS BELL-WRIGHT INTERNATIONAL CONSULTANTS

The tests conducted by the Research Institutes of Sweden (RI.SE) and Thomas Bell-Wright were initiated at the request of Johnson Controls International (JCI) and Tyco, then partners of Unifire, to evaluate the FlameRanger's effectiveness in protecting high-rise building façades from fire. For these large-scale tests, a building façade mock-up was constructed specifically to simulate real-world fire scenarios. Numerous fires were ignited both on the surface of and within the structure, challenging the FlameRanger to detect, locate, precisely target, and suppress fires originating in and spreading across the wall. Each test validated the system's capabilities, demonstrating with undeniable clarity that the FlameRanger could achieve these objectives reliably and effectively.

The Research Institutes of Sweden (RISE) and Thomas Bell-Wright International Consultants are recognized authorities in safety testing, certification, and technological advancement. RISE, a leading Swedish research institution, operates across sectors such as fire safety, energy, and engineering, offering comprehensive testing, certification, and research services to promote industrial competitiveness and sustainability. Known for its scientific rigor, RISE collaborates with Swedish government agencies, industry leaders, and European regulatory bodies. Its certification services ensure that products and systems meet established regulations and standards, reinforcing its reputation as a trusted evaluator for critical safety systems like fire suppression.

Thomas Bell-Wright International Consultants, based in Dubai, UAE, is a premier independent testing and certification organization specializing in building and fire safety testing within the Middle East. The organization's extensive experience in fire performance testing spans a diverse range of industries. Known for strict adherence to international standards, Thomas Bell-Wright works closely with government regulators and private sector clients to validate product safety and ensure regulatory compliance. This commitment to quality and international standards has established Thomas Bell-Wright as a leader in safety testing across the region.

Together, RISE and Thomas Bell-Wright conducted approximately 60 separate tests of the Unifire FlameRanger, all based on globally recognized testing standards. This rigorous joint assessment further demonstrates the FlameRanger's capabilities, confirming its consistent effectiveness in rapidly detecting, locating, and suppressing fires. The collaboration between these two esteemed institutions provides a robust, scientifically grounded validation of the FlameRanger's reliability and suitability for high-risk environments, solidifying it as a trustworthy solution in the fire suppression landscape.

A summary of the findings is set out below and in Appendix 2. Note that the name SPRAYSAFE was JCI/Tyco's brand name of Unifire's FlameRanger. Furthermore, the document in Appendix 2, is a summary by JCI/Tyco of the full reports, which are the property of Johnson Controls and Tyco and hence not available to Unifire. Video clips of some of the testing can be viewed on YouTube:

Summary of the SPRAYSAFE [FlameRanger] Autonomous Fire Suppression System

The document summarizes a test program conducted to assess the effectiveness of the SPRAYSAFE [FlameRanger] Autonomous Fire Suppression (AFS) system. The system is designed to address the growing global concern of fires spreading rapidly on buildings with combustible cladding materials.

Test Program

A full-scale fire test program was conducted in January and February 2018 by Thomas Bell-Wright International Consultants (TBWIC) and the Research Institute of Sweden (RISE).

Objectives:

Validate the system's ability to detect and locate early-stage fires.

Assess water distribution to the fire location.

Evaluate the system's ability to prevent fire spread on buildings with combustible façade materials.

Test Setup

A 35-meter-wide by 25-meter-high test wall was built, representing a portion of the maximum system coverage area.

Flame Detectors: Two Tyco model FV311 flame detectors, spaced 50 meters apart, were installed, providing a detection coverage area of 1,250m2 (30% greater than the test wall area).

Robotic Monitors: Two independent SPRAYSAFE AFS [Unifire Force 50] robotic monitors were installed at the wall's vertical edge.

One at the bottom to simulate fighting a fire upwards, and one at the top to simulate fighting a fire downwards.

This setup allowed assessment of the total coverage area of a single monitor by combining upward and downward coverage.

Tests: Two test series were conducted:

Targeting tests (T1): Assessed the system's ability to detect and accurately target small fires within its coverage area under various pressure and flow conditions.

Large-scale performance tests (T2): Evaluated the system's ability to prevent fire spread on a simulated full-scale façade using combustible cladding.

Test Results

Targeting Tests (T1):

28 tests were successfully completed.

Average detection time: Under 10 seconds.

Average water delivery time: 12 seconds.

All targeted fires were highly suppressed or extinguished.

Large-Scale Performance Tests (T2):

3 tests and a free-burn (no suppression) were conducted.

Suppression tests resulted in less than 10% exterior cladding damage.

Peak temperature in the eave and cladding cavity was 95°C for less than one minute.

Temperature remained below 40°C for over 90% of the test duration.

Water application provided rapid fire knockdown and local extinguishment of flames.

The cascading water flow prevented significant delamination, failure, and breach of the aluminum façade material.

6. Conclusions

The SPRAYSAFE AFS **[FlameRanger] system can effectively target and contain combustible façade fires involving polyethylene core aluminum composite panels**.

C. Tests Conducted with the 3-Year LASH FIRE Study

The LASH FIRE project (https://lashfire.eu/) was an ambitious, three-year EU-funded initiative conducted from 2020 through 2023. The study was aimed at enhancing fire safety aboard Roll-on/Roll-off (RoRo) passenger and cargo ships, which present unique and complex fire risks due to their design and operations. Bringing together a consortium of leading maritime industry stakeholders—including Unifire AB—research institutions, and regulatory bodies, the project focused on developing innovative fire prevention, detection, and suppression technologies tailored to the challenges of RoRo vessels. These challenging environments, characterized by high fire loads, and limited compartmentalization, demand advanced solutions capable of responding quickly and effectively to mitigate potential disasters.

Unifire AB was a Consortium partner, serving in the Fire Detection and Fire Suppression work packages. As part of the LASH FIRE project, the Unifire FlameRanger was subjected to rigorous testing to evaluate its performance in the demanding conditions of open weather deck fire detection and suppression. The tests aimed to assess the system's ability to detect fires rapidly, locate them precisely within large, open spaces, and suppress them effectively before they could escalate. Given the critical need for dependable fire protection on RoRo vessels, the FlameRanger's capabilities were put to the test under realistic and challenging scenarios. The results demonstrated the system's reliability, precision, and effectiveness, confirming its suitability for deployment in the maritime industry and reinforcing its position as a cutting-edge solution in fire suppression technology.

Public reports from the LASH FIRE study are available at: https://lashfire.eu/deliverables/. Of relevance to this white paper and the FlameRanger, see: Work Package 9 and Work Package 10. Some of the relevant portions of these reports are summarised below and see attached as Appendices 3, 4 and 5.

The LASH FIRE project (www.lashfire.eu) is an international research project aiming to significantly reduce the risk of fires on board ro-ro ships by developing and validating effective operative and design solutions. LASH FIRE is addressing a total of 20 challenges covering the entire 'fire protection chain', and it comprises both preventive and mitigating risk control measures in all stages of fires originating in ro-ro spaces. The project has received funding from the European

1. Report: D10.2 Onboard demonstration of weather deck fire-extinguishing solutions, June 2023

1. Executive summary

This report summarizes the findings and outcomes of an onboard demonstration conducted by Unifire AB (UNIFIRE) to validate the effectiveness of an autonomous fire monitor system in detecting and suppressing fires on a ro-ro weather deck (Task T10.8). The demonstration was conducted onboard the Stena Scandinavica vessel in the Harbor of Gothenburg on May 23, 2023.

Problem definition

The objective of action 10-B is to develop and demonstrate feasible and effective system solutions. While doing this, several aspects need to be considered, such as the weather and other environmental conditions, the fire hazards, specific requirements, and other challenges that influence the installation and operation of the systems.

The project description states that “Quick system activation, safe controlling, high coverage and fast fire suppression are fundamental criteria for the systems, which also need to sustain the harsh environmental conditions.” The development work should additionally be based on the most recent technological advances in the field, in other words a state-of-the art review is required, identifying the newest technology, ideas, and features.

Task T10.8, the subject of this report, is to demonstrate the developed solutions by means of live, onboard fire tests.

Method

The performance of the autonomous fire monitor system was demonstrated in a series of onboard fire tests conducted on the open weather deck of the Stena Scandinavica ro-ro vessel. The vessel was equipped with an autonomous fire monitor system positioned to detect and suppress fires on the weather deck as described in Deliverable D10.3 (Description of the development of weather deck fire-extinguishing systems and selected solutions).

Two small propane gas burners were used to generate flames on the open weather deck (Figure 8). Each produced flames with approximate dimensions of 60 cm × 60 cm at the base and a height of 60 cm.

A total of twelve (12) separate fire tests were conducted. For each of the twelve tests, the fire was positioned in a different location on the weather deck. Prior to the ignition of the propane gas burners, the autonomous fire monitor system had no information about whether, when or where a fire would be ignited.

Results and achievements

The results of the demonstration were highly successful. The autonomous fire monitor system demonstrated its ability to rapidly and accurately detect fires, determine their

locations, and aim the water stream for effective fire suppression, initiating suppression in under 15 seconds of fire ignition. Moreover, the system extinguished all twelve fires in under 15 seconds from ignition, without any human intervention.

…

Exploitation

The overall results of Task T10.8 was to demonstrate the developed solutions by means of live, onboard fire tests. The purpose of the onboard demonstration was to assess the effectiveness of an autonomous fire monitor system in rapidly detecting and suppressing fires on a real weather deck, thereby improving fire safety measures. By showcasing the system's capabilities, the demonstration aimed to build confidence among stakeholders, highlighting its autonomous functionality and its successful integration as an example for ship installations.

…

4 Description of the developed fire monitor system solutions

4.1 Autonomous fire monitor system

4.1.1 Overview of system parameters and installation

A remote control and fully autonomous fire monitor system developed by UNIFIRE and design and installation criteria in terms of fire detector and fire monitor placement and flow rate demand was developed (see Report D10.3, Description of the development of weather deck fire-extinguishing systems and selected solutions). For best performance, the detectors should be installed as high up as practically possible. This provides better viewing angles that allow more precise positioning of a fire. For a similar reason, the fire monitors should also be elevated. One autonomous system (one fire monitor and two detectors) has been confirmed to cover an area of 30 meters (W) by 50 meters (L) using 1200 liters/min at 5 bar inlet pressure. The width is representative t of weather decks.

A minimum of two systems must cover the same area from opposing angles. A fire will then be effectively suppressed from opposing angles, and under windy conditions, it is expected that the effect of the wind will be balanced out. It should be emphasized that the two systems operate simultaneously and completely independently of each other. The autonomous fire monitor system that was developed is considered a viable and realistic solution to provide effective autonomous fire protection on weather deck. The assumption is that ships in the future will be operating increasingly autonomously, and the crew will be small.

4.1.2 Description of the developed remote control and fully autonomous fire monitor system

The fully autonomous fire monitor system developed by Unifire is capable of rapid and accurate fire detection and targeted fire suppression by means of a two-inch (2”) fire monitor1, without any human intervention required. The autonomous fire monitor system is also capable of being remote controlled by a human operator at any time, regardless of whether autonomous suppression has been initiated.

The fire monitor can also be installed without detectors and be remote controlled by crew members by means of a variety of remote control devices. It can also record an operator's use of the remote control device, store it to memory, and play it back in a continuous loop; which recording can be initiated by pressing the "play" button on the remote control device, or can be activated by means of an input from an external detector alarm signal or other input signal. In the case of both the autonomous fire monitor system and the remote control fire monitor system, each fire monitor can be controlled by multiple remote control devices, which can be a tethered joystick and/or can operate wirelessly by radio remote control and/or by a computer over a WAN or LAN. Furthermore, the remote control devices can be placed in any location (or locations) on the ship, allowing for safe control access in the event of a fire.

…

6 The installations and their objectives

In a series of tests conducted in Borås, Sweden, in May 2020, it was established that the developed autonomous fire monitor system was able to rapidly detect fires in multiple locations, accurately determine their locations in three-dimensional space, and accurately and effectively aim the fire monitors water stream to suppress the fire at and around its source.

In a second series of large-scale fire tests conducted in Trondheim, Norway, in September 2022, it was established that the developed fire monitor system could effectively suppress and contain fires simulating a burning freight truck trailer fire.

The objective of the installation of the system that is the subject of this document was to achieve a real-life demonstration of the effectiveness of an autonomous fire monitor system to suppress fires on an actual ro-ro weather deck.

To achieve this aim, the autonomous fire monitor system was installed to protect the weather deck of the Stena Scandinavica (refer to Figure 7). Propane gas burner fires were ignited in twelve different positions on the weather deck of the to determine whether and how the autonomous fire monitor system would perform.

Figure 7. Autonomous fire monitor suppressing a weather deck fire and showing the position of the system's Force 80 fire monitor and its two IR3 flame detectors.

7 Results and observations

7.1 Fire test results

In each of the twelve demonstration fire tests conducted, the autonomous fire monitor system rapidly and successfully detected the fire and aimed the water stream directly at and around the fire. Moreover, the system extinguished each of the twelve weather deck fires in under 15 seconds from ignition, without any human intervention.

7.2 Observations

It was observed that in each of the twelve demonstration fires placed in separate locations onboard the Stena Scandinavica:

- that the autonomous fire monitor system was able to rapidly detect the fire; and
- accurately determine the three-dimensional coordinates of the fire; and
- accurately guide the fire monitor's stream of water to suppress the fire by oscillating over and around the fire; and
- the autonomous fire monitor extinguished each of the fires in less than 15 seconds from the ignition of the propane burners.

8 Discussion

This document describes the demonstration and testing of a remote controlled and autonomous fire monitor system for the protection of weather decks, as part WP10-B, Task T10.8.

The objectives of Task T10.8 were met, and **the demonstration clearly established the effectiveness of the system to rapidly detect fires on a ro-ro weather deck, accurately determine the fires' three-dimensional positions and autonomously and effectively suppress the fires—all without any human intervention, yet with the ability of a human operator to remotely control the fire monitor at any time.**

2. Report: D10.3 Description of the development of weather deck fire-extinguishing systems and selected solutions, February 2023

The following are excerpts on the testing portion of the report. The full report is set out in Appendix 3.

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

8.1 Objectives of the tests

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

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

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

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

8.2 The FlameRanger system

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

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

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

8.3 The test area

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

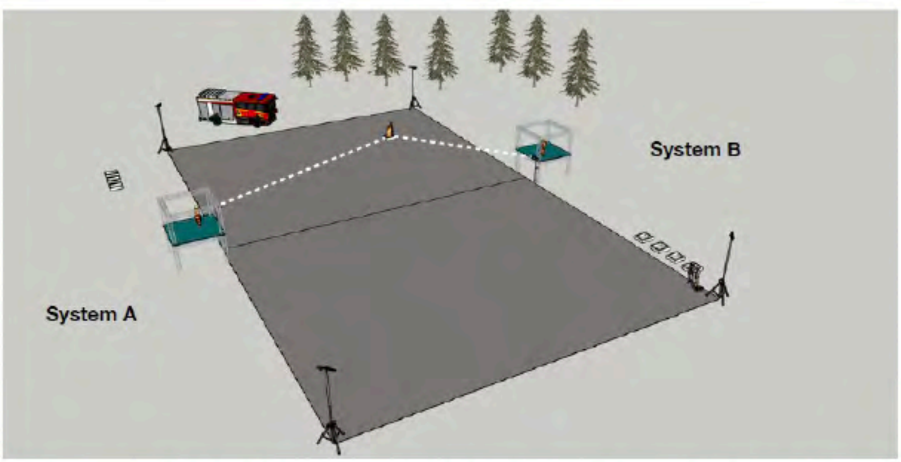


Figure 16. An illustration of the testing approach, where two complete autonomous systems (denoted System A and System B, respectively) were installed to provide full coverage of the 30 m x 50 m test area.

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

8.4 The fire monitors

The fire monitors in an actual installation are typically installed at a vertical distance of 7 m or more over the surface of the weather deck. However, for these tests, the ground surface was assumed to represent the top of the cargo (freight trucks, semitrailers, and similar

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

types of vehicles) on a deck. In Europe, their maximum allowed height is 4,0 m. Based on this restriction on height of vehicles, the fire monitors were installed vertically 3 m above the ground. Figure 18 shows one of the two fire monitors and the truss tower used for the installation. Water was supplied via DN63 fire hoses laid on the ground.

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

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

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

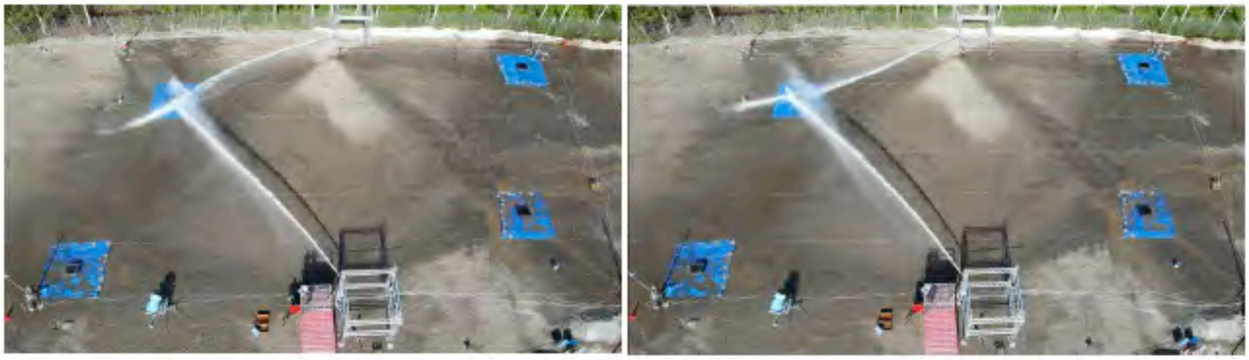


Figure 24. Sequential ignition of four fire test sources positioned symmetrically on the test area, using two autonomous systems.

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

8.5 The fire detectors

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

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

8.6 The fire test sources

The fire test sources were commercial fire generators developed and used for training purposes. Each device consists of a propane gas burner connected via a hose to a propane gas cylinder. The flow of gas is remotely controlled and electrically ignited. The fire could therefore be ignited and turned off with a push-button and the gas flow was turned off as soon as water from the fire monitors was applied, i.e., the fires were not extinguished by

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

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

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

the application of water. The flame height was approximately 1 meter. The fire sources were positioned on a tarpaulin that protected the ground from the impact of the water stream. Figure 20 shows the burner arrangement.

8.7 The water supply

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

Figure 21. The water supply arrangement.

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

8.8 Measurements and documentation

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

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

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

8.9 Simulation of wind conditions

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

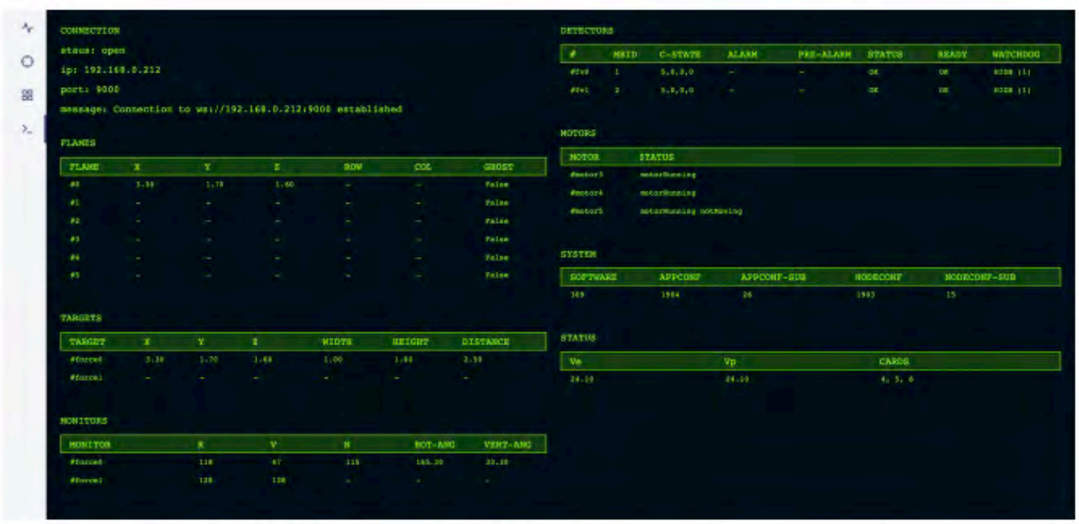


Figure 22. Example view of data from the software of the autonomous system.

8.10 The test program set-ups

The following was tested:

- **Fire detection testing:** For these tests, the fire sources were positioned at different locations. The fires were lit in sequence and the time to detection was measured. In addition, a comparison was made between the actual coordinates and the coordinates documented in the software.

- **Precision testing using one autonomous system:** The first series of tests involved one FlameRanger system, i.e., a system with one fire monitor and two fire detectors. The fire sources were positioned at different locations and sequentially ignited and turned off. The time from the ignition of the first fire source to the last was about 70 seconds. The test was repeated to confirm results and to collect additional measurement data. The scenario was also repeated with fire ignition in a different order.

- **Precision testing using two autonomous systems:** These tests were similar to the ones described above but involved both autonomous systems simultaneously.

- **The influence of wind on the water stream:** These tests were conducted with a snow cannon that locally generated high air velocities. The cannon was either positioned perpendicular to, or directly opposite of, the water stream using different water stream throw lengths.

• **The influence on fire detection of rain and fog:** Rain and fog were simulated using a fire hose stream of water directed into the air flow of the snow cannon and by using the water spray nozzles on the perimeter of the cannon itself. The possibilities for fire detection in such weather environments was tested.

8.11 Test observations

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

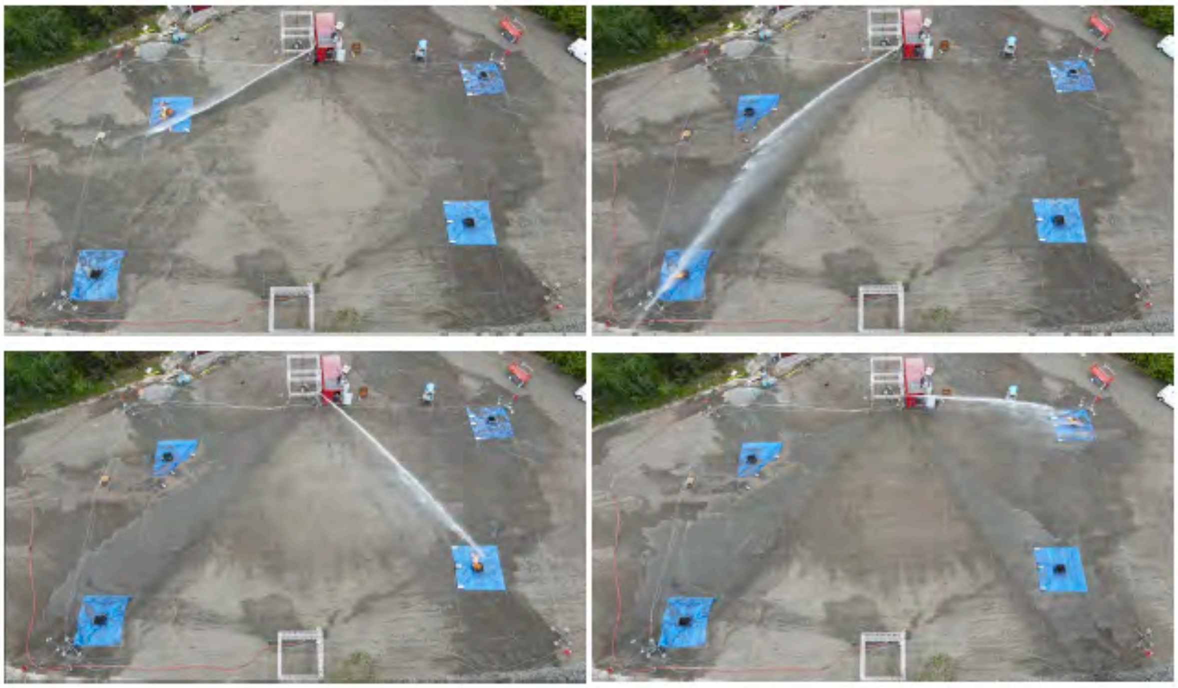


Figure 23. Sequential ignition of four fire test sources positioned symmetrically in the test area, using one autonomous system.

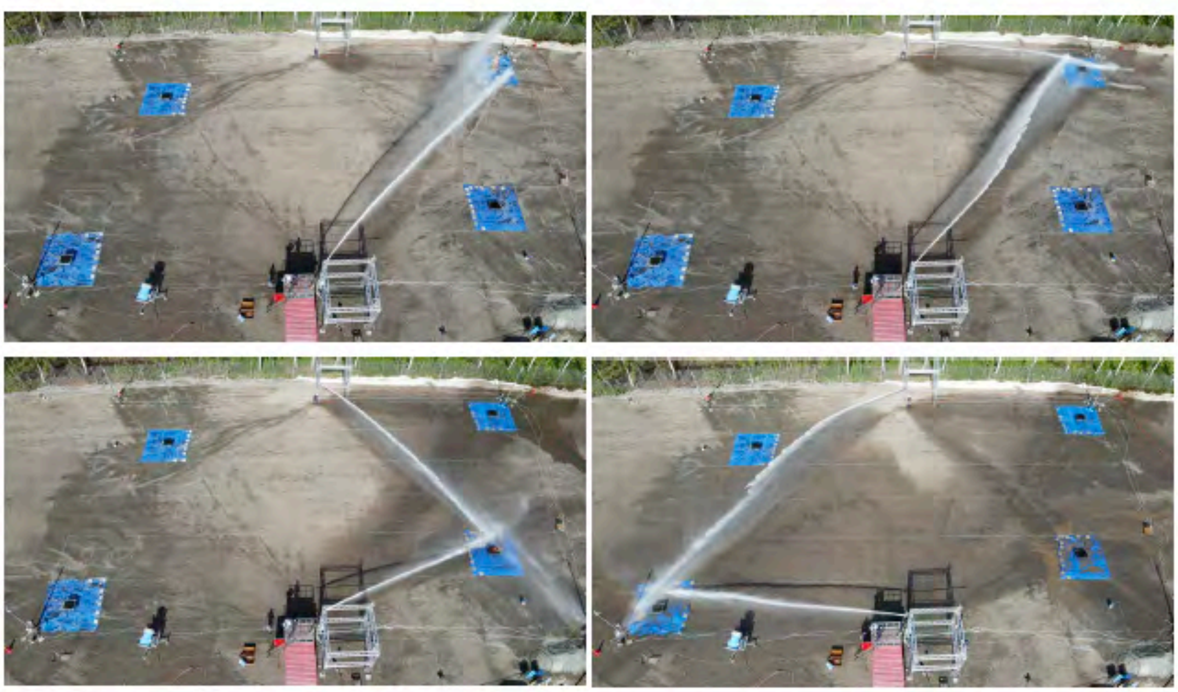


Figure 28. *Rain and fog were simulated using a fire hose stream of water directed into the air flow of the snow cannon. The intent was to test the possibilities for fire detection in such environment. Fire detection ability was not influenced.*

8.12 Test results and conclusions

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

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

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

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

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

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

9 Large-scale fire monitor validation tests

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

9.1 The test area

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

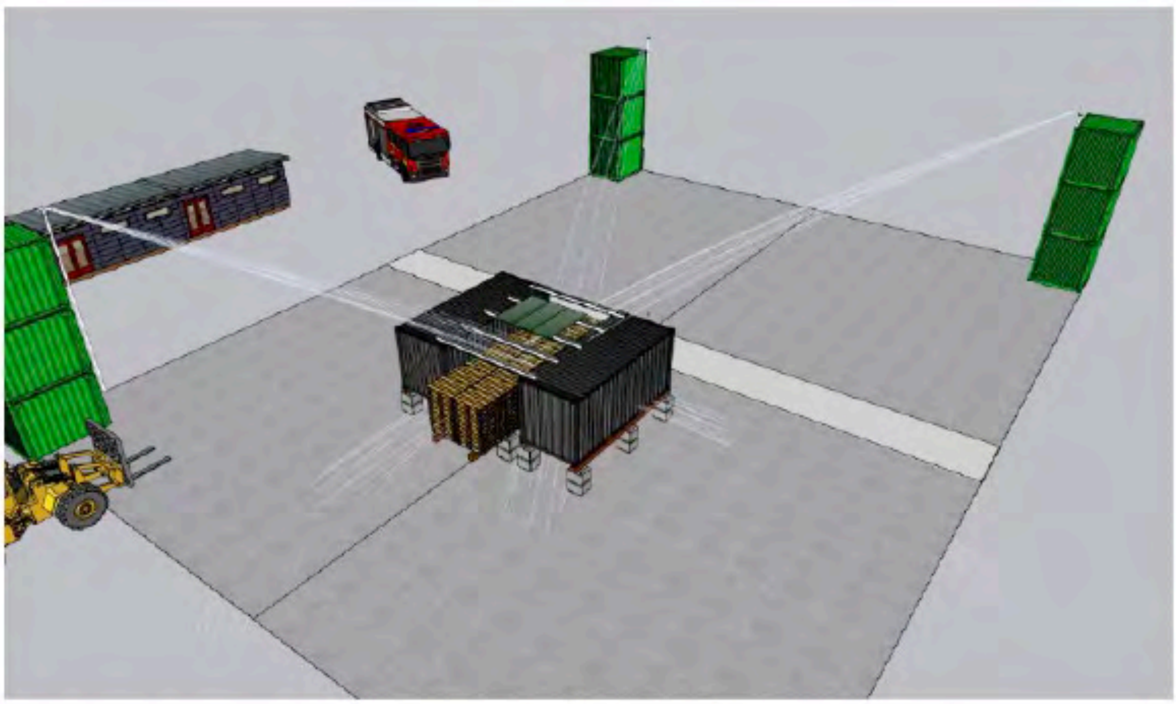


Figure 29. The test area and the principal arrangement of the tests. Illustration: UNF.

towards the drainage dike. Figure 29 shows an illustration of the test area and the arrangement of the tests.

9.2 The fire test scenario

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

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

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

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

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

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

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

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

9.3 The fire monitor system

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

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

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

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

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

- Fire monitor C: At the South-West corner, diagonally 30,5 m from the center point of the main array.

The fire monitors were connected to a water pump using large diameter (76 mm) fire hoses. Each line of fire hose had a water flow meter. The pump unit had a maximum capacity of 5 000 l/min at about 8 to 10 bar at the outlet of the pump. The inlet of the pump was connected to a large (60 m3) tank filled with potable water.

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

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

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

9.4 Instrumentation and measurements

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

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

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

location and height of the surface thermocouple at mid-height of the container wall, facing the point of fire ignition.

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

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

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

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

9.5 Fire test program

The system parameters that were explored were water only vs. foam, the delay time from

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

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

Table 3 shows the fire test program.

Table 3. The fire test program.

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

9.6 Fire test procedures

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

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

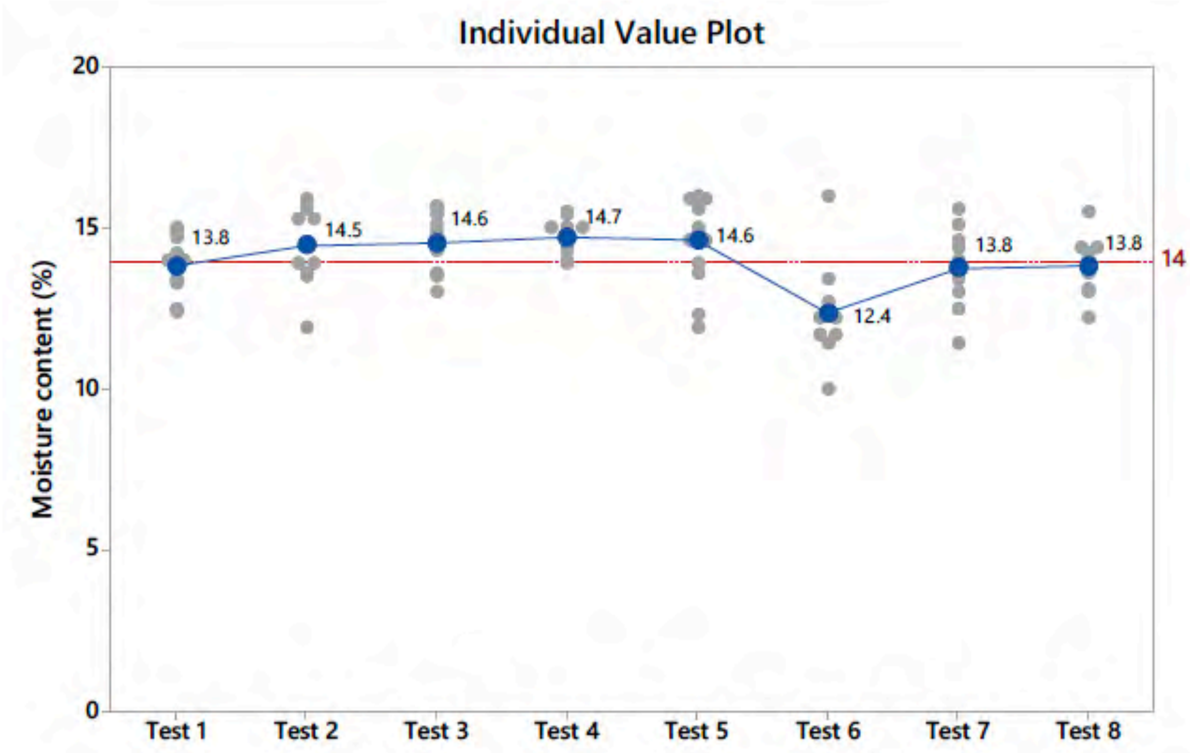


Figure 34. The measured moisture content of randomly selected individual

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

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

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

9.7 Fire test observations

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

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

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

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

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

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

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

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

[Tests 3 and 4 are omitted here, as they were of a compressed air foam system (CAFS) developed by another partner in the consortium, these test results can be found in the full report attached in the Appendix.]

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

Figure 49 shows the fire damage.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

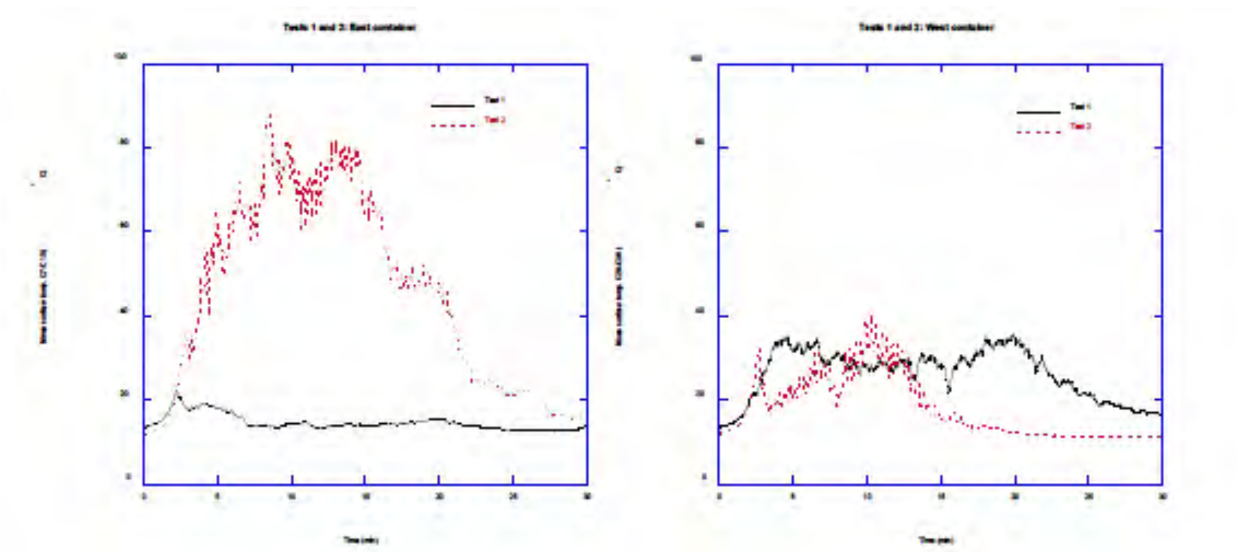
Figure 57. ***Test 7****: The fire damage documented after the test.*

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

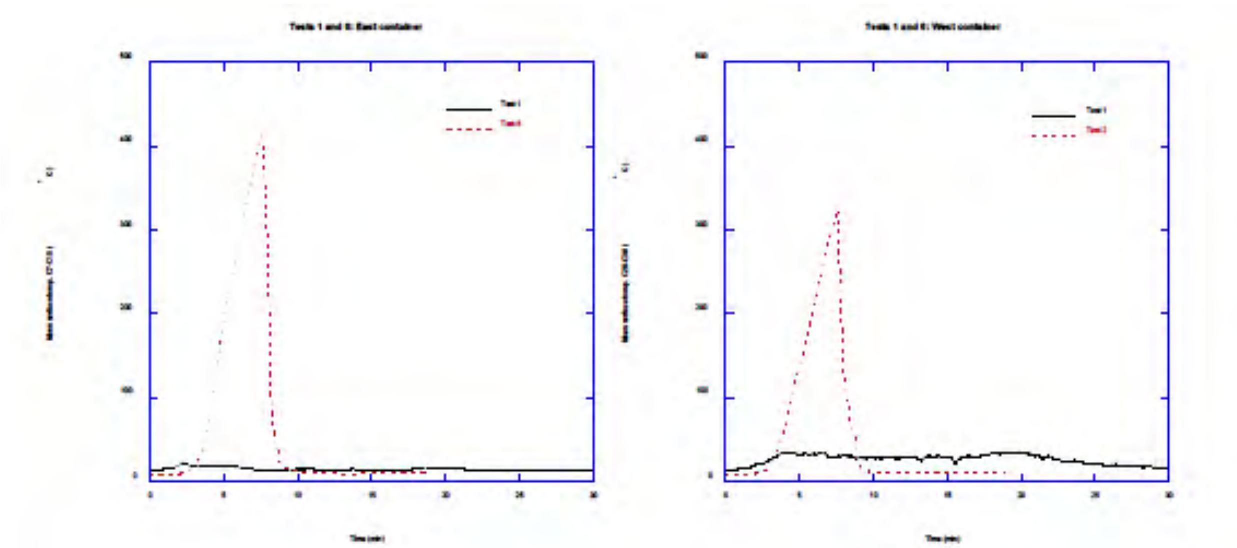
Figure 58. ***Test 8****: The initial application of water from fire monitors A and B positioned at the east long-side corners of the test area.*

9.8 Fire test results

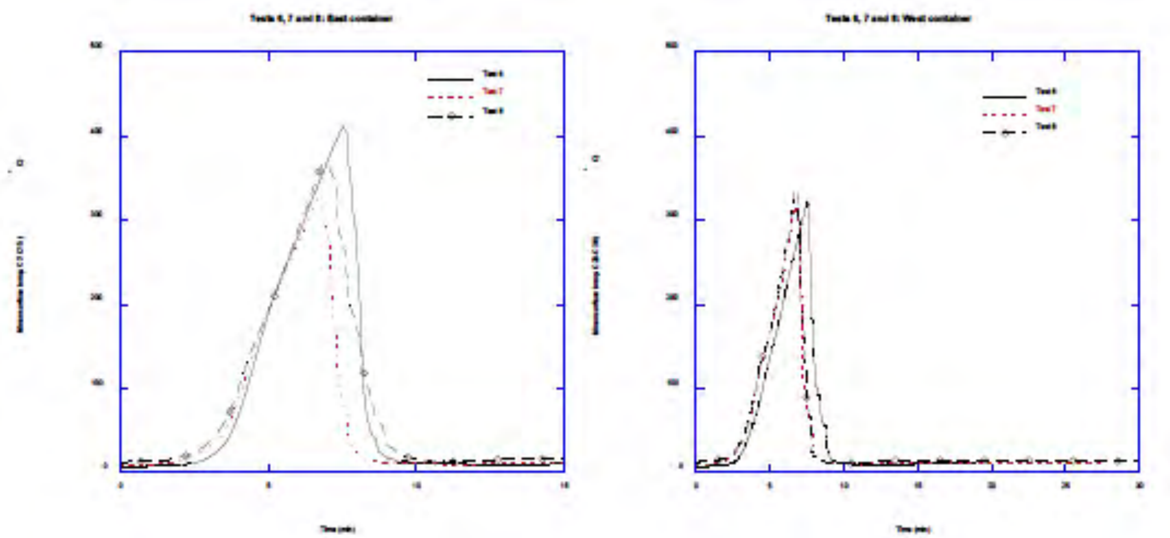
The influence of the use of one vs. two fire monitors when water was applied early, i.e., 30 s after sustained flames were observed above the array, is compared in Test 1 and Test 2, refer to Figure 62. It is observed that the mean surface temperature on the cargo container east of the main array was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



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



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



9.9 Overall conclusion

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

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

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

IV. Comparative Analysis of the FlameRanger System

The Unifire FlameRanger™ stands apart in the evolving landscape of "smart fire monitors." Unlike competitors who spread resources across multiple product types, Unifire is solely focused on Autonomous Robotic Fire Suppression Systems (ARFSS). This exclusive focus has positioned Unifire as the clear benchmark in the category. To understand why, it's useful to view FlameRanger against the broader spectrum of smart fire monitor systems.

As outlined in *The Smart Monitor Revolution: From Remote to Autonomous* (2025) [Appendix 4], there are three principal categories of monitor-based suppression systems:

- Remote Operator (RO): human operators remotely control fire monitors via detectors and live video.
- Automatic Fire Monitors (AFM): combine monitors with detectors for automatic discharge and shutoff, but operate as stand-alone units with limited precision.
- Autonomous Robotic Fire Suppression Systems (ARFSS): the most advanced class—integrating three-dimensional detection, dynamic targeting, intelligent shutoff, coordination across multiple units, and full remote control.

The FlameRanger is an ARFSS, meaning it does everything RO and AFM systems can do—and significantly more. The following highlights its defining advantages:

1. Revolutionary Speed and Precision

The FlameRanger can detect and suppress fires in as little as five seconds, far faster than sprinklers, deluge systems, or fire brigades that respond after minutes. Using three-dimensional fire detection and dynamic tracking, it delivers high-density water or foam streams directly at the source with pinpoint accuracy, suppressing fires before they spread.

Key Advantage: **Speed & Accuracy:** RO and AFM systems improve on conventional suppression but still face delays, imprecision, or blind spots. The FlameRanger combines speed and accuracy unmatched by either.

2. Unmatched Precision and Detection Flexibility

Unlike any other smart fire monitor system on the market, the FlameRanger ARFSS is designed to integrate seamlessly with any fire detection technology, including flame detectors, thermal imaging camera systems, video analytics, hybrid detectors, and all others. It can also triangulate the precise three-dimensional size and position of the fire using pairs of detectors.

This unparalleled precision and detector compatibility ensures that the system can be tailored to the specific needs of any environment, from waste and recycling plants to aircraft hangars, and ships to high-rise buildings. Moreover, the FlameRanger can integrate multiple detection technologies simultaneously, providing enhanced reliability and minimal false alarms.

Key Advantage: **Detection Flexibility:** FlameRanger is uniquely capable of using all fire detection technologies and combining them, providing the fastest, most accurate system for the risk, with extremely low risk of false alarms. Competing systems are typically limited to proprietary or single detection technologies, reducing flexibility and adaptability, and subject to significantly greater risk of false alarms.

3. Networking and Scalability

While AFMs and ROs operate individually, the FlameRanger's ARFSS architecture allows units to share data, coordinate suppression, divide tasks, and provide redundancy. This makes it ideal for protecting large or complex facilities where resilience and scalability are critical.

Key Advantage: **Coordinated Resilience & Redundancy:** Networked FlameRanger systems can provide coordinated responses and redundancy in both detection and suppression—providing significantly greater performance as established in the LASH FIRE testing discussed above. Remote Operator and Automatic Fire Monitor systems lack coordinated, facility-wide response and redundancy.

4. The Most Advanced Remote Control Options

The FlameRanger offers unparalleled remote control functionality, allowing operators to control the system from anywhere in the world. Whether using joystick, radio remote control, an iOS or Android device or a computer, users can monitor and manage the system in real time. ONE-Direct provides an additional intuitive control function by pointing to the desired location on a floor plan. These capabilities provide uninterrupted oversight and quick action, even when personnel are offsite.

Key Advantage: **Wide-ranging Remote Control Solutions Included:** No competing smart monitor systems offer the end user such an array of easy-to-use remote control options.

5. No Recurring Fees

Unlike RO-based services, which require ongoing subscriptions for staffing and monitoring, the FlameRanger involves no recurring fees. Remote commissioning, Ammolite GUI access, and technical support are included in the purchase price.

Key Advantage: **High Value Total Cost of Ownership:** Over the lifecycle, FlameRanger delivers far greater value and predictability.

6. Rigorous Validation

Since 2010, FlameRanger systems have undergone numerous independent tests by the U.S. Naval Research Laboratory, Jensen Hughes, RISE, Thomas Bell-Wright, and the EU-funded LASH FIRE project. These validations confirm its performance in the most demanding environments, from naval vessels to high-rise façades and RoRo ships. ***With more than 230 systems operating worldwide, FlameRanger has a flawless record of performance, with no reported failures since its introduction.***

Key Advantage: **Proven Reliability & Peace of Mind:** No competing system has undergone such breadth and depth of independent testing, and FlameRanger has a perfect track record in installations around the world.

7. Intuitive Graphical User Interface (GUI)

The FlameRanger features Ammolite, Unifire's state-of-the-art, powerful and user-friendly graphical user interface (GUI) that simplifies system setup, status monitoring, diagnostics, and technical support. This intuitive interface enables operators to quickly understand system functionality, access data, and address any issues without requiring specialized training.

Key Advantage: **Simple Setup with Powerful Features:** FlameRanger's Ammolite GUI provides easy configuration, real-time diagnostics, and around-the-clock remote commissioning support. By contrast, many competing systems lack intuitive interfaces, requiring complex setup and costly on-site support.

8. Comprehensive Technical Support

Unifire includes remote technical support and remote commissioning in the purchase price of the FlameRanger. These services ensure that customers receive seamless assistance for system setup, configuration, and ongoing maintenance, minimizing downtime and optimizing performance.

Key Advantage: **Fast, World-Wide Tech Support Included:** Unifire's comprehensive and remote technical support capabilities, included in the purchase price, substantially lower the total cost of ownership. Competing smart monitor manufacturers often charge significant fees for on-site technical support and commissioning, further increasing expenses.

9. Market Leadership Since 2010

In 2010, Unifire was the first company in the world to unveil its fully autonomous robotic fire suppression system based on IR Array flame detection technology. Since then, Unifire has rapidly and relentlessly developed its capabilities to work with any fire detection technology, provide extremely fast and accurate detection and suppression, hone the intelligence of the system's response based on numerous fire tests, and to offer features and capabilities that go far beyond any other system on the market. Unifire's FlameRanger systems are currently in operation 24/7/365 on 6 continents around the world.

Key Advantage: **Global Leader:** As the first mover and longest-standing provider solely focused on Autonomous Robotic Fire Suppression Systems (ARFSS), Unifire combines more than 15 years of dedicated experience with continuous innovation—delivering a level of maturity, reliability, and global field-proven performance that newer entrants and diversified competitors cannot match.

Together, these advantages demonstrate why the FlameRanger is not simply another smart monitor, but the benchmark ARFSS platform against which all others are measured.

V. FlameRanger Capabilities & Benefits

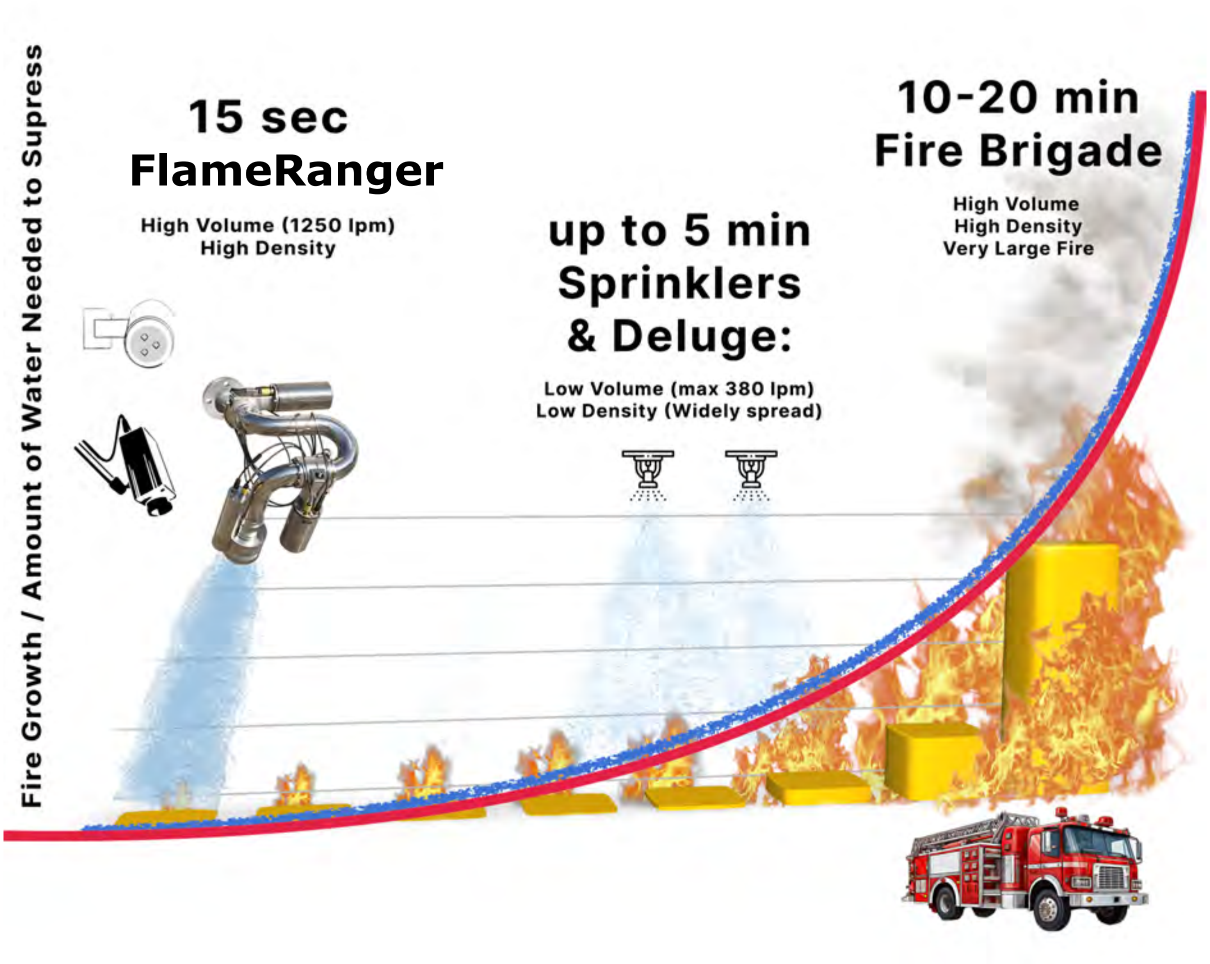
UNIFIRE

FLAMERANGER CAPABILITIES & BENEFITS	
Capabilities	
Time to detect visible flame or heat alarm (typically):	Miliseconds
Time from fire ignition to fire suppression (typically):	5-15 seconds
Extremely low false-alarm rate	✔
Detection Technologies offered:	
☑ IR3 flame detectors with video analytics to accurately locate the fire	✔
☑ IR3 IR array flame detectors with flame coordinates	✔
☑ Thermal imaging cameras with algorithms to reduce false alarms	✔
☑ Video analytics	✔
☑ Hybrid thermal imaging and video analytics	✔
☑ Optical fibre linear heat detection	✔
☑ Standard IR3 flame detectors	✔
☑ Sniffers	✔
☑ all other detection technologies possible	✔
Ability to combine 2 or more detection technologies	✔
Maximum number of detectors per system	10
Flame Suppression Methods	
☑ 3-dimensional fire location and suppression	✔
☑ Dynamic fire suppression (nozzle follows the flame)	✔
☑ Vector aiming with a single detector	✔
☑ Pre-defined zone responses (up to 10 zones)	✔
☑ Ability to detect multiple fires simultaneously and suppress them in the order detected	✔
Automatic control of the valve (open when fire is detected, close after it's extinguished)	✔
Ability to remote control the system at any time, regardless of whether the system detected a fire or not	✔
Ability to control the system from anywhere in the world over a secure WAN connection	✔
Ability to provide remote commissioning and remote technical support anywhere in the world over a secure WAN connection	✔
Advanced robotic nozzles with industrial-robot-type brushless DC (BLDC) motors & extremely high-spec gears preventing loss of calibration over time	✔
Designed for extremely harsh environments (including stainless steel 316L construction of robotic nozzles)	✔
Tested by multiple accredited and renowned 3rd party testing authorities	✔
Over 130 systems in operation on 5 continents	✔
FlameRanger technology first tested and operational in:	2010

VI. Conclusion

Fires can grow exponentially, doubling in size every 10 to 60 seconds depending on fuel type, ventilation, and fire load. This makes immediate, high-volume suppression directly at the source the only effective strategy for containment. Traditional methods—sprinklers, deluge systems, or fire brigades—are limited by slow response times, low water density, or broad coverage that fails to attack the core of the fire.

By contrast, Unifire's FlameRanger™ Autonomous Robotic Fire Suppression Systems (ARFSS) deliver rapid, pinpoint suppression within seconds of ignition. Once extinguishment is achieved, they shut off automatically, minimizing collateral damage, environmental impact, and costly downtime.



Key Advantages of FlameRanger Systems

- **Immediate Response:** Suppression typically begins within 15 seconds while fires remain small and manageable.

- **Three-Dimensional Detection and Tracking:** Ensures precise localization and dynamic suppression directly at the fire's source.
- **High-Density Targeted Suppression:** Concentrated agent streams of 1,250 liters/minute or more maximize effectiveness while minimizing water use.
- **Flexible Detection Integration:** Compatible with all fire detection technologies—and their combinations—for unmatched reliability and minimal false alarms.
- **Automatic Shut-Off:** Stops discharging once the fire is out, reducing collateral damage and toxic runoff.
- **Remote Control Options:** Full manual override via joystick, radio, smartphone, or secure PC, anywhere in the world.
- **Reduced Downtime:** Fires are contained quickly, minimizing operational disruption and financial losses.

Diverse Applications of FlameRanger Systems

Due to the numerous, significant advantages and benefits it offers, Unifire's FlameRanger systems are increasingly being adopted across a range of high-risk sectors, each benefiting from the technology's unique capabilities. Below are just some of the many applications for which FlameRanger systems are very well suited.

- **Waste and Recycling Facilities:** Effective in environments prone to fires from lithium-ion batteries and combustible materials.
- **Military & Civilian Warehouses:** Ideal for facilities storing explosives, fuels, and sensitive assets where rapid suppression is critical.
- **Ro-Ro Passenger & Car Carrier Ships:** Secures weather decks and car decks from fires spreading through tightly packed vehicles.
- **Manufacturing & Heavy Industry:** Protects facilities filled with machinery, materials, and stored goods.
- **Aircraft Hangars:** Provides precise suppression without collateral damage typical of foam deluge systems.
- **High-Rise Buildings with ACM Façades:** Protects vulnerable exteriors cost-effectively, reducing the need for façade replacement.
- **Cement Plants:** Suppresses fires in facilities handling refuse-derived fuel and other combustible materials.
- **Historical Buildings:** Preserves irreplaceable structures with minimal risk of collateral damage.

- **Tunnels and Confined Spaces:** Offers quick containment in challenging, enclosed environments.

Proven Reliability and Market Leadership

Since introducing the world's first fully autonomous robotic fire suppression system in 2010, Unifire has been solely focused on ARFSS. With more than 230 FlameRanger systems operating worldwide, rigorous validation by independent authorities (U.S. Naval Research Laboratory, Jensen Hughes, RISE, Thomas Bell-Wright, and the EU-funded LASH FIRE project), and a flawless record of performance with no reported failures, FlameRanger has established itself as the most advanced and reliable system on the market.

The Future of Fire Protection

The fire protection industry is undergoing a **transformative shift**. Smart fire monitor technologies are rapidly emerging as the new standard for large-scale, high-risk environments, where conventional systems can no longer keep pace with the speed and intensity of modern fire risks.

Within this new landscape, **Unifire's FlameRanger™ stands alone as the only true Autonomous Robotic Fire Suppression System (ARFSS)**—delivering capabilities far beyond Remote Operator and Automatic Fire Monitor solutions.

With its unmatched speed, three-dimensional detection and tracking, adaptability to any risk environment, and proven reliability across six continents, the FlameRanger is not just today's leader. It is the **benchmark for the future of fire protection**, redefining safety standards for waste and recycling plants, warehouses, Ro-Ro ships, heavy industry, aircraft hangars, high-rise façades, cement plants, historical structures, and more.

FlameRanger is the clear global leader in ARFSS, safeguarding lives, property, and the environment—and setting the course for the future of fire suppression worldwide.

Appendices

Appendix 1: FlameRanger Test Report from the US Naval Research Laboratory and Jensen Hughes

Appendix 2: Summary of FlameRanger Test Report from the Research Institutes of Sweden (RISE) and Thomas Bell-Wright

Appendix 3: Test Reports D10.2 & D10.3 from the LASH FIRE study

Appendix 4: The Smart Monitor Revolution - From Remote to Autonomous (Sept. 2025)

Appendix 5: Customer References

APPENDIX 1

FlameRanger Test Report from the

US Naval Research Laboratory & Jensen Hughes

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
4555 OVERLOOK AVE SW
WASHINGTON DC 20375-5320

IN REPLY REFER TO:
3900
Ser 6180/0216
DEC 2 2 2015

From: Commanding Officer, Naval Research Laboratory
To: Director, Operational Test and Evaluation/Live Fire Test and Evaluation (Spraitzer)

Subj: SUPPRESSION OF SHIPBOARD FIRES IN LARGE VOLUME SPACES USING MONITORS – FINAL REPORT

Encl: (1) One copy of subject report

1. Enclosure (1) is forwarded for your information review.

2. Under certain circumstances, large quantities of Class A materials (ordinary combustibles) are stowed in Large Volume Spaces (LVS) on U.S. Navy (USN) ships/platforms. These large volume spaces include aircraft hangars and Vehicles Storage Areas (VSAs) which are typically equipped with an overhead Aqueous Film Forming Foam (AFFF) sprinkling system. Tests conducted to date have demonstrated the limitations of the current overhead AFFF sprinkling system for extinguishing these large Class A fuel packages.

3. The overall objective of this program was to conduct a preliminary assessment of the capabilities of automated monitors to suppress large quantities of Class A materials (ordinary combustibles) stowed in LVS on USN platforms. The performance testing conducted during this program focused on assessing the system's capabilities for simple geometries and configurations. Future testing is recommended to challenge the system with more complex (fully loaded) geometries and configurations.

4. This report provides a preliminary assessment of the capabilities of automated monitors for protecting LVS on USN Ships/Platforms. These large-scale tests were conducted aboard the Navy's Fire Test Ship ex-USS SHADWELL during the last two weeks in September 2015.

5. The Naval Research Laboratory's points of contact are Mr. Hung V. Pham, Code 6186: (251) 433-0352; e-mail: hung.pham@nrl.navy.mil and Mr. John P. Farley, Code 6186: (202) 404-8459; e-mail: john.farley@nrl.navy.mil.

B. Spargo
By direction
BARRY J. SPARGO

6180/0216A:JPF
20 Dec 2015

Suppression of Shipboard Fires in Large Volume Spaces Using Monitors – Final Report

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Ser 6180/0261

CONTENTS

LIST OF ACRONYMS AND ABBREVIATIONS

AFFF	Aqueous Film-Forming Foam
cm	centimeter
cfm	cubic feet per minute
cmm	cubic meters per minute
ft	feet
ft^2	square feet
FHA	Fire Hazards Analysis
gpm	gallon per minute
in	inch
JHSV	Joint High Speed Vessel
JLF	Joint Live Fire Office
LFT&E	Live Fire Test and Evaluation
LHA(R)	LHA Replacement
L	Liter
Lpm	Liter per minute
LVSA	Lower Vehicle Stowage Area
m	meter
m^2	square meters
m^3/s	cubic meter per second
MPF(F)	Maritime Prepositioning Force (Future)
MW	mega watt
NFPA	National Fire Protection Association
NRL	Naval Research Laboratory
NSTM	Naval Ships Technical Manual
RO-RO	Roll-on, roll-off vessel
TC	Thermocouple
UVSA	Upper Vehicle Stowage Area
VSA	Vehicle Stowage Area
WD	Well deck

SUPPRESSION OF SHIPBOARD FIRES IN LARGE VOLUME SPACES USING MONITORS – FINAL REPORT

1.0 INTRODUCTION

Under certain circumstances, large quantities of Class A materials (ordinary combustibles) are stowed in Large Volume Spaces (LVS) on U.S. Navy (USN) ships/platforms. These large volume spaces include aircraft hangars and Vehicles Storage Areas (VSAs) which are typically equipped with an overhead AFFF sprinkling system. Tests conducted to date have demonstrated the limitations of the current overhead AFFF sprinkling system for extinguishing these large Class A fuel packages as well as one or two other representative fire scenarios [1-3]. Fire hazard analyses (FHAs) for the Joint High Speed Vehicle (JHSV) [4], and Maritime Prepositioning Force (Future) (MPF(F)) [5,6] have all identified similar conditions and concerns.

Results from the LHA(R) testing indicated that an overhead Aqueous Film Forming Foam (AFFF) delivery system is capable of extinguishing a Class B pool fire within 2-3 minutes of activation at an application rate of 6.5 Lpm/m^2 (0.16 gpm/ft^2). The system was unable to suppress a high density Class A and three-dimensional Class B fire. It was recommended that higher AFFF area application rates, in the range of 8.1-12.2 Lpm/m^2 (0.2–0.3 gpm/ft^2), be evaluated for Class A and running Class B fires. It was recognized that an overhead AFFF sprinkler system was unlikely to extinguish a Class B three-dimensional fire, even at higher application rates.

A recent Preliminary Hazard Assessment (PHA) conducted by the Naval Research Laboratory (NRL) identified foam/water monitors as the “best valued” solution for protecting large volume space with high Class A fuel loadings (i.e., as a supplemental system to the overhead AFFF sprinkling system) [7]. Recent experimental studies conducted by Factory Mutual have also determined that monitors (referred to as water cannons in the FM article) can respond and extinguish fire events much faster than automatic sprinklers [8].

This report provides a preliminary assessment of the capabilities of automated monitors for protecting large volume spaces on USN Ships/Platforms. These large-scale tests were conducted aboard the Navy’s Fire Test Ship ex-USS SHADWELL during the last two weeks in September 2015.

2.0 OBJECTIVES

The overall objective of this program was to conduct a preliminary assessment of the capabilities of automated monitors to suppress large quantities of Class A materials (ordinary combustibles) stowed in large volume spaces on USN platforms.

Specific objectives of the test series were to demonstrate:

- The suppression capabilities of a multi-axis, swiveling nozzle capable of flow rates up to 950 Lpm (250 gpm).

- The ability of a manual Monitor Control Unit (MCU) and operator to direct the agent/water stream to all locations in the protected area.

- The ability of the automatic control system/software to detect a fire (using infrared flame detectors), provide targeting coordinates to the monitor control unit, and direct the agent/water stream at the fire.

- The ability of an operator to either validate detection prior to automatic system activation and/or the ability to manually override the automatic mode and shift to manual control during a fire.

3.0 MONITOR FIRE SUPPRESSION SYSTEM

The technical data provided by the manufacturer is provided in Appendix A.

3.1 Unifire Force 50 Monitor

The Unifire Force monitors are manufactured in Sweden to high standards of quality at International Organization for Standardization (ISO) Certified facilities. The monitors are made of 316L stainless steel and contain multiple swivel joints to allow movement/control in all three axis. Each swivel joint is controlled by an integrated gear system and brushless (BLDC) motors. With fully protected and uniquely integrated gear technology, the monitors/nozzles motor and advanced gears are fully integrated into the body with no external or exposed parts. A photograph of the Unifire Force 50 monitor is provided as Figure 1.

Fig. 1 — Unifire Force 50 Monitor (installed on Shadwell)

The discharge characteristics/flow rates are dictated by the nozzle installed on the monitor. The Force 50 monitor used during this program is equipped with an Integ 50 Nozzle. The Integ 50 nozzle has a variable/controlled spray pattern covering the range from straight stream to an 180° fog pattern. The spray pattern is controlled by an integrated gear box and brushless (BLDC) motors. The nozzle's spray pattern position is monitored and displayed at all times providing the user with the required information. Photographs showing a narrow angle and wide fog pattern are provided as Figure 2.

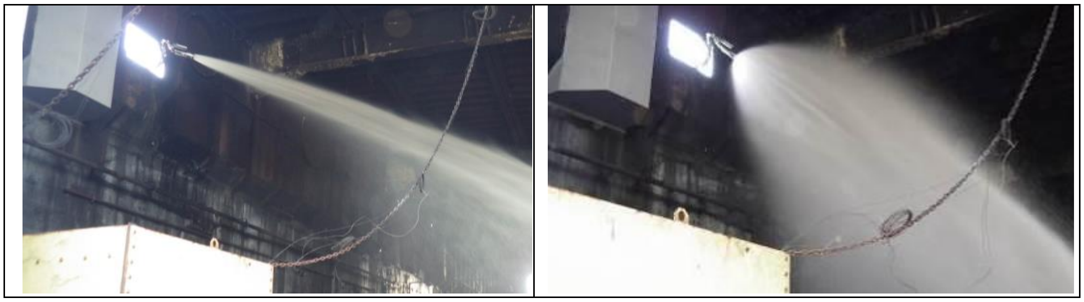


Fig. 2 — Spray Pattern Photographs

The flow rate characteristics are selected by adjusting the flow set screw/nut located behind the diffuser of the nozzle. The flow is factory set to a specified value but can be adjusted and fine-tuned to the application after installation. The flow rate and stream reach characteristics of the Force 50 monitor with the Integ50 nozzle (manufacturer's data) is provided in Figure 3.

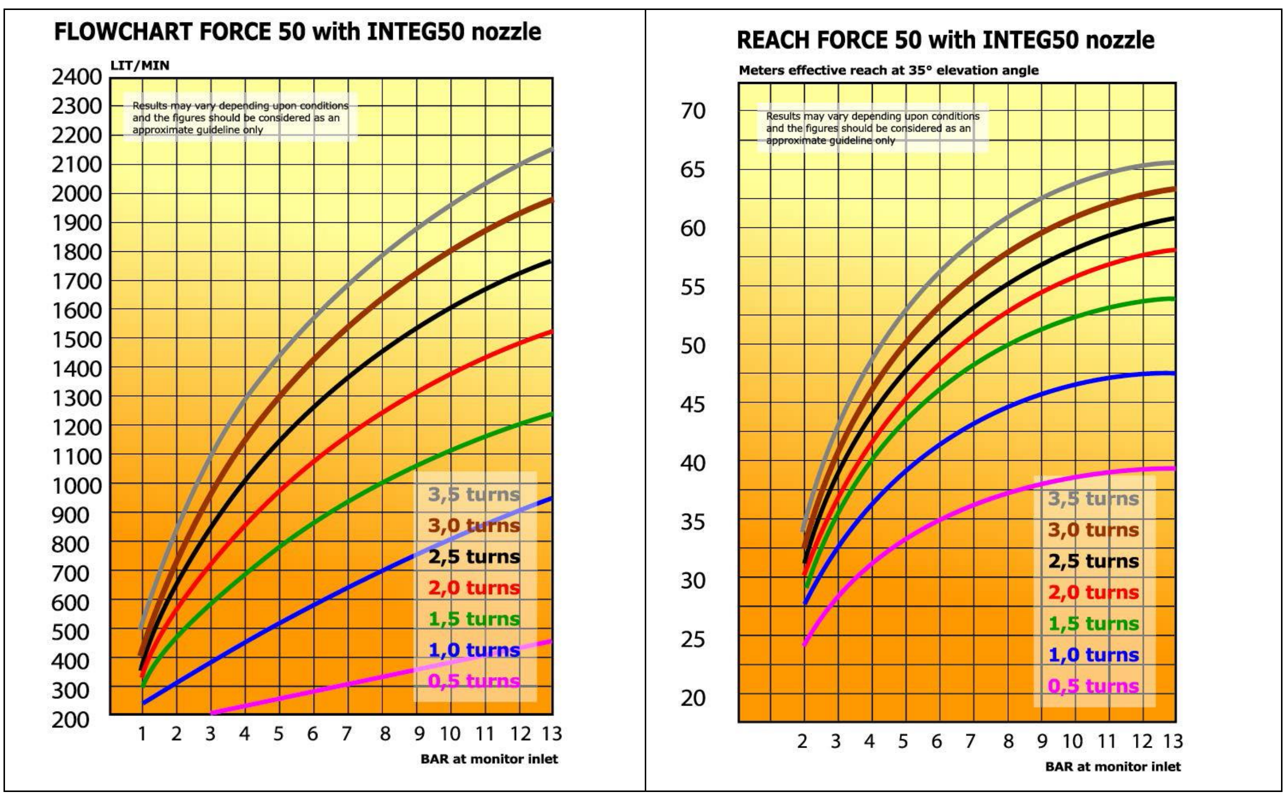


Fig. 3 — Unifire Force 50 Monitor Flow Rate and Stream Reach Data

3.2 Control Systems

Force monitors can be controlled both manually and automatically using a number of electronic devices. The most common device used to control the monitor manually is a joystick although, the monitor can also be networked/connected to a server and controlled using a tablet, laptop and even a standard smart phone. Force monitors can be networked not only with each other, but with virtually any electronic device including CCTV and infrared cameras as well as alarm systems equipped with flame detectors.

The monitor and control system are interfaced via Unifire's TARGA PLC. Unifire's TARGA PLC has embedded PC's and Web Servers, so that control and display of all system data can be achieved using any web browser, without any need for software (it's all built in). A photograph of the TARGA interface is provided in Figure 4.

Fig. 4 — TARGA Control System Interface

3.2.1 Manual Control (Joystick)

The Unifire π ("PI") Joystick is light weight (~1.2 kg / 2½ lbs) and simple to use, even under the stress of fighting fires. There are two models available; tethered to the control system and wireless. The joystick is designed to allow for one-hand operation. The axis control of the monitor is achieved through the vertical position of the joystick. The monitor moves in the horizontal plain by toggling the stick right and left. The vertical control of the monitor is achieved by moving the stick forward and backward. The spray pattern of the nozzle is controlled by twisting the stick (i.e., a clockwise rotation increases the spray pattern and a counter-clockwise rotation decreases the spray pattern). There are built-in monitor position and spray pattern indicator lights providing feedback to the operator. The speed of movement is based on the degree of movement of the control. Specifically, if the joystick is pushed slightly to the right, the monitor will slowly rotate to the right. If the joystick is pushed all the way to the right, the monitor will quickly rotate to the right. This allows either ultra-slow and precise targeting or rapid, full speed responses. There are also a number of control switches on both sides of the joystick. These buttons control the supply valve and the retraction (parking) of the monitor. There are also two auxiliary buttons on the left side that can be used to operate lights, exhaust fans and alarm systems. An illustration of the Unifire π joystick is provided in Figure 5.

Fig. 5 — Unifire π Joystick

The joystick is also programmable using the Record (REC) and Play (PLAY) buttons located on the right side of the stick. This allows the device to be programed for a specific hazard. As an example, consider a large array of combustible materials stacked in the corner of a large volume space. After the ship has been loaded, a laser can be installed on the monitor and the operator can record a series of sweeps across the array of fuel to be stored and played back in the event of a fire. The movement is recorded with the agent/water supply valve secured to prevent collateral water damage and the laser provides the feedback required to aim the monitor. In the event of a fire, the rapid responder can activate the monitor in play-back mode to conduct the initial attack on the fire while the DC party dons the appropriate PPE.

3.2.2 Automatic Control

Unifire offers the Flame Ranger system which is a fully automatic fire detection and suppression system which combines the Force Monitors with state-of-the-art flame detection technologies to detect and suppress a fire with within seconds of detection.

3.2.2.1 FV300 Series Flame Vision Detection System

The FV300 Series Flame Vision detectors are a family of advanced infrared sensor array flame detectors with wide view areas and excellent false alarm immunity. The FV300 Flame Vision detectors are manufactured by TYCO Fire Products and offer major improvement in both flame detection capability and immunity to false alarm sources over triple IR detectors. The detector can be supplied with an optional built in color video camera for connection to CCTV systems to display the field of view with an overlay showing alarm location and status information. All FV300 models provide fire and fault relays, 4-20mA output and a field network interface as standard for connecting to external equipment.

The FV300 Series Flame Vision detectors use an array of 256 sensitive infrared sensors to view the protected area. The IR array is combined with 2 other optical sensors to provide 3 highly sensitive optical channels. The processing algorithms which are running on a Digital Signal Processor (DSP) analyze the signals from these 3 channels to reliably identify fires. The FV300 series detectors provide sensitive flame detection over a great distance with a wide field of view. Per the manufacturer, the detector can reliably detect a 150 kW fire at a distance of 50 m across the 90° horizontal and 80° vertical field of view. The built-in sensor array provides the capability to identify the location of the flame within the field of view. The location information is used to overlay a marker on the live camera image to highlight the fire. The user can quickly see the location of the fire and decide on the appropriate action. The location information is also available on the field network interface which is fed to the monitor control system to target the fire.

The FV300 Flame Vison detectors are housed in a rugged stainless steel enclosure making them suitable for almost any environment. An explosion proof housing/model is also available. A photograph of a FV300 Series detector is provided in Figure 7.

Fig. 6 — Tyco FV300 Series Flame Detector

A summary of FV300 Series Flame Vision features and benefits is provided as follows:

- The FV300 series detectors provide highly sensitivity flame detection with high false alarm immunity, undiminished throughout a wide field of view.
- A built-in infrared sensor array combined with 2 other optical sensors provides 3 sensitive optical channels. Signals are analyzed by software running on a DSP to give reliable flame detection. The base algorithms have been extensively validated using real fires.
- The detector operational range is 50 m for a 150 kW fire with no reduction in range across the 90° horizontal and 80° vertical field of view.
- The system has been validated using a range of fire sizes and hydrocarbon fuels from alcohol to aviation fuel (JP4 and JP5).
- The system has been proven to be able to see flames through heavy black smoke allowing them to continue to target the fire as the space fills with smoke.
- The system has excellent false alarm immunity and has been shown to be immune to common radiation sources (continuous or modulated) such as sunlight, halogen lamps, welding, and heaters.
- By using a built-in sensor array, the FV300 series detectors can locate the flame within the field of view and display the information on the video overlay to pinpoint the location of the fire enabling more effective counter measures to be taken. The location information is also available on the network interface for use in targeting the monitor.

3.2.2.2 Activation and Targeting

The information from the FV300 series detectors is fed into the TARGA control system interface where additional processing occurs. The embedded software analyzes the alarm information and determines when to activate the monitor and where it should be aimed.

As currently programmed, at least two FV300 series detectors (with a maximum of four) must be installed in the system. Two are required to provide the aiming coordinates for the monitor. Specifically, the various detector locations (installation coordinates) are stored in the software database. Alarms from two detectors are required to triangulate the exact location of the fire. As a result, the monitor is not deployed/activated until two alarms are received. This tends to minimize the likelihood for false activation of the monitor.

Consistent with the activation logic, the system is automatically secured if less than two detectors are in alarm. This is potentially problematic for a two detector system if the view of the fire from one detector becomes obstructed during suppression. The manufacturer is considering potential solutions such as only securing the monitor if none of the detectors are in alarm. Since the software cannot triangulate on a single set of coordinates, the monitor would be programed to sweep over the area where the fire was last located.

3.3 Test Area/Space Description

The tests were conducted in the hangar section of the well deck test area on the ex-USS SHADWELL located in Mobile AL. The well deck test area is located between FR67 and

FR102 as shown in Figures 7 and 8. The test area is completely enclosed from the 3rd deck to the 01 level by wing walls on the port and starboard side, sliding doors at FR 67 and FR102, and the flight deck at the 01 level.

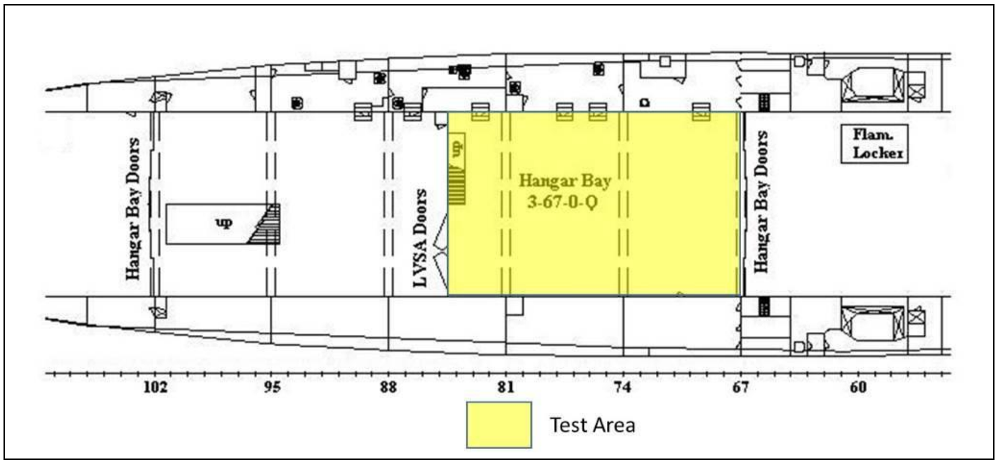


Fig. 7 — ex-USS SHADWELL Well Deck Test Area (Plan View)

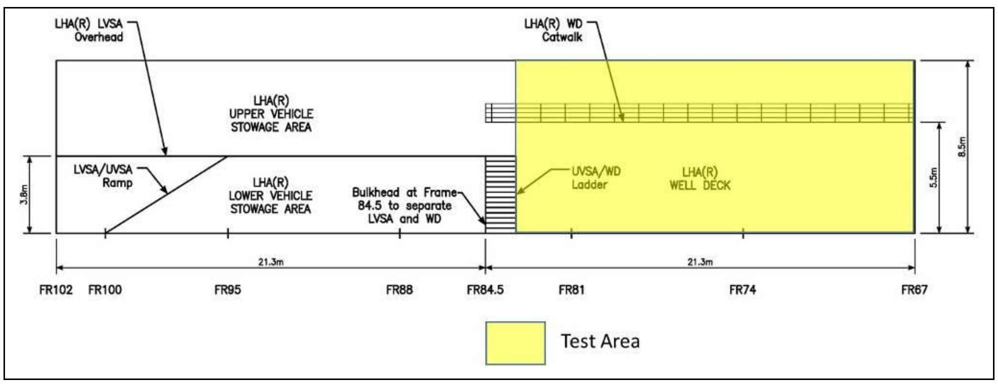


Fig. 8 — ex-USS SHADWELL Well Deck Test Area (Elevation View)

The hangar section of the well deck is located between FR67 and FR 84.5. The hangar is 21.3 m (70 ft) long, by 13.4 m (44 ft) wide, with an 8.5 m (28 ft) high overhead. Total deck area is 285 m^2 (3,080 ft^2). The total volume is 2426 m^3 (86,240 ft^3). A photograph of the hangar is provided in Figure 9. The hangar layout is shown in Figure 10.

Fig. 9 — Hangar Test Area

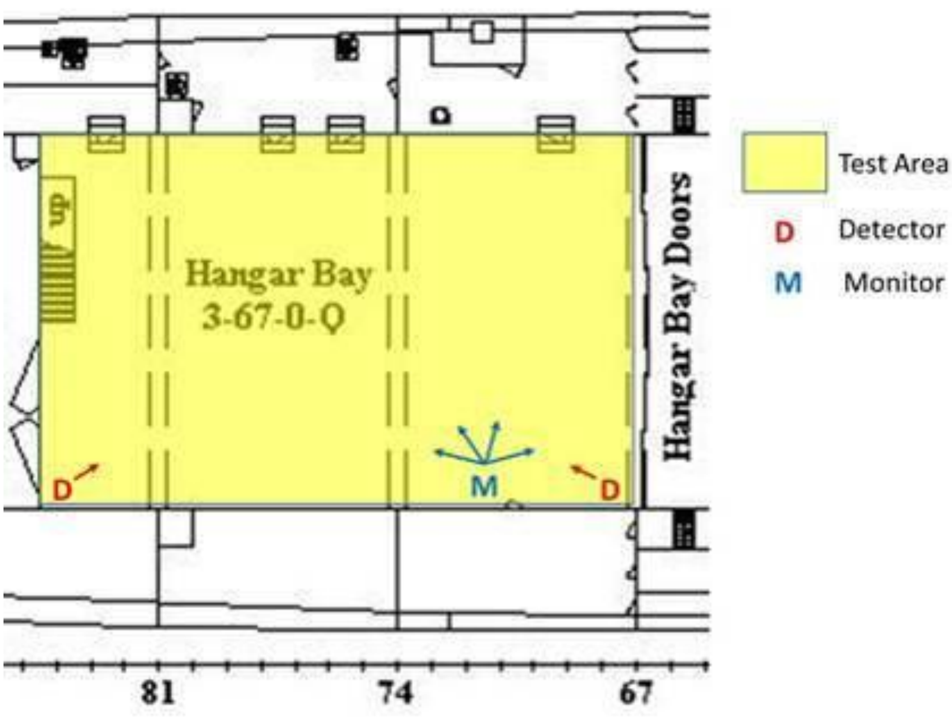


Fig. 10 — Hangar Layout

3.4 Monitor Installation

The monitor was installed just outside of the space on the Main Deck between FR71 and FR72. Once activated, the monitor moves into the hangar through an opening cut into the starboard wing wall about a meter above the Main Deck (See Figure 1). Once deployed, the monitor nozzle is approximately 6.8 m (22.5 ft) above the Hangar Deck.

The location of the monitor is shown in Figures 10. A photograph showing the monitor in operation is provided in Figure 11. The control system interface is located in the CONFLAG station adjacent to the monitor.

Fig. 11 — Unifire Force 50 Monitor in Hangar

3.5 Detector Locations

Two FV300 series detectors (FV311SC-N) were installed in the hangar for these tests. The detectors were installed in the forward and aft corners of the hangar on the starboard side of the ship approximately 4.3 m (14 ft) above the deck. The detector locations are shown in Figure 10. The original intent was to install four detectors for this test series (one installed in each corner of the hangar) but the additional detectors were not received in time to be included in these tests. A photograph showing a typical detector installation is provided in Figure 12.

Fig. 12 — Typical Detector Installation (aft/starboard location)

3.6 Protected Area Configuration/Analysis

The hangar is approximately 21.3 m (70 ft) long, by 13.4 m (44 ft) wide. For testing purposes, the hangar was divided into a four by three grid. Each sector of the grid was approximately 5.3 m (17.5 ft) long (forward-aft) and 4.6 m (15 ft) wide (port-starboard). The grid layout is shown in Figure 13. The testing assessed the ability of the monitor system to; manually discharge water into each sector, detect a fire in each sector, automatically aim the monitor at each sector and to extinguish a fire in each sector.

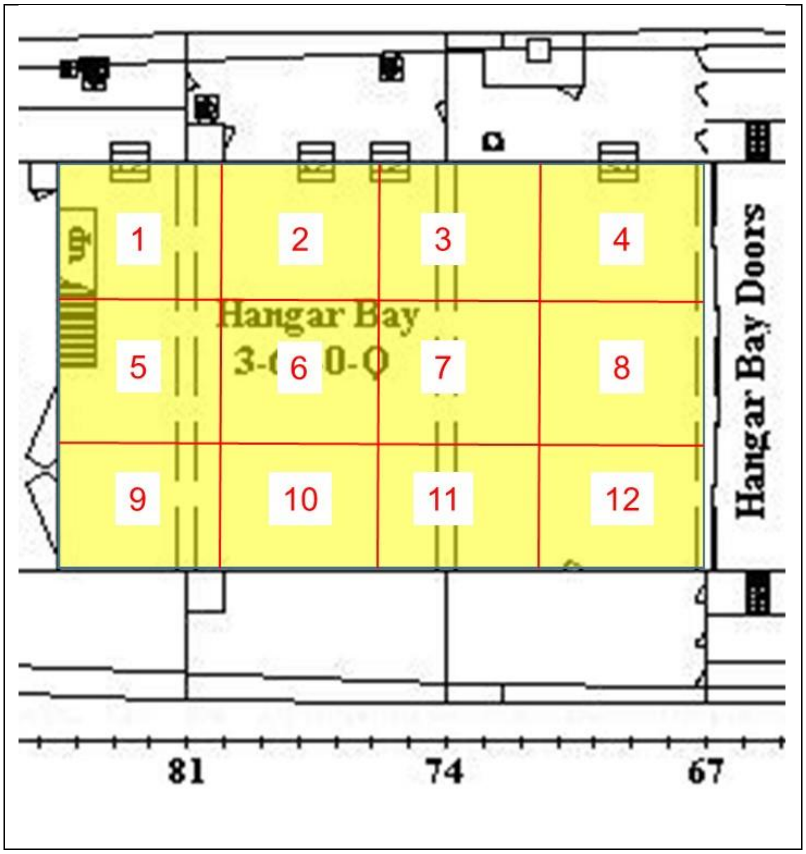


Fig. 13 — Grid Sector Configuration

3.7 Water Supply/Operating Pressure

The original intent was to use the ex-USS SHADWELL's fire pumps to supply the monitor with water during these tests. However, problems with the installed pumps/systems prevented their use during this test program. As a result, the local fire boat moored at the USCG Sector Mobile was used to provide water to the monitor during these tests. The fire boat was connected to the ship's firemain using two, 2.5" hoses. The ship's firemain was pressurized to 550 kPa (80 psi) during these tests producing a monitor flow rate of 950 Lpm (250 gpm).

4.0 PERFORMANCE TESTING/VALIDATION

The performance testing conducted during this program focused on assessing the system's capabilities for protecting simple geometries and configurations. Future testing is recommended to challenge the system with more complex (fully loaded) geometries and configurations.

4.1 Coverage of Protected Area and Manual Control

4.1.1 Stream Reach

The first series of tests assessed the ability of the monitor to manually discharge water (using the joystick control) into all 12 sectors of the hangar. This was verified through visual observation.

4.1.2 Manual Operation/Aiming

During this exercise, the ability of a novice to operate the system and to accurately aim the monitor was evaluated. Initially, the water supply to the monitor was secured and the ability of the operator to hit a target was determined using a laser that was installed on the top of the monitor. Additional tests were also conducted with the monitor discharging water into the space.

4.2 Detection

4.2.1 Critical Fire Size/Fire Location Assessment

The second series of tests assessed the ability of the detection system to detect and locate a small growing fire in each of the 12 sectors. The intent of these tests was to determine the smallest fire that could be reliable detected by the system as a function of location as well as to assess/verify the system could detect a fire at all locations in the protected space and aim the monitor at that location.

During these tests, the system was set in automatic mode but the water supply to the monitor was secured. A high intensity red light laser was fastened to the monitor to identify the location the monitor was aimed. The system was configured to save the coordinates of the fire once detected to develop a coordinate's map of the test area. A small propane burner (oval in shape approximately 20 cm long and 7.6 cm wide (8 inches long and 3 inches wide)) was placed in the center of each grid and ignited. A photograph of the burner is provided in Figure 14. The flow of propane to the burner was slowly increased until detection occurred. In this instance, detection was defined as the time when both of the detectors installed in the space went into alarm (i.e., the time when the monitor would be deployed and activated). The detection time, propane flow rate and the corresponding heat release rate of the fire at the time of detection were recorded for each test.

Fig. 14 — Propane Burner

After the deck-level tests were complete, an assessment of the system's ability to detect a fire as a function of elevation was also conducted. A similar grid approach was used during the elevation assessment. During these tests, the burner was placed on scaffolding (2.4 m (8 ft) above the deck) in the center of each grid and ignited. The flow of to the burner was slowly increased until detection occurred.

4.3 Suppression

4.3.1 Small/Growing Fires

A number of tests were planned to assess the capabilities of the system against small/growing fires. Small, wood cribs (1A per UL 711[9]) were built for this assessment. A photograph of a 1A wood crib is provided in Figure 15. The cribs were to be placed at preselected locations (the ones considered to be the most challenging) and ignited. These tests were to be conducted with both manual control and automatic detection and activation.

During the initial stages of this test program, it became apparent that the monitor system would be overmatching for these small fire scenarios due to the detection/targeting accuracy and the high delivered water density of the monitor (210 Lpm/m^2 (5gpm/ft^2)). In layman's terms, the small wood crib fire scenarios are in no way challenging to the system. As a result, the small wood crib fires were never conducted. However, a test was conducted at the end of the test series to assess the system capabilities against multiple small fires. This test is described in the results section of this report.

Fig. 15 — 1A Wood Crib

4.3.2 Large Fire Suppression Tests

A number of large fire suppression tests were conducted to assess the ability of the monitor system to suppress/extinguish large Class A fires for a range of operating conditions.

The large fires consisted of two stacks (16 high) of standard size oak pallets (1.2 m (46 in) square x 12 cm (4-5/8 inches) high, for a total stack height of 1.8 m (6 ft). The two pallet stacks were placed side-by-side (touching) producing a single large fuel package. The pallets were elevated 20.3 cm (8.0 in) above the deck to allow for ignition from below using two heptane pan fires (~ 0.4 m^2 (5 ft^2)), one located under each pallet stack.

The fire size generated from each stack of pallets at full involvement is approximately 6 MW for a total heat release rate of 12 MW [10].

A photograph of the two stacks of pallets at full involvement is provided in Figure 16.

Fig. 16 — Pallet Stack Fire (Full Involvement)

4.3.2.1 Large Fire Suppression (Manual Control)

The first large fire suppression test assessed the ability of a manually operated monitor to suppress/extinguish a large Class A fire. During this test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e. ~ 3 minute preburn time). Once at full involvement, a novice operator used the joystick to activate the system and manually aim the monitor at the fire. This scenario is representative of a large Class A fire onboard ship that is not immediately detected and is fought by a rapid responder/novice operator using manual control of the monitor system.

4.3.2.2 Large Fire Suppression (Pre-programmed Targeting)

The next large fire suppression test assessed the ability of a preprogrammed, manually operated monitor to suppress/extinguish a large Class A fire. Prior to the test, a laser was fastened to the monitor and a series of sweeps across the fuel package/pallet stacks was programed into the monitor (using the "Record" function on the joystick). During the test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time). Once at full involvement, the monitor was manually activated using the joystick and the "Play Back" function to allow the monitor to automatically suppress/extinguish the fire. This scenario is representative of a large Class A fire onboard ship that is not immediately detected and is fought by a rapid responder/novice operator using a pre-programmed sweeping sequence.

4.3.2.3 Large Fire Prevention (Automatic Activation and Targeting)

The next large fire suppression test assessed the ability of the all-up system (detection and automatic targeting) to detect and suppress/extinguish a fire in a large Class A fuel package.

During the test, the two stacks of wood pallets were ignited and the system was allowed to automatically detect, activate and suppress the fire. The test was conducted to assess/quantify the advantages of a fully automatic system (i.e., early detection and rapid water application on the fire). This scenario is representative of a large Class A fuel package onboard ship that catches fire and is automatically detected and suppressed/extinguished without any manned intervention.

4.3.2.4 Large Fire Suppression (Delayed Automatic Activation and Targeting)

The final large fire suppression test assessed the ability of the all-up system (detection and automatic targeting) to suppress/extinguish a large, fully involved Class A fire. During this test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time). The all-up system was activated and allowed to detect the fire, deploy and aim the monitor but the water supply was not activated until the fire became fully involved. The test assessed the ability of the system to automatically combat a large Class A fire (i.e., effectively aim the monitor at the fire and adjust to the changing conditions as the fire is suppressed/extinguished). This scenario is representative of a large Class A fuel package onboard ship that catches fire and grows to full involvement but is not automatically suppressed/extinguished until confirmation by on-site personnel.

4.4 Overall System Performance Documentation

During the test program, the following information was also collected and documented:

- The deployment time of the monitor.
- The water application time of the monitor.
- The reach characteristics of the nozzle as a function of spray pattern
- The optimal spray pattern to reach all areas of the protected space and provide reasonable coverage (impact area) at all locations. (A number of fire tests may be conducted to determine an optimal spray pattern angle to suppress a range of fire types and sizes within the protected space. However, the initial angle(s) was selected based on visual observations of the spray as it hits the various locations throughout the space (a 5-10 degree, narrow fog pattern appears to be a good starting point).
- A number of control algorithm parameters were assessed and discussed during this program including:
    - Deployment and Activation logic
    - Aiming and Spray Pattern Selection/Control
    - System Deactivation logic

4.5 Potential Future Testing

The performance testing conducted during this program was designed to serve as a general capabilities assessment of the system. Future testing is recommended to challenge the system in more complex, representative geometries and configurations (i.e. fully load spaces).

Specifically, the limitations of the system under adverse conditions needs to be quantified. This testing should include:

1. An assessment of the capabilities of the system against irregular shaped fires (both with respect to detection and monitor aiming).

2. An assessment of the capabilities of the system against obstructed fires (both with respect to detection and monitor aiming).

3. An assessment of potential nuisance alarms.

4. Refinement of the control algorithms may also be performed during this future program.

5.0 INSTRUMENTATION

The Unifire Force 50 monitor was instrumented for pressure and flow rate. The detection system was monitored to note alarm times. The aiming effectiveness was based on visual observations of where the laser hits the target during the cold tests and where the water stream hits the fuel package during the fire tests. In addition each test was photographed and video-taped to provide supporting documentation.

Fire suppression and extinguishment were based on visual observations and documented through a series of snap shots taken from the video footage.

Control/suppression was defined as a 90% reduction in fire area. A fire was considered to be extinguished at the point where no flaming combustion was visible inside of the pallet stack(s) or wood cribs. Both parameters were based on the observations made by the firefighting party in the space and verified through video analysis.

5.1 Monitor Operating Conditions

The firemain on the ex-USS SHADWELL is equipped with an ultrasonic flow meter that was used to measure the flow rate of the monitor during each test. A pressure transducer was installed at the inlet to the monitor to measure the system pressure during each test. This pressure transducer has a full scale range of 0-690 kPa (0-100 psi).

5.2 Photography

Video and infrared (IR) cameras were located throughout the well deck to monitor and record the status of each fire. Video cameras located near the fire were installed in protective enclosures. One video and IR pair were located adjacent to the large fuel packages to monitor fire progression and suppression during each test.

5.3 Wind Speed and Direction

Wind speed and direction were measured outside the well deck during all tests. One wind speed and direction meter was mounted at the 02 level directly above the well deck to measure ambient wind conditions. The wind speed meters use a 3-cup anemometer to produce a time varying pulse where the frequency of the pulse is proportional to the wind velocity.

6.0 GENERAL TEST PROCEDURES

At the beginning of each test series, a number of photographs of the test setup were taken to provide documentation for the final report.

Prior to the start of the each test, a pre-test brief was conducted by the test director and the safety team leader to review the test parameters, safety team assignments, and safety procedures.

The following sections provide a high level overview of the test sequence and procedures.

6.1 Cold Discharge Tests

At the start of the test, the firemain was charged and set to the desired pressure. The monitor system was configured in the required mode (i.e., manual versus automatic)

All “Test Team” members manned their positions which were verified prior to the start of the test. The hangar was cleared of all none essential personnel. The Safety Team was positioned just inside the hangar bay door and allowed to walk around the space during the test. During manual operation, the monitor operator was located next to monitor on the Main Deck level.

The Test Director announced that the test was in progress and the video and data acquisition systems were activated. After a preselected period of time, the monitor system was activated and the stream reach and targeting information documented.

On completion of the test, the monitor system was secured. A short period of time later, the video and data acquisition systems were secured and the results of the test were documented and post test results photographed (where applicable).

6.2 Detection Tests

Prior to the start of the detection test series, the grid locations (i.e., center point of each grid section) were marked on the deck to expedite the turn-around time for each test.

At the start of the test, the monitor system was configured in the automatic mode but the water supply to the monitor was secured. A laser was fastened to the monitor to identify the targeting location. The portable propane burner was placed at the desired location in the grid. A torch was located next to the burner controls to ignite the burner during the test. A portable CO_2 extinguisher was located next to the burner controls to extinguish the fire at the end of the test or for use in emergency situations.

All “Test Team” members manned their positions which were verified prior to the start of the test. The hangar was cleared of all none essential personnel. The Safety Team was positioned inside the hangar at the burner location.

The Test Director announced that the test was in progress and the video and data acquisition systems were activated. After a preselected period of time, a Safety Team member held a lit torch above the burner and the flow of propane to the burner was initiated. The flow of propane to the burner was increased every 30 seconds until both detectors went into alarm. Once the monitor had been automatically aimed at the fire by the control system, the target location was marked with a soap stone to be documented after the test was complete.

On completion of the test, the propane/burner was secured. A short period of time later, the video and data acquisition systems were secured and the results of the test was documented.

6.3 Fire Suppression Tests

At the start of the test, the firemain was charged and set to the desired pressure. The monitor system was configured in the required mode (i.e. manual versus automatic). For the tests conducted against the fully involved fuel package, the valve to monitor was secured at the start of the test.

The fuel package (i.e., stacks of wood pallets/small wood crib and ignitor pan) was placed/assembled at the desired location in the hangar. A container of heptane and a torch was placed adjacent to the fuel package. A backup fire hose (charged) was located just outside the hangar bay doors at FR 67.

All “Test Team” members assumed their positions which were verified prior to the start of the test. The hangar was cleared of all none essential personnel. The Safety Team was positioned just inside the hangar adjacent to the fuel package. During manual operation, the monitor operator was located just inside the hangar bay door (mid-ship at FR 67).

The Test Director announces that the test was in progress and the video and data acquisition systems were activated. The pans beneath the pallet stacks/wood cribs were then fueled with heptane. After a preselected period of time, the pans were ignited by a suited-out Safety Team member using the pre-staged torch.

For the tests conducted against the fully involved fuel package, the valve to monitor was opened once the fire has become fully involved (i.e., 3 minute preburn time). After the fire had been extinguished, the monitor was secured and the end of the test was noted. A short period of time later, the video and data acquisition systems were secured and the results of the test was documented. Any residual flaming and/or glowing embers in the fuel package was documented and then manually extinguished (i.e., overhauled) by the Safety Team using the hose positioned outside the hangar bay door.

7.0 TEST RESULTS

As stated previously, the original intent was to conduct these tests with detectors installed in each corner of the hangar (i.e., a four detector system). However, only two detectors were available at the time the tests were conducted. As a result, the system was less than optimal as tested.

There are two ways to calibrate the detection/targeting algorithm. The first way is the default and uses the geometry of the space (i.e., x, y and z coordinates of the detectors and monitor) to calculate/identify the fire location. These tests were conducted using this default configuration. The second way, which is recommended in an actual installation/application, is to install a laser on top of the monitor and manually aim it at the fire location and save/record the value. This is repeated at various locations throughout the space (i.e., at a minimum the four corners of the protected area/space). This provides the most accurate calibration of the system.

Prior to the start of these tests, the spray pattern was varied and stream reach was assessed to select an optimal spray pattern for use during these fire suppression tests. A five degree spray pattern provided good coverage of the protected area and produces about a 5-8 ft diameter area where the stream impacted the deck. This impact area corresponds to a delivered water density of about 210 Lpm/m^2 (5 gpm/ft^2), which is more than adequate to extinguish deep seated Class A fires.

The deployment time of the monitor and the water application time (i.e., time required to open the valve to initiate water flow) were measured prior to the start of these tests. Upon detection of the fire, the monitor is first deployed and aimed at the fire location prior to water discharge. The deployment and aiming time of the monitor was just under ten seconds. An additional five seconds is required to open the valve resulting in a total response time for the system of about 15 seconds from fire detection.

7.1 Coverage of Protected Area and Manual Control

7.1.1 Stream Reach

The first series of tests assessed the ability of the monitor to manually discharge water (using the joystick control) into all areas of the hangar. This was verified through visual observation.

The approach/procedure consisted of first aiming the monitor at the deck in the center of each the 12 sectors and then moving the spray upward to impact the same location on the overhead. This approach ensured complete coverage of the protected space.

During these tests, the monitor system was able to apply significant amounts of water to all locations in the hangar.

7.1.2 Manual Operation/Aiming

During this exercise, the ability of a novice operator to accurately aim the monitor was determined/assessed. Initially, a laser was installed on the monitor and the ability of the operator to hit a number of targets was assessed. The water supply to the monitor was secured during these tests. A number of tests were also conducted with the water supply activated.

The results showed that even a novice operator was able to hit a target within 15-20 seconds of system activation.

7.2 Detection

7.2.1 Critical Fire Size/Fire Location Assessment

The objectives of these tests were to determine the smallest fire that could be reliable detected by the system as a function of location as well as to assess/verify the system can detect a fire at all locations in the protected space and aim the monitor at that location.

During these tests, the system was set in automatic mode but the water supply to the monitor was secured. A high intensity red light laser was fastened to the monitor to identify the location the monitor is aimed. The system was configured to save the coordinates of the fire once detected to develop a coordinate's map of the test area. A small propane burner was placed in the center of each grid and ignited.   The flow of propane to the burner was slowly increased until detection occurred. Detection was defined as the time when two detectors went into alarm (i.e., the time when the monitor would be deployed and activated). The propane flow rate and the corresponding heat release rate of the fire at the time of detection was recorded for each test. The critical fire sizes measured for two elevations at each grid location are listed in Table 1.

Table 1 – Critical Fire Size for Detection

Test #	Test Type	Elevation	Grid Sector	Critical Fire Size (kW)
DS-1	Detection	Deck Level	1	88
DS-2	Detection	Deck Level	2	78
DS-3	Detection	Deck Level	3	78
DS-4	Detection	Deck Level	4	84
DS-5	Detection	Deck Level	5	88
DS-6	Detection	Deck Level	6	72
DS-7	Detection	Deck Level	7	72
DS-8	Detection	Deck Level	8	88
DS-9	Detection	Deck Level	9	116
DS-10	Detection	Deck Level	10	66
DS-11	Detection	Deck Level	11	64
DS-12	Detection	Deck Level	12	116
DS-13	Detection	2.4 m (8 ft)	1	60
DS-14	Detection	2.4 m (8 ft)	2	54
DS-15	Detection	2.4 m (8 ft)	3	54
DS-16	Detection	2.4 m (8 ft)	4	60
DS-17	Detection	2.4 m (8 ft)	5	52
DS-18	Detection	2.4 m (8 ft)	6	40
DS-19	Detection	2.4 m (8 ft)	7	36
DS-20	Detection	2.4 m (8 ft)	8	54

Test #	Test Type	Elevation	Grid Sector	Critical Fire Size (kW)
DS-21	Detection	2.4 m (8 ft)	9	52
DS-22	Detection	2.4 m (8 ft)	10	40
DS-23	Detection	2.4 m (8 ft)	11	40
DS-24	Detection	2.4 m (8 ft)	12	52

As shown in Table 1, the critical sizes for fires located at deck level ranged from about 60-120 kW with the highest critical fire sizes occurring the greatest distances from the detectors and in the corners of the space directly below the detectors. Lowest critical fire sizes were located in the center of the space and were typically on the order of 75 kW.

The critical sizes for elevated fires were less than those observed at deck level and ranged from about 30-60 kW. The lower critical fire sizes for the elevated fires were attributed to the shorter distances between the fires and the detectors at the higher elevation. The highest critical fire sizes again occurring the greatest distances from the detectors and in the corners of the space directly below the detectors, which was similar to the deck level fires. The lowest critical fire sizes for the elevated fires were located in the center of the space and were typically on the order of 40 kW.

Once the fire had been detected and the monitor aimed at the fire location, the target location on the deck was marked with a soup stone and measured once the fire had been secured. A photograph showing the target location and the makings on the deck is provided as Figure 17.

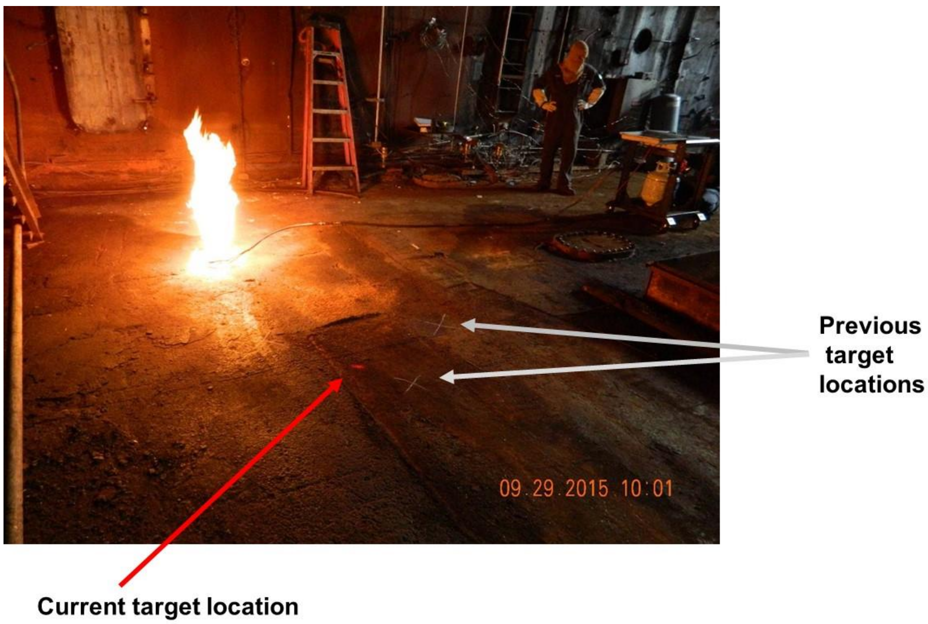


Fig. 17 — Aiming Location Documentation

The results of the targeting assessment are summarized in Table 2 and illustrated in Figures 18 and 19. The “X” values shown in the table are the distances between the fire location and the aiming location in the athwart ship (port-starboard) direction. Positive values correspond to aiming above the fire and negative values correspond to aiming below the fire. The "Y" values shown in the table are the distances between the fire location and the aiming location in the longitudinal direction (forward to aft). Positive values correspond to aiming to the left of the fire and negative values correspond to aiming to the right of the fire.

Table 2 – Aiming Accuracy Test Results

Test #	Test Type/Objective	Elevation	Grid Sector	ΔX (ft)	ΔY (ft)
DS-1	Detection	Deck Level	1	-3.0	-2.0
DS-2	Detection	Deck Level	2	-1.6	0.0
DS-3	Detection	Deck Level	3	2.0	3.0
DS-4	Detection	Deck Level	4	5.9	-1.0
DS-5	Detection	Deck Level	5	-4.9	-2.6
DS-6	Detection	Deck Level	6	0.0	0.0
DS-7	Detection	Deck Level	7	3.0	1.3
DS-8	Detection	Deck Level	8	4.9	0.0
DS-9	Detection	Deck Level	9	-3.0	-5.9
DS-10	Detection	Deck Level	10	0.0	-4.9
DS-11	Detection	Deck Level	11	1.0	-1.3
DS-12	Detection	Deck Level	12	4.9	0.0
DS-13	Detection	2.4 m (8 ft)	1	-7.9	-3.9
DS-14	Detection	2.4 m (8 ft)	2	-3.9	-1.3
DS-15	Detection	2.4 m (8 ft)	3	-3.0	2.0
DS-16	Detection	2.4 m (8 ft)	4	5.9	1.0
DS-17	Detection	2.4 m (8 ft)	5	0.0	-1.0
DS-18	Detection	2.4 m (8 ft)	6	-4.9	-3.0
DS-19	Detection	2.4 m (8 ft)	7	0.0	0.0
DS-20	Detection	2.4 m (8 ft)	8	2.6	-1.0
DS-21	Detection	2.4 m (8 ft)	9	-3.0	-9.8
DS-22	Detection	2.4 m (8 ft)	10	-1.3	-6.9
DS-23	Detection	2.4 m (8 ft)	11	1.0	-1.0
DS-24	Detection	2.4 m (8 ft)	12	3.3	0.0

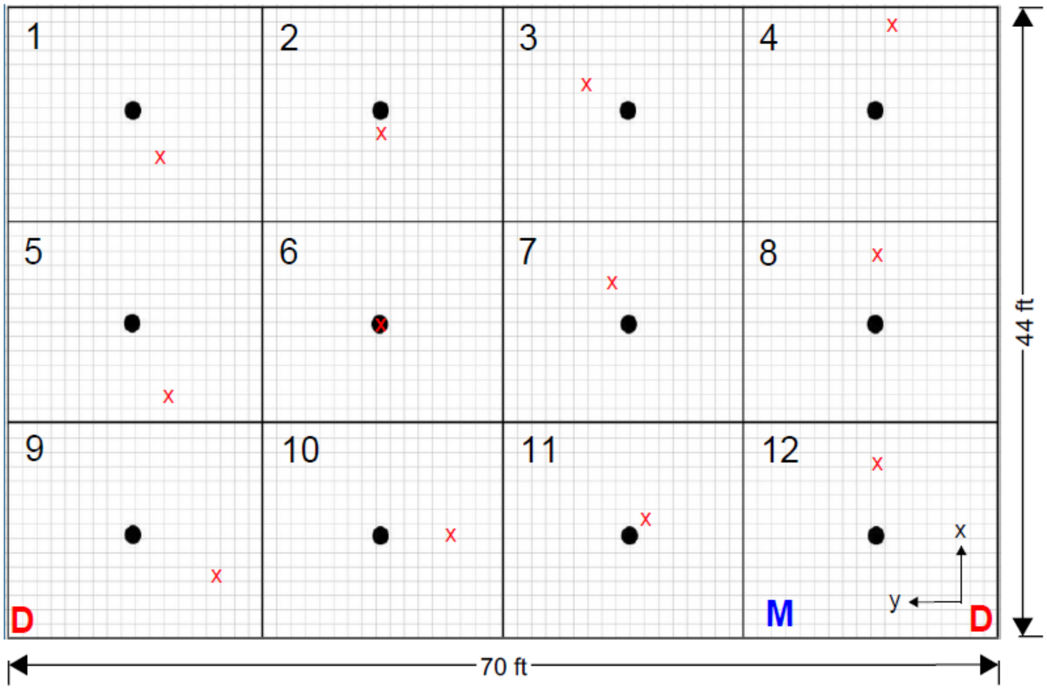


Fig. 18 — Aiming Accuracy Deck Level

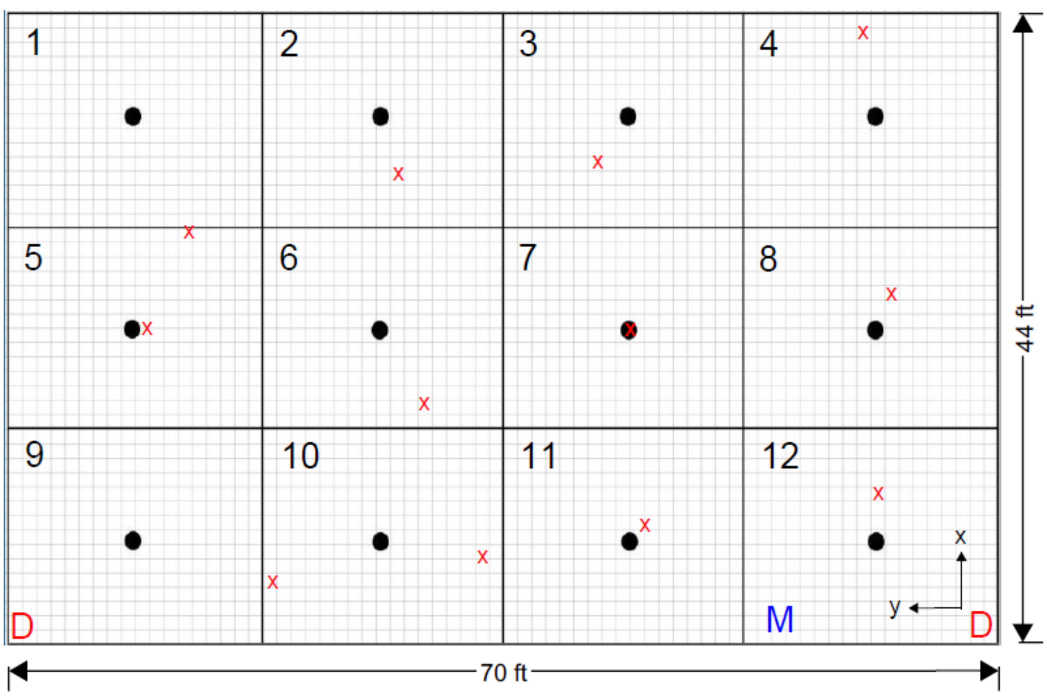


Fig. 19 — Aiming Accuracy Mid-Level (2.4 m (8 ft) elevation)

As stated previously, there are two ways to calibrate the detection/targeting algorithm; using x, y and z coordinates of the detectors and monitor to calculate/identify the fire location or to manually calibrate the system using a fire source and a laser pointer. The software calculation method was used during these tests.

As shown in Table 2 and Figures 18 and 19, the calculation method was slightly off but still provided reasonable accuracy. Specifically, the inaccuracies in targeting were compensated for by the width of the spray pattern and programmed tight oscillation of the spray when it was aimed at the target/fire.

The deviation in accuracy appears to be a function of rotation around the center point of the space. Specifically, rotating the target locations about 5-10 degrees clockwise will provide much better agreement between the fire and target locations as illustrated in Figure 20.

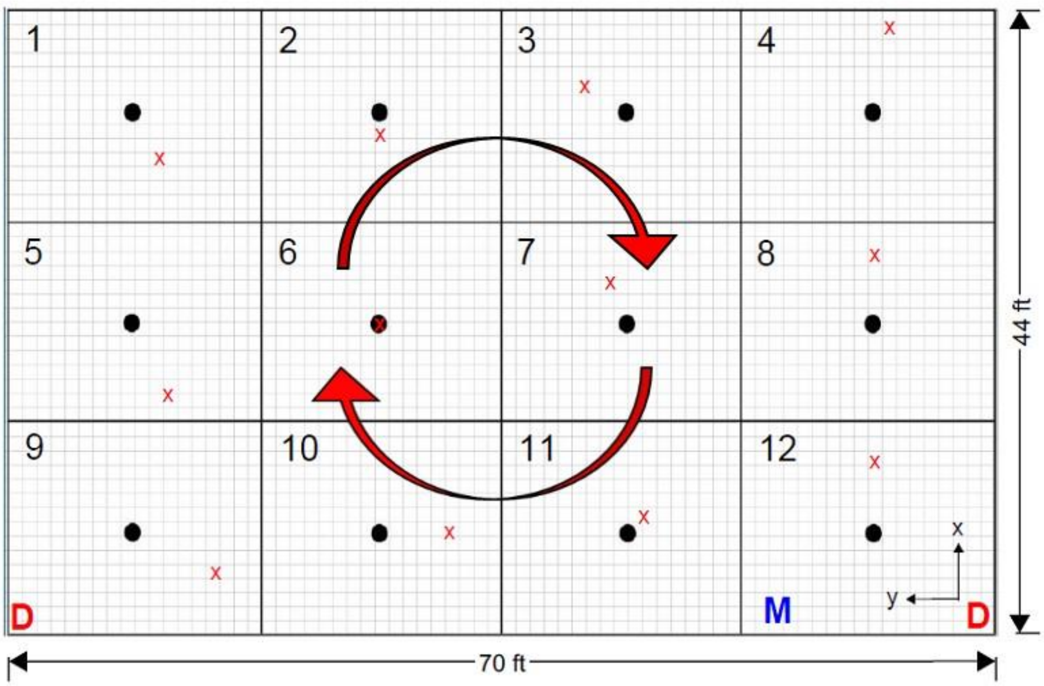


Fig. 20 — Aiming Accuracy Mid-Level (2.4 m (8 ft) elevation)

7.3 Suppression

7.3.1 Small/Growing Fires

A number of small fire tests were planned with the intent to assess the capabilities of the system against small/growing fires. However, during the initial stages of this test program, it became apparent that the monitor system would be overmatching for these small fire scenarios due to the detection/targeting accuracy and the high delivered water density of the monitor 210 Lpm/m^2 (5 gpm/ft^2)). Since the fuel packages/small wood cribs had been previously assembled, a test was conducted at the end of the test series to assess the systems' capabilities against multiple fires. The results of this test are dissed later in this section.

7.3.2 Large Fire Suppression Tests

Four large fire suppression tests were conducted to assess the ability of the monitor system to suppress/extinguish large Class A fires for a range of operating conditions.

The large fires consisted of two stacks of 16 standard size oak pallets placed side-by-side. The pallets were elevated 20.3 cm (8.0 in) above the deck to allow for ignition by heptane pan fire located under each pallet stack.

The results of the large fire suppression tests are summarized in Table 3. A series of video snapshots showing the suppression sequence for each test are provided as Figures 21-24.

In short, all of the fires were quickly suppressed and controlled within a few seconds of the stream reaching the fire/fuel package. A short time later (seconds), both stacks of wood pallets were completely extinguished. In a few tests, this occurred before the heptane pan fires used to ignite the pallet stacks self-extinguished (i.e., burned out of fuel). A detailed description of each test is provided in the following sections.

Table 3 – Large Fire Suppression Test Results

Test #	Description	Activation Time	Control min:sec	Extinguishment min:sec	Total Water (gal)
FS-7	Large Fire Suppression (Manual Control)	3:00 pre-burn	0:10	0:20	<100
FS-8	Large Fire Suppression (Pre-programmed Targeting)	3:00 pre-burn	0:15	0:30	125
FS-9	Large Fire Prevention (Automatic Activation and Targeting)	0:10 act.	instant	instant	<25
FS-10	Large Fire Suppression (Delayed Automatic Activation and Targeting)	3:00 pre-burn	0:10	0:15 wood 1:00 pans	~65 wood 250 pans

Water Activation (Time = 0)

Time = 5 seconds

Time = 10 seconds

Time = 20 seconds

Fig. 21 – Test FS-7 Large Fire Suppression - Manual Control

Fig. 22 – Test FS 8 Large Fire Suppression - Pre-programmed Targeting

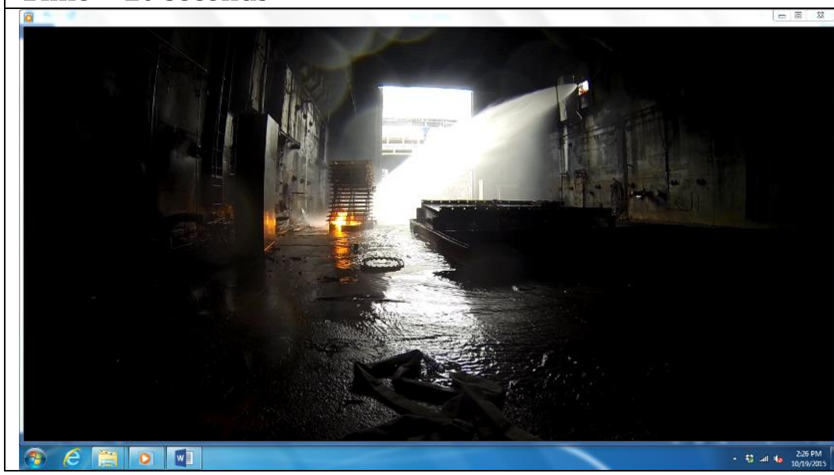
Water Activation (Time = 0)	Time = 10 seconds
	
Time = 20 seconds	**Time = 30 seconds**
	

Fig. 23 – Test FS-9 Large Fire Prevention - Automatic Activation and Targeting

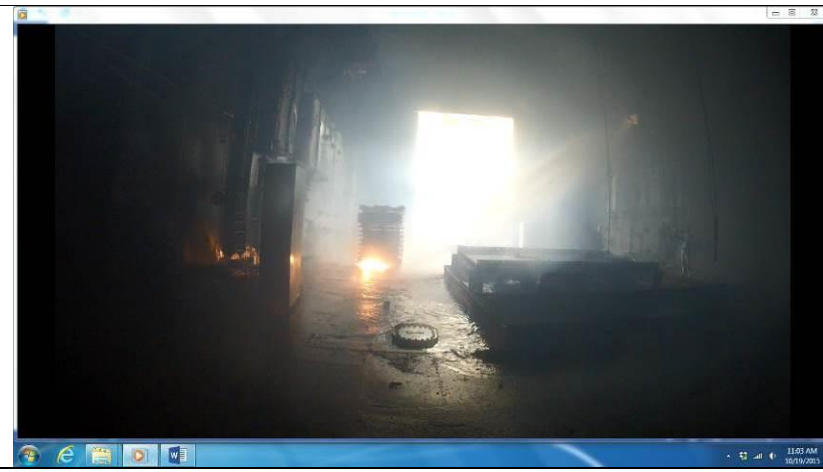
Water Activation (Time = 0)	Time = 5 seconds
	
Time = 10 seconds	**Time = 15 seconds**
	

Fig. 24 – Test FS-10 Large Fire Suppression - Delayed Automatic Activation and Targeting

7.3.2.1 Test FS-7: Large Fire Suppression (Manual Control)

The first large fire suppression test assessed the ability of a novice operator to combat a large Class A fire. During this test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time). After the three minute preburn, the monitor was manually activated using the joystick (by a novice) and the fire was extinguished.

The suppression sequence for FS-7 is shown in Figure 21. The novice operator was able to apply water to the fire within a few seconds of system activation. Within seconds, the fire was quickly suppressed with the residual burning located low, on the backside of the two stacks. By 20 seconds into the discharge, there was no visible flaming inside of the stack of pallets and the fire was determined to be extinguished.

7.3.2.2 Test FS-8: Large Fire Suppression (Pre-programmed Targeting)

The second large fire suppression test assessed the ability of a preprogrammed manually operated monitor to suppress/extinguish a large Class A fire. Prior to the test, a laser was fastened to the monitor and a series of sweeps across the fuel pack/pallet stacks was programed into the monitor (using the “Record” function on the joystick). During the test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time). After the three minute preburn, the monitor was manually activated using the “Play Back” function to allow the monitor to automatically suppress/extinguish the fire.

The suppression sequence for FS-8 is shown in Figure 22. The monitor was able to apply water to the fire within a few seconds of system activation (i.e., from the start of the play back function). The monitor made a series of sweeps across the fuel array, starting at the bottom and slowly moving upward (as programmed by the novice operator prior to the test). By 10-15 seconds into the discharge, the bottom of the array had been extinguished with only a limited amount of burning observed near the top of the two stacks. By 30 seconds into the discharge, there was no visible flaming inside of the stack of pallets and the fire was determined to be extinguished.

7.3.2.3 Test FS-9: Large Fire Prevention (Automatic Activation and Targeting)

The third large fire suppression test assessed the ability of a fully automatic system (detection and automatic targeting) to detect and suppress/extinguish a fire in a large stack of Class A materials. During the test, the two stacks of wood pallets were ignited and the system was allowed to automatically detect, activate and suppress the fire.

The suppression sequence for FS-9 is shown in Figure 23. The system detected the fire so quickly, that the firefighting party igniting the heptane pan fires below the stacks of pallets, had to run out of the hangar after ignition. The system applied water to the fuel package within 5 seconds of ignition. The applied water prevented the pallets from igniting but the heptane pans located below the stacks continued to burn until all of the fuel (heptane) in the pan had been consumed. The continued burning of the pans was expected since the monitor was discharging water during this test. If the monitor had been discharging AFFF, the heptane pans would have been immediately extinguished.

7.3.2.4 Test FS10: Large Fire Suppression (Delayed Automatic Activation and Targeting)

The final large fire suppression test assessed the ability of a fully automatic system (detection and automatic targeting) to suppress/extinguish a large, fully involved Class A fire. During this test, the two stacks of wood pallets were ignited and allowed to burn until fully involved (i.e., ~ 3 minute preburn time). The all-up system was allowed to detect the fire, deploy and aim the monitor but the water supply was not activated until the fire became fully involvement.

The suppression sequence for FS-10 is shown in Figure 24. The system detected and aimed the monitor at the fire within five seconds of ignition but the water supply was not activated until three minutes later. Within seconds of water application, the fire was quickly suppressed with the residual burning located low, on the backside of the two stacks. By 15 seconds into the discharge, there was no visible flaming inside of the stack of pallets but the heptane pan fires located below the pallets continued to burn for almost a minute. FS-10 was actually the first test conducted in the test series and the amount of heptane used in the pans to ignite the pallets was reduced after this test.

7.3.3 Multiple Small Fires

Since a number of small wood cribs (1A per UL 711[9]) had been fabricated and were still available for testing, a test was conducted at the end of the test series to assess the systems' capabilities against multiple fires. Three wood cribs were used during this test. The cribs were located in Grid Sectors 2, 5 and 7 (reference Figure 13) and are shown in Figure 25. The cribs were ignited (using small pans of heptane) and allowed to burn for one minute prior to activating the monitor system.

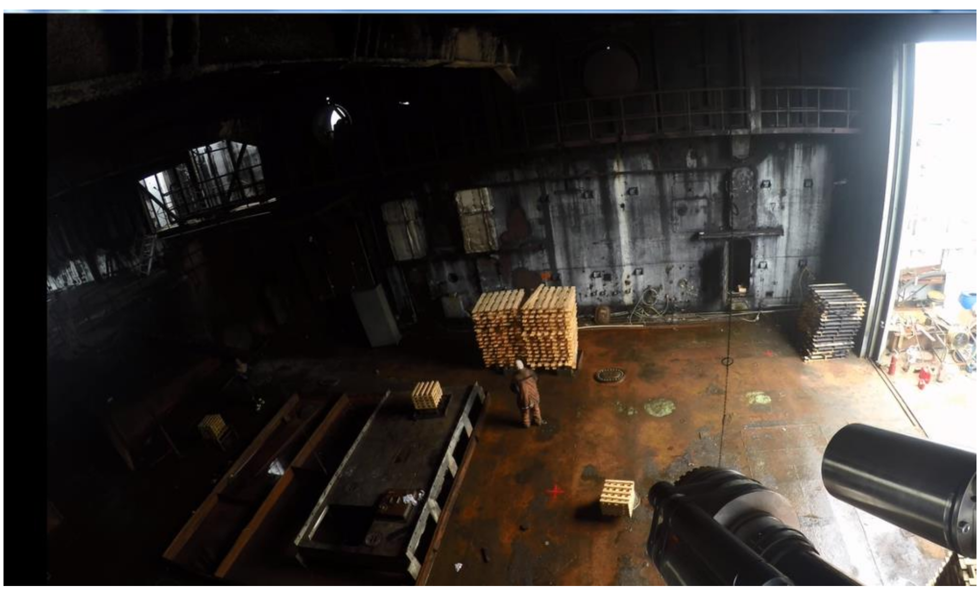


Fig. 25 — Multiple Fire Suppression Test Configuration

The suppression sequence for the multiple fire test is shown in Figure 26.

Water Activation (Time = 0)

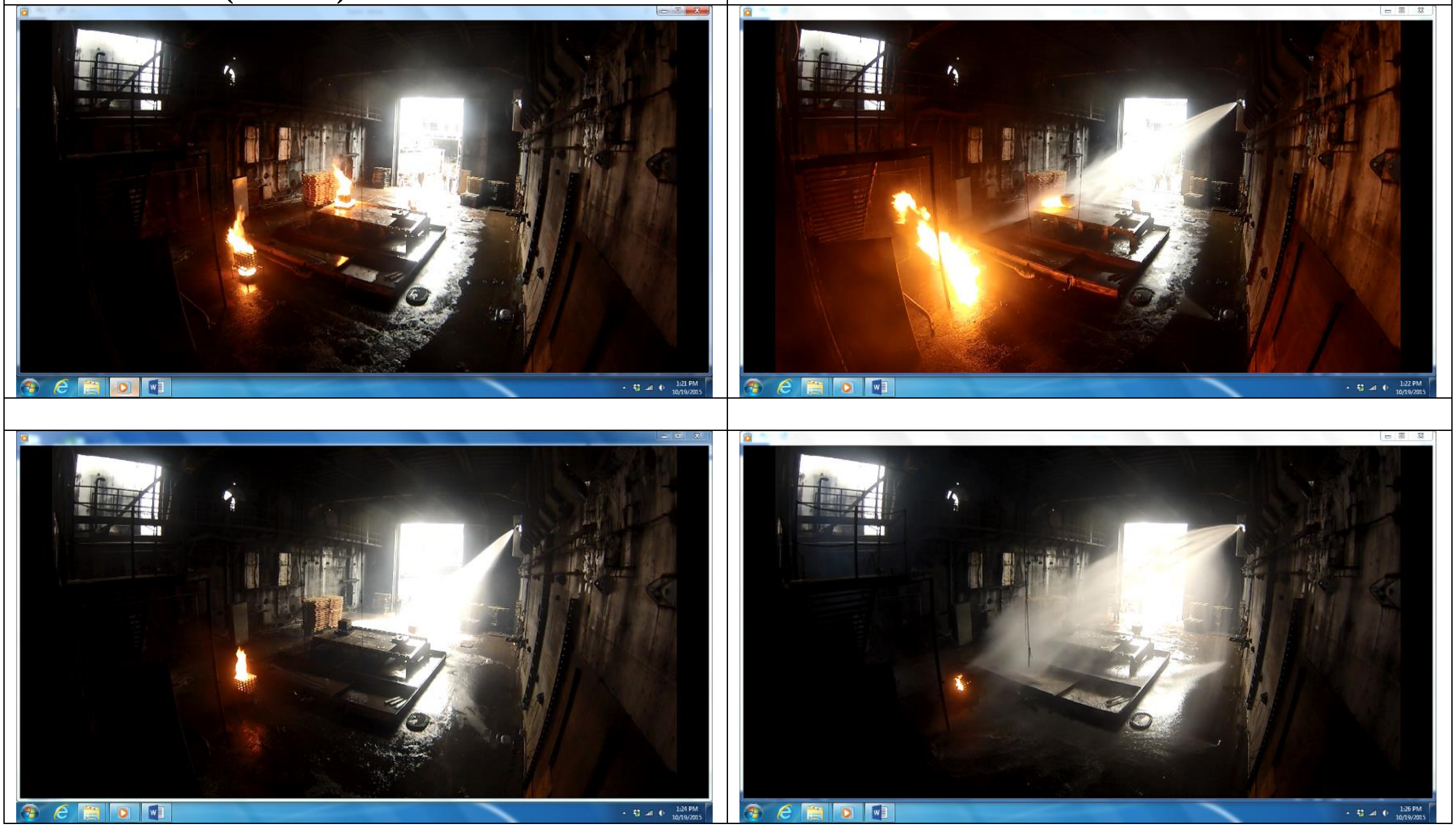


Fig. 26 – Multiple Small Fire Suppression Test

According to the manufacturer, the detection system records the location of the three fires and attacked the fires in the order in which they were detected. The system initially applied water to the fire located in Grid Sector 2. Within a few seconds of water application, the fire was completely extinguished. The system then applied water to the fire located in Grid Sector 7. Within a few seconds of water application, the fire at this location was also completely extinguished. The system then applied water to the remaining fire located in Grid Sector 5. Within a few seconds of water application, the fire at this location was also completely extinguished.

8.0 SUMMARY AND CONCLUSIONS

Under certain circumstances, large quantities of Class A materials (ordinary combustibles) are stowed in Large Volume Spaces (LVS) on U.S. Navy (USN) ships/platforms. These large volume spaces include aircraft hangars and Vehicles Storage Areas (VSAs) which are typically equipped with an overhead Aqueous Film Forming Foam (AFFF) sprinkling system. Tests conducted to date have demonstrated the limitations of the current overhead AFFF sprinkling system for extinguishing large Class A fuel packages.

The overall objective of this program was to conduct a preliminary assessment of the capabilities of automated monitors to suppress large quantities of Class A materials (ordinary combustibles) stowed in LVS on USN platforms. The performance testing conducted during this program focused on assessing the systems capabilities for protecting simple geometries and configurations. Future testing is recommended to challenge the system with more complex (fully loaded) geometries and configurations.

The first series of tests parametrically assessed the ability of the monitor to manually discharge water (using the joystick control) into all areas of the hangar. As currently installed, the monitor system was able to apply significant amounts of water to all locations. This was verified through visual observation.

The second series of tests parametrically assessed the ability of the detection system to detect and locate a small growing fire in all areas of the hangar. The intent of these tests was to determine the smallest fire that could be reliable detected by the system as a function of location as well as to assess/verify the system could detect a fire at all locations in the protected space and aim the monitor at that location.

The critical sizes for fires located at deck level ranged from about 60-120 kW with the highest critical fire sizes occurring the greatest distances from the detectors and in the corners of the space directly below the detectors. The critical sizes for elevated fires were less than those observed at deck level and ranged from about 30-60 kW with the same trends in location as observed on the deck. The lower critical fire sizes for the elevated fires were attributed to their closer proximity to the detectors as compared to the ones located at deck level.

There are two ways to calibrate the detection/targeting algorithm; using x, y and z coordinates of the detectors and monitor to calculate/identify the fire location or to manually calibrate the system using a fire source and a laser pointer. The software calculation method used during these tests was slightly off but still provided reasonable accuracy. Specifically, the inaccuracies in targeting were compensated for by the width of the spray pattern and programmed tight oscillation of the spray when it was aimed at the fire.

Four large fire suppression tests were conducted to assess the ability of the monitor system to suppress/extinguish large Class A fires for a range of operating conditions.

The large fires consisted of two stacks (16 high) of standard size oak pallets. During all of the large fire tests, the fires were quickly suppressed and controlled within a few seconds of the stream reaching the fire/fuel package independent of the operating mode of the monitor system. Within 20-30 seconds, both stacks of wood pallets were completely extinguished. In a few tests, this occurred before the heptane pan fires used to ignite the pallet stacks self-extinguished (i.e., burned out of fuel).

The results of this investigation demonstrate the potential for using automated monitors for protecting LVS on USN Ships/Platforms. Additional testing is recommended to assess the capabilities of this technology in fully loaded, highly clutter spaces representative of actual LVS.

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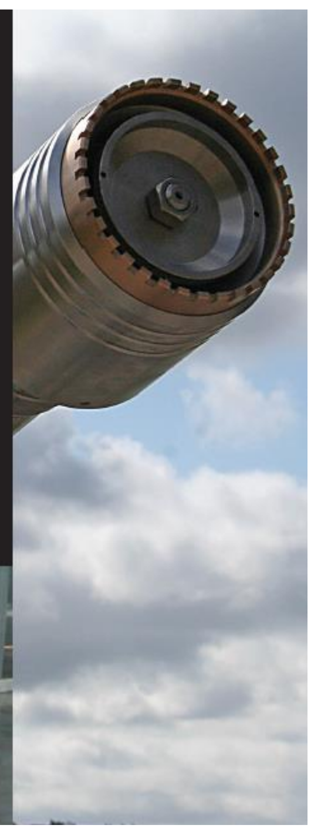
APPENDIX A
UNIFIRE FORCE 50 TECHNICAL DATA/DOCUMENTATION

UNIFIRE

Robotic Nozzles

advanced robotic nozzle technologies ™

Contents



Force Robotic Nozzles

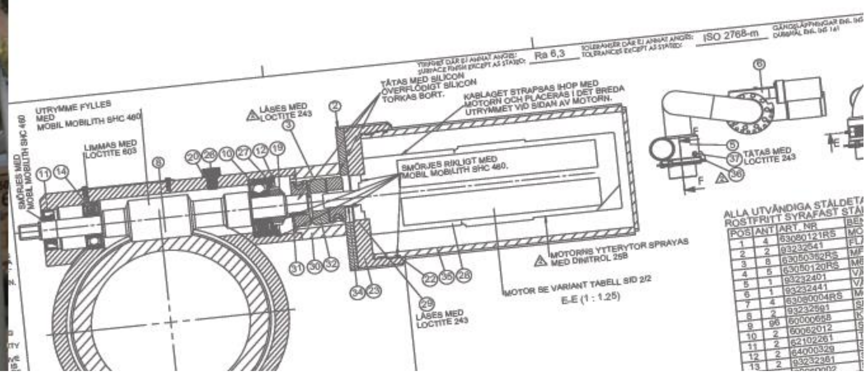
Unifire designed its Force™ monitors in the 21st Century with a clear vision in mind–to create the world's most advanced, high-performance robotic nozzles.

Precision engineered and manufactured in Sweden to the highest possible standards of quality at ISO Certified facilities, Force robotic nozzles are the quintessence of cutting edge nozzle technology.

In every detail the Force series is designed to be effective, reliable, robust, easy to use, simple to maintain, service and troubleshoot. And, you can control them with your phone from anywhere in the world.

But that's not all. Force monitors are accompanied by Unifire's cutting-edge electronic control systems that take firefighting to a whole new level. Force monitors can be networked not only with each other, but with virtually any electronic device, including CCTV and infrared cameras, flame detectors, valves, lights, alarms, and much more.

Unifire's advanced electronics allow us to offer what are undoubtedly the most advanced automatic systems that utilize monitors.



Force50™

Technical Specifications

Material:	Stainless Steel 316L (bronze gears)
Flow Range @ 10 bar / 145 psi:	400-2000 lpm / 100-530 gpm
Motors:	24V Brushless (BLDC)
Horizontal movement (max.):	360° (+/-180° from center)
Vertical movement (max.):	180° (+/-90° from horizontal)
Rotational velocity (max.):	20°/second (40°/second optional)
Vertical movement velocity:	12°/second
Fox angle with Integ50 (max.):	120°
Dimensions with Integ50 nozzle:	51 x 35 x 22 cm
Weight with Integ50 nozzle:	18.5 kg / 41 lbs.
Ambient operational temperature:	-25°C to +70°C / -13°F to 158°F
Power consumption normal/max. (@24V):	5-15 Amps
Voltage:	12- or 24V DC
Cable length Monitor-MCU:	5 Meters / 16 Ft.
Max. Joystick Cable Length:	Unlimited
Communication Protocol:	CANBUS
Maximum recommended pressure:	10 bar / 145 psi
Monitor base connection:	2" Male BSP
Nozzle connection:	2" Male BSP
Multi-connectors on all connection points:	YES
Supports Multiple Joysticks:	YES
Auxiliary control buttons:	YES (Two)
CE Marked:	YES
EMC Tested:	YES
Wireless radio remote option:	YES
Record / Play feature:	YES
Programmable park (stow) position:	YES
Soft stops:	YES
Software upgrade capable:	YES
Adjustable flow settings:	YES
	YES

The POINTER synchron controller.

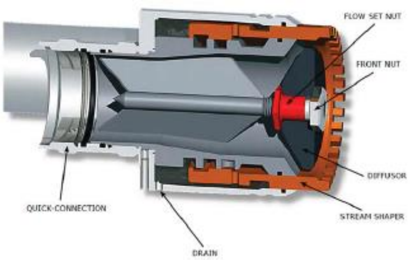
Effective. Intelligent. Elegant. Reliable.

The Unifire Force50 is the most advanced remote controlled monitor of its class.

Compact, light weight, industrial robot type BLDC motors with fully-integrated gears and motors, the Force50 is ideal for land- and sea-based firefighting and industrial applications

CE

Integ50™ Jet/Spray Nozzle



The Integ50 Nozzle is designed specifically for the Unifire Force50 monitors.

With an entirely integrated gear design, brusless (BLDC) motors, and precision engineering, the Integ50 provides unbeatable performance in jet stream, full fog, and everything in between. With fully protected and uniquely integrated gear technology, the nozzle's motor and advanced gears are fully integrated into the nozzle with no external or exposed parts.

The Integ50's sleek appearance is matched by its intelligence. Precise knowledge of the nozzle's spray pattern position at all times provides the user with total control. This feature is also what gives Unifire's nozzles the ability to record exact spray patterns and play them back at the press of a single button.

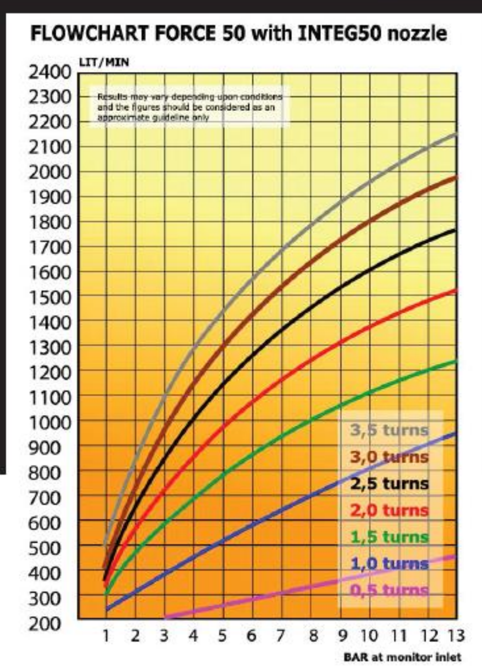
INTEG50 ADJUSTABLE FLOW SETTINGS

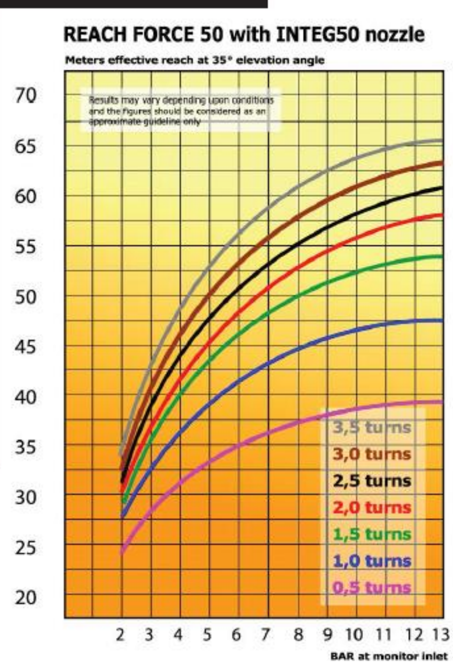
Flow is selected by adjusting the flow set nut of the nozzle, located behind the diffuser.

The flow is factory set to your specifications and can be adjusted and fine-tuned manually.

The flow set nut should, after adjustment, be locked with Loctite 243 or similar. The diffuser and front nut, pictured right, can be then remounted.

FLOW & REACH
of the Force50 with Integ50 Nozzle





π

the ultimate firefighting joystick™

The Unifire π ("PI") Joystick is an all-new, intelligent joystick that is light-weight and simple to use, even under the stress of fighting fires. It comes in tethered and wireless versions.

With built-in monitor position indicators right on the joystick, progressive control from ultra slow and precise to increasingly faster to full speed, the ability to change the spray pattern by simply twisting the tip of the joystick shaft, to control of valves and other peripherals and even stowing. . . the π joystick represents the latest generation in joystick technologies.

- Light Weight (≈1.2 Kg / 2½ Lbs.)
- Record & Play Buttons (Full, Natural Record)
- Progressive Control For Precise Targeting
- One-Hand Operation
- Monitor Position Indicator LED's
- Spray Pattern Indicator LED
- Valve On/Off Button
- Two Auxiliary Buttons (For Valves, Lights, etc.)
- Park Button (Programmable)
- Highly Water Resistant
- Multi-Connector At Base
- "Twist Top" For Simple Spray Pattern Control
- Led Lights To Indicate Status

ROBOTIC NOZZLE CONTROL SYSTEMS

Unifire prides itself on making the world's most advanced robotic nozzle control systems.

Control our robotic nozzles, or even networks of them, by any device you can imagine. Our joysticks and controllers, 3rd party, commercially available joysticks, tablets, laptops, and yes, even your smart phone.

Unifire's TARGA and X-TARGA PLC's have embedded PC's and Web Servers, so you can control and view all system data from any web browser, without any need for software (it's all built in).

And, our systems are simply integrated with other peripheral devices, such as CCTV and infrared cameras, flame detectors, valves, lights, tank level indicators, wind speed and direction detectors, and virtually any other electronic device you can think of.

Unifire even offers the FlameRanger™—our fully automatic fire detection and suppression system which combines the Force robotic nozzles with cutting-edge flame detection technologies to detect and suppress a fire with pinpoint accurracy within seconds of detection.

APPENDIX 2

Summary of FlameRanger Test Report from the

Research Institutes of Sweden (RISE) & Thomas Bell-Wright

Johnson Controls
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Tel +1 401 781 8220
www.JohnsonControls.com

Johnson Controls

Executive Summary

SPRAYSAFE Autonomous Fire Suppression (AFS) System

SPRAY SAFE

Evaluation as an External Building Fire Protection System

Overview:

Many buildings have been constructed using combustible cladding materials. The use of this material is widespread and has become a global problem for fire safety. In recent years we have seen that exterior fires can spread quickly due to the combustible cladding material installed on high-rise buildings, making it more challenging for the fire brigade to suppress the fire before a large amount of damage is done. As combustible cladding has been installed in thousands of buildings around the world, many cities are trying to find a solution.

The Challenge:

In most cases a fire can spread quicker on the exterior of a building which has combustible cladding material than the fire brigade is able to get to that location. Timely intervention is made even more challenging due to the ever-increasing traffic congestion on the roads today, which is putting the fire brigade at an immediate disadvantage. Additionally, when at the scene of the fire, the height which the flames could be reaching on tall buildings, which can be anything up to 800 meters high, may be difficult to reach with firefighting equipment that only reaches approximately 60 meters from the ground.

Solution:

SPRAYSAFE Autonomous Fire Suppression (AFS) system is a fully automatic, standalone fire detection and suppression system, designed to deliver rapid fire protection for the external façade of a building and can utilize existing building fire protection infrastructure which minimizes the need for additional water supplies, pipework and/or pumps by integrating with existing components to protect the external cladding and the wall cavity between cladding and inner wall.

The AFS System uses two or more Flame Detectors that are installed in the exterior of the building, are directly connected to the AFS Programmable Logic Controller (PLC) and constantly detect for the presence of flames on the façade. In case of a fire the flame detectors identify the position of a flame, as well as the size and volume of the flame, and provide the coordinates to the PLC.

When a flame is detected, the system deploys the extension boom outside the building and positions the robotic monitor to directly target the identified fire based on three dimensional coordinates. The extension boom is installed within the building and can extend up to 4 meters outside the building in under 8 seconds.

Once the robotic monitor is positioned, the deluge valve is actuated to open and allows water flow through the boom and robotic monitor to suppress the identified fire. The monitor can spray up to 2,000 LPM of water at the flame with high accuracy. The high-performance, state-of-the-art AFS Robotic Monitor is controlled by the intelligent algorithm in the PLC software.

Test Program:

During the months of January and February 2018, a full-scale fire test program was conducted by Thomas Bell-Wright International Consultants (TBWIC) in cooperation with the Research Institute of Sweden (RISE) to assess the performance of the SPRAYSAFE Autonomous Fire Suppression (AFS) system. The purpose of the test program was to validate the ability of the SPRAYSAFE AFS system to detect and locate an early-stage fire, distribute water to the position of the fire, and to prevent a fire from spreading on the exterior surface of a building with combustible façade materials.

A 35-meter-wide by 25-meter-high test wall was erected at the TBWIC facility in Dubai, UAE – representing a portion of the maximum system coverage area. A schematic representation of the test wall can be found in Figure 1. Two Tyco model FV311 flame detectors were installed on top of the wall, spaced 50 meters apart. This provided a total detection coverage area of 1,250m^2, 30% greater than the surface area of the test wall.

Two separate and independent SPRAYSAFE AFS robotic monitors were installed at the vertical edge of the wall to assess the total monitor coverage area. The first monitor was installed at the bottom of the wall to simulate a system fighting a fire vertically upwards, and to validate the maximum coverage area above the monitor. The second monitor was installed at the top of the wall to simulate system fighting a fire vertically downwards, and was used to assess the coverage area below the monitor. With this configuration, the total coverage area of a single monitor could be assessed by combing both the upward and downward components.

To validate system performance, two separate tests series were conducted: a targeting test series (T1), and a large-scale fire performance test (T2) using combustible façade cladding. During the series of tests, the size of the monitor orifice was manually changed to achieve two different nominal discharge coefficients (K-Factors): 370 $\frac{LPM}{\sqrt{bar}}$ (26 $\frac{GPM}{\sqrt{psi}}$) and 433 $\frac{LPM}{\sqrt{bar}}$ (30 $\frac{GPM}{\sqrt{psi}}$). All tests were repeated for both K-factor settings and at different pressures ranging from 5 bar (72.5 psi) to 8 bar (116 psi), thus flowing as little as 850 LPM (225GPM) and up to 1230 LPM (325GPM).

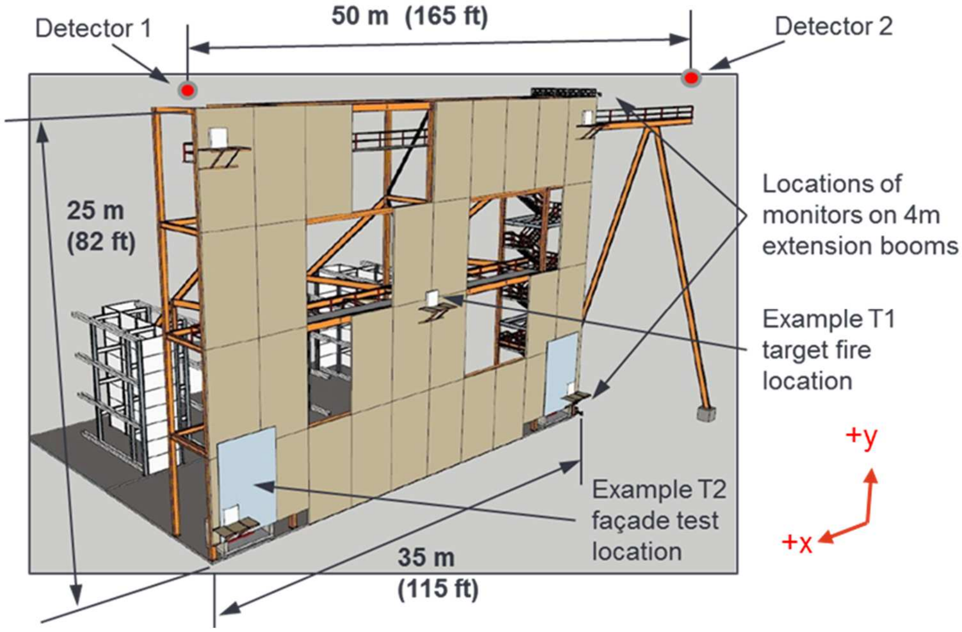


Figure 1 - Schematic representation of the test wall structure. Some wall panels are omitted to show the underlying structure.

Targeting tests (T1):

The objective of the targeting tests was to verify that system could both detect and accurately direct the water spray at small target fires within the limits of its coverage area for a given orifice setting and minimum and maximum operating pressures. The target fires consisted of various combinations of up to two 0.75 m^2 mineral-foam insulation panels soaked in lacquer thinner and up to two 0.5 m^2 pans filled with lacquer placed on ledges. Targets were strategically placed to define the maximum coverage area under specific hydraulic conditions, as shown in Figure 2.

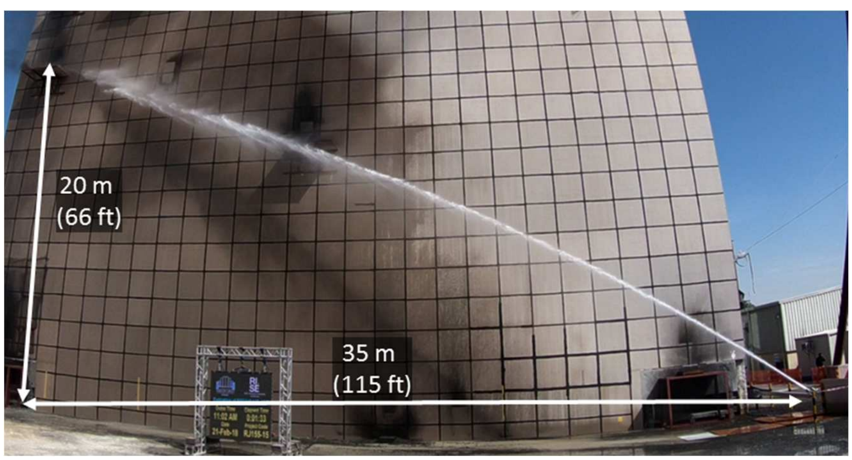


Figure 2 - Targeting Test (T1) where the extinguished target was located at the maximum diagonal reach for the active system

A total of twenty-eight T1 tests were successfully completed. Time to detection, time of water delivery to the burning fuel, and visible suppression were assessed. The average detection time for the T1 test series was under 10 seconds after ignition of the fire, with the fastest detection time being 6 seconds and the slowest detection time being 19 seconds. The average water delivery time to the target after the system detected the fire was 12 seconds, with minimum time of 6 seconds and a maximum of 28 seconds. All targets were either highly suppressed or extinguished. Targeting test results are summarized in Table 1.

Table 1 - Targeting Test Summary Table. Horizontal and Vertical distances measured using the monitor location as the origin

Test Ref	Monitor Location	Horizontal Distance [m]	Vertical Distance [m]	Nominal Pressure [bar]	Nominal K-Factor [LPM/√bar]	Detection Time [s]	Water Delivery Time [s]
15	Bottom	33	18	8	433	7	28
18	Bottom	17.5	12.5	5	433	7	11
19	Bottom	17.5	12.5	8	433	8	11
22	Bottom	2	23	5	433	6	14
23	Bottom	33	2	5	433	19	9
26	Bottom	2	2	5	433	8	8
27	Bottom	2	2	8	433	8	8
28	Bottom	25	2	5	433	9	8
29	Bottom	2	23	5	433	7	20
33	Top	33	-23	5	370	8	13
34	Top	2	-23	5	370	17	6
37	Top	17.5	-12.5	5	370	8	8
38	Top	17.5	-12.5	5	433	8	6
39	Top	2	-2	8	370	10	6
42	Bottom	20	20	5	433	11	14
46	Bottom	15	25	5	370	13	10
47	Bottom	20	20	5	370	11	14
48	Bottom	2	20	5	370	7	13
49	Bottom	2	23	8	370	8	14
52	Bottom	30	2	8	370	8	12
53	Bottom	25	3	5	370	7	14
54	Bottom	10	10	5	370	6	10
56	Bottom	2	2	8	370	8	10
57	Bottom	17.5	12.5	8	370	11	15
60	Top	2	-23	8	433	8	8
61	Top	17.5	-12.5	8	433	8	8
62	Top	17.5	-12.5	5	433	8	6
66	Bottom	33	18	8	370	10	26

Large scale performance tests (T2):

The objective of the large-scale performance tests, or T2 test series, was to verify that the system was able to adequately prevent fire spread on a simulated full-scale façade. The T2 test was modeled after the SP 105 test program. SP 105 is similar to the NFPA 285 and BS 8418 test programs in that it consists of a shielded fire source designed to apply constant heat from a simulated flashover condition to assess resistance to fire attack and vertical spread on a building façade surface. The fire scenario consisted of an insulated combustion chamber containing two pans filled with 60 L of heptane – corresponding to a total fire load of approximately 75 MJ/m^2 and a sustained burn time of 15-20 minutes. A 24 m^2 simulated façade surface was installed directly above the opening of the combustion chamber consisting of aluminum composite panels with polyethylene combustible core installed on a framework creating an exposed 50 mm cavity as shown in Figure 3. The test specimens were located at the bottom corners of the test wall as shown in Figure 1.

Tests were conducted at the minimum pressure and flow determined to reach the target distance during the T1 test series. Three different attack types were assessed: vertical downward (top system), diagonal downward (top system), and horizontal (bottom system). In addition, a free-burn was conducted to verify the combustibility and response of the façade material without suppression. Performance of the system was determined based on visual observations both during and after the test in conjunction with the temperature data obtained during the fire test.

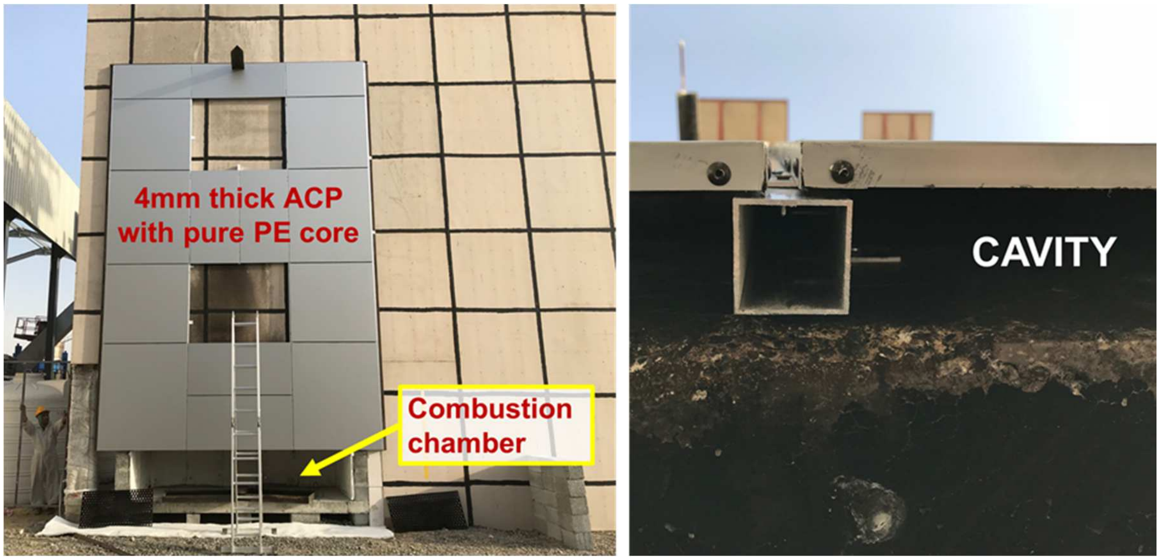


Figure 3 - Performance test specimen (left) and 50mm cavity as viewed looking up at top of combustion chamber opening (right)

A total of three T2 tests and a free-burn were successfully completed with very positive results. Visual observations after all three T2 tests with suppression showed less than 10% exterior cladding material fire damage – significantly less than observed during free-burn conditions. The temperature data collected in the eave and in the cavity of the cladding system showed a peak temperature of 95°C for less than one minute collectively. The temperature was controlled and under 40°C for over 90% of the test duration in all cases. An example of the fire development and subsequent damage observations can be found in Figure 4.

Figure 4 - Photos depicting the T2 fire scenario shortly after ignition (left), fully developed approximately 5-7 minutes after ignition (center), and subsequent damage (right) for the horizontal attack test.

The application of water by the monitor was observed to provide rapid knock-down and local extinguishment of flaming on the exposed combustible façade materials for the duration of the tests. In addition, the cascade of water on the cladding surface was observed to prevent significant delamination, failure, and breach of aluminum façade materials – likely due to the cooling effect of the water spray in preventing melting of the polyethylene core.

Conclusions:

A total of twenty-eight targeting tests and three full scale combustible façade tests were conducted. The results indicate that the SPRAYSAFE AFS system is capable of targeting and effectively containing a combustible façade fire involving pure polyethylene core aluminum composite panels. The maximum horizontal reach (HR) of the robotic monitor was verified to range from 20m to 35m, the maximum vertical upward reach (VUR) was verified to range from 15m to 25m, and the maximum downward range (VDR) was assessed at 40m for the range of pressures and k-factors tested. These ranges correspond to system coverage areas of up to 4,200m^2, spaced up to 65 meters apart vertically. The assessed coverage areas for different hydraulic conditions is shown in Table 2, below.

Table 2 - Assessed coverage area for different hydraulic conditions

Pressure [bar]	Nominal K-Factor [LPM/√bar]	Flow [LPM]	HR [m]	VUR [m]	VDR (m)	Total Coverage Area [m^2]
5	370	838	20	20	40	2400
			25	15	40	2750
	433	967	20	25	40	2600
			30	20	40	3600
6	370	918	23	22	40	2878
			28	17	40	3211
	433	1059	23	25	40	3033
			32	20	40	3800
7	370	992	27	23	40	3378
			32	18	40	3694
	433	1144	27	25	40	3466
			33	20	40	4000
8	370	1060	30	25	40	3900
			35	20	40	4200
	433	1223	30	25	40	3900
			35	20	40	4200

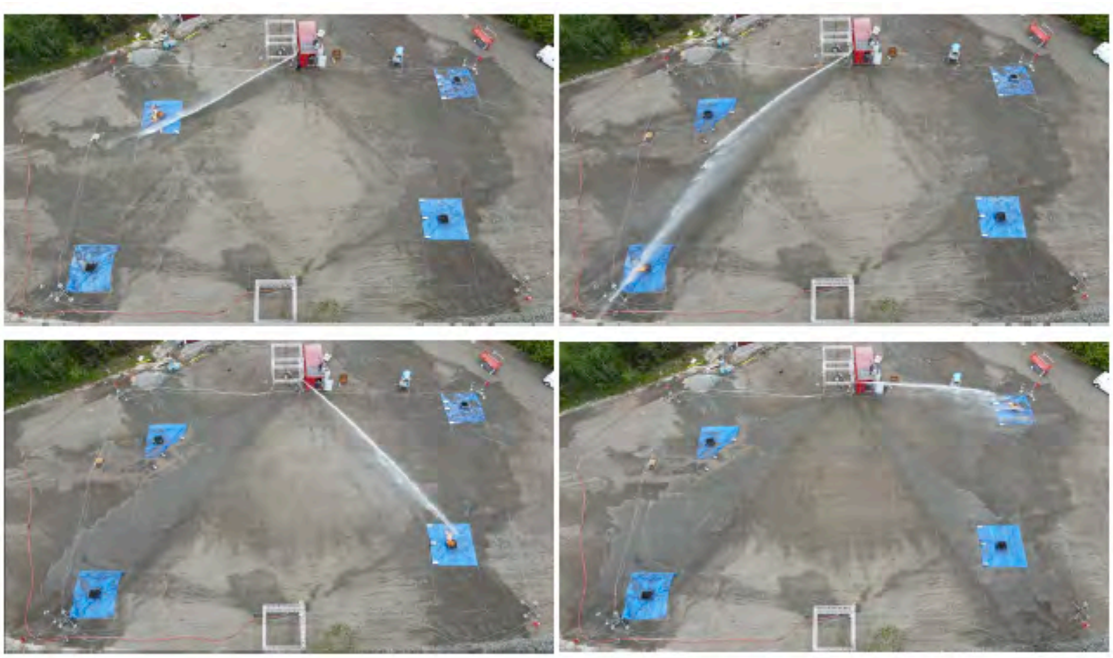
Note: Due to the size limitations of the test wall, the tested VDR was 25m. The maximum VDR of 40m was determined on the basis of 2x the maximum VUR and accounting for 10m of overlapping coverage between systems. This considered the positive impact of gravity, cascading flow down the building surface, and the potential for fires at the extents of the vertical coverage to be addressed by both the system above and below.

APPENDIX 3

Summary of Test Reports from the

3-Year LASH FIRE Study

LASH FIRE



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 D10.2

Onboard demonstration of weather deck fire-extinguishing solutions

June 2023

Dissemination level: **Public**

Abstract

This report summarizes the findings and outcomes of an onboard demonstration conducted by Unifire AB (UNF) to test the effectiveness of an autonomous fire monitor system in detecting and suppressing fires on the weather deck of the Stena Scandinavica ro-ro vessel.

The demonstration validated the results of the development and of previous testing conducted in Borås, Sweden (in 2022), and Trondheim, Norway (in 2022), which established the system's ability to detect and guide water onto fires as well as suppress large-scale fires. The demonstration on the Stena Scandinavica vessel was successful, showcasing the capabilities of the system in a real-world scenario.

The autonomous fire monitor system used on the vessel consisted of an actuated valve, a UNIFIRE Force 80 remote control fire monitor, Unifire's X-TARGA PLC with FlameRanger software, and IR3 Array Flame detectors. Twelve fire tests were conducted, each with a different fire location on the weather deck. In all tests, the fire monitor system extinguished the fires within 15 seconds from ignition without any human intervention. These results were consistent with previous testing, demonstrating the system's rapid and accurate fire detection and suppression capabilities.

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

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02	2023-06-18	Mattias Eggert and Roger James	Draft of final report, circulated to reviewers
03	2023-06-29	Mattias Eggert and Roger James	Final report

Content

1 Executive summary

This report summarizes the findings and outcomes of an onboard demonstration conducted by Unifire AB (UNF) to validate the effectiveness of an autonomous fire monitor system in detecting and suppressing fires on a ro-ro weather deck (Task T10.8). The demonstration was conducted onboard the Stena Scandinavica vessel in the Harbor of Gothenburg on May 23, 2023.

Problem definition

The objective of action 10-B is to develop and demonstrate feasible and effective system solutions. While doing this, several aspects need to be considered, such as the weather and other environmental conditions, the fire hazards, specific requirements, and other challenges that influence the installation and operation of the systems.

The project description states that "Quick system activation, safe controlling, high coverage and fast fire suppression are fundamental criteria for the systems, which also need to sustain the harsh environmental conditions." The development work should additionally be based on the most recent technological advances in the field, in other words a state-of-the art review is required, identifying the newest technology, ideas, and features.

Task T10.8, the subject of this report, is to demonstrate the developed solutions by means of live, onboard fire tests.

Method

The performance of the autonomous fire monitor system was demonstrated in a series of onboard fire tests conducted on the open weather deck of the Stena Scandinavica ro-ro vessel. The vessel was equipped with an autonomous fire monitor system positioned to detect and suppress fires on the weather deck as described in Deliverable D10.3 (Description of the development of weather deck fire-extinguishing systems and selected solutions).

Two small propane gas burners were used to generate flames on the open weather deck (Figure 8). Each produced flames with approximate dimensions of 60 cm × 60 cm at the base and a height of 60 cm.

A total of twelve (12) separate fire tests were conducted. For each of the twelve tests, the fire was positioned in a different location on the weather deck. Prior to the ignition of the propane gas burners, the autonomous fire monitor system had no information about whether, when or where a fire would be ignited.

Results and achievements

The results of the demonstration were highly successful. The autonomous fire monitor system demonstrated its ability to rapidly and accurately detect fires, determine their locations, and aim the water stream for effective fire suppression, initiating suppression in under 15 seconds of fire ignition. Moreover, the system extinguished all twelve fires in under 15 seconds from ignition, without any human intervention.

Contribution to LASH FIRE objectives

The overall objective of WP10 is to provide for efficient, effective, and safe fire extinguishment in ro-ro spaces, regardless of the type or size of the space and with less crew dependence. The objective of Action 10-B is to develop and demonstrate feasible and effective fixed fire-extinguishment solutions for ro-ro weather decks.

Report D10.3 documents the results of Tasks 10.5-10.7, as follows:

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

This report documents the results of Task T10.8, the onboard demonstration and testing of the selected system solutions by real installations onboard a ro-ro passenger ship on a relevant weather deck.

Exploitation

The overall results of Task T10.8 was to demonstrate the developed solutions by means of live, onboard fire tests. The purpose of the onboard demonstration was to assess the effectiveness of an autonomous fire monitor system in rapidly detecting and suppressing fires on a real weather deck, thereby improving fire safety measures. By showcasing the system's capabilities, the demonstration aimed to build confidence among stakeholders, highlighting its autonomous functionality and its successful integration as an example for ship installations.

2 List of symbols and abbreviations

CE	Conformité Européenne. Note: CE marking is a mandatory administrative marking asserting conformity with relevant standards, applied to certain products offered for sale within the European Economic Area
DoA	Description of Actions
DC	Direct Current
EMC	Electromagnetic Compatibility
EU	European Union
F4M	FiFi4Marine B.V. (partner in the LASH FIRE project)
FLOW	FLOW Ship Design d.o.o. (partner in the LASH FIRE project)
GUI	Graphical User Interface
IMO	International Maritime Organization
IR	Infrared
LAN	Local Area Network
PLC	Programmable Logic Controller
RISE	RISE Research Institutes of Sweden
UNF	Unifire AB (partner in the LASH FIRE project)
WAN	Wide Area Network

3 Introduction

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

Fire monitor systems are not currently required to be installed for the protection of ro-ro weather decks on ships, although the fire load is substantial and manual firefighting operations are both difficult and hazardous. Recently, the International Maritime Organization (IMO) has recognized the use of "fixed fire-extinguishing measures on weather decks" in the Interim guidelines of MSC.1/Circ.1615 [1]. Member States are invited to bring the Interim guidelines to the attention of all parties concerned and to recount their experience gained using the guidelines to the IMO. The guidelines use the term "fire monitors" to describe the system technology. Although the term is not defined in the document, it is recognized as a fixed, remote-controlled device that can deliver a large water or foam stream and is mounted on a stationary support that is elevated above the deck flooring (refer to Figures 1 and 6). The nozzle tip can also be adjusted to control the spray angle from jet to spray. Fire monitors are widely known to be a highly effective means of suppressing fire, particularly when intervention is rapid.

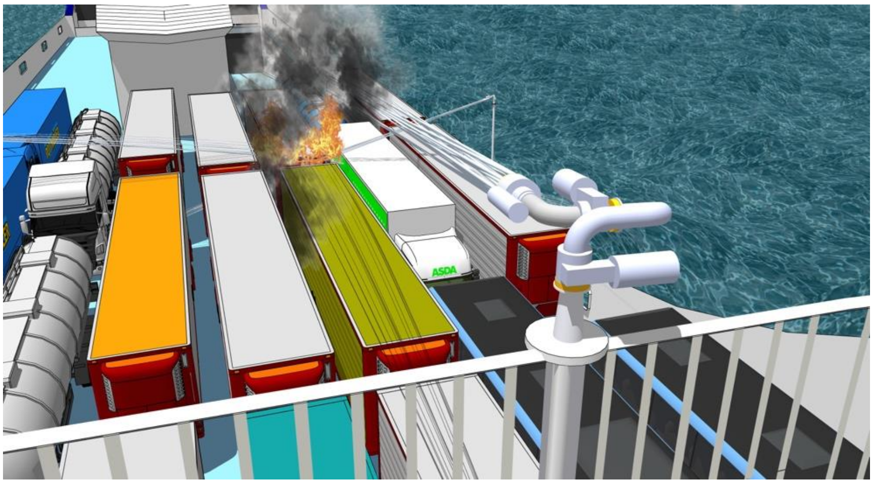

Figure 1. Example layout of remote control, semi-autonomous or fully autonomous fire monitors for weather deck fire protection.

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

The system solution developed by project partner Unifire AB (UNF), , who independently developed the novel technologies, comprised an autonomous and remote-controlled fire monitor system for weather deck protection. The development included theoretical evaluations and system development testing. The task also included installation and maintenance cost assessments.

Task T10.8 of WP10 calls for the onboard demonstration and testing of the selected system solutions by real installations onboard a ro-ro passenger ship on a relevant weather deck. This report describes the onboard demonstration and testing of the Unifire autonomous and remote-controlled fire monitor system.

4 Description of the developed fire monitor system solutions

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

4.1 Autonomous fire monitor system

4.1.1 Overview of system parameters and installation

A remote control and fully autonomous fire monitor system developed by UNF and design and installation criteria in terms of fire detector and fire monitor placement and flow rate demand was developed (see Report D10.3, Description of the development of weather deck fire-extinguishing systems and selected solutions). For best performance, the detectors should be installed as high up as practically possible. This provides better viewing angles that allow more precise positioning of a fire. For a similar reason, the fire monitors should also be elevated. One autonomous system (one fire monitor and two detectors) has been confirmed to cover an area of 30 meters (W) by 50 meters (L) using 1200 liters/min at 5 bar inlet pressure. The width is representative t of weather decks.

A minimum of two systems must cover the same area from opposing angles. A fire will then be effectively suppressed from opposing angles, and under windy conditions, it is expected that the effect of the wind will be balanced out. It should be emphasized that the two systems operate simultaneously and completely independently of each other. The autonomous fire monitor system that was developed is considered a viable and realistic solution to provide effective autonomous fire protection on weather deck. The assumption is that ships in the future will be operating increasingly autonomously, and the crew will be small.

4.1.2 Description of the developed remote control and fully autonomous fire monitor system

The fully autonomous fire monitor system developed by Unifire is capable of rapid and accurate fire detection and targeted fire suppression by means of a two-inch (2”) fire monitor[1], without any human intervention required. The autonomous fire monitor system is also capable of being remote controlled by a human operator at any time, regardless of whether autonomous suppression has been initiated.

The fire monitor can also be installed without detectors and be remote controlled by crew members by means of a variety of remote control devices. It can also record an operator’s use of the remote control device, store it to memory, and play it back in a continuous loop; which recording can be initiated by pressing the “play” button on the remote control device, or can be activated by means of an input from an external detector alarm signal or other input signal. In the case of both the autonomous fire monitor system and the remote control fire monitor system, each fire monitor can be controlled by multiple remote control devices, which can be a tethered joystick and/or can operate wirelessly by radio remote control and/or by a computer over a WAN or LAN. Furthermore, the remote control devices can be placed in any location (or locations) on the ship, allowing for safe control access in the event of a fire.

[1] A two-inch (2”) monitor was determined to provide sufficient flow and reach for the effective fire suppression on weather decks, while also minimizing weight, the necessity for larger pumps and piping, and thereby keeping costs to a minimum. See Report D10.3. The demonstration discussed in this document used a three-inch (3”) Force 80 fire monitor identical to the developer’s (Unifire’s) Force 50 two-inch (2”) fire monitor in every way except for the pipe diameter—it was used because it had previously been outfitted on the Stena Scandinavica and was identically suited for the demonstration tests and allowed for lower costs of the demonstration without affecting the validity of the tests in any way.

4.1.3 Components of the developed remote control fire monitor

The remote control fire monitor developed by Unifire (refer to Figures 2 and 3) comprises the following primary components:

- Unifire Force 50 remote control fire monitor with: a two inch (2”) internal pipe diameter; made of stainless steel 316L (EN1.4404) with fully integrated and enclosed stainless steel worm gears and Bronze (CuSn12) gear wheels; fully enclosed 24V DC brushless (BLDC) motors for high torque and extremely precise, long-lasting position feedback; and designed for the harsh conditions of marine environments; and

Figure 2. Unifire Force 50 2" remote control fire monitor made of stainless steel 316L.

- an Integ 50 steplessly-adjustable jet/spray water or foam firefighting nozzle tip that controls the spray angle, also made of stainless steel 316L and Bronze and with a fully enclosed 24V DC brushless (BLDC) motor; and
- an X-TARGA PLC that contains a proprietary PLC designed and manufactured by Unifire, a built-in power converter from 110-230V AC (50/60Hz) to the PLC’s native 24VDC/20Amp requirements. The PLC is CE marked and EMC tested and is housed in an IP66 cabinet designed for the harsh marine environment; and
- quick-connect, highly sealed motor power and control cables; and
- one or more remote control devices.

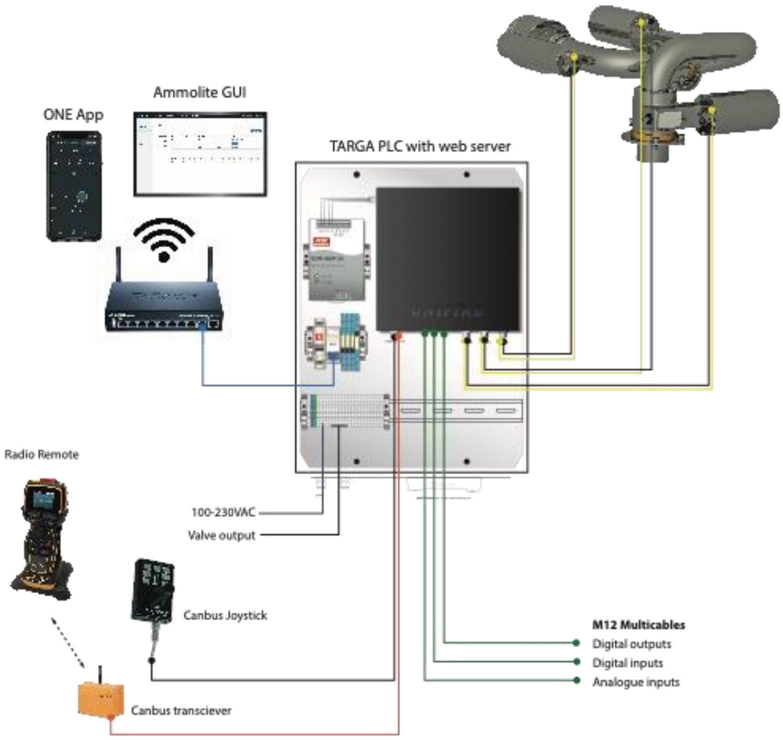

Figure 3. Schematic layout of a Unifire remote control fire monitor system.

4.1.4 Components of the developed autonomous fire monitor system

The autonomous fire monitor system developed by Unifire (refer to Figure 4), called FlameRanger, comprises the remote control fire monitor system described in 4.1.3 above, and two Tyco FV311 IR3 flame detectors[2]. Additionally, the autonomous system's X-TARGA PLC has inputs for the flame detectors and specialized electronic hardware and software that process signals from the flame detectors.

The flame detectors must be carefully and precisely positioned during system setup so that their respective viewing angles allow for accurate and precise triangulation of a fire's (or fires') position(s) by the system's software.

[2] The Tyco FV311 is not the only available fire detection technology for autonomous fire monitor systems. Unifire has also developed autonomous fire monitor systems that utilize other fire detection technologies, including other makes of flame detectors, thermal imaging cameras, and hybrid detectors, and others.

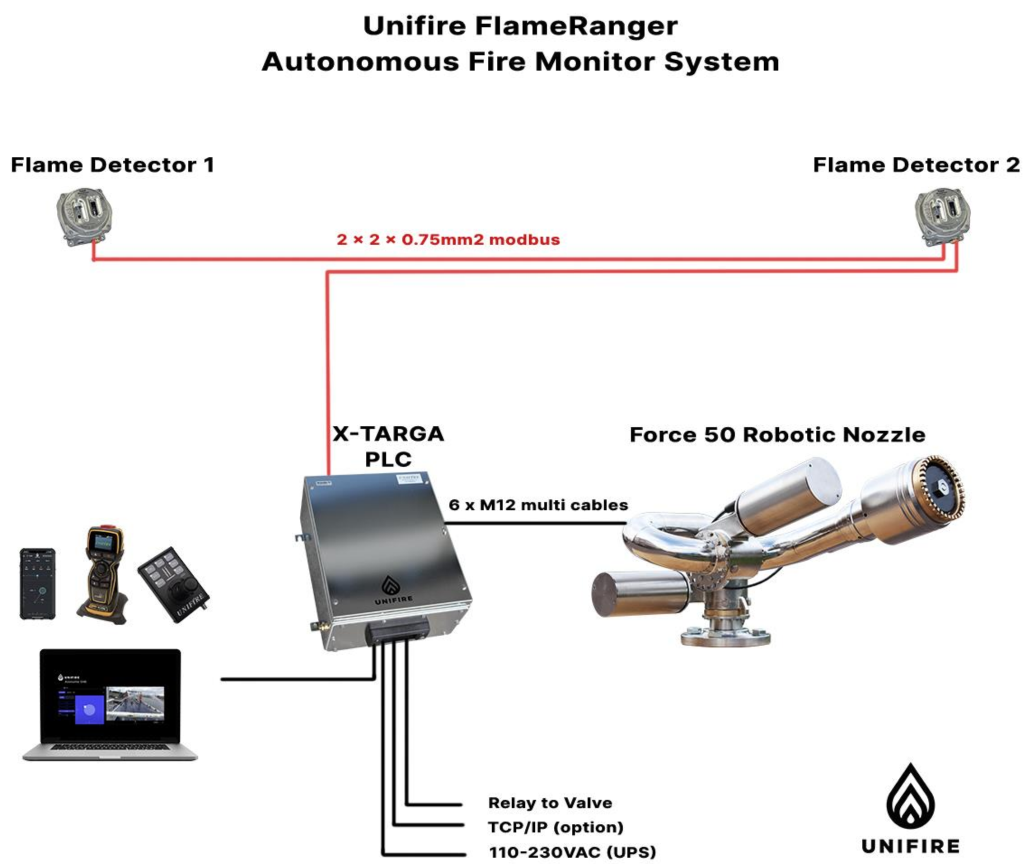

Figure 4. Schematic diagram of Unifire FlameRanger autonomous fire monitor system.

5 The ship chosen for the installation and demonstration

Main author of the chapter: Roger James, UNF

The ship selected for the onboard demonstration of the remote controlled and autonomous fire monitor system was the Stena Scandinavica (refer to Figure 5).

Figure 5. Stena Scandinavica (Stena Line).

In addition to having a typical weather deck for the carriage of vehicles, the Stena Scandinavica had previously been outfitted with a Unifire Force 80 (3”) remote control fire monitor with an Integ jet/spray nozzle tip that protects the weather deck and which was suitable for the demonstration of the system (see footnotes 1 and 2, above). This fact reduced the required installation of the fire monitor and, accordingly, saved time and cost of the of the demonstrated system.

The Stena Scandinavica had also previously been outfitted with two Tyco FV311 IR3 flame detectors, as part of Work Package 9, for gathering long-term data, determine possible susceptibility to false alarms and to determine whether the detectors were suited for long-term used in the harsh conditions of a weather deck. It should be noted that the detectors remained in perfect working condition throughout the study and recorded no false alarms.

The open weather deck of the Stena Scandinavica measures approximately 70 m (L) by 28 m (W).

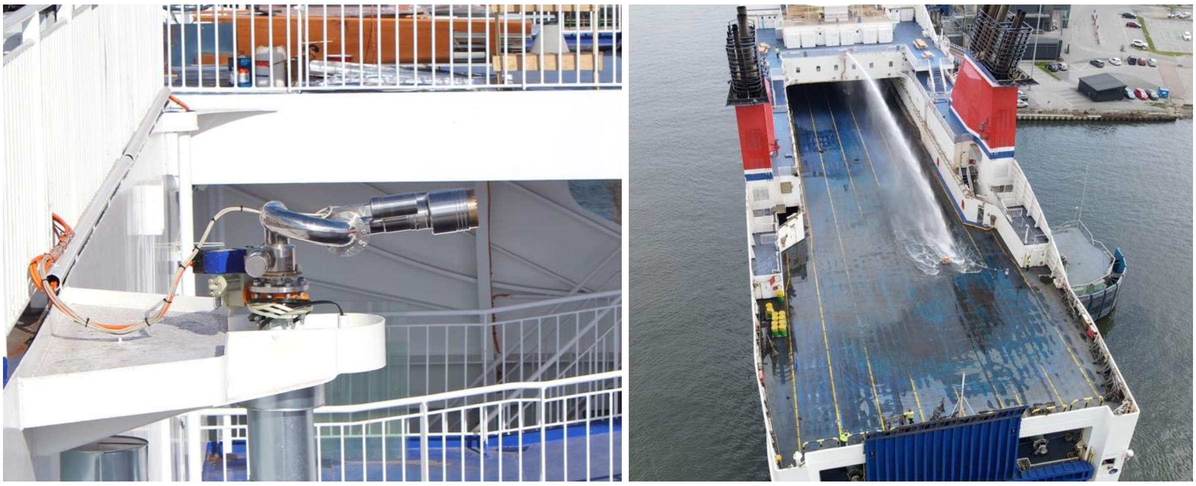

Figure 6. Unifire Force 80 remote control fire monitor protecting the weather deck of Stena Scandinavia (left) and a photo taken (right) during of one of the twelve demonstrations in which the autonomous fire monitor detected, located, and extinguished a propane burner fire onboard the Stena Scandinavica.

6 The installations and their objectives

Main author of the chapter: Roger James, UNF.

In a series of tests conducted in Borås, Sweden, in May 2020, it was established that the developed autonomous fire monitor system was able to rapidly detect fires in multiple locations, accurately determine their locations in three-dimensional space, and accurately and effectively aim the fire monitors water stream to suppress the fire at and around its source.

In a second series of large-scale fire tests conducted in Trondheim, Norway, in September 2022, it was established that the developed fire monitor system could effectively suppress and contain fires simulating a burning freight truck trailer fire.

The objective of the installation of the system that is the subject of this document was to achieve a real-life demonstration of the effectiveness of an autonomous fire monitor system to suppress fires on an actual ro-ro weather deck.

To achieve this aim, the autonomous fire monitor system was installed to protect the weather deck of the Stena Scandinavica (refer to Figure 7). Propane gas burner fires were ignited in twelve different positions on the weather deck of the to determine whether and how the autonomous fire monitor system would perform.

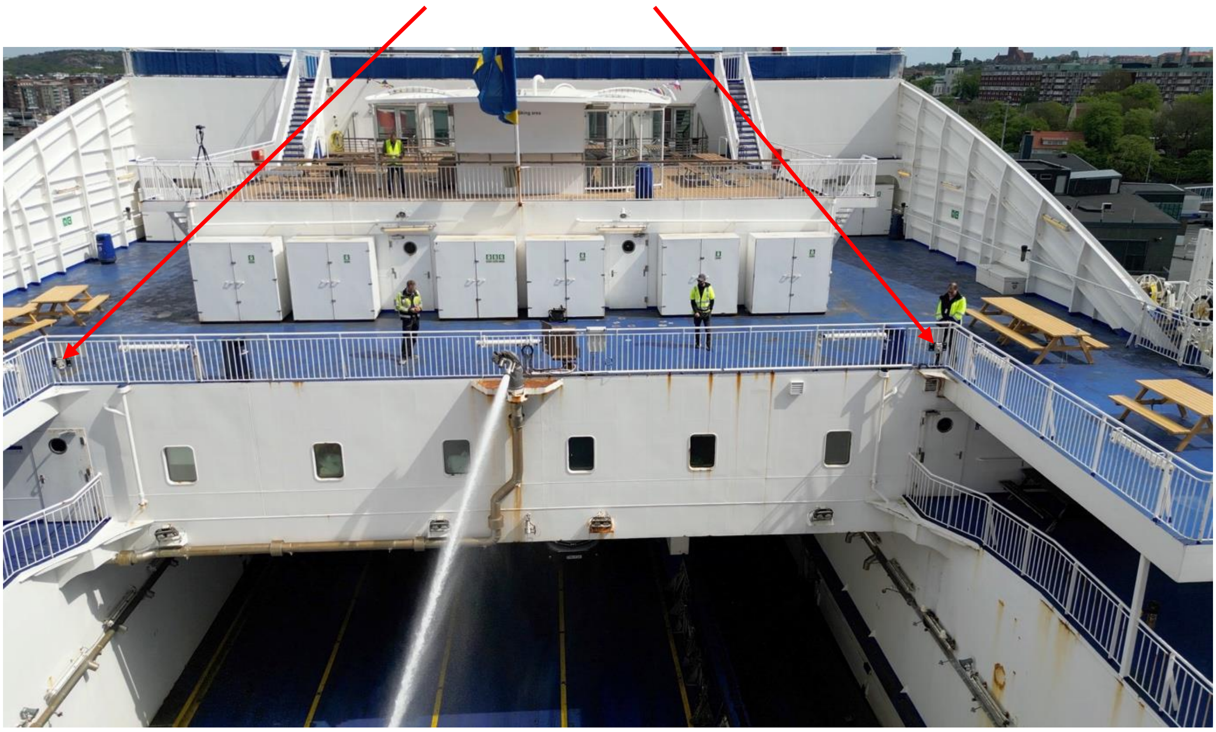

Figure 7. Autonomous fire monitor suppressing a weather deck fire and showing the position of the system's Force 80 fire monitor and its two IR3 flame detectors.

Two small propane gas burners were used to generate flames on the open weather deck (refer to Figure 8). Each produced flames with approximate dimensions of 60 cm × 60 cm at the base and a height of 60 cm. A total of twelve (12) separate fire tests were conducted.

In each of the twelve tests, the propane gas burners were placed at separate random positions on the weather deck (refer to Figures 9 and 10), ranging from 15 meters away from the fire monitors, up to 60 meters, which is further than the design recommendations established in the project. The monitor was supplied with a flow of water of 3000 l/min at 6 bars. With a higher flow and pressure, a larger area can be protected by each fire monitor.

Prior to the ignition of the propane gas burners, the autonomous fire monitor system had no information about whether, when or where a fire would be ignited.

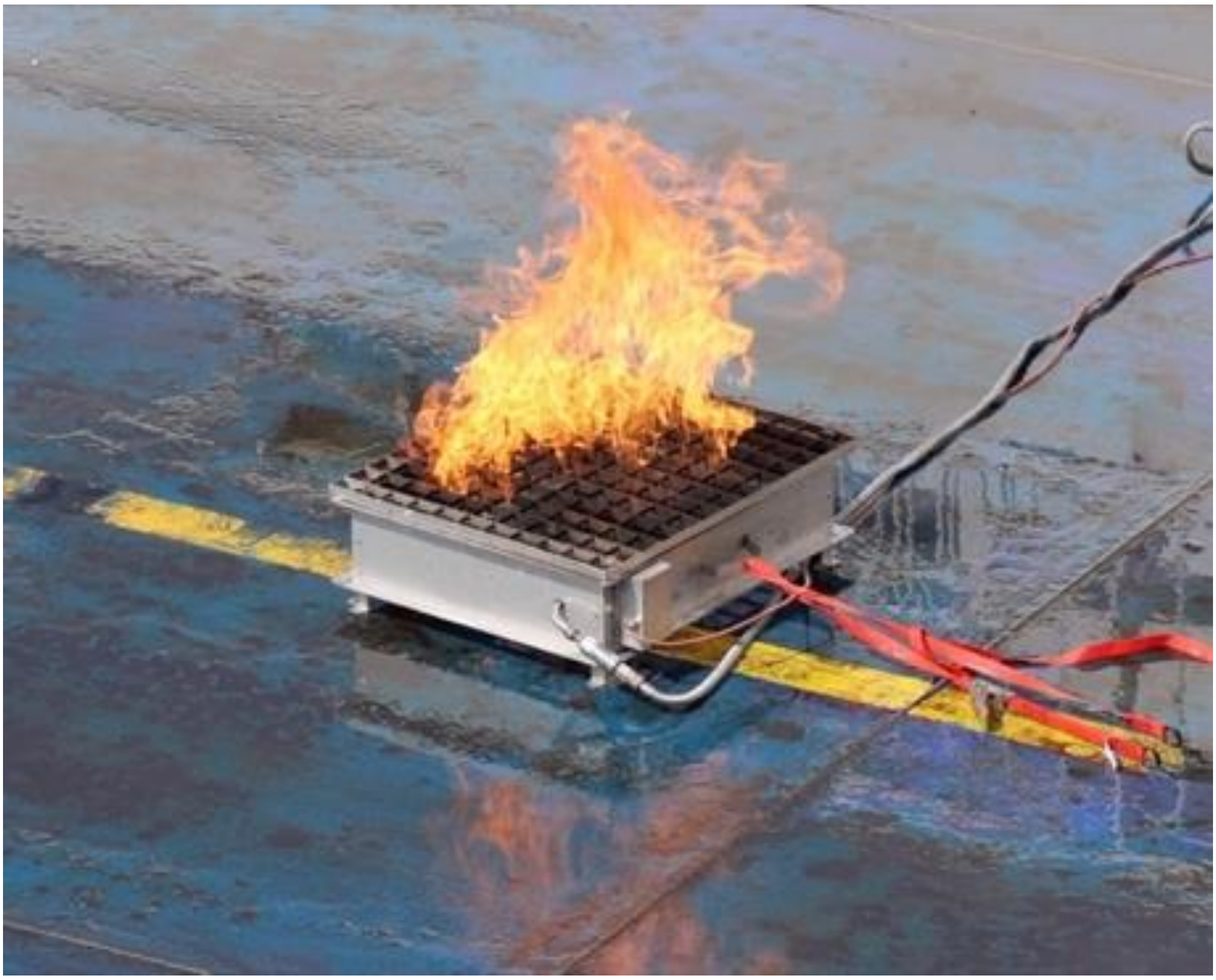

Figure 8. A close-up photo of one of the two identical propane gas burners used in the demonstration to generate flames on the weather deck.

Figure 9. Photo from the perspective of the autonomous fire monitor suppressing one of twelve fires located in twelve random positions on the weather deck during the demonstration onboard the Stena Scandinavica.

7 Results and observations

Main author of the chapter: Roger James, UNF.

7.1 Fire test results

In each of the twelve demonstration fire tests conducted, the autonomous fire monitor system rapidly and successfully detected the fire and aimed the water stream directly at and around the fire. Moreover, the system extinguished each of the twelve weather deck fires in under 15 seconds from ignition, without any human intervention.

Figure 10. Photo taken during of one of the twelve demonstrations in which the autonomous fire monitor detected, located, and extinguished a propane burner fire onboard the Stena Scandinavica.

7.2 Observations

It was observed that in each of the twelve demonstration fires placed in separate locations onboard the Stena Scandinavica:

- that the autonomous fire monitor system was able to rapidly detect the fire; and
- accurately determine the three-dimensional coordinates of the fire; and
- accurately guide the fire monitor’s stream of water to suppress the fire by oscillating over and around the fire; and
- the autonomous fire monitor extinguished each of the fires in less than 15 seconds from the ignition of the propane burners.

8 Discussion

Main author of the chapter: Roger James, UNF.

This document describes the demonstration and testing of a remote controlled and autonomous fire monitor system for the protection of weather decks, as part WP10-B, Task T10.8.

The objectives of Task T10.8 were met, and the demonstration clearly established the effectiveness of the system to rapidly detect fires on a ro-ro weather deck, accurately determine the fires' three-dimensional positions and autonomously and effectively suppress the fires—all without any human intervention, yet with the ability of a human operator to remotely control the fire monitor at any time.

9 Conclusion

Main author of the chapter: Roger James, UNF.

The objectives of the demonstration were to confirm, onboard the Stena Scandinavica, the ability of an autonomous fire monitor system to rapidly detect fires on a ro-ro weather deck, accurately determine the fire’s position and autonomously and effectively suppress the fire—all without any human intervention. The findings of this demonstration confirmed that the developed autonomous fire monitor system achieved each of these capabilities in a real-world installation. Furthermore, because the system can also be remote controlled by a human operator, the demonstration also confirms that a remote control fire monitor can also be effective, particularly if the system is rapidly commenced.

The demonstration also confirmed the viability of autonomous fire monitor technology to significantly enhance fire safety on ro-ro weather decks and in other industrial applications. The system's rapid and effective fire detection and suppression capabilities—with all twelve separate, randomly-placed weather deck fires having been extinguished autonomously in less than 15 seconds—clearly establishes the potential to dramatically improve overall fire safety and substantially minimize the risk of fire-related incidents on ro-ro vessel weather decks.

The onboard demonstration of the autonomous fire monitor system was successful and validated the objectives of Action 10-B and Task T10.8. The system's ability to rapidly detect fires, accurately determine their locations, and promptly initiate suppression without human intervention provides a valuable solution for improving fire safety and prevention.

10 Indexes

10.1 Index of figures

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 D10.3

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

February 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

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

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

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

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

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05	2023-02-28	Magnus Arvidson	Final report

Content

1 Executive summary

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

1.1 Problem definition

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

1.2 Method

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

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

1.3 Results and achievements

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

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

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

1.4 Contribution to LASH FIRE objectives

The overall objective of WP10 is to provide for efficient, effective, and safe fire extinguishment in ro-ro spaces, regardless of the type or size of the space and with less crew dependence. The objective of Action 10-B is to develop and demonstrate feasible and effective fixed fire-extinguishment solutions for ro-ro weather decks. This report documents the results of Tasks 10.5 – 10.7 as follows:

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

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

1.5 Exploitation

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

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

2 List of symbols and abbreviations

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

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

3 Introduction

Main author of the chapter: Magnus Arvidson, RISE

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

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

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

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

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

4 Regulation review

Main author of the chapter: Blandine Vicard, BV.

4.1 General

4.1.1 Scope

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

4.1.2 Applicable regulations

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

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

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

4.1.3 Definitions

The following key terms are used in the relevant regulations:

IACS International Association of Classification Societies

IMO International Maritime Organization

SOLAS International Convention for the Safety of Life at Sea

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

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

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

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

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

4.1.3.2 Closed, open and weather deck

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

- A “*weather deck is a deck which is completely exposed to the weather from above and from at least two sides.*”
- IACS UI SC 86 [5] additionally details that: “*For the purposes of Reg. II-2/19 a ro-ro space fully open above and with full openings in both ends may be treated as a weather deck.”*
- For practical purposes, a drencher fire-extinguishing system cannot be fitted on weather decks due to the absence of a deckhead. This criterion is often used for a practical definition of weather decks.
- An open vehicle or ro-ro space is “*either open at both ends or [has] an opening at one end and [is] provided with adequate natural ventilation effective over [its] entire length through permanent openings distributed in the side plating or deckhead or from above, having a total area of at least 10 % of the total area of the space sides.*”
- A closed vehicle or ro-ro space is any vehicle or ro-ro space which is neither open nor a weather deck. As a reference criterion, it can be considered that a vehicle space that needs mechanical ventilation is a closed vehicle space.

4.2 Requirements

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

SOLAS II-2/20

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

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

MSC.1/Circ.1615 §3.4

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

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

4.3 Other regulations

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

Weather deck monitor systems can be found on:

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

Other systems installed on open decks include:

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

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

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

5 Functional design and ship integration requirements

Main authors of the chapter: Magnus Arvidson, RISE, Roger James, UNF, Mattias Eggert, UNF and Goran Pamic, FLOW.

5.1 Performance objectives

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

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

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

5.2 Operational aspects

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

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

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

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

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

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

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

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

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

5.3 Design and production aspects

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

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

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

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

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

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

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

5.4 Drainage system

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

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

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

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

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

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

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

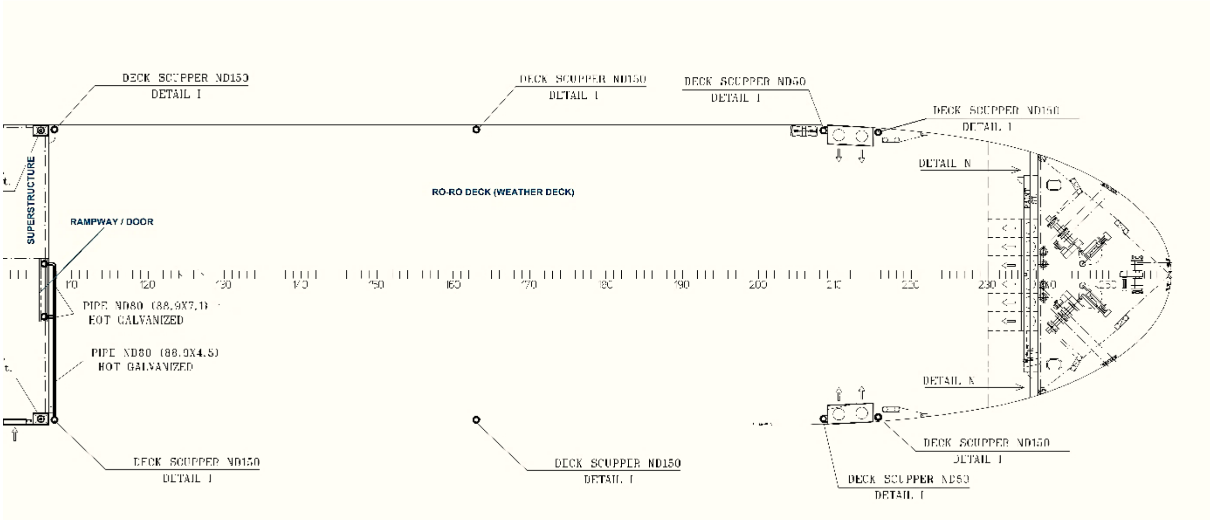


Figure 2. Typical ro-ro weather deck drainage arrangement with the position of the deck scuppers.

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

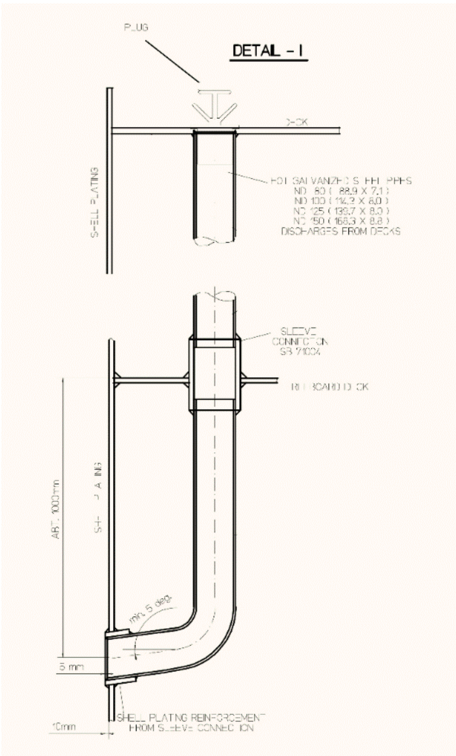


Figure 3. Typical scupper detail on a ro-ro weather deck where water or other any liquids are discharged into the sea.

5.5 Weather and other environmental considerations

5.5.1 Weather conditions

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

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

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

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

5.5.2 Operating on deck in heavy weather

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

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

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

5.5.3 Environmental aspects

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

5.6 Life Cycle Assessment of solutions

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

5.7 Necessary functions

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

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

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

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

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

5.8 Durability requirements

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

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

Any parts of the system that may be exposed to temperatures below +4°C should be protected from freezing either by having temperature control of the space, heating coils and thermal insulation on pipes, antifreeze agents or other equivalent measures.

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

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

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

5.9 Arrangement and possible positions of fire monitors

5.9.1 Quantity of fire monitors to protect the entire weather deck

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

5.9.2 Vertical positioning of fire monitors

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

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

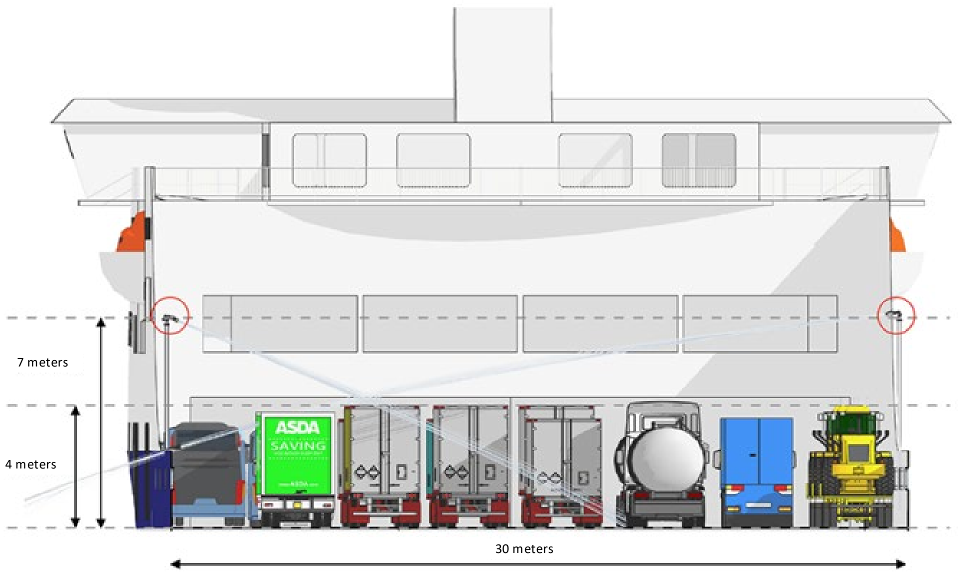


Figure 4. An elevated fire monitor position will provide a more favourable attack angle, allowing more of the water stream to hit the flames more directly.

5.9.3 Locations of fire monitors

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

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

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

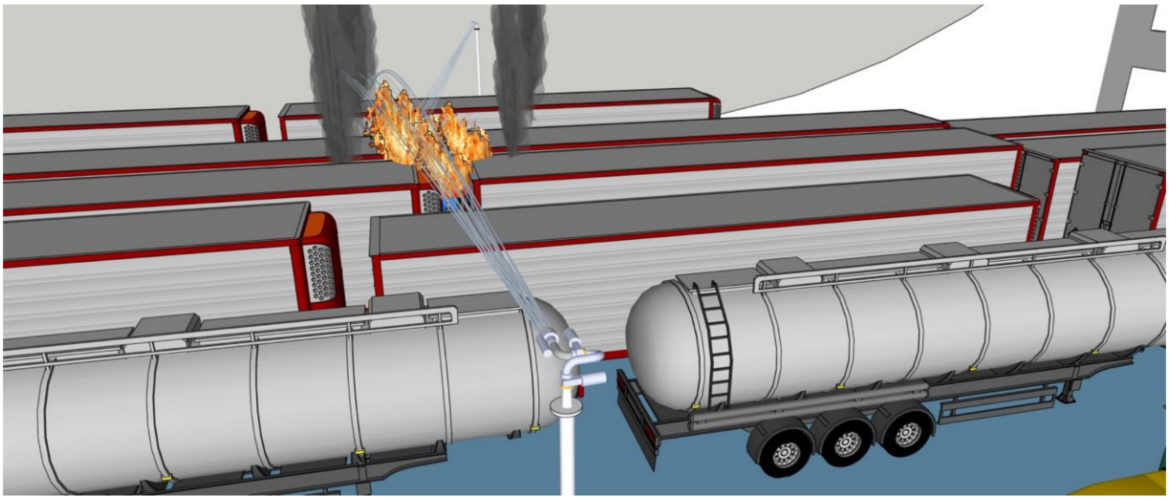


Figure 5. *Fire monitors in opposite angles, i.e., positioned directly opposite each other at both sides of the weather deck.*

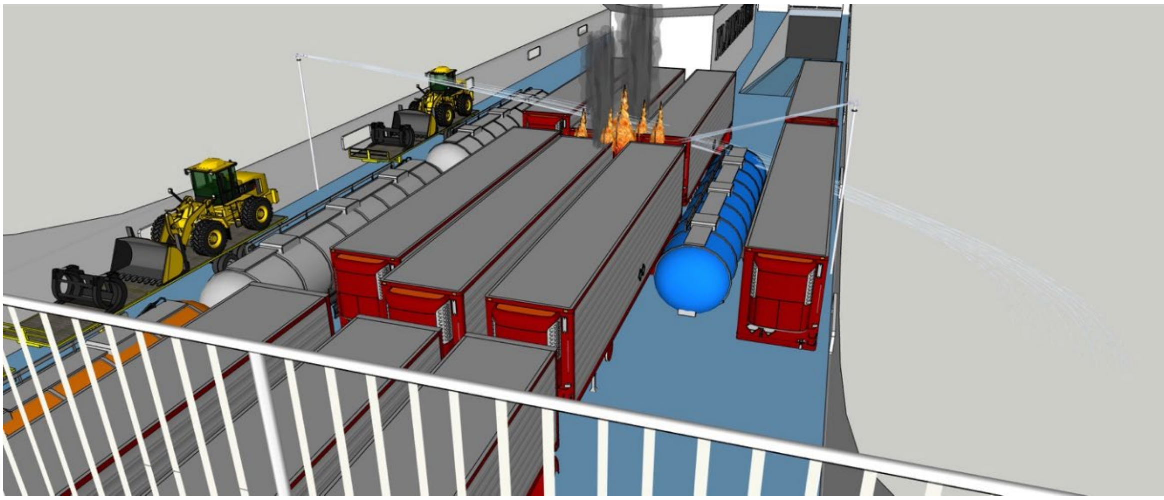


Figure 6. *Fire monitors in opposite angles.*

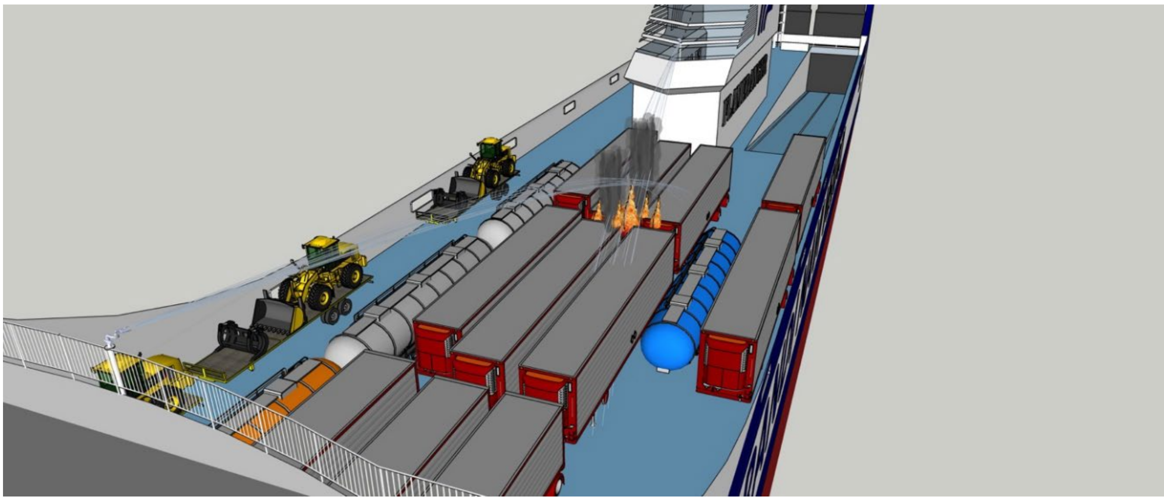


Figure 7. *The opposite angles can also be achieved by installing the fire monitors' mid-ship on superstructures of the ship.*

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

5.10 Fire suppression agents or additives

5.10.1 The use of additives

Any fire suppression enhancing foam concentrate or additive shall be fluorine-free and biodegradable. Furthermore, it should be approved for fire protection service by an independent authority. The approval should consider possible adverse health effects to exposed personnel, including inhalation toxicity, and any environmental impact.

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

5.10.2 Water supply requirements

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

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

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

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

6 Cargo and cargo loading considerations

Main author of the chapter: Magnus Arvidson, RISE.

6.1 Type of cargo

6.1.1 General cargo and vehicles

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

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

6.1.2 Dangerous goods

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

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

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

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

6.1 Length and width of the weather deck

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

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

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

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

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

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

6.3 Distance between cargo

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

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

6.4 Securing (lashing) of cargo

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

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

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

7 State-of-the-art review

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

7.1 Weather deck fire protection

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

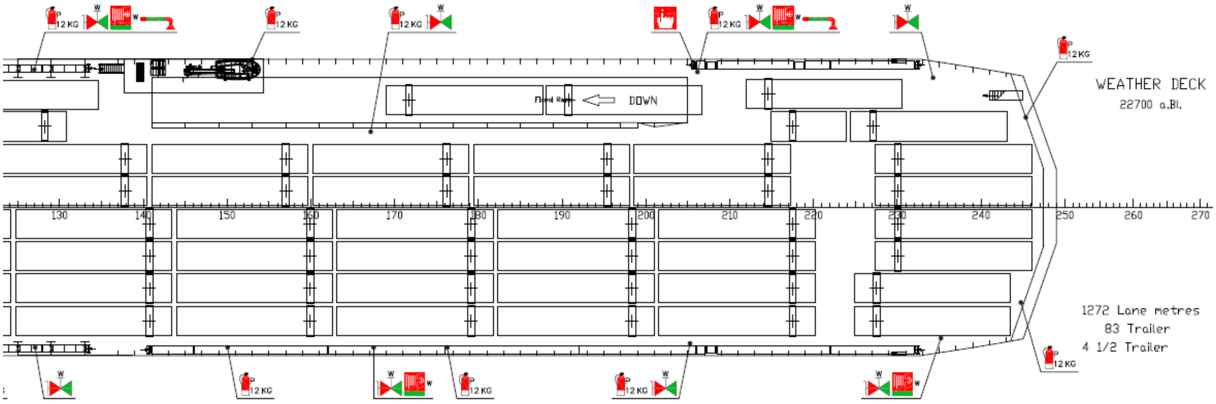


Figure 8. *Fire protection appliances plan (detail) from Magnolia Seaways. The valve symbols indicate the positions of the fire hydrants and the other symbols the positions of the portable fire extinguishers and foam applicator units.*

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

7.2 Fire monitors

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

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

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

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

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

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

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

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

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

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

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

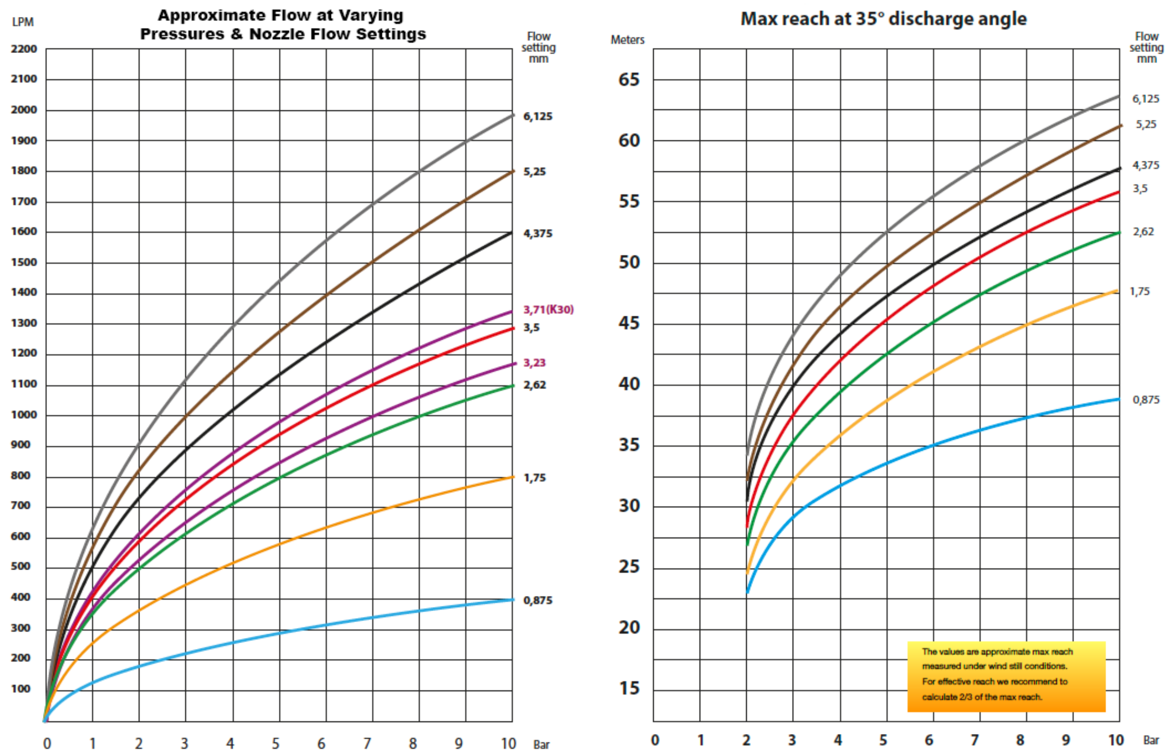


Figure 12. Example of 2" monitor flows at varying pressures and settings (left) and monitor theoretical stream reach @ 35° discharge angle at varying pressures and settings (right).

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

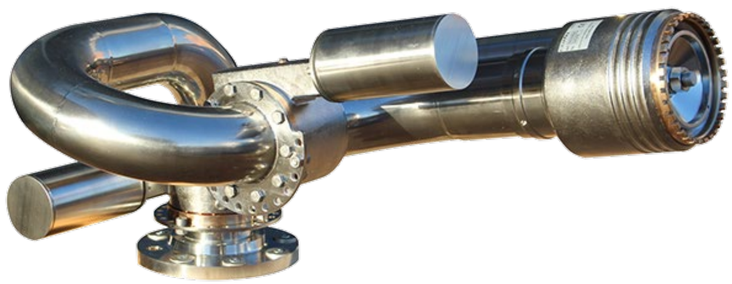


Figure 13. Example of a Unifire FORCE 80 (3") stainless-steel remote-controlled fire monitor with three 24V BLDC motors and adjustable jet/spray nozzle tip.

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

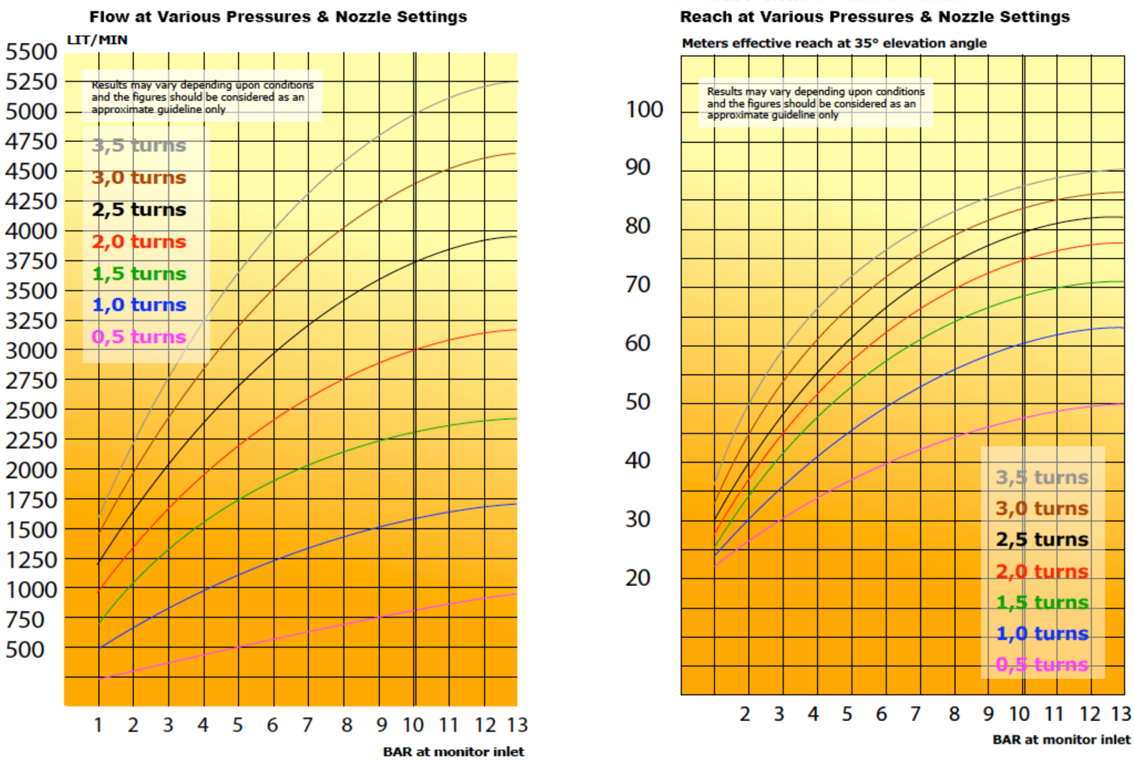


Figure 15. Example of 3" monitor flows at varying pressures and settings (left) and monitor theoretical stream reach @ 35° discharge angle at varying pressures and settings (right).

7.3 Recent technological advances

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

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

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

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

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

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

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

7.4 Fire detectors

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

7.4.1 Detection technologies

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

7.4.1 Flame detectors

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

7.4.2 Thermal imaging cameras

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

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

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

7.4.3 Video analytics

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

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

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

7.4.4 Hybrid fire detectors combining thermal imaging & video analytics

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

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

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

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

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

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

7.4.5 Linear heat detectors

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

7.5 The use of foam or other fire suppression enhancing additives

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

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

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

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

7.6 CAF fire monitor systems

7.6.1 General

A Compressed Air Foam (CAF) system releases a firefighting foam for the extinguishment of a fire or for the protection of unaffected adjacent areas. System components of CAF systems are typically a water source, a centrifugal pump, a foam concentrate tank, a foam proportioning and injection component, a mixing chamber or device, an air compressor, and a control system ensuring suitable mixing of the water, foam concentrate and air. CAF systems are normally used for the protection of spaces where flammable liquids are stored, handled, or processed and are applicable for the protection of specific hazards and equipment. Applications may include exposed or shielded Class B pool or spill fires.

CAF systems are usually pre-engineered and must be designed by the manufacturer for the specific application. To provide a discharge distribution over a large area, rotation nozzles or rotor nozzles are generally used. Alternatively, multi-orifice nozzles have been developed. The foam consists of a homogeneous bubble structure and low proportioning rates, typically from 0,3 % to 1,0 % with either Class A or B foam concentrates. NFPA 11 [20] includes recommendations for the design and installation of foam fire-extinguishing systems, including CAF systems. The generation of foam is considered to provide better foam quality than nozzles where foam generation occurs in the nozzle itself. For indoor fire hazards in buildings where spill fires may occur, NFPA 11 recommends an application rate equivalent to 4,1 mm/min with film-forming foams and 6,5 mm/min with protein foams. For CAF, NFPA 11 recommends a design density according to the system's approval requirements but not lower than 1,63 mm/min for petroleum products. No design and installation recommendations are given for Class A fires in NFPA 11, but CAF systems are used for wildland fires (portable equipment) and, for example, for the protection of waste bunkers in recycling plants and cable tunnels. The foam provides a certain adhesion to vertical surfaces, helping to prevent or delay spread of fire between objects. With rotating nozzles located at the ceiling, each nozzle can cover a relatively large surface area. CAF systems are usually fire tested with Class B fuel spill fires, for example to UL 162 [21] or FM 5130 [22] standards.

7.6.2 Type of foam agents

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

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

7.6.3 Foam agent storage and reserve supply

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

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

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

7.6.4 CAF fire monitors

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

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

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

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

8.1 Objectives of the tests

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

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

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

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

8.2 The FlameRanger system

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

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

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

8.3 The test area

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

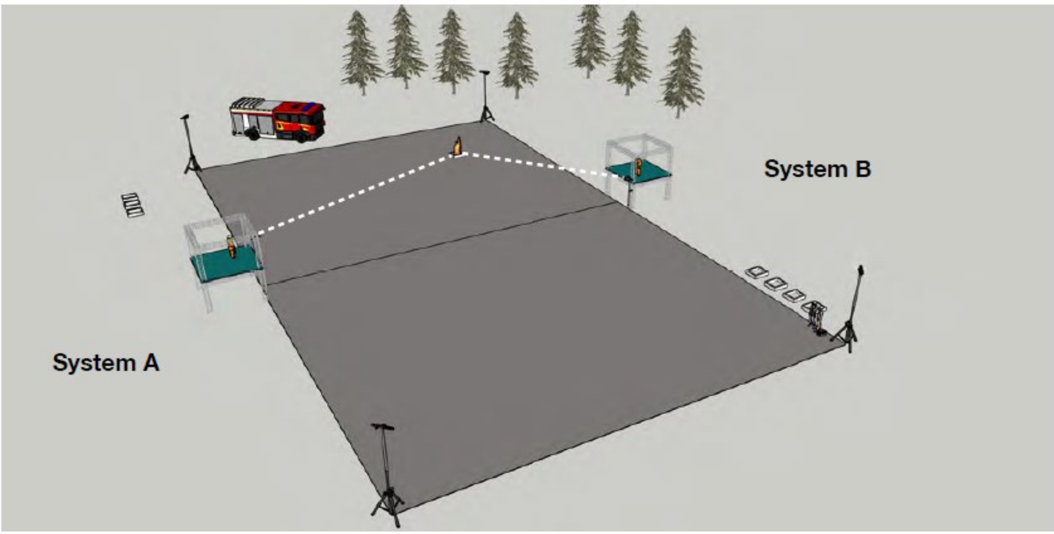


Figure 16. An illustration of the testing approach, where two complete autonomous systems (denoted System A and System B, respectively) were installed to provide full coverage of the 30 m x 50 m test area.

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

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

8.4 The fire monitors

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

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

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

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

8.5 The fire detectors

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

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

8.6 The fire test sources

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

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

8.7 The water supply

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

Figure 21. The water supply arrangement.

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

8.8 Measurements and documentation

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

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

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

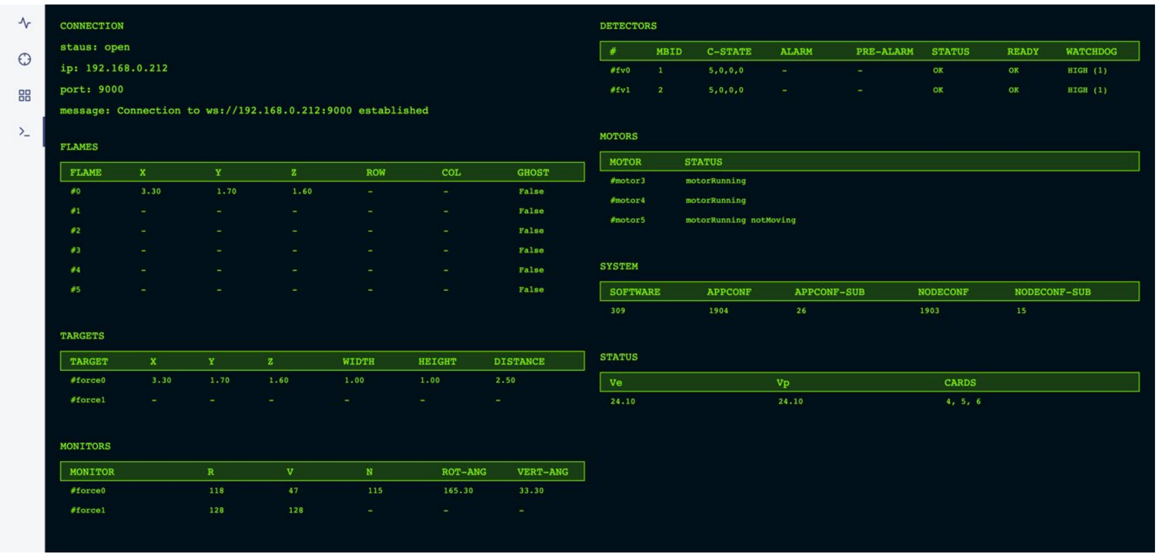


Figure 22. Example view of data from the software of the autonomous system.

8.9 Simulation of wind conditions

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

8.10 The test program set-ups

The following was tested:

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

8.11 Test observations

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

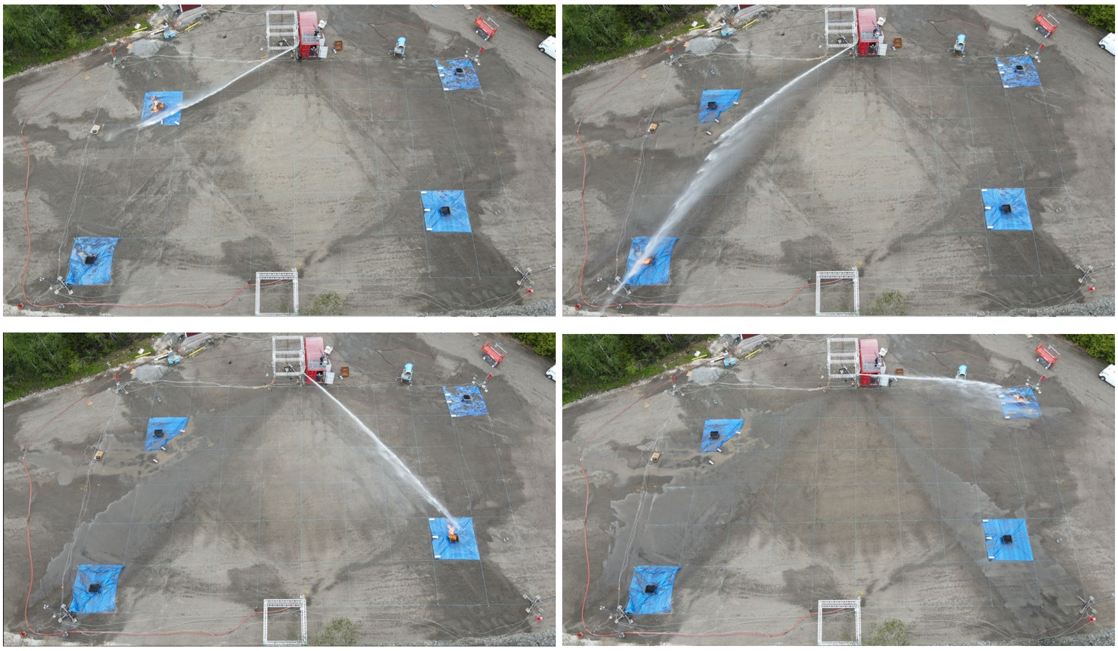
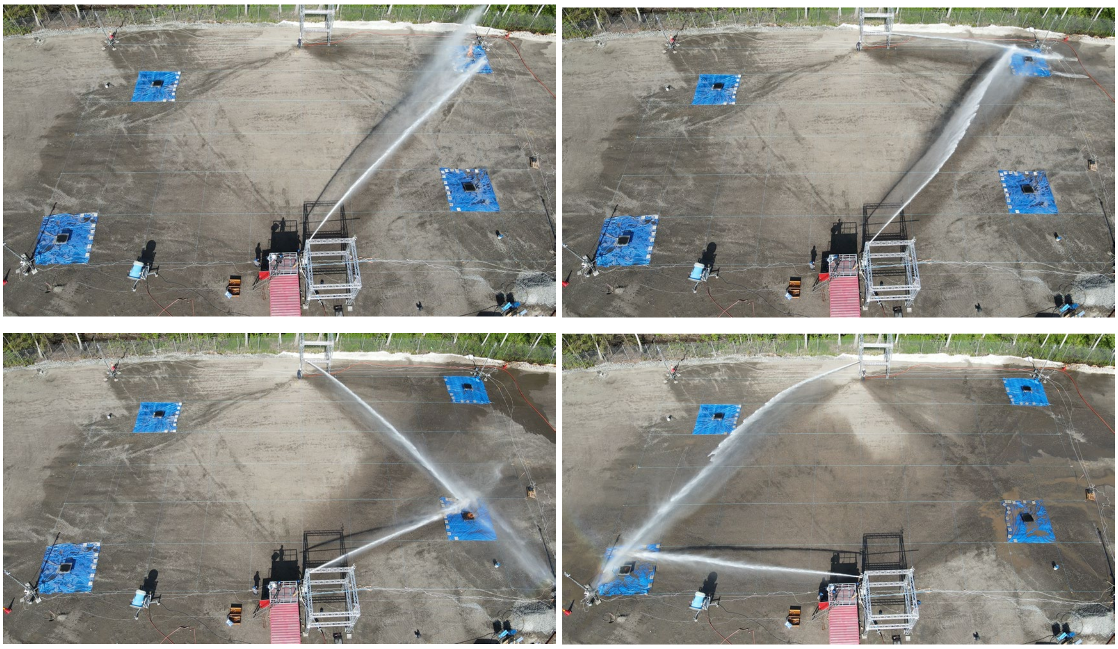


Figure 23. Sequential ignition of four fire test sources positioned symmetrically in the test area, using one autonomous system.



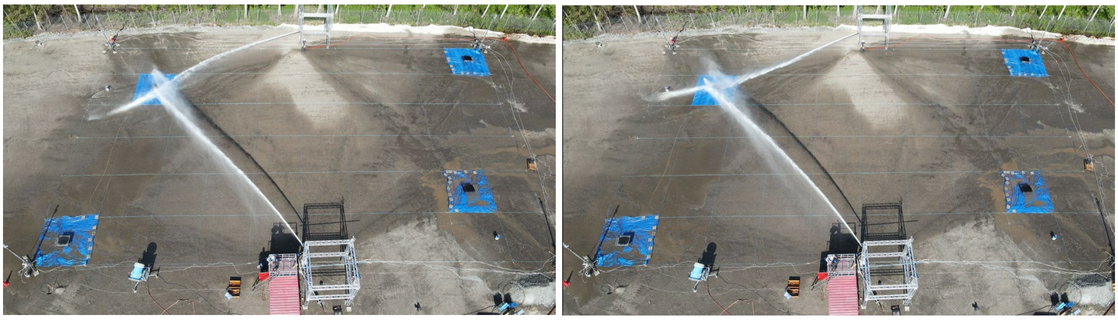


Figure 24. Sequential ignition of four fire test sources positioned symmetrically on the test area, using two autonomous systems.

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

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

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

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

8.12 Test results and conclusions

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

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

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

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

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

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

9 Large-scale fire monitor validation tests

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

9.1 The test area

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

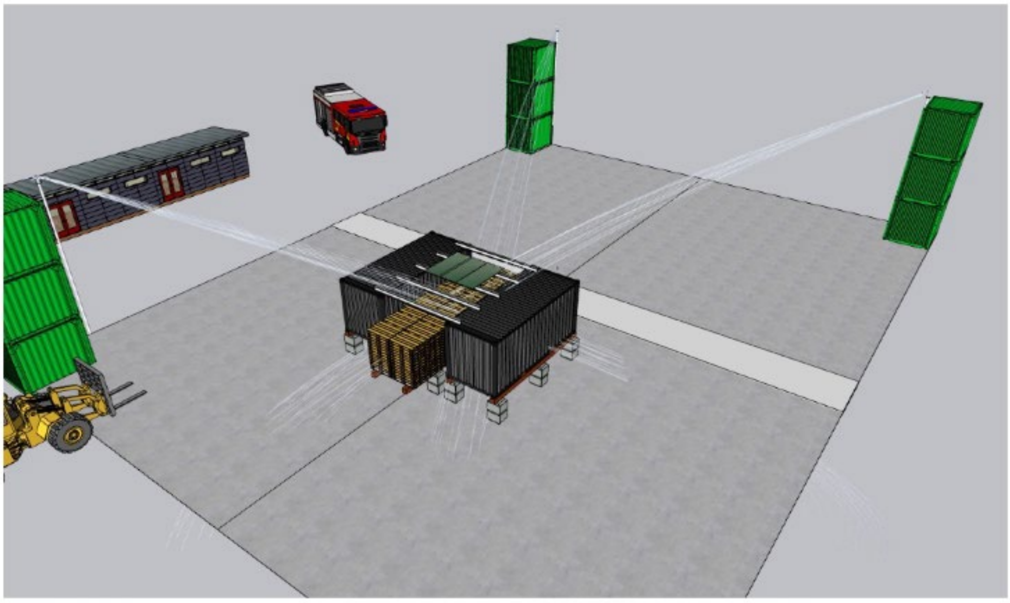


Figure 29. The test area and the principal arrangement of the tests. Illustration: UNF.

9.2 The fire test scenario

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

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

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

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

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

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

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

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

9.3 The fire monitor system

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

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

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

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

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

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

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

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

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

9.4 Instrumentation and measurements

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

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

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

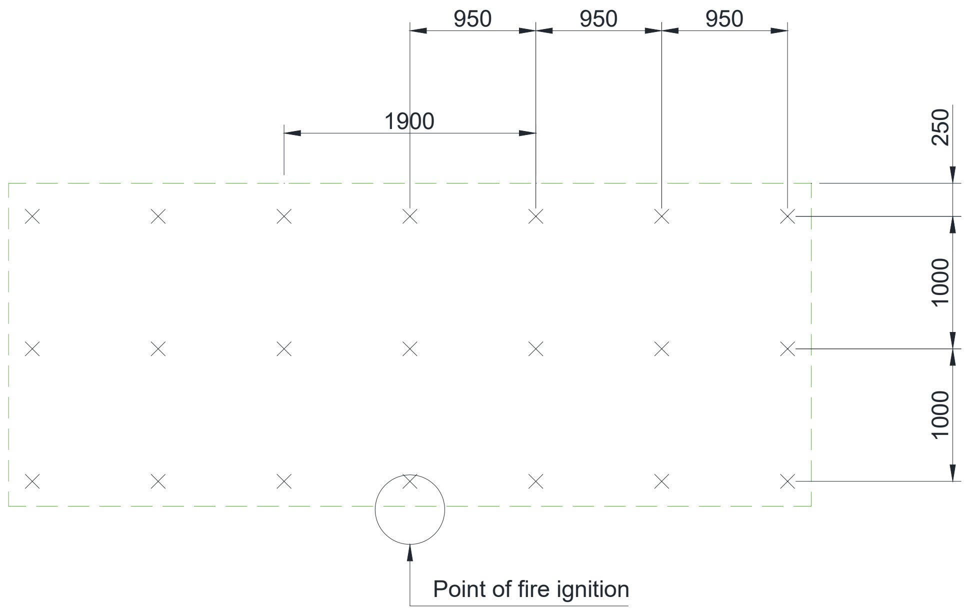


Figure 33. A drawing with the locations of surface temperature measurements on the cargo container walls that were facing the main array, i.e., the fire. Dimensions are in mm.

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

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

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

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

9.5 Fire test program

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

Table 3 shows the fire test program.

Table 3. The fire test program.

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

9.6 Fire test procedures

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

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

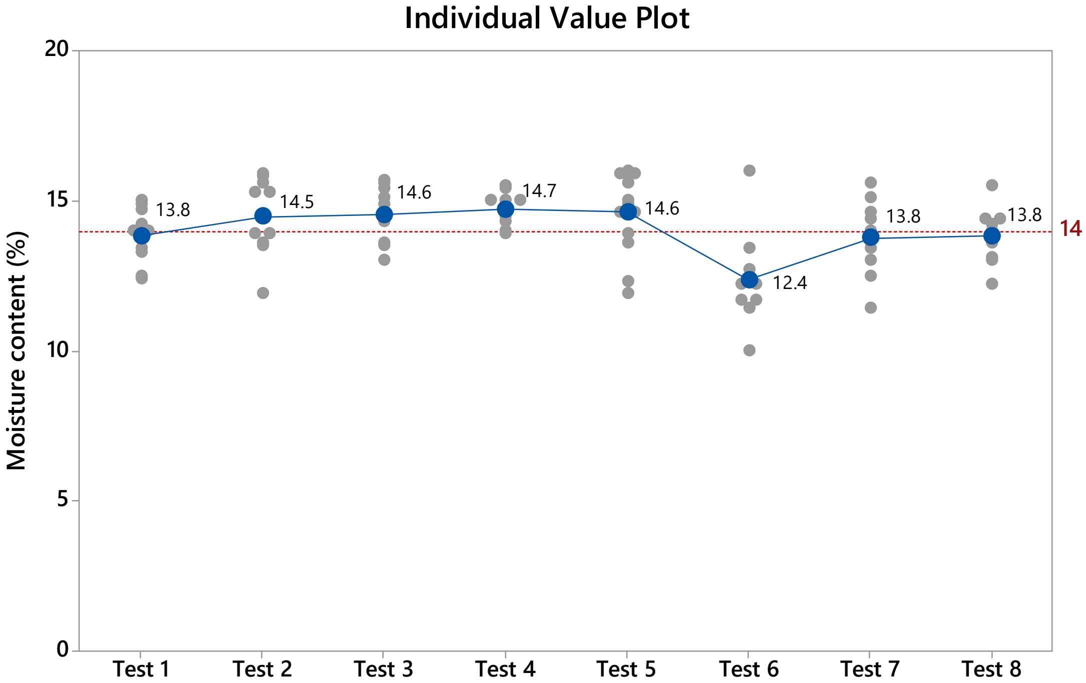


Figure 34. The measured moisture content of randomly selected individual pallets prior each test.

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

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

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

9.7 Fire test observations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Figure 49 shows the fire damage.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

9.8 Fire test results

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

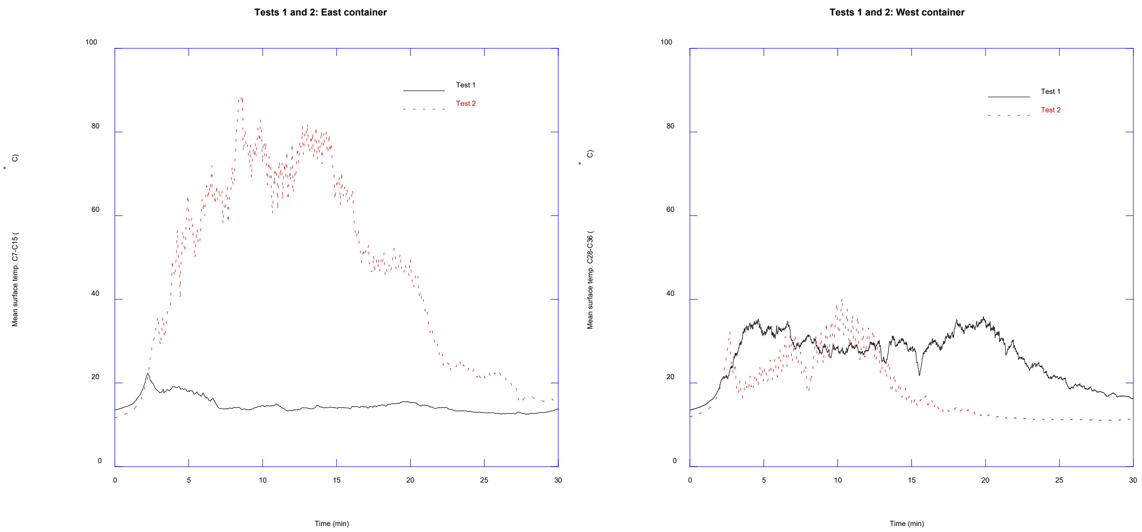


*Figure 62. **Tests 1 and 2**: The impact of the use of one vs. two fire monitors when water was applied early. Note: The temperature scale on the y-axis is significantly different than that of the tests discussed below as the surface temperatures were low.*

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

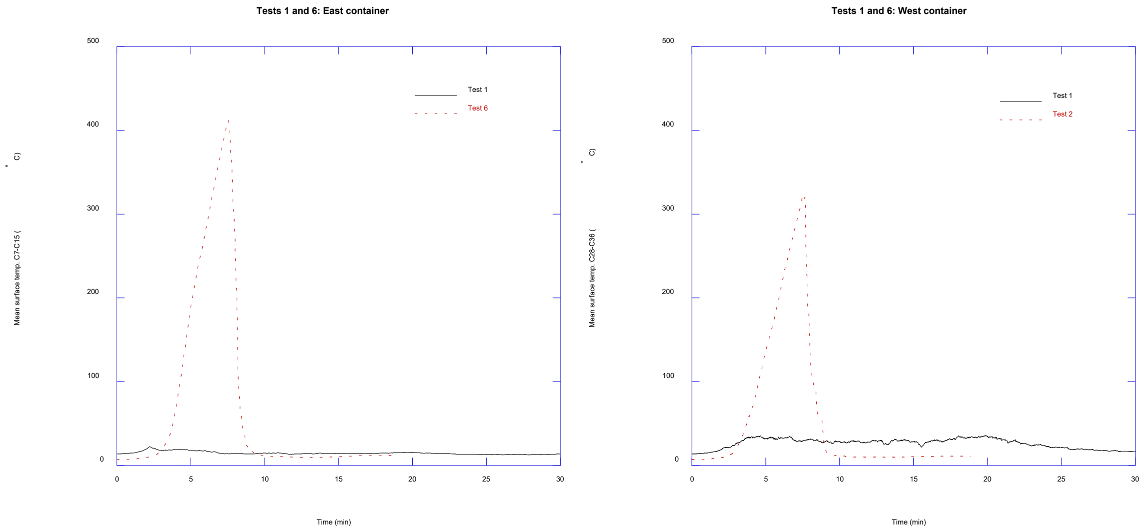


Figure 63. ***Tests 1 and 6****: The results with an early (Test 1) and late (Test 6) application of water.*

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

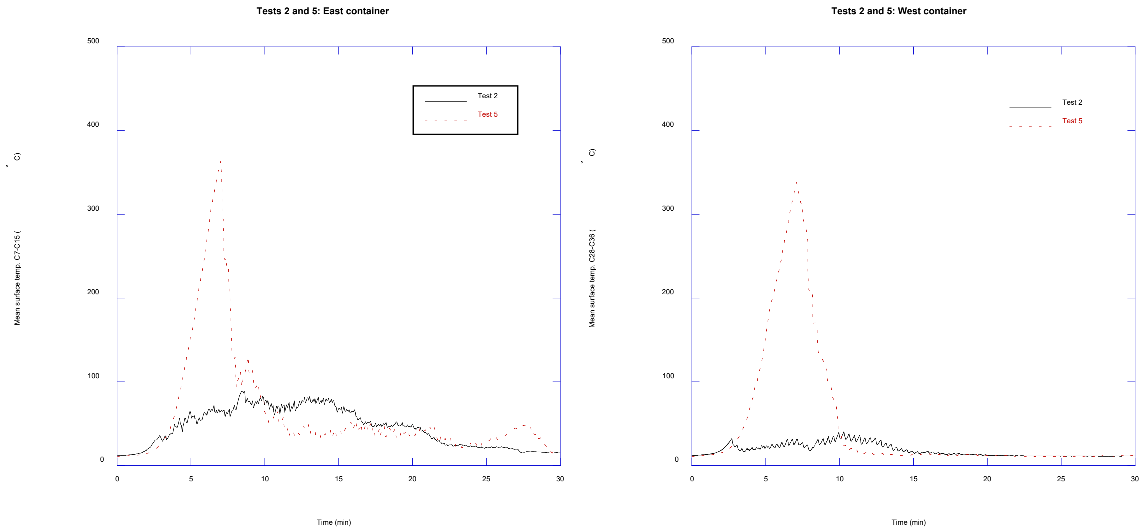


Figure 64. ***Tests 2 and 5****: A comparison of the performance of a single fire monitor (C) with an early (Test 2) and late (Test 5) application of water.*

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

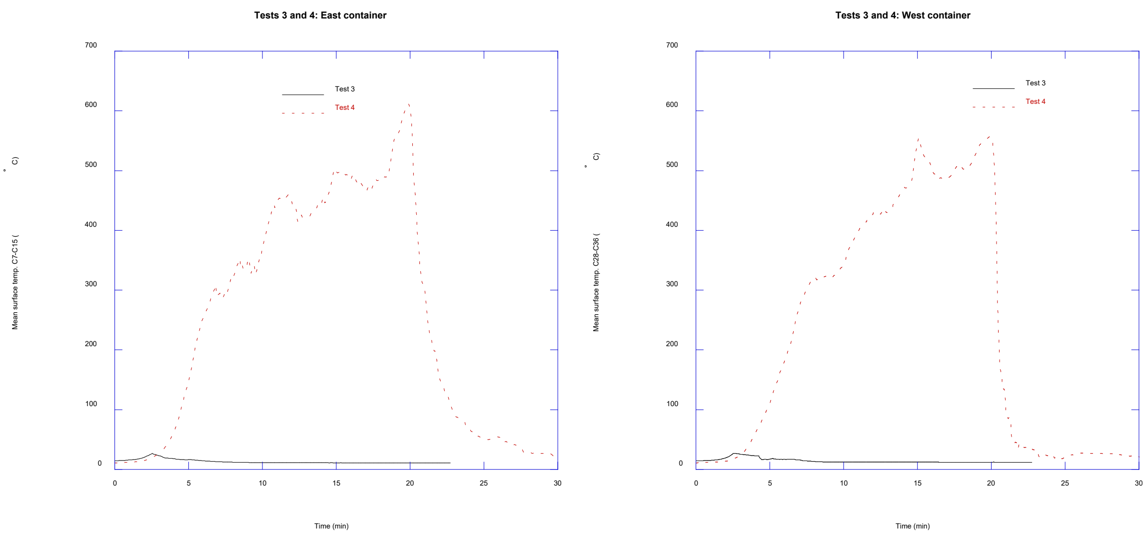


Figure 65. ***Tests 3 and 4****: The two tests with the CAF system. In Test 3, foam was applied early from two fire monitors (A and C) and in Test 4 the application was at a late stage and from one single fire monitor (C).*

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

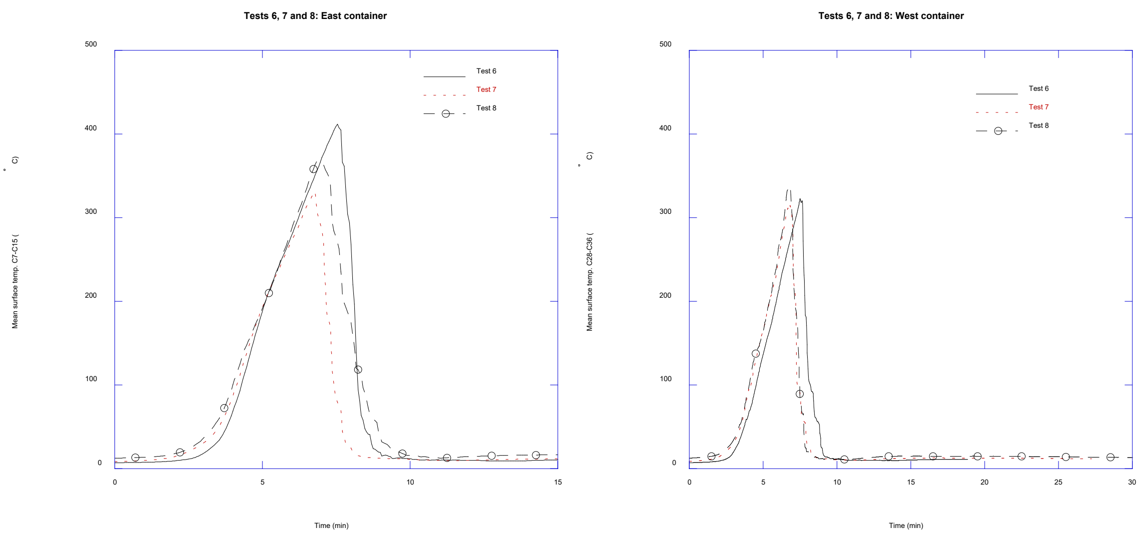


Figure 66. ***Tests 6, 7 and 8****: A comparison of using two fire monitors (A and C, B and C as well as A and B) and late application of water. These tests therefore offer the possibility to compare the performance due to the application angle.*

9.9 Overall conclusion

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

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

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

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

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

10 Installation cost assessments

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

10.1 General

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

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

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

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

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

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

10.2 The generic ship

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

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

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

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

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

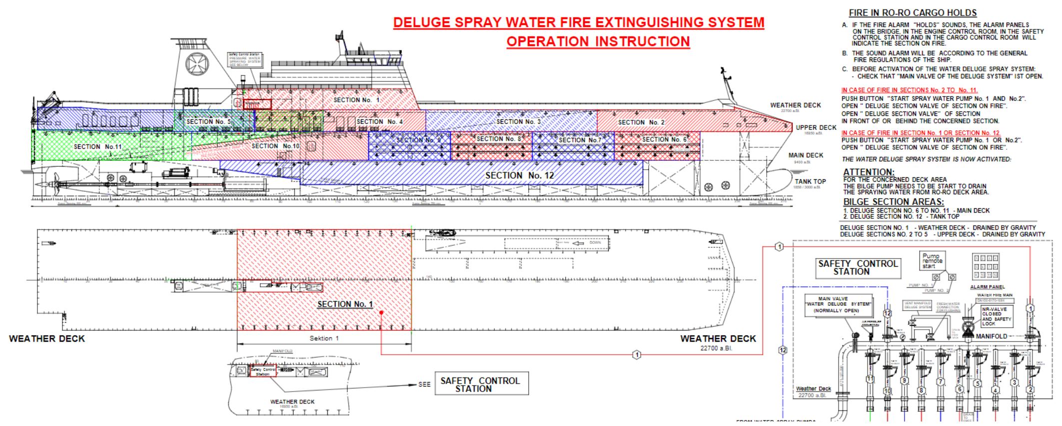


Figure 69. The weather deck on Magnolia Seaways, with the deluge water spray system protecting the deck area under the superstructure.

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

10.3 Cost assessment assumptions

The following assumptions were made for the cost assessment:

- Although the cost assessment was based on information and conditions of an existing ship, it was assumed that the installation was made during the construction of the ship and not as a retrofit installation;
- The fire monitor system is connected to one of the freshwater tanks. This allows the piping to be flushed with freshwater (after any testing or training), to avoid stagnant sea water in the pump and piping;
- A fire may occur such that simultaneous operation of the drencher system under the superstructure and the intended fire monitor system is necessary. Therefore, a dedicated water pump for the fire monitor system is required;
- The water pump is driven by an electrical motor that is connected to the main electrical power supply of the ship;
- The water pump is designed for a total water demand of 2 500 l/min at 10 bars, providing a minimum flow rate of 1 250 l/min simultaneously to each of the two hydraulically most remote fire monitors; and
- Three fire monitors are to be installed on the aft weather deck area of the ship and two fire monitors on the front weather deck area, i.e., a total of five fore monitors are to be installed.

Figure 70 shows the assumed system layout.

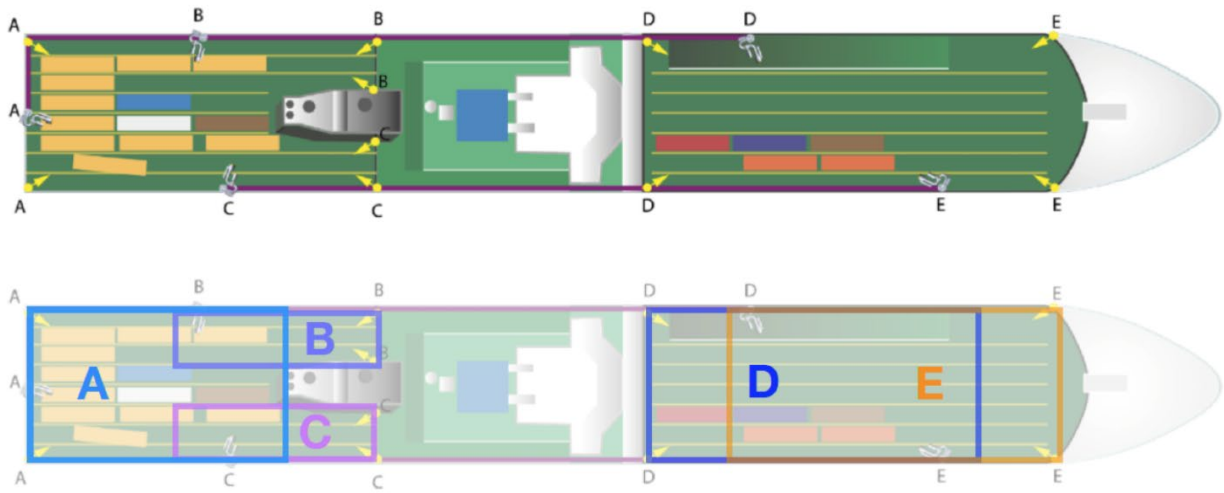


Figure 70. The layout of an autonomous fire monitor systems on the weather deck on Magnolia Seaways, with the positions of the monitors and the fire detectors.

The costs are based on price levels in 2021.

10.4 Cost assessment results

10.4.1 Remote-controlled fire monitor system (water only)

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

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

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

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

Components	Cost (€)
Subtotal:	€ 28 500
Total:	**€ 150 000**

10.4.2 Autonomous fire monitor system (water only)

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

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

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

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

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

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

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

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

10.4.3 Fire monitor system using CAF

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

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

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

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

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

10.4.4 Estimation of system weights

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

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

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

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

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

11 Cost assessments for system inspections, testing, and maintenance

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

11.1 General

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

"2.2 Maintenance, testing and inspections

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

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

Surveyors are required to approve that inspections, testing and maintenance are carried out as part of the safety equipment survey in accordance with the maintenance plan on the ship. Classification societies typically consider MSC.1/Circ. 1432 [24] and MSC.1/Circ. 1516 [25] as minimum guidelines on which such inspections are to be based. MSC.1/Circ. 1432 superseded MSC/Circ. 850, recognizing the need to include maintenance and inspection guidelines for the latest advancements in fire protection systems and appliances. It applies to all ships and provides the minimum recommended guidance. The guidelines may be used as a basis for the ship's onboard maintenance plan required by SOLAS regulation II-2/14. MSC.1/Circ. 1516 includes amendments to MSC.1/Circ. 1432.

Table 8 provides an overview of the requirements in MSC.1/Circ. 1432 and MSC.1/Circ. 1516 for fixed foam fire-extinguishing, water mist, water spray and sprinkler systems.

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

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

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

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

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

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

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

	Autonomous fire monitor system (water only)	• As per above, plus: • Test all fire detection systems used to automatically control the system, as appropriate.
	Fire monitor system using CAF	• As per above, dependent if the system is remote-controlled or autonomous, plus: • Flow-test all water supply and foam pumps for proper pressure and capacity and confirm flow at the required pressure in each section Ensure all piping is thoroughly flushed with fresh water after service. • Take samples from all foam concentrates carried on board and subject them to the periodical control tests in MSC.1/Circ.1312, for low expansion foam, or MSC/Circ. 670 for high expansion foam. Note: Except for non-alcohol resistant foam, the first test need not be conducted until 3 years after being supplied to the ship.
Two-year	Remote-controlled fire monitor system (water only)	• No recommendations.
	Autonomous fire monitor system (water only)	• No recommendations.
	Fire monitor system using CAF	• No recommendations.
Five-year	Remote-controlled fire monitor system (water only)	• Perform internal inspection of all control/section valves and all fire monitors. • Replace motor cables.
	Autonomous fire monitor system (water only)	• As per above.
	Fire monitor system using CAF	• As per above, dependent if the system is remote-controlled or autonomous, plus: • Test all foam proportioners or other foam mixing devices to confirm that the mixing ratio tolerance is within +30 to -10 % of the nominal mixing ratio defined by the system approval.
10-year	Remote-controlled fire monitor system (water only)	• These systems should be inspected and tested by a competent person as per the manufacturer's instructions, and as a minimum should include a hydrostatic test and internal examination for gas and water pressure cylinders according to EN 1968:2002.
	Autonomous fire monitor system (water only)	• As per above.
	Fire monitor system using CAF	• As per above.

11.2 Cost assessment assumptions

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

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

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

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

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

11.3 Cost assessment results

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

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

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

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

12 Conclusions

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

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

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

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

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

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

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

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

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

13 References

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14 Indexes

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ANNEX A

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

1 General

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

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

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

1.4 These guidelines were developed in the project LASH FIRE.

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

2 Definitions

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

2.2 *Area of coverage* is the maximum coverage area of an individual fire monitor.

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

2.4 *Class B foam* is a foam intended for use on Class B fires, i.e., fire in flammable liquids, combustible liquids, petroleum greases, tars, oils, oil-based paints, solvents, lacquers, alcohols, and flammable gases.

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

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

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

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

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

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

2.11 *Foam* is an aggregation of bubbles lighter than water created by forcing or entraining air into a foam solution by means of suitably designed equipment or by cascading it through the air.

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

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

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

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

3 Principle requirements for all systems

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

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

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

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

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

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

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

3.8 Any parts of the system that may be exposed to temperatures below +4°C should be protected from freezing either by having temperature control of the space, heating coils and thermal insulation on pipes, antifreeze agents or other equivalent measures.

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

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

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

3.12 All installation, operation and maintenance instruction/plans for the system should be in the working language of the ship. If the working language of the ship is not English, French, or Spanish, a translation into one of these languages should be included.

4 Water and foam concentrate or additive (if used) supply

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

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

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

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

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

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

4.7 A Class B foam concentrate complying with the revised Guidelines for the performance and testing criteria and surveys of foam concentrates for fixed fire-extinguishing systems (MSC.1/Circ.1312) should be used. The foam concentrate should be fluorine free.

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

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

4.10 There should be a reserve supply of foam concentrate, or additive, on board the ship (if used) to put the system back into service after operation, alternatively, concentrate of the correct brand and type should be able to be obtained from an external source within 24 hours.

4.11 Foam concentrate, or additive should be approved for fire protection service by an independent authority. The approval should consider possible adverse health effects to exposed personnel, including inhalation toxicity, and any environmental impact.

5 Fire detection and alarm

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

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

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

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

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

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

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

6 Additional requirements for autonomous systems

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

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

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

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

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

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

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

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

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APPENDIX 4

UNIFIRE

Article:

The Smart Monitor Revolution - From Remote to Autonomous (September, 2025)

The Smart Monitor Revolution: From Remote to Autonomous

An ARFSS in action during a successful live-fire test conducted by the U.S. Naval Research Labs in collaboration with Jensen Hughes. Credit: Unifire AB.

Introduction

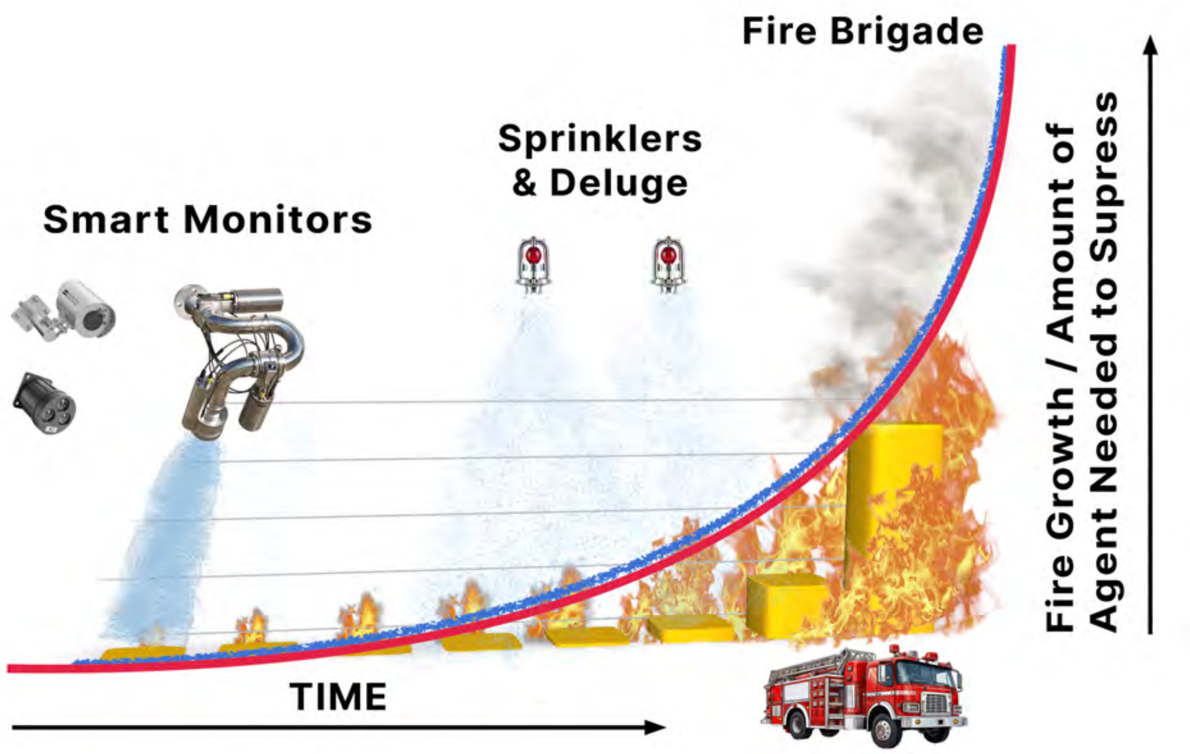
Reaction time is the single most critical factor in successful fire suppression. Fires grow exponentially, and even seconds of delay can mean the difference between a quickly extinguished incident and a catastrophic loss.

A revolution in rapid, high-volume fire suppression is now underway, powered by "smart fire monitor" systems with varying levels of automation and accuracy. These systems mark a paradigm shift and are beginning to disrupt the fire protection landscape. Unlike conventional approaches, they react within seconds to deliver concentrated streams of agent[1] directly to the hazard. They also shut off automatically after the fire has been extinguished. These capabilities are particularly critical in large, high-risk environments—

[1] Throughout this article, the term "agent" is used generically to include water, foam, and water-based solutions with additives. All three system types can be configured to operate with these agents, depending on the risk environment and requirements.

recycling and waste-to-energy plants, storage warehouses, ship decks, aircraft hangars, petrochemical sites, and others—where the scale of the space demands both speed and precision and where minimizing toxic run-off is a priority. In such settings, they offer a huge advantage over conventional methods.

Conventional methods—sprinklers, deluge systems, fixed fire monitors, or waiting for the fire brigade—are often too slow or too blunt to stop a fire before it causes severe damage. Sprinklers react slowly and are designed mainly to protect a building's structure rather than its contents, releasing water broadly at low density. Deluge systems may act more quickly, but they flood entire zones indiscriminately. Both sprinklers and deluge systems also continue discharging once activated until manually shut off, typically by the fire brigade after confirming the fire has been extinguished. This prolonged discharge can cause extensive water damage to assets not at risk and produce large volumes of contaminated run-off. Traditional fixed fire monitors, whether manual or remote-controlled, can also be difficult to operate—even when located on site—especially in emergencies where facility staff are not professional firefighters. In practice, personnel may lack training, hesitate, panic, evacuate, or be uncertain who should act, leading to dangerous delays or inaction. Fire brigades, while essential, typically arrive many minutes after ignition—time in which a fire can grow to devastating proportions.



Smart monitors intervene rapidly with a high-volume, targeted response—then auto-shut off once suppression is complete, providing faster, more efficient protection than conventional systems while minimizing water use, runoff, and collateral damage.

By contrast, modern fire monitor–based systems, or "smart monitors," can detect a fire almost immediately and deliver a concentrated, high-volume stream of agent within seconds. Depending on the configuration, this may mean directing agent toward the seat of the blaze with high precision, or, in zone-based systems, rapidly covering the affected area. Either way, with proper design this combination of speed, volume, and targeting provides a decisive advantage: the ability to suppress or extinguish a fire before it spreads, while also reducing unnecessary agent use and minimizing collateral damage.

The smart monitor technologies are evolving so quickly that even the terminology has not yet been firmly established or agreed upon. This article explores three classes of "smart fire monitors"—also referred to as water cannons or robotic nozzles—outlined below in order of sophistication, using terminology adopted here for clarity:

- **Autonomous Robotic Fire Suppression Systems ("ARFSS")**
- **Automatic Fire Monitors ("AFM")**
- **Remote Operator ("RO")**

Understanding the differences is important: while all three represent major advances over conventional sprinklers, deluge systems, or purely manual firefighting, they are not the same. Systems vary in speed, accuracy, flexibility, and susceptibility to false alarms. The following sections discuss each class and highlight their defining features, advantages, and limitations.

Autonomous Robotic Fire Suppression Systems (ARFSS)

Autonomous Robotic Fire Suppression Systems (ARFSS) represent the most advanced evolution of the smart fire monitor. They can do everything Automatic Fire Monitors and Remote Operator models can—and more. ARFSS bring multiple advanced functions together in a single system: three-dimensional fire localization, dynamic targeting to minimize intervention time, zone-based protection, rapid automatic shutoff, networking and coordination across multiple units, integration of diverse detection technologies to match specific risks and minimize false alarms, and remote operation with full technical support from anywhere. Collectively, these strengths place ARFSS in a class of their own—delivering speed, precision, and adaptability beyond other smart monitor types.

ARFSS integrate multiple detectors with robotic nozzles to deliver fast, intelligent detection and pinpoint suppression at the fire's source.

Advantages

What sets ARFSS apart is how these capabilities work together in practice. They can integrate virtually any type of detector—IR3 flame detectors, thermal imaging, video analytics, linear heat detection, and others. Multiple detectors may be combined not only to confirm an event, but also to expand coverage with additional detection zones, making false activations exceedingly rare. When two detectors are strategically placed—whether specialized flame detectors, thermal imaging cameras, or video analytics—ARFSS are capable of triangulating the precise three-dimensional location and size of a fire, depending on detector setup. When equipped with thermal imaging cameras, they are positioned independently from the nozzle, so their view is not obstructed by the agent stream during suppression. This allows fires to be attacked at their exact source, suppression to adapt in real time, and even multiple incidents to be managed simultaneously. Once a fire is confirmed, ARFSS act within seconds, directing agent exactly where it is needed—first containing the perimeter, then sweeping the flames down at their core.

ARFSS visualized: rapid, targeted suppression at the fire's source

Like other smart monitor systems, ARFSS shut off agent flow once suppression is complete. But unlike AFM models, ARFSS are able to confirm actual extinguishment and apply only a brief over-spray for cooling—making them more efficient in both precision and agent use (with the overspray duration fully programmable). Importantly, ARFSS remain fully armed and ready to respond immediately should a flare-up occur.

ARFSS units can act completely independently, but they can also communicate with each other, enabling coordinated response strategies across an entire facility. Multiple systems can share detection inputs, divide suppression tasks, and execute higher-level behaviors—while also providing redundancy, so if one unit fails, others can compensate. This level of coordination delivers protection and resilience unmatched by other smart monitor types.

ARFSS are ideal to protect high-value equipment and high-risk environments

Beyond these core functions, ARFSS offer additional advantages. ARFSS can operate in three-dimensional, zone-based, or hybrid configurations, with detectors and monitors positioned flexibly to ensure the most effective coverage for each facility. They also add the precision of "robotic nozzles"[2], which have unmatched accuracy and long-term reliability. They also incorporate significant computing power, enabling advanced behavior programming and networking, remote commissioning and support, and seamless integration with pumps, valves, alarms, and other facility systems.

Although fully autonomous by design, ARFSS can also be remotely controlled by designated staff when desired, both on-site and off-site. They can be deployed initially in simpler, more economical configurations and later upgraded with more advanced features such as three-dimensional dynamic tracking, newer detectors, or expanded integration, making them highly scalable and adaptable over time.

Limitations

The advanced capabilities of ARFSS may involve a slightly higher initial cost than AFM or RO systems, yet they deliver exceptional value in safeguarding both people and high-value assets, while also avoiding the ongoing fees of RO models and potentially providing the most cost-effective investment. In addition, because ARFSS platforms are highly flexible and configurable, each system must be carefully designed and tailored to the facility's specific risks and requirements. This customization is a strength, but it requires additional planning and consultation to achieve optimal performance.

Automatic Fire Monitors

Automatic Fire Monitors (AFMs) combine a fire monitor with a flame detector or thermal imaging camera to deliver rapid detection, localized suppression, and automatic shutoff—all without human intervention. While they do not offer the same level of sophistication

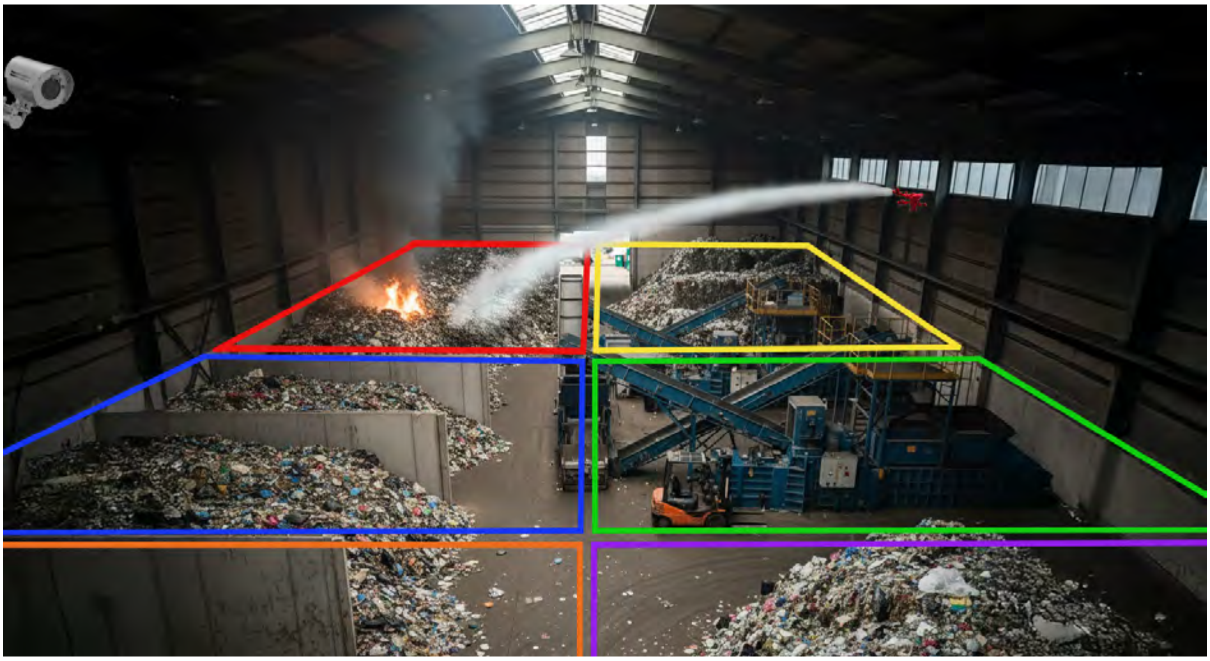
[2] For further background on robotic nozzles, see: "Robotic Nozzles Defined: A New Generation of Remote-Controlled Fire Monitors & Water Cannons" (https://unifire.com/robotic-nozzles-defined/).

as ARFSS, they remain a solid option for many facilities, delivering round-the-clock protection. AFMs fall into two broad subcategories: scanning types and zone types. Both operate as stand-alone units, without communication or coordination between multiple monitors.

Scanning AFMs typically use a flame detector to identify a fire in general and a thermal imaging camera mounted above the nozzle tip. When the flame detector triggers, the monitor scans with the camera until it identifies the hottest spot, then directs agent toward it. Once agent discharge begins, however, the thermal imaging camera's view is obscured by the relatively cool spray. As a result, suppression is carried out for a preprogrammed duration before the system shuts off, reassesses, and redeploys if necessary.

Visualization of a scanning Automatic Fire Monitor with a thermal imaging camera mounted above the nozzle tip.

Zone AFMs generally rely on a thermal imaging camera, which is typically mounted separately from the monitor, allowing optimal viewing angles and reducing blinding during suppression. The camera's field of view is divided into zones, each with its own alarm threshold. When a hot spot in a zone triggers an alarm, the monitor responds by oscillating repeatedly across the entire zone. Discharge continues for a pre-programmed interval, after which the system shuts off automatically and reassesses.



Visualization of a zone-based Automatic Fire Monitor system, where the colored boxes represent the pre-programmed detection and suppression zones.

Advantages

The primary advantages of AFMs are their rapid activation, automatic shut-off, and independence from human intervention. Operating continuously, 24/7, they stand ready to respond the moment a fire is detected.

AFMs tend to be less expensive than fully configured ARFSS systems because they lack the advanced accuracy, flexibility, and sophisticated features of those platforms. They may also prove more economical over time than Remote Operator models, which involve recurring fees (discussed later).

AFMs typically include an automatic shut-off function, stopping the flow of agent after a pre-programmed amount of time, and reactivating if a hot spot is again detected.

Zone-type AFMs add design flexibility: unlike scanning AFMs and RO models, the detector and monitor can be positioned independently. Like ARFSS, the detector may be mounted for maximum viewing coverage—on walls, ceilings, or in corners—while the fire monitor can be placed for optimal suppression angles, improving protection of large or irregular spaces.

Finally, most AFMs permit manual override via joystick, providing operators an additional layer of control if needed.

Limitations

While simplicity and independence are strengths, they also impose limits.

Scanning AFMs generally take a bit longer to begin suppression, as a fire must first be detected by a flame detector and then the monitor must scan the area to locate the hot spot. Because they cannot pinpoint a fire’s three-dimensional position, they compensate by using wider vertical oscillation. This reduces precision and increases both agent use and the time required for full suppression compared with other systems. In addition, because scanning AFMs rely on thermal imaging to locate heat, they go blind once discharge begins, forcing them to shut off after a timed interval before reassessing and redeploying if needed.

Zone AFMs, by contrast, can only identify the general zone where an alarm is triggered. Suppression is confined to relatively broad coverage, achieved by oscillating across the entire zone (though zones can be defined in whatever size or shape best suits the facility, or as required by local code). This relative imprecision slows suppression, requiring more agent and producing greater runoff.

Zone AFMs are also more prone to false activation. Because thermal cameras detect only temperature, benign heat sources—such as hot engines or exhaust from forklifts, bulldozers, or wheel loaders—can trigger unwanted discharges (so-called “false alarms” or “nuisance alarms”). Although this risk is reduced by increasingly sophisticated algorithms in thermal imaging systems, false alarms remain a concern, with the added risk of inadvertently spraying nearby staff or equipment.

Finally, AFMs follow pre-set responses and cannot adapt dynamically as a fire grows, spreads, or shifts. Their performance is ultimately constrained by the strengths and weaknesses of the detector type they use, and they operate only as stand-alone units with no ability to communicate or coordinate with other monitors in a facility. This lack of networking capability also limits redundancy and reduces the overall resilience of facility-wide protection.

Despite their fewer advanced features when compared with ARFSS, Automatic Fire Monitors remain an effective and economical choice for many facilities, providing fast, reliable, around-the-clock protection with flexible coverage.

Remote Operator

Visualization of a Remote Operator system: detection alerts and live video are transmitted to a centralized command center, where operators remotely aim and discharge fire monitors using joystick controls.

The third model is the "Remote Operator" (RO) approach. In this setup, fire monitors (water cannons) are paired with flame detectors and thermal imaging cameras and linked via the internet to a centralized command center staffed around the clock by human operators. When the detection system identifies a potential fire, the alert, together with live video and sensor data, is transmitted to the control center, where personnel verify the event in real time. While RO systems are neither automatic nor autonomous, they may be considered a "smart fire monitor" technology because they combine rapid detection with the judgment and intervention of trained human operators working remotely.

Once an incident is confirmed, responsibility shifts entirely to the operator. Using a joystick or other control interface, the operator must interpret the video and sensor data correctly—as viewed through the transmitted feed—before remotely aiming and discharging the fire monitor to suppress the fire.

Advantages

Like ARFSS and AFM models, this model offers significant improvements over conventional systems, delivering a faster and more targeted response via human control. Because these systems are equipped with detectors and trained operators can visually verify incidents before activating suppression, false alarms can be minimized or avoided altogether. Once suppression is complete, the operator can remotely shut off the flow of agent, ensuring the system is immediately ready for reactivation.

Another strength is the human element itself. A single command center can monitor multiple sites around the world, centralizing expertise and oversight, and ensuring that a trained operator is ready to respond at any hour of the day. In some facilities, managers prefer the reassurance of human judgment before suppression begins—especially where accidental discharge could cause costly disruption, damage to equipment, or potential risk to personnel—and value the peace of mind of having a trained human operator controlling the response.

Limitations

While the human element offers certain advantages, it is also a limitation. The model depends on a stable internet connection and a continuously staffed service—typically with significant recurring fees—and remains vulnerable to operator performance. Interruptions in connectivity, delayed reactions, fatigue, or misinterpretation of signals can all compromise effectiveness. Even in the same room, remotely controlling a fire monitor is challenging; relying only on video or thermal feeds makes it considerably more difficult, increasing the risk of delayed or inaccurate suppression when every second counts.

Another limitation is system design. Typically, detectors and the fire monitor must be mounted together, sharing the same field of view. This restricts flexibility in placement. By contrast, ARFSS and some AFM models allow detectors to be positioned wherever they are most effective, while monitors can be mounted in optimal locations for coverage, including on the ceiling.

Remote Operator systems are therefore best suited for facilities where human oversight is a priority, false activations must be minimized, budget or operational philosophy favors centralized monitoring, and a reliable internet connection can be assured.

Choosing the Right System

Each of the three smart monitor system types—Autonomous Robotic Fire Suppression Systems (ARFSS), Automatic Fire Monitors (AFM), and Remote Operator (RO)—offers distinct advantages, and each of them dramatically enhances fire protection compared with traditional sprinklers, deluge systems, fixed monitors, or reliance on fire brigades.

ARFSS deliver the fastest detection-to-suppression cycle, the highest potential accuracy, and the flexibility to adapt strategies to almost any facility, with the added ability to expand as needs or technologies evolve. AFMs provide rapid, reliable, and cost-effective protection in both scanning and zone configurations, with zone systems allowing flexible placement of detectors and monitors for efficient coverage of large or irregular spaces. RO systems centralize oversight and provide the reassurance of trained human judgment, often appealing where minimized false activations and centralized monitoring are valued, and where recurring service fees are acceptable.

By understanding the strengths and limitations of each class, decision-makers can align technology with their priorities—whether that is maximum protection, cost, or human oversight.

Written By
Roger Barrett James, Esq.
Roger is Unifire's
General Counsel and
Executive Vice President,
with two decades of
experience in the fire
fighting industry.

APPENDIX 5

UNIFIRE

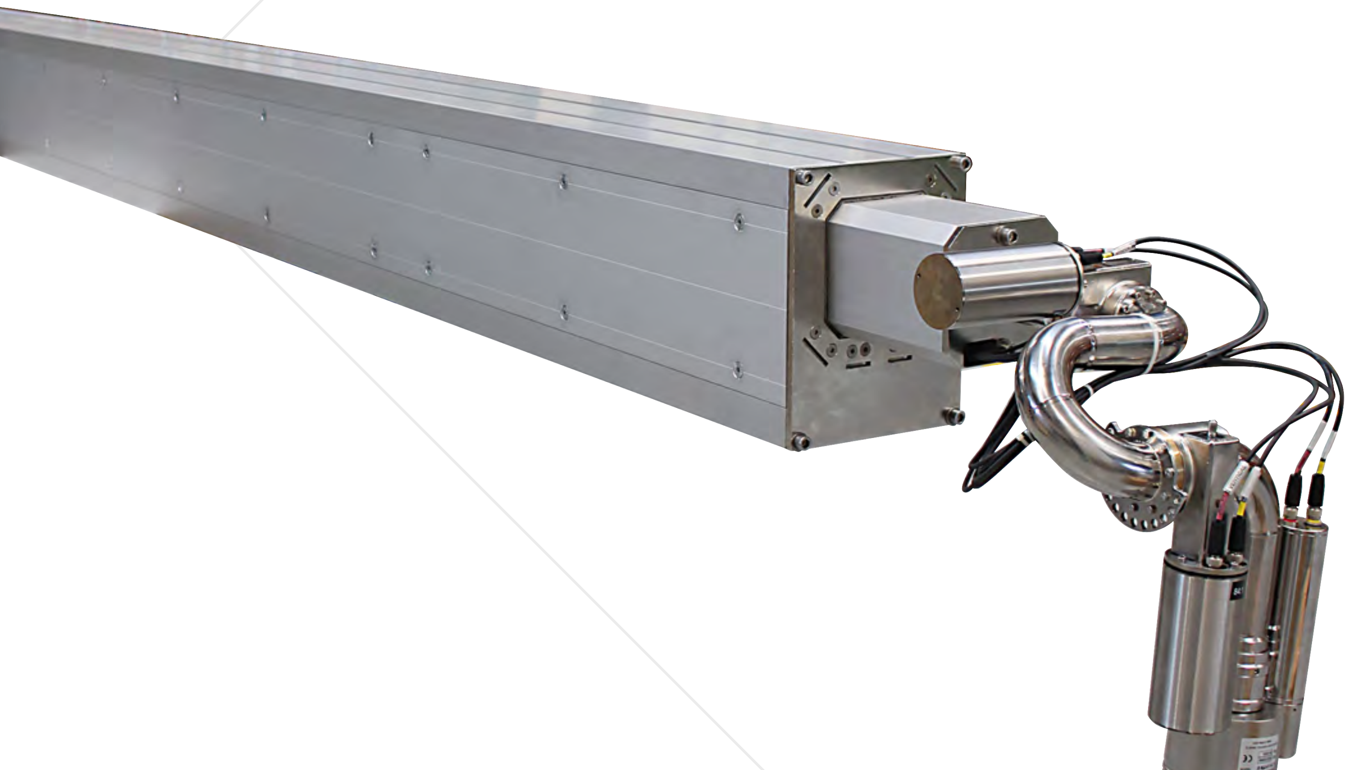
Customer References

UNIFIRE

Made in Sweden

Unifire.com
Sales@Unifire.com

Installations & Customer References



Swedish Quality, Since 1969

Since 1969 Unifire of Sweden has designed and manufactured professional nozzles of the highest quality and performance.

Our Force™ robotic nozzles are used in some of the harshest and most demanding applications around the globe.

Our revered customers span many industries.

We are proud to share just some of our valued customers below.

Company Overview

Unifire AB of Sweden is a globally renowned manufacturer of professional nozzles and high-end, state-of-the-art robotic nozzle technologies.

Established in 1969, Unifire has built a brand name known around the world as a trusted maker of the highest quality nozzles on the market.

Unifire’s products are sold to a wide variety of customers for numerous applications, ranging from an array of fire fighting applications both on- and off-shore, to industrial applications, such as mining, riot control, anti-pirate protection, water fountains, dust control and wash down, and many more.

We offer robotic nozzle systems that can be controlled by joystick, radio remote control, from any iOS or Android device via our ONE app, and by computer from anywhere in the world.

We are also global leaders in the development and supply of fully automatic fire detection and suppression systems that couple state-of-the-art fire detection technologies with our advanced robotic nozzles.



We Meet Challenges with Innovation

Unifire has for many years been at the cutting-edge of robotic nozzle development. Our rapid development, year after year, has been driven both our customers’ needs combined with our own vision of what is possible.

Exceptional quality, industrial-robot-type brushless (BLDC) motors, extremely high position accuracy, more functions, better integration, fully automatic systems, networked systems, simple installation, set-up and upgrades, web-based technical support and Graphical User Interfaces (GUI’s) are some of what our customers have asked for. And we have delivered.

By implementing cutting edge and cost-saving technology in our products, and producing them in some of the most modern factories in Europe, we have earned a reputation of delivering what are undoubtedly the highest quality and most advanced robotic nozzle systems available anywhere.

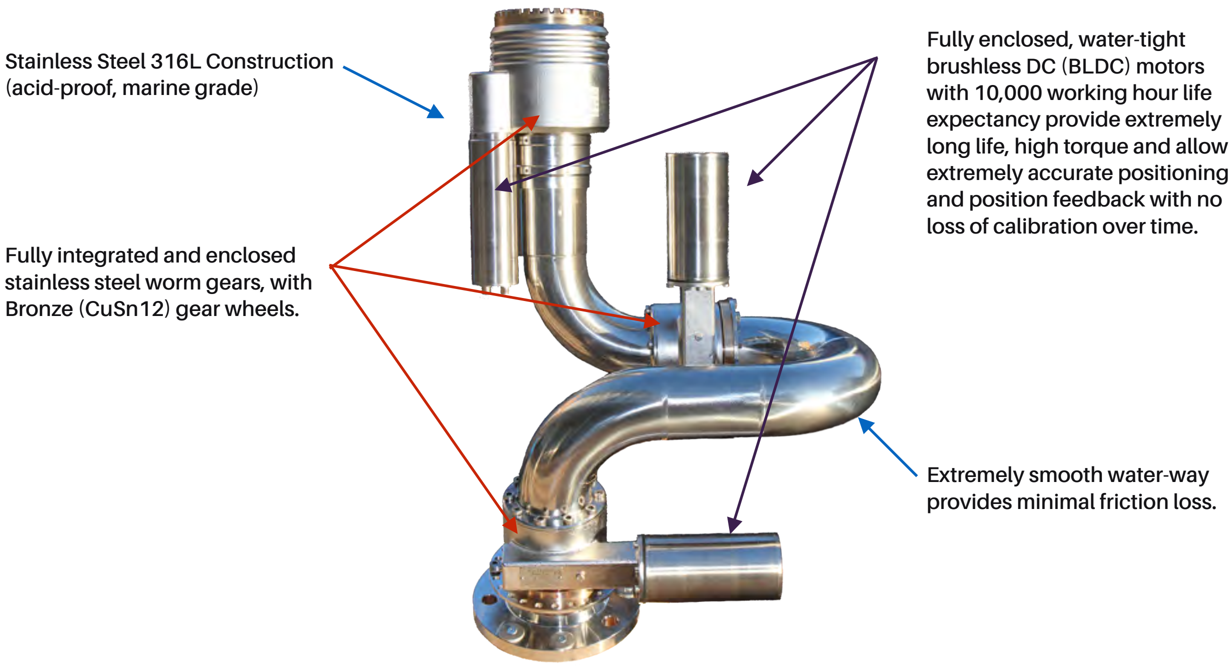


Products Built to Last

Unifire’s products are designed and manufactured to the highest quality standards on the market.

All of Unifire’s robotic nozzle systems have a proven track record in the harshest conditions—in mines operating around the clock, on ships and off-shore vessels, in waste and recycling plants, as seawater fountains, and countless other indoor and outdoor applications around the world.

FORCE Robotic Nozzles



PLC's / Electronics

Unifire designed and Swedish manufactured electronics in IP66 or IP67 stainless steel cabinet, CE Market, ISO Certified Facilities manufacturing and EMC tested with over a decade of proven track record in marine and other extremely harsh environments.

Fire Detectors

Unifire's FlameRanger and FlameRanger XT systems use only world-class, certified fire detectors manufactured by world-leading brands and made for harsh indoor and outdoor environments.

Controllers & Software

Unifire's controllers are robust and designed and proven for reliable control in in harsh conditions. Our Π™(PI) CANbus joystick has a proven track record since 2002; the ERGO-S wireless remote is a world-class radio manufactured by world-renowned Hetronic, and we offer other first-in-class controllers on request.

Unifire has also developed our own proprietary software for our proprietary electronic hardware, providing flexible and robust functions, including fully autonomous fire detection and suppression, recordable sequences, logic, control of and inputs from virtually any electronic device, and much more. Rigorously tested and proven in the field around the world with a flawless track record since 2002 and numerous generations of updates and enhancements since that time.

Our ONE app for iOS/Android is a unique, easy-to-use tried and true app, enabling intuitive, robust control from any device.

Some of the Many Industries We Serve

Aircraft Rescue Fire Fighting	Waste-to-Energy (WtE)	Riot Control
Automatic Firefighting	Marine & Offshore	Recycling Plants
Mining & Dust Control	Naval Vessels & USV's	Yachts & Boats
Fixed Installations	Municipal Firefighting	Commercial & Passenger Ships
Fountains	Oil & Gas	Wash Down & Cleaning
Helideck Fire Protection	Offshore Firefighting	Zoos

Customer's Around the World

For over 40 years Unifire's products have been sold around the world. Below are just some of our numerous, valued customers and end-users of our equipment whom we have proudly served and continue to serve.

Company	Country
ABB AB	Sweden
Ainsworth Inc.	Canada
Ajax Chubb	Sweden
Albert Ziegler GmbH & Co. KG	Germany
Alf Lea & Co Brannvern	Norway
Algebra Group BV	The Netherlands
Alloy Yachts	New Zealand
Alnmaritec Ltd	United Kingdom
Alpine Helicopter AB	Sweden
Amels	The Netherlands
Angus Fire Armour Ltd	United Kingdom
APT Antincendo	Italy
Arctia Offshore OY	Finland
Arduino Srl	Italy
Armour Flavors & Fragrances Ltd	Israel
Attika Vehicle & Machine Industry	Greece
Asiatic Fire System Pte Ltd	Singapore
Asker og Bærum brannvesen	Norway

Company	Country
Atlas AG Feuerlöscher	Switzerland
Autokaross Rescue Systems i Floby AB	Sweden
BAI - Brescia Antincendi International	Italy
Barbagelata Adriatica S.r.l.	Italy
BASF Performance Products GmbH	Germany
Basin Electric Power Cooperative	United States
Båtservice Mandal AS	Norway
Batservice Shipbuilding Industry	Turkey
Benci Marine Srl	Italy
Bezopasnost OOO	Russia
Bio-El Fredriksstad AS	Norway
BL Transport	Sweden
Bluetek	South Korea
BOLIDEN Mineral AB	Sweden
Br Hukkelberg AS	Norway
Brandstop BV Handelsonderneming	The Netherlands
Bravida Danmark A/S	Denmark
Brissmans Brandredskap	Sweden
BRONTO Skylift AB	Sweden
BUMAR-KOSZALIN S.A.	Poland
Burton's Fire, Inc.	United States
Carmor Ltd.	Israel
Chong Kui Marine Engine Ltd	Hong Kong
Chubb Fire Australia	Australia
Chubb Flame Control B.V.	The Netherlands
Coast & Middle East Elect. Devices L.L.C	United Arab Emirates
Coastal Environmental Operations INC	United States
COMANCO Environmental Corporation	United States
Consilium Incendium AB	Sweden
Cork City Fire Brigade	Ireland
Cosalt N.V.	Belgium
Crash Rescue Equipment Service, Inc.	United States

Company	Country
Cristoffanini S.R.L	Italy
Damen Yachting BV	The Netherlands
Darwish Bin Ahmed & Sons	United Arab Emirates
DELTA FIRE Australasia Pty Ltd	Australia
Delta Fire Ltd	United Kingdom
DemacLenko	Italy
Denver International Airport	United States
Disney	Hong Kong
Domeyer GmbH & Co. KG	Germany
DRC International	United States
DSG	South Africa
DSV Corporation	South Korea
Dundee Precious Metals	Bulgaria
Dynaset OY	Finland
Dytecna Engineering Ltd	United Kingdom
Echotechnology LTD (OOO)	Sweden
Efectis Nederland BV	The Netherlands
Elektroland End. Elk.	Turkey
Emdad Najed Trading Est.	Kingdom of Saudi Arabia
EMPL Fahrzeugwerk	Germany
Engineering for Industries (Indefire)	Egypt
ERIKS BV	The Netherlands
ET "Kalin Radev – 3000"	Bulgaria
Eteha Bv Slangtechniek	The Netherlands
Euromining AB	Sweden
Evergas Ship Management	Singapore
Evrelco S.A.	Greece
Falck Teknik	Denmark
Fiemca Suministros Industriales	Spain
Fire Armour Pte Ltd	Singapore
Fire Control beveiligingen bv	The Netherlands
FIRECO s.r.l.	Italy

Company	Country
FireNor AS	Norway
Flowtroniks	United Arab Emirates
Foulds Clark (London) Ltd.	United Kingdom
FOZFOGO	Portugal
GEL Engineering LTD	United Kingdom
Glencore	Norway
Google, Inc.	United States
Greenpeace International	The Netherlands
Griffon Hoverwork Ltd.	United Kingdom
Grove-Knutsen & Co AS	Norway
Grupo CEMESA	Spain
Guillevin Int.Co.Ind-Saf	Canada
Gummischwarz AG	Switzerland
Hafslund Miljøenergi AS	Norway
Hillsborough County Fleet	United States
Hiromax Gmbh Switzerland	Switzerland
Hobrand Algebra	The Netherlands
Incipresa S.A.	Spain
Indeco Engineers Pte Ltd	Singapore
Indobara Bahana	Indonesia
Industrial & Safety Equipment Pte Ltd	Singapore
Inglasco Fire Systems B.V.	The Netherlands
International Shipping Partners, Ltd.	United States
JaCintO	Portugal
Jakarta Fire Brigade	Indonesia
Johnson Controls (JCI)	Multiple countries
K.A Blöchliger AG	Sweden
Kamaz	Russia
Katmerciler	Turkey
KCS - Komi Contractor Supply	Denmark
Kenbri Fire Fighting B.V.	The Netherlands
Kidde Australia Pty Ltd	Australia

Company	Country
Kidde Finland OY	Finland
Kidde Products	United Kingdom
Kidde Sweden AB	Sweden
Korea Fire Truck Co., Ltd.	South Korea
Kuwait Oil Tanker Co. S.A.K.	Kuwait
La Securité Incendié	France
Lindrup Martinsen	Norway
Lingjack Offshore & Marine Pte Ltd	Singapore
Lonestar Shipping HB	Sweden
Lotek A/S	Denmark
Lundgrens Sverige AB	Sweden
Lürssen-Kröger Werft GmbH & Co KG	Germany
Macron Safety Systems (UK) Ltd	United Kingdom
MARCE Fire Fighting Technologies	South Africa
Mercury Firesafety	Australia
METZ Aerials GmbH & Co KG	Germany
Mideast Ship Management Ltd JLT.	United Arab Emirates
Minimax GmbH & Co. KG	Germany
Minimax Mobile Services GmbH	Germany
MINIMAX OE-Feuerschutz GmbH	Germany
MINIMAX Österreich Feuerschutz GmbH	Austria
Minimax SpA	Italy
NAFFCO	United Arab Emirates
Nasser Bin Khaled Automobiles	Qatar
National Fire Fighting Manufacturing FZCo	United Arab Emirates
NAVANTIA (Grupo SEPI)	Spain
NBB Controls & Components AG	Germany
Nederman Polska Sp. z o.o.	Poland
NKCF Co., Ltd.	South Korea
Noha Norway AS	Norway
Norwegian Society for Sea Rescue	Norway
Oceanco	The Netherlands

Company	Country
Odfjell Asia II Pte. Ltd.	Singapore
Odfjell Tankers	Norway
Olafur Gislason & Co. HF	Iceland
Oregon Iron Works, Inc.	United States
Oshkosh / Pierce Manufacturing	United States
Oslo Fire Brigade	Norway
OTT Technologies	South Africa
Pierce Manufacturing	United States
Rafael Advanced Defense Systems Ltd.	Israel
RAVASINI S.p.A.	Italy
Rejlers Ingenjörer AB	Sweden
Remontowa S.A	Poland
Republic of Singapore Navy	Singapore
Rosenbauer International AG	Austria
Rosenfire - FIRECO Antincendi s.r.l.	Italy
Royal Norwegian Navy	Norway
Saab AB	Sweden
SAFE-TEC	Germany
Safety Innovators (International) Pte Ltd	Singapore
Safety Service Center	The Netherlands
San Francisco International Aiport	United States
Sanmar Denizcilik Makina Ve Ticaret A.S.	Turkey
Sea Eagle Machine Equipment(HK) Co.,Ltd.	China
Segway Inc	United States
Shanghai Safetec Marinte Services Co., Ltd.	Singapore
Simtronics Fire & Gas Pte Ltd	Singapore
Somati Vehicles	Belgium
STATOIL (Orient) Inc.	China
Stena Line Scandinavia AB	Sweden
Streit Security Vehicles	United Arab Emirates
Sun Engineering Corporation	Japan
Svebab	Sweden

Company	Country
Svenska SKUM AB	Sweden
Swede Ship Marine AB	Sweden
Swedish Air Force	Sweden
Teck Coal Limited	Canada
Teknosafe	Norway
Thoreb IT vehicle AB	Sweden
Tokyo Bosai Setsubi Co Ltd	Japan
Tough Marine International Co., Ltd.	China
Track Straight	Ausralia
Transfér Technológii	Slovakia
Tridente, S.L.	Spain
Trinity Fire Services	Australia
TSM Fire	Indonesia
TYCO Building Services	Sweden
TYCO Building Services (Norway) AS	Norway
TYCO Building Services Products B.V.	The Netherlands
TYCO Fire & Integrated Solutions	France
TYCO Fire & Integrated Solutions	Norway
TYCO Fire & Integrated Solutions	Scotland
TYCO Fire & Integrated Solutions	United Kingdom
TYCO Fire & Security	Singapore
TYCO Marine Services	South Korea
U.C. San Diego, SCRIPPS Institute	United States
U.S. Air Force	United States
U.S. Naval Research Laboratory	United States
UBM JAPAN CO LTD	Japan
VAMPA srl	Italy
Vigor Works LLC	United States
VOLVO Trucks AB	Sweden
Wärtsilä Singapore Pte. Ltd.	Singapore
WAWRZASZEK (WISS)	Poland

Company	Country
Weng Hock Hardware Pte Ltd	Singapore
Wilhelm RUBERG AB	Sweden
Wilhelmsen Maritime Services	The Netherlands
Wilhelmsen Ship Service	The Netherlands
Zinkgruvan Mining AB	Sweden

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FlameRanger
Customers & End Users

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
ADT FIRE & SECURITY PLC	Goldman Sachs	United Kingdom	Atrium	1
Tyco Building Services Products B.V. (Johnson Controls)	Unifire FlameRanger XT (SPRAYSAFE)	Netherlands	High Rise Building Exteriors	3
Delta Fire (FireShield)	[CONFIDENTIAL]	United Kingdom	Waste/ Recycling	4
Dongbo Electric Co., Ltd. 160 Cheongan-ro Yeoju-si Gyeonggi-do Korea	K.C. Eco Logistics South Korea	South Korea	Waste/ Recycling	3
Delta Fire (FireShield)	[CONFIDENTIAL]	United Kingdom	Waste/ Recycling	1
Korea Institute of Machinery & Materials 156 Gajeongbuk-Ro, Yuseong-Gu, Daejeon, Korea http://www.kimm.re.kr	Korea Institute of Machinery & Materials Daejeon, Korea	South Korea	Research / vibration laboratory	1
Delta Fire (FireShield)	Hamilton Waste & Recycling LTD Smeaton Recycling Centre East Lothian, UK	United Kingdom	Waste/ Recycling	10
GK RØR AS, Moss Solgaard Skog 139 1599 MOSS Norge	GK RØR AS, Moss Solgaard Skog, Norway	Norway	Waste	3
Tore Eide Ingeniørfirma Spelhaugen 8 5147 FYLLINGSDALEN Norway	[CONFIDENTIAL]	Norway	Waste	2
VEKOS AS Skreppestadsveien 50 3261 Larvik Norway	ROAF / ESAR bygget Bølerveien 93 2020 Skedsmokorset Norway	Norway	Recycling	4

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Customers & End Users
(Continued)

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
LASH FIRE / RISE	LASH FIRE / RISE	Sweden	Marine - RoRo weather decks	2
VEKOS AS Skreppestadsveien 50 3261 Larvik Norway	GLENCORE / Nikkelverk Norway	Norway	Nickel production plant	4
KC Glass & Materials Co., Ltd. South Korea	Ssangyong C&E	South Korea	Cement factory	1
KC Glass & Materials Co., Ltd. South Korea	Samho Environmental Technology Co., Ltd. Yongin Factory	South Korea	SRF (Solid Recovered Fuel)	2
VisionTIR Calle Pierre Laffitte 8 PTA 29590 Malaga Spain	National Cement Company of Alabama, Inc. 2000 Southbridge Parkway Suite 600 Birmingham AL 35209	United States	Waste/ Recycling	4
BSS Brandschutz Sichelstiel GmbH Nürnberg, Germany	Remondis, Köln Germany	Germany	Waste	1
Wormald Australia Welshpool WA Australia	[CONFIDENTIAL]	Australia	Waste/ Recycling	2
Kidde Australia (Carrier) 10 Ferntree Place, Notting Hill VIC 3168	Kriaris Transport Parkhurst, Queensland	Australia	Recycling	1

FlameRanger
Customers & End Users
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Purchaser Name & Address	End User Name & Address	Country	Application	QTY
KC Glass & Materials Co., Ltd. South Korea	Ssangyong C&E	South Korea	SRF (Solid Recovered Fuel)	3
FIRESAFE AS Skreppestadsveien 50 3261 LARVIK Norway	[CONFIDENTIAL]	Norway	Waste/ Recycling	2
Wormald Australia Pty Ltd Contracts WA 138 Pilbara Street Welshpool WA 6106 Australia	[CONFIDENTIAL]	Australia	Waste/ Recycling	2
Fire Shield Systems Limited Stump Cross House, London Road Quarrington, Sleaford, NG34 8NX United Kingdom	[CONFIDENTIAL]	United Kingdom	Waste/ Recycling	1
Al-Futtaim Logistics Company LLC P.O. Box: 61450 Dubai – UAE	[CONFIDENTIAL]	United Arab Emirates	Waste/ Recycling	2
Merlin Fire Protection Ltd First Floor, Block One Quayside Business Park Dundalk, Co. Louth A91 DP8R Republic of Ireland	[CONFIDENTIAL]	Ireland	Waste/ Recycling	1
KC Glass & Materials Co., Ltd. South Korea	[CONFIDENTIAL]	South Korea	SRF (Solid Recovered Fuel)	3
Kidde Australia Carrier Kidde Fire Products Australia & NZ 10 Ferntree Place, Notting Hill VIC 3168	[CONFIDENTIAL]	Australia	Waste/ Recycling	1

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FlameRanger
Customers & End Users

(Continued)

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
KC Glass & Materials Co., Ltd. South Korea	[CONFIDENTIAL]	South Korea	Confidential	19
Johnson Controls Tyco Fire & Security UAE LLC PO Box 3333 Bin Brook Bldg Hamdan St Abu Dhabi	Dubai Waste to Energy Project-BESIX, Dubai Municipality	United Arab Emirates	Waste to Energy	8
[CONFIDENTIAL]	[CONFIDENTIAL]	Canada	Confidential	3
[CONFIDENTIAL]	[CONFIDENTIAL]	Canada	Confidential	4
KC Glass & Materials Co., Ltd., South Korea	[CONFIDENTIAL]	South Korea	Confidential	1
Kidde Australia 10 Ferntree Place, Notting Hill VIC 3168	[CONFIDENTIAL]	Australia	Mining Dewatering Facility	3
Fire Shield Systems Limited Stump Cross House, London Road Quarrington, Sleaford, NG34 8NX United Kingdom	[CONFIDENTIAL]	United Kingdom	Waste/Recycling	10
Fire Shield Systems Limited United Kingdom	[CONFIDENTIAL]	United Kingdom	Waste/Recycling	7
I-CAT Percy Van Cyl, South Africa	[CONFIDENTIAL]	South Africa	Mining processing plant	8
[CONFIDENTIAL]	[CONFIDENTIAL]	United States	Waste/Recyling	3
KC Glass & Materials Co., Ltd. South Korea	[CONFIDENTIAL]	South Korea	Cement factory	1
Fire Shield Systems Limited United Kingdom	[CONFIDENTIAL]	United Kingdom	Waste/Recycling	2
BST AB Lerkrogsvägen 21 126 79 Hägersten Sweden	[CONFIDENTIAL]	Sweden	Waste/Recycling	2
Kidde Fire Products Australia 10 Ferntree Place, Notting Hill VIC 3168	[CONFIDENTIAL]	Australia	Outdoor protection of buildings and surrounding areas where gas is stored	4

FlameRanger
Customers & End Users
(Continued)

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
Fire & Gas Detection Technologies Ltd. D.N. Hof Ashkelon Bror Hayil 7915200 Israel	[CONFIDENTIAL]	Israel	Confidential	1
Merlin Fire Protection Ltd First Floor, Block One Quayside Business Park Dundalk, Co. Louth A91 DP8R, Rep. of Ireland	[CONFIDENTIAL]	Ireland	Waste to Energy	2
Concept One Source Solution LTD 21 Bullbridge Hill Ambergate Belper Derbyshire DE56 2EW United Kingdom	[CONFIDENTIAL]	United Kingdom	Recycling Facility	1
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Confidential	1
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Aircraft Hangar	1
FIRESAFE AS Skreppestadsveien 50 3261 LARVIK Norway	Stena Recycling	Norway	Waste/ Recycling	5
Jobson Italia SRL Via delle Pianazze, 150 A 19136 La Spezia Italy	[CONFIDENTIAL]	Italy	Ro-Pax Ship Weather Deck Fire Protection	4
Baja Ferries Ignacio Allende, Marcelo Rubio 1024 Zona Central 23000 La Paz, B.C.S. Mexico	[CONFIDENTIAL]	Mexico	Ro-Pax Ship Weather Deck Fire Protection	2

FlameRanger
Customers & End Users
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Purchaser Name & Address	End User Name & Address	Country	Application	QTY
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Coal Mine	3
Re-Gen Waste Management United Kingdom	Re-Gen Waste Management	United Kingdom	Waste / Recycling	2
ILUVIA bv Nederweg 12 8870 Izegem Belgium	[CONFIDENTIAL]	Belgium	Waste/ Recycling	1
Delta Fire 2 Burtt Way Broadland Business Park Norwich Norfolk NR7 0FE UK	[CONFIDENTIAL]	United Kingdom	Waste/ Recycling	3
FIRESAFE AS Skreppestadsveien 50 3261 LARVIK Norway	Stena Recycling	Norway	Waste/ Recycling	3
Groupe Comet Rivage de Boubier 25 B- 6200 Châtelet Belgium	[CONFIDENTIAL]	Belgium	Metal Recycling	1
Tokyo Bosai Setsubi Co., Ltd. Ochiai Takayama bldg.4F 2-28-7 Kamiochiai, Shinjuku-ku, Tokyo, 161-0034 JAPAN	[CONFIDENTIAL]	Japan	Waste to Energy	2
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	[CONFIDENTIAL]	1

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Customers & End Users
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Purchaser Name & Address	End User Name & Address	Country	Application	QTY
BST AB Lerkrogsvägen 21 126 79. Hägersten	[CONFIDENTIAL]	Sweden	Military Fire Protection	16
FIKE Safety Technology Ltd. 31 Springvale Industrial Estate Cwmbran NP44 5BD United Kingdom	[CONFIDENTIAL]	United Kingdom	[CONFIDENTIAL]	1
Jobson Italia SRL Via delle Pianazze, 150 A 19136 La Spezia Italy	Grimaldi	Italy	Ro-Ro Passenger Ship Weather Deck Protection	4
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	USA	Waste & Recycling	2
BST AB Lerkrogsvägen 21 126 79. Hägersten	[CONFIDENTIAL]	Norway	Waste & Recycling	1
Kidde Australia 10 Ferntree Place, Notting Hill VIC 3168	[CONFIDENTIAL]	Australia	Mining Dewatering Facility	1
KC Glass & Materials South Korea	[CONFIDENTIAL]	South Korea	Waste & Recycling	1
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	USA	Waste & Recycling	2
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	Brazil	Waste & Recycling	2
Enrich Environmental Limited Larch Hill, Kilcock Co. Meath, W23 W9DN Republic of Ireland	Enrich Environmental Limited	Ireland	Bio Mass Recycling	2

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Customers & End Users
(Continued)

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
BST AB Lerkrogsvägen 21 126 79. Hägersten	[CONFIDENTIAL]	Sweden	Aircraft Hangar	2
FIKE Safety Technology Ltd. 31 Springvale Industrial Estate Cwmbran NP44 5BD United Kingdom	[CONFIDENTIAL]	United States	Laundry Facility	1
Nobel Fire Systems Ltd 7 Quest Park Moss Hall Road Heywood Lancs, BL9 7JZ United Kingdom	[CONFIDENTIAL]	United Kingdom	Waste & Recycling	6
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	3
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	2
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	7
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	2

FlameRanger
Customers & End Users
(Continued)

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
BST AB Lerkrogsvägen 21 126 79. Hägersten	[CONFIDENTIAL]	Sweden	Aircraft Hangar	2
FIKE Safety Technology Ltd. 31 Springvale Industrial Estate Cwmbran NP44 5BD United Kingdom	[CONFIDENTIAL]	United States	Laundry Facility	1
Nobel Fire Systems Ltd 7 Quest Park Moss Hall Road Heywood Lancs, BL9 7JZ United Kingdom	[CONFIDENTIAL]	United Kingdom	Waste & Recycling	6
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	3
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	2
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	7
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	2
Kidde Fire Products Australia & NZ 10 Ferntree Place, Notting Hill VIC 3168, Australia	[CONFIDENTIAL]	Australia	Aircraft Hangar	4
Firefly Heliosgatan 3 120 30 Stockholm Sweden	[CONFIDENTIAL]	Sweden	[Confidential]]	1

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(Continued)

Purchaser Name & Address	End User Name & Address	Country	Application	QTY
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Waste & Recycling	2
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	Canada	Wate & Recycling	2
Baja Ferries Ignacio Allende, Marcelo Rubio 1024 Zona Central 23000 La Paz, B.C.S. Mexico	Baja Ferries	Mexico	Ro-Ro Weather Deck Protection	1
T&B electronic GmbH Industriestraße 3 31061 Alfeld Germany	[CONFIDENTIAL]	Czech Republic	Waste & Recycling	1
Fike Corporation 704 SW 10th Street Blue Springs, MO 64015 USA	[CONFIDENTIAL]	United States	Coal Mining	1
			TOTAL	236





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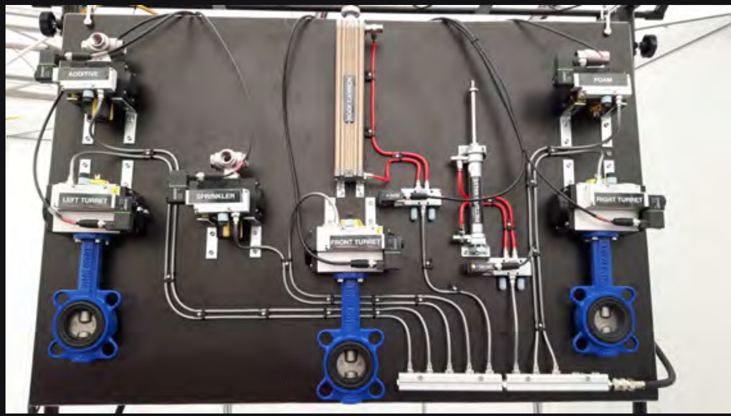


HINO
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Helidecks




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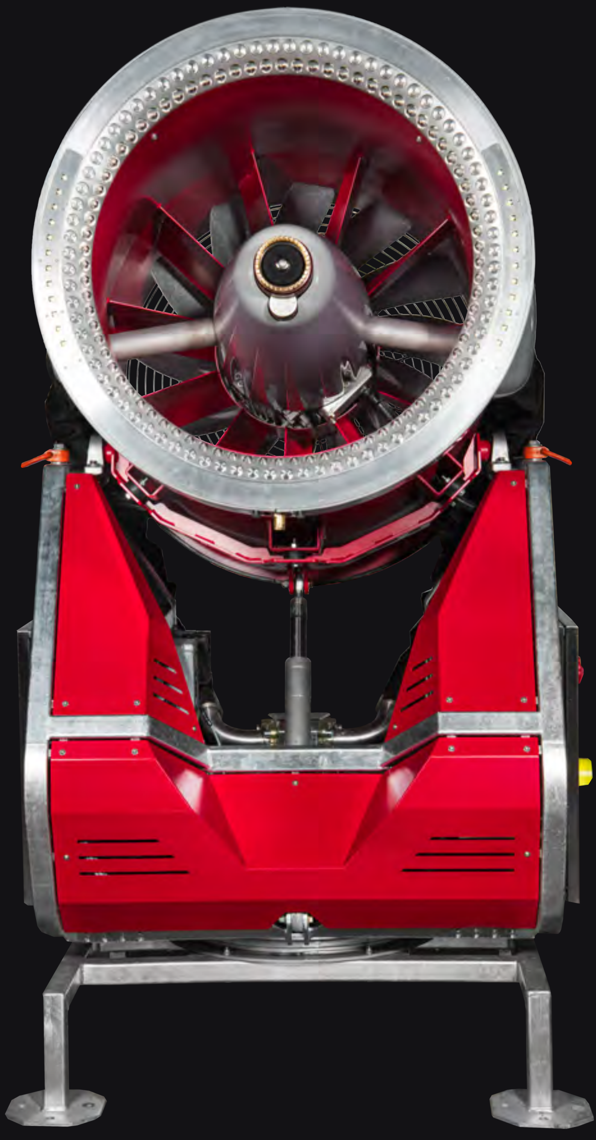
Other Installations

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