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Updated test standard for alternative fixed fire-fighting systems

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Abstract

MSC.1/Circ.1430, published in 2012, supersedes previous requirements in IMO Resolution A.123 (V) and MSC.1/Circ. 1272 and contains design and installation requirements for prescriptive-based and performance-based (i.e., 'alternative') fire protection systems for vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces. Prescriptive-based systems should be designed according to the design tables in MSC.1/Circ.1430, whilst performance-based systems should be tested in compliance with the fire test procedures in its Appendix. Concerns related to the performance-based option have been raised because the required level of fire suppression is not significantly better than that of the superseded Resolution A.123(V).

The objective of the work presented in this report was to develop revised fire test procedures that include new, more realistic fire test scenarios representing fires in a passenger car and in a freight truck trailer.

The design of the test mock-ups resembled those used in the current fire test procedures in the Appendix of MSC.1/Circ.1430, but they generate more intense fires. The proposed performance acceptance criteria of the revised fire test procedures were based on the fire suppression performance of the prescriptive-based system design of MSC.1/Circ.1430. It should, however, be noted that the performance of the prescriptive-based system varies in the conducted tests, which means that the performance acceptance criteria had to be based on a certain degree of assessment. Still, if the proposed revisions to the fire test procedures are adopted by IMO, the performance level of prescriptive-based and performance-based systems will be more harmonized than today.

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Content

1 Executive summary

1.1 Problem definition

Vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces shall be fitted with a fixed water-based fire-fighting system complying with the provisions of the Fire Safety Systems Code (FSS Code). Detailed design and installation requirements for prescriptive-based and performance-based (i.e., 'alternative') systems are given in MSC.1/Circ.1430, published in its first version in 2012. Prescriptive-based systems should be designed according to the design tables in MSC.1/Circ.1430, whilst performance-based systems should be tested to the satisfaction of the Administration in accordance with the fire test procedures in its Appendix. Note: With "the Administration" should be understood the maritime authority of the flag state of the ship.

Concerns related to the performance-based option have been raised because the required level of fire suppression is not significantly better than that of the superseded Resolution A.123(V). The primary objective of Action 10-C, denoted "Updated performance of alternative fixed fire-fighting systems", is to propose revisions to the fire test procedures that harmonize the fire suppression performance level for prescriptive-based and performance-based systems.

1.2 Method

The initial work, as documented in the report D10.4, "Large-scale validation of the new fire test standard for alternative fixed fire-fighting systems" [1] included a literature review that summarises the requirements in SOLAS Chapter II-2, the FSS Code and MSC.1/Circ.1430 (as revised) along with a description of the development work, research, and previous IMO circulars that resulted in the requirements in MSC.1/Circ.1430. This report also includes a short review of fire investigation reports to identify which types of vehicles are involved in fires, how the fires start, the performance of the fixed fire protection system and the consequences in terms of fire damage. A literature review documented the characteristics of fires in electric vehicles (EV) as compared to conventional combustion engine vehicles (ICEV).

As also documented in D10.4, revised fire test scenario mock-ups were developed, partly based on input from free-burn fire tests as well as a series of large-scale fire suppression benchmark tests. These tests were conducted with prescriptive-based systems designed per MSC.1/Circ.1430/Rev.2 to establish a basis for new performance acceptance criteria for testing of performance-based systems. Fire tests involving actual vehicles were also conducted; they indicated that a fire in a battery electric vehicle is no more challenging than a fire in an in a gasoline-fueled vehicle for a system design in accordance with the prescriptive-based requirements in MSC.1/Circ.1430.

The focus of this report is the development of the revised fire test procedures. This work is documented in the main part of the report and the suggested, revised fire test procedures are found in Annex A.

1.3 Results and achievements

The intent is that the new fire test scenarios representing fires in a passenger car and a freight truck trailer should reflect fires in modern vehicles. The design of the mock-ups resembles those used in the current fire test procedures in the Appendix of MSC.1/Circ.1430 but generates more intense fires. The passenger car fire test scenario was revised to include heptane pool fire trays underneath the mock-up, arranged to spread the fire to the other (solid) combustible fuel loading. As these fire trays are completely shielded from the overhead sprinklers or nozzles being tested, the flames from underneath the vehicle mock-up simulates a fire in a fuel spill or in a battery pack. The rearrangement of the fire load (idle wood pallets) in the cargo space of the freight truck trailer scenario makes the fire more intense but uses a similar number of pallets compared to the current fire test procedures.

In the earlier truck fire test scenario, the fire load was arranged closer to the ceiling, at the top level of a freight truck, with the intent of maximizing the heat at the ceiling level and consequently the number of automatic nozzles activating. The number of activated nozzles was applied in defining the system specific design area. In the revised fire test procedures, the design area is not defined in the tests but is fixed and is the same for all systems, and the proposed fire load is positioned on a platform that is positioned on height similar to that of a freight truck trailer bed for evaluating the suppression performance only.

The benchmark fire suppression tests and the tests using actual (ICEV and BEV) vehicles indicate that the performance of the prescriptive-based system design is adequate. However, performance of the prescriptive-based system varies greatly given the specific system parameters, which meant that the performance acceptance criteria had to be based on a certain degree of assessment.

1.4 Contribution to LASH FIRE objectives

The overall objective of WP10 is to propose 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-C, denoted "Updated performance of alternative fixed fire-fighting systems", is to establish a harmonized fire suppression performance level for alternative fixed water-based fire-fighting systems for ro-ro spaces and special category spaces. The following tasks are included, as given in the Description of Work, with the role of partners:

Task T10.1: WP10 management (RISE).

Task T10.9: Literature study (RISE), with focus on regulations, research, fire hazards and previous test methods for alternative fixed water-based fire-fighting systems for ro-ro spaces and special category spaces.

Task T10.10: Development of relevant fire test procedures for alternative fixed water-based fire-fighting systems intended for ro-ro spaces and special category spaces. RISE, with the support of MAR, will develop a more realistic and relevant fire test standard (to replace the procedure described in MSC.1/Circ.1430) that has a safety level similar to that provided by current prescriptive-based system requirements.

Task T10.11: Validation of fire test standard by large-scale tests (RISE) performed with fixed water-based fire-fighting system. Performance assessment delivery to WP04 and consolidation of D10.4 (RISE).

This report covers Task T10.10. Tasks T10.9 and T10.11 were documented in report D10.4, "Large-scale validation of the new fire test standard for alternative fixed fire-fighting systems".

Exploitation and implementation

This report and report D10.4 summarize the work in Action 10-C. The outcome can be used to revise the current fire test procedures in the Appendix of MSC.1/Circ.1430.

2 List of symbols and abbreviations

BEV	Battery electric vehicle
CINEA	The European Climate, Infrastructure and Environment Executive Agency
EUR	Marking on load pallets as specified by the European Pallet Association
EV	Electric vehicle
FSS	International Code for Fire Safety Systems, also known the Fire Safety Systems Code
ICEV	Internal combustion engine vehicle
IMO	International Maritime Organization
ISO	International Organization for Standardization
MAR	Marioff Corporation Oy (partner of WP10)
MSC	Maritime Safety Committee
RISE	RISE Research Institutes of Sweden
SOLAS	Safety of Life at Sea
SP	SP Technical Research Institute of Sweden and SP Swedish National Testing and Research Institute (the former names of RISE)
SSE	IMO Sub-Committee on Ship Systems and Equipment
WP	Work Package

3 Introduction

Main author of the chapter: Magnus Arvidson, RISE.

Vehicle spaces and ro-ro spaces not capable of being sealed and special category spaces shall be fitted with a fixed water-based fire-fighting system complying with the provisions of the Fire Safety Systems Code (FSS Code). Detailed design and installation guidelines for such systems are given in (MSC.1/Circ.1430). These guidelines were published in 2012 and are intended to replace both the prescriptive requirements of Resolution A.123(V) (from 1967) for conventional water spray systems (often denoted 'drencher systems') and the performance-based requirements of MSC.1/Circ.1272 (from 2008) for automatic sprinkler and deluge systems.

Two system options can be used according to MSC.1/Circ.1430:

- **Prescriptive-based systems**: These systems are designed and installed per sections 1, 2 and 3 in MSC.1/Circ.1430. In addition, prescriptive-based systems should comply with section 4 and be designed per the design tables 4-1 to 4-3 of MSC.1/Circ.1430.
- **Performance-based (or 'alternative') systems**: These systems are designed and installed per sections 1, 2 and 3 in MSC.1/Circ.1430. In addition, performance-based systems should comply with section 5 and should be tested to the satisfaction of the Administration in accordance with the fire test procedures in the Appendix of MSC.1/Circ.1430. Notes: 1) Performance-based (or 'alternative') systems are typically water mist fire protection systems. 2) With "the Administration" should be understood the maritime authority of the flag state of the ship.

Concerns related to the performance-based option have been raised because the required level of fire suppression is not significantly better than that of the superseded Resolution A.123(V). The primary objective of Action 10-C, denoted "Updated performance of alternative fixed fire-fighting systems", is to propose revisions to the fire test procedures and harmonize the fire suppression performance level for prescriptive-based and performance-based systems.

Two fire test scenarios are described in the Appendix of MSC.1/Circ.1430, a scenario simulating a passenger car fire and a scenario simulating a cargo fire of a simulated freight truck.

The two primary inadequacies of the fire test procedures are that:

1. The fire test scenarios do not reflect the severity in terms of the fire load of modern vehicles and cargo.
2. The acceptance criteria in terms of the maximum allowed ceiling gas temperatures, fire damage and ignition of the targets were established using a water spray system designed according to Resolution A.123(V).

Therefore, the concern is that the performance-based systems that have passed the tests do not provide comparable fire suppression performance to that of the prescriptive-based system design in MSC.1/Circ.1430. Consequently, the design discharge densities for the currently certified performance-based systems are low or very low (from about half to almost one tenth) of the minimum discharge densities required for prescriptive-based systems. However, it should be noted that there is currently no field experience indicating that the performance-based system would not perform satisfactorily.

The objective of the work summarized in this report and in the report D10.4 is to develop revised fire test procedures, containing fire test scenarios that better reflect fires in modern vehicles and cargo.

The revised acceptance criteria were established based on large-scale fire suppression tests as documented in D10.4, “Large-scale validation of the new fire test standard for alternative fixed fire-fighting systems”.

4 The main revisions of the current fire test procedures in MSC.1/Circ.1430/Rev.2

Main author of the chapter: Magnus Arvidson, RISE.

4.1 General

This section summarizes the main revisions in the revised fire test procedures (refer to Annex A) as compared to the current fire test procedures in MSC.1/Circ.1430/Rev.2.

4.2 The scope of the procedures

The current fire test procedures limit the scope to ro-ro spaces and special category spaces with deck heights up to and including 2,5 m and 5 m, respectively. The revised fire test procedures would expand the ceiling height limitations to include ceiling heights of 2,5 m and 6,5 m, allowing optional testing in spaces exceeding 6,5 m. It is noted that a prescriptive-based system may be designed and installed in spaces up to 10,0 m in height per Table 4-3 of MSC.1/Circ.1430/Rev.2.

Part 4 of the current fire test procedures describes how to determine the area of operation for wet-, dry- and pre-action systems, which is reflected in the scope. For the revised fire test procedures, this part has been eliminated and the intent is that the areas of operation prescribed in the main part of MSC.1/Circ.1430/Rev.2 for prescriptive-based system should also be applied for performance-based systems.

4.3 The fire test hall and the environmental conditions

Minor changes were made. The description of the fire test hall, the ceiling and the ventilation conditions remain unchanged, but the ambient air temperature of test area was changed from "between 10 and 25 °C" to 20 °C ±10 °C. This will facilitate testing in countries with high air temperature in summer.

4.4 Measurement equipment

The part describing the instrumentation and measurements has been partly expanded in the revised fire test procedures, as additional measurements, e.g., temperatures of simulated spot-type heat detectors and surface temperatures of the target steel sheet screens are made.

Furthermore, the revised fire test procedures contain a description of how to determine the moisture content of wood pallets.

Ceiling gas temperatures in the revised fire test procedure are measured 75 mm below the ceiling as in the current fire test procedures. However, the thermocouple position and thickness (1 mm instead of 0,5 mm) are different. The thermocouples are not protected against direct water impingement, as the tested nozzles are required to be installed at a vertical distance from the ceiling that is lower than the position of the thermocouples.

The system water pressure and water flow rates are measured in a similar fashion.

4.5 System operational conditions

The current fire test procedures state that the tests should simulate the conditions of an actual installed system regarding factors such as time delays between the activation of the system and minimum system water pressure or water delivery. In addition, the use of a pre-primed fire suppression enhancing additive, if applicable, should be considered. The current fire test procedures also require that the fire test scenario should be allowed to burn freely for a period of at least

2,5 minutes. If automatic sprinklers activate during the 2,five-minute pre-burn period, feeding water to the system should be delayed until after the 2,5 minutes.

This part has been re-written in the revised fire test procedures in a section denoted “System preparation and system control procedures”. Instead of the more generic description in the current fire test procedures, detailed guidance is given on how to test 1) wet-pipe systems, 2) dry- and pre-action systems and 3) deluge systems in terms of activation principles and water delivery delay times.

4.6 The fire test scenarios

4.6.1 General

This part and Section 4.8, covering the fire suppression performance acceptance criteria, is where the largest changes are proposed.

4.6.2 The EUR standard wood pallets

The stacks of EUR standard wood pallets (per ISO 6780:2003) remains the primary fire source for both fire test scenarios. However, the desired moisture content and moisture measurement procedure were changed. This is discussed in Section 5 of this report.

The current fire test procedures specify that plywood panels made of pine or spruce with a thickness of 12 mm and certain ignition and flame spread properties are to be used as ‘targets’ to determine fire spread to fictive trailers to the sides. For the revised fire test procedures, these panels are instead to be made from nominally 1 mm thick steel sheets and instrumented with spot-welded thermocouples. One of the performance acceptance criteria is based on the mean surface temperature of these steel sheet screens.

For ignition of the wood pallets, commercial heptane in fire trays is used in both the current and revised test procedures. However, for the revised test procedures, the fire tray(s) are larger and positioned underneath the passenger car mock-up.

4.6.3 The passenger car fire test scenario

The primary fuel package of the passenger car mock-up in the current fire test procedures consists of a total of 12 EUR wood pallets arranged in an array of 1 pallet (wide) by 6 pallets (high) by 2 pallets (long) stacked inside a shield made from steel sheets, simulating the body of a car. The 2 m (long) by 1,2 m (wide) roof of the simulated car body shields the stacks of wood pallets from direct application of water from overhead nozzles. The fire should be ignited by a square 100 mm by 100 mm heptane fire tray centrally located under the wood pallets.

For the revised fire test scenario, the passenger car fire test scenario should involve 30 EUR wood pallets in an array that is 2 pallets (wide) by 5 pallets (high) by 3 pallets (long). The array of wooden pallets should be positioned on a rectangular platform sized 2,0 m (wide) by 4,0 m (long), made from nominally 5 mm thick steel sheets supported by a steel frame made from nominally 100 mm by 100 mm square iron. The vertical distance between the top of the platform and the floor should be 0,35 m. Vertical supports should be arranged at each corner of the platform and at the mid-point of the long sides.

Half of the array should be shielded from direct application of water from overhead nozzles by a horizontal steel sheet plate. The other half should be fully exposed to the water spray.

The passenger car fire test scenario should also involve a flammable liquid fuel spill (heptane is used to simulate gasoline) underneath the mock-up. The intent is to simulate a fire in a fuel spill or a traction battery fire that spreads to the other combustible parts of a car, such as the tires and the passenger compartment. The fire in a fuel spill underneath a car or in a traction battery generates flames from the lower parts of the long side of a car and the fire is completely shielded from direct application of water from overhead nozzles.

Two fire trays are to be positioned on the ground underneath this platform and filled with heptane on a bed of water. Each tray is sized 600 mm by 900 mm by 100 mm (H). Each fire tray is to be filled with 7 litres of heptane on 7 litres of water, i.e., the total amount of liquid fuel is 14 litres. The intent is that flames from the fire trays will ignite the stacks of wood pallets on the platform as the platform is fitted with a small, horizontal opening.

The fire in ordinary combustibles of a passenger car is simulated by an array of wood pallets that is partly shielded from direct application of water from overhead nozzles by a roof. The amount of fuel represents a total energy of about 11 GJ per the estimations given below:

<u>Heptane pool fire trays</u>

Volume = 14 l.

Density = 0,7 kg/l.

Net calorific value = 45 MJ/kg (from Eurocode 1).

Energy content = 14 × 0,7 × 45 = 441 MJ.

<u>Array of wood pallets</u>

Number of pallets: 30 (36 pallets were used in the large-scale benchmark fire suppression tests).

Nominal weight per pallet: 20 kg.

Net calorific value = 17,5 MJ/kg (from Eurocode 1).

Energy content = 30 pallets × 20 kg × 17,5 MJ/kg = 10 500 MJ.

Assuming a burning efficiency of 0,8, the scenario would provide a total heat release of about 8,8 GJ, which is realistic for large, modern passenger cars.

The inclusion of the pool fire trays underneath the mock-up was made after the large-scale benchmark fire suppression tests. The approach was therefore tested in separate free-burn tests and proved to work sufficiently. The hole in the floor plate of the mock-up spread the fire from the pool fire trays to the stacks of wood pallets in a proper way and at a pace that seems reasonable realistic for an actual passenger car. The fire size in the wood pallets started to increase before the heptane fuel in the trays had been consumed. Figure 1 shows the fire at 04:30 [min:s] when the stacks of wood pallets started to be involved in the fire.

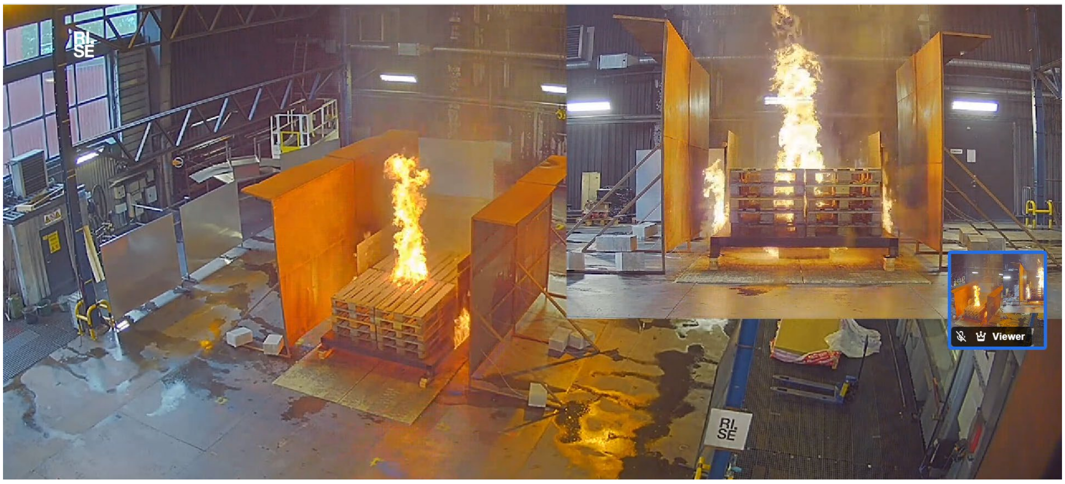


Figure 1. *The fire at 04:30 [min:s]. A larger flame is observed which indicates that the wood pallets are becoming involved in the fire, increasing the heat release rate. Note: No roof was used over the mock-up.*

The mean temperature of the steel sheet screens on each side was very similar, refer to Figure 2. The peak mean temperature was 344 °C (left) and 330 °C (right).

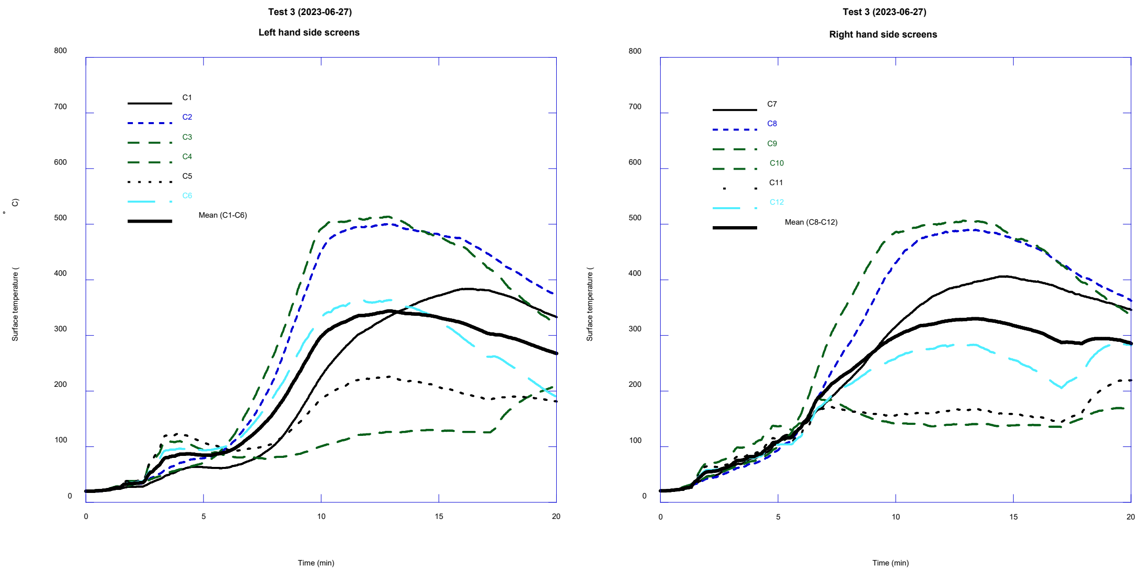


Figure 2. *The surface temperature of the steel sheet screens.*

The contribution from the pool fire trays can be observed in the surface temperature graphs. The heptane fuel in the fire trays burnt out at about 06:30 [min:s]. Visually it was observed that the fire in the wood pallets started to be involved in the fire at about 04:30 [min:s] and the influence on the surface temperature of the steel sheet screens can be observed a few minutes later.

4.6.4 The freight truck trailer fire test scenario

The primary fuel package of the freight truck trailer mock-up in the current fire test procedures consists of 112 standard EUR wood pallets arranged in an array of 2 pallets (wide) by 7 pallets (high) by 8 pallets (long). The array is raised to a level of 2,8 m using a rack so that the top level of the array is at a vertical distance of 3,8 m to 3,9 m above the floor. The wood pallet array should be half-shielded by a 4,5 m (long) × 2,6 m (wide) steel plate (thickness at least 2 mm) at a 4 m height to reflect the maximum conceivable height of a truck trailer and to lead to maximum conceivable number of sprinkler activations for defining the design area. The plate should be properly fixed so that it provides an obstruction to water impingement onto this part of the wood pallet array from overhead nozzles. Plywood panel 'targets', acting also as obstructions, of dimensions 3,6 m (wide) by 2,4 m (high) should be arranged symmetrically on both long sides of the mock-up at a horizontal distance of 1 m. The top edge of the target panels should be at the same level as the top level of the wood pallet array.

For the revised fire test scenario, the top of the platform is 1,3 m above ground, similar to an actual trailer. The freight truck trailer fire test scenario should involve 96 EUR wood pallets in an array that is 2 pallets (wide) by 12 pallets (high) by 4 pallets (long). With a nominal height of 1,7 m (12 pallets times 144 mm per pallet), the stability of the wood pallet array may be an issue. It is therefore required that the long sides of each stack and the outer short side should be supported by vertical 45 mm by 90 mm wood studs, going from the bottom to the top of the stack. The wood studs should be attached by nominally 6.0 mm × 120 mm wood screws. Four screws should be attached at the bottom, top and mid-height of the stack, respectively.

The amount of fuel used in the tests represents a total energy of almost 34 GJ per the estimation given below:

<u>Array of wood pallets</u>

Number of pallets: 96 (112 pallets were used in the large-scale benchmark fire suppression tests).

Nominal weight per pallet: 20 kg.

Net calorific value = 17,5 MJ/kg (from Eurocode 1).

Energy content = 96 pallets × 20 kg × 17,5 MJ/kg = 33 600 MJ.

As in the current fire test procedures, half of the array should be shielded from direct application of water from overhead nozzles by a horizontal steel sheet plate. The other half is fully exposed to the water spray. Even though the total number of wood pallets is less, their arrangement will provide a more intense fire. The fire should be initiated using a fire tray sized 600 mm (L) by 150 mm (W) by 150 mm (H) filled with 20 mm (1,8 litres) of heptane on a 50 mm water bead (4.5 litres) that is ignited by a torch. The fire tray should be symmetrically positioned between the centremost stacks of wood pallets, i.e., at the border line between the exposed and shielded part of the array. The size of the fire tray is smaller as compared to the one used in the large-scale benchmark fire suppression tests to provide a slightly slower initial fire growth rate.

4.7 The fire test programme and the positioning of sprinklers or nozzles

According to the current fire tests procedures, sprinklers or nozzles should be installed in an array at the ceiling level in accordance with the manufacturer's design and installation criteria. Tests should be repeated with three different relative locations between the nozzle array and the fire ignition position:

- Centre of ignition under one nozzle.
- Centre of ignition between two nozzles.
- Centre of ignition between four nozzles.

Testing at two different ceiling heights, 2,5 m and 5,0 m, resulted in a fire test program totaling six tests.

For the revised fire test procedures, tests are suggested to be conducted with the point of fire ignition directly under one sprinkler or nozzle and between four sprinklers or nozzles at a ceiling height of 2,5 m and 6,5 m, respectively. This results in a fire test program totaling four tests, with two optional fire tests at a ceiling height exceeding 6,5 m at the discretion of the manufacturer, refer to Table 1.

Table 1. The fire test program of the revised fire test procedures.

Ceiling height	Fire test scenario	Point of fire ignition
2,5 m	Simulated passenger car fire	Directly under one sprinkler or nozzle
	Simulated passenger car fire	Between four sprinklers or nozzles
6,5 m	Simulated freight truck trailer fire	Directly under one sprinkler or nozzle
	Simulated freight truck trailer fire	Between four sprinklers or nozzles
Exceeding 6,5 m, at the discretion of the manufacturer	Simulated freight truck trailer fire	Directly under one sprinkler or nozzle
	Simulated freight truck trailer fire	Between four sprinklers or nozzles

By specifying that the ceiling-to-nozzle distance should be 150 mm, the test conditions will be similar for any system and the benchmark fire suppression tests. This vertical distance will influence the activation time of automatic sprinklers and the cooling of hot combustion gases at the ceiling.

4.8 Acceptance criteria

Major changes are proposed as compared to the current fire test procedures in this section.

First of all, it should be recognized that the extent of fire damage to the idle wood pallets is not part of the acceptance criteria in the revised fire test procedures. In addition, the requirement that the plywood panels on each long side should not be ignited has been replaced with surface temperature measurements of the steel sheet screens.

The vertical distance from the underside of the ceiling to the deflector or the tip of a nozzle should be nominally 150 mm, irrespective if upright or pendent nozzles are used in the tests. The reason is that this vertical distance was used in the benchmark fire suppression tests and the distance influences the ceiling gas temperature in a test.

A total of five thermocouples should be installed at the ceiling. One thermocouple should be positioned directly above the point of fire ignition and four additional thermocouples should be positioned at an orthogonal angle, at a 1,5 m radius from the centremost thermocouple. The thermocouples should be installed 75 mm below the ceiling. The mean gas temperature of the five ceiling gas measurements should be calculated. Thereafter, this reading should be ‘smoothed’ by using a five-minute (300 s) filter. The peak of the five-minute ceiling gas temperature is one part of the acceptance criteria.

The mean surface temperature of all measurement points on the steel sheet screens on both of the sides of the mock-up should also be calculated and the data smoothed in the same fashion. The peak of the five-minute surface temperature forms the other part of the acceptance criteria.

The performance of the two prescriptive-based systems (a deluge water spray and a dry-pipe system) was established in large-scale benchmark fire suppression tests and is documented in detail in D10.4. Regarding the fire test scenarios, the measurements, and the proposed performance acceptance criteria, it was concluded that:

- The fire growth rate seems very repeatable.

- For some of the fire tests, the fire was very severe, which calls for a reduction of the fire load by reducing the idle wood pallet stack heights. This reduction is discussed previously in the report.
- The use of five (5) ceiling gas thermocouples oriented and positioned as suggested captures system performance well.
- The surface temperature on target steel sheet screens worked well and the measurements captures system performance.
- The performance varied significantly with the position of the fire ignition location relative to the sprinklers or nozzles at the ceiling and the performance acceptance criteria need to reflect this.

Figures 3 and 4 shows the ceiling gas temperatures at the two different ceiling heights, 2,5 m and 5,0 m, that was used in the benchmark fire suppression tests. The graphs show the mean temperature of the five (C1-C5) thermocouples at the ceiling and the five-minute average ('smoothed') temperature value of this reading.

It is observed that the peak of the mean ceiling gas temperatures varied significantly during the eight tests, from about 350 °C to over 700 °C. The peak of the five-minute average temperature is generally considerably lower than the mean ceiling gas temperature for the cases the fire was 'suppressed' rather than the cases it was 'controlled'. As mentioned, it is suggested that the performance acceptance criteria are based on the calculated five-minute average temperature. By smoothing the data, short temperature peaks would be levelled out, for example peaks that occur during the delay time from system activation to water discharge or short peaks that occur when a fire flares up but is thereafter suppressed. The approach of using a running time average of gas temperatures is used in other fire test methods, such as IMO Resolution A.800(19), "Revised Guidelines for Approval of Sprinkler Systems Equivalent to that Referred to in SOLAS Regulation II-2/12" [2].

Based on the ceiling gas temperature measurements, it can be observed that the dry-pipe system generally performed better than the water spray system. However, the difference is not larger than the difference due to the fire ignition location relative to the nozzles or sprinklers at the ceiling. It was therefore concluded that the same criteria should apply, independent of the type of tested type of system (wet-, dry-, pre-action or deluge) and the ceiling height.

It was also concluded that one set of requirements should apply for a single test, but that the two tests at a specific ceiling height should also meet a set of criteria based on the overall performance of two tests.

The ceiling gas temperature criteria is given as follows in the revised fire test procedures: **"The average gas temperature of the five ceiling gas measurement points above the fire should be calculated, and thereafter a five-minute average gas temperature based on this reading.**

The peak of the five-minute average gas temperature, as determined during the period from two minutes after the start of water application until the termination of water application, should not exceed 600 °C in any of the tests.

The mean gas temperature calculated based on the peak of the five-minute average gas temperature determined from each of the two tests (fire ignition directly under one nozzle and fire ignition below four nozzles, respectively), should not exceed 450 °C. ***Example: If the peak of the five-minute average gas temperature in the first test is 600 °C, the peak of the five-minute average gas temperature in the second test is not allowed to be more than 300 °C."***

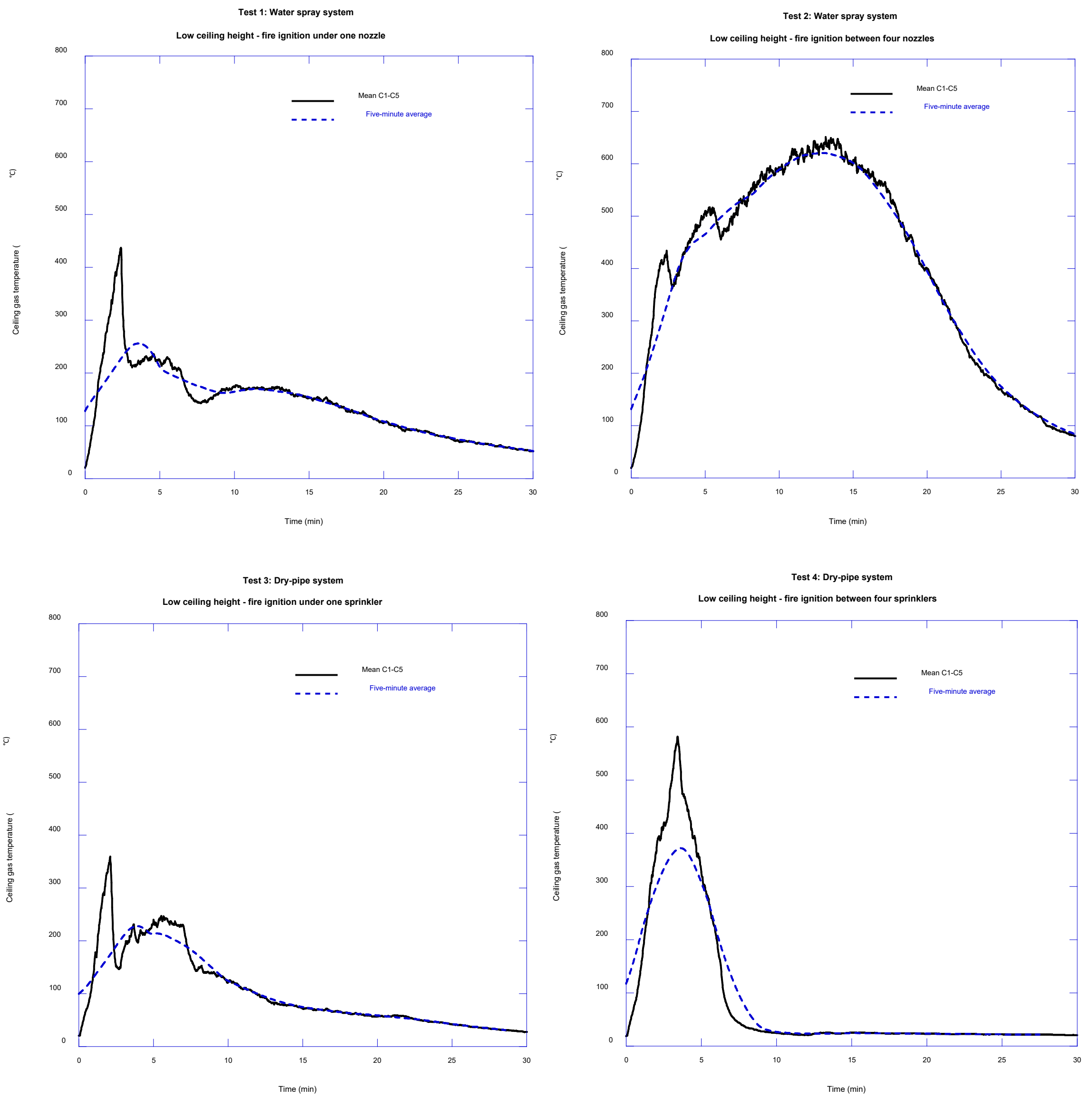
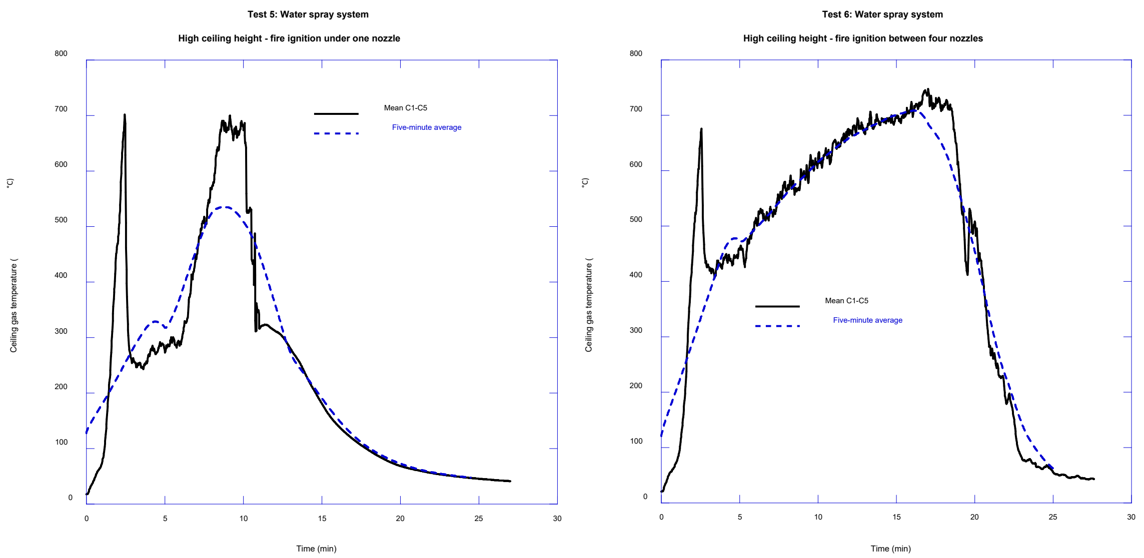


Figure 3. *The mean ceiling gas temperatures of the five thermocouples (C1-C5) and the five-minute average of this reading for the benchmark tests at the low ceiling height.*



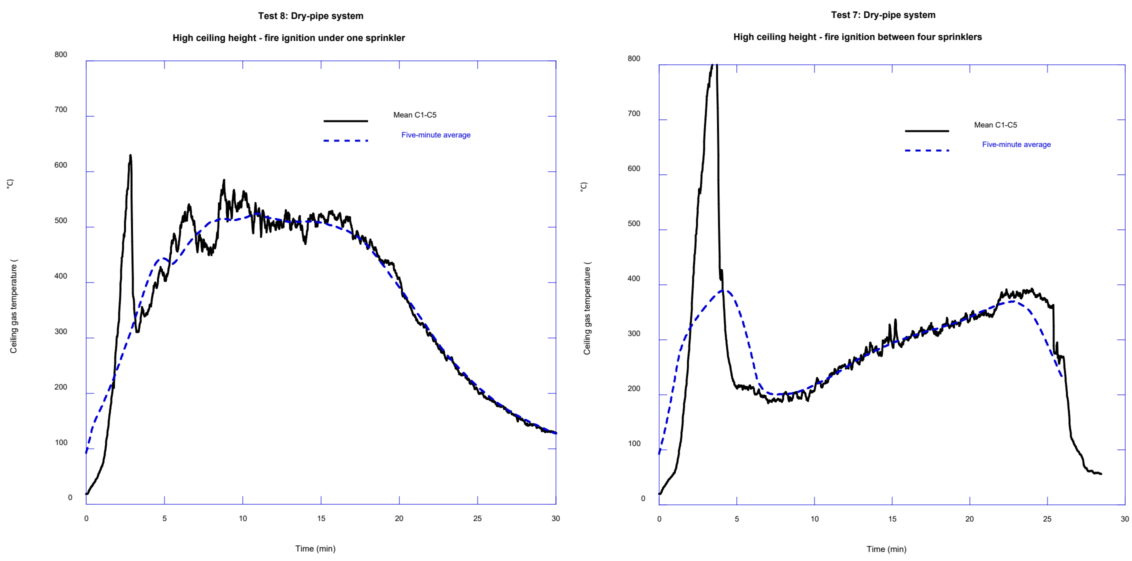


Figure 4. The mean ceiling gas temperatures of the five thermocouples (C1-C5) and the five-minute average of this reading for the benchmark tests at the high ceiling height.

The suggested maximum peak of the five-minute average gas temperature of 600 °C is slightly lower than the maximum experienced in the benchmark test. However, as previously discussed, the decision was made to reduce the fire load in terms of the number wood pallets in the final version of the fire test procedures as compared to the number used in the tests.

Figures 5 and 6 show the mean (of all measurement points) surface temperature of the steel sheet screens to the sides of the mock-up, at the two different ceiling heights, 2,5 m and 5,0 m that was used in the benchmark fire suppression tests. The five-minute average temperature ('smoothed') value of this reading is also shown.

It is observed that that mean surface temperature is relatively low, despite the fact that some of the tests generated severe fires with high ceiling gas temperatures over a relatively long period of time, as Tests 2 and 6.

The surface temperature criteria are given as follows in the revised fire test procedures: "**The mean surface temperature of all measurement points of the steel sheet screens on both sides should be calculated, and thereafter a five-minute average surface temperature based on this reading.**

The peak of the five-minute average surface temperature, as determined during the period from two minutes after the start of water application until the termination of water application, should not exceed 150 °C in any of the tests.

The mean surface temperature calculated based on the peak of the five-minute average surface temperature determined from each of the two tests (fire ignition directly under one nozzle and fire ignition below four nozzles, respectively), should not exceed 100 °C. ***Example: If the peak of the five-minute average surface temperature in the first test is 150 °C, the peak of the five-minute average surface temperature in the second test is not allowed to be more than 50 °C."***

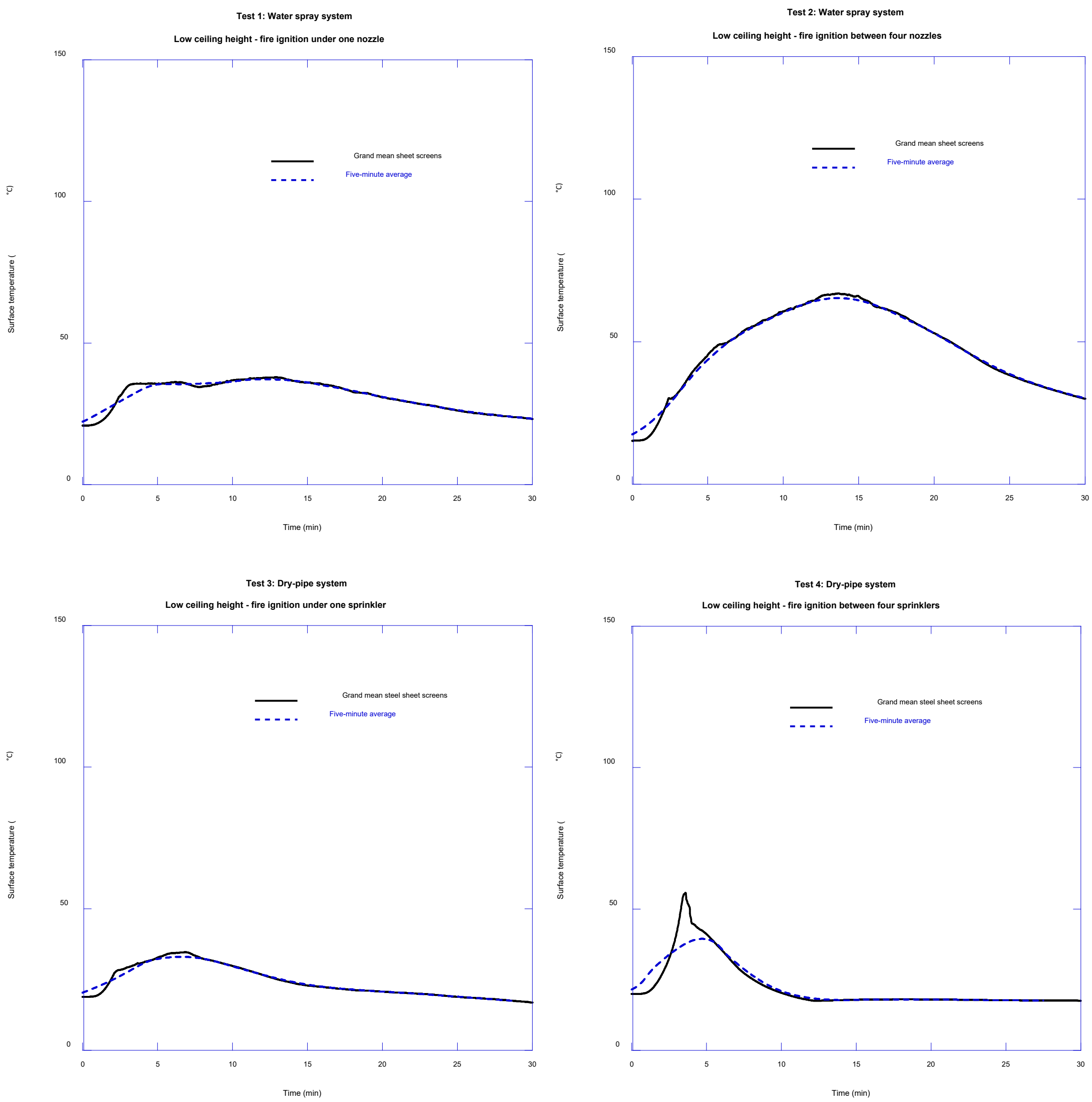


Figure 5. The mean surface temperatures of the steel sheet screens to the sides of the mock-up (all measurement points) and the five-minute average of this reading in the benchmark tests at the low ceiling height.

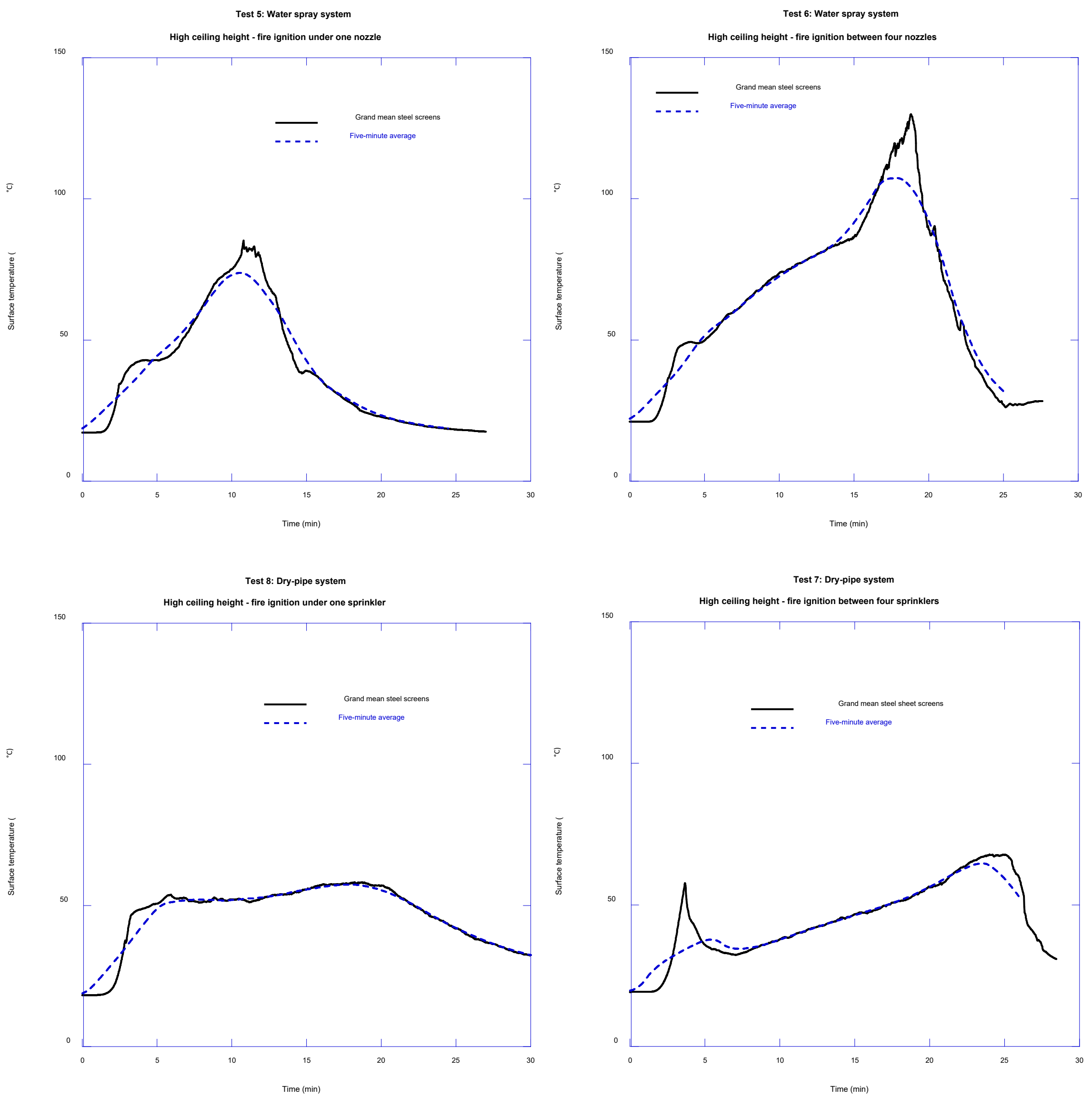


Figure 6. The mean surface temperatures of the steel sheet screens to the sides of the mock-up (all measurement points) and the five-minute average of this reading in the benchmark tests at the high ceiling height.

4.9 The test approach

The nozzles and other components to be tested should be supplied by the manufacturer together with design and installation criteria, operational instructions, drawings, and technical data sufficient for the identification of the components.

The objective of the fire test programme is to establish the maximum nozzle spacing and minimum system operating pressure of the tested nozzles. For the revised fire test procedures, it is stated that unique nozzle characteristics and installation criteria for different ceiling heights are allowed, but the same operating pressure should be used. It also states that systems successfully completing the fire test programme for a certain ceiling height are suitable for use with the same system specifications for a lower ceiling height.

As previously mentioned, the part that describes the determination of the area of operation has been eliminated with the intent that the areas of operation prescribed for prescriptive-based systems in the main part of MSC.1/Circ.1430/Rev.2 should also be applied for performance-based systems.

4.10 Other changes

4.10.1 Ceiling height definitions

For prescriptive-based systems, the applicable ceiling height is defined as the “free height”. Although this dimension is not defined, it should be understood as the height of the space that is usable for cargo. This vertical distance is measured from the deck flooring to the underside of any obstructions such as ceiling structural members, lights, ducts, piping or similar. For ships, the synonym “clear height” is often used. For performance-based systems, the ceiling height is measured from the floor to the underside of the ceiling surface, as no beams are used in the fire tests.

4.10.2 Ceiling construction

The current fire test procedure does not include any ceiling beams and this practice was kept in the revised fire test procedures. However, guidance on the positioning of automatic sprinklers or nozzles with respect to the ceiling construction is included in the revised fire test procedures.

4.10.3 Simulation of a heat detection system

Section 4.8 of MSC.1/Circ.1430/Rev.2 requires that manual deluge systems, automatic deluge systems and pre-action systems should include a fire detection system that complies with the FSS Code.

The fire detection system should consist of flame, smoke, or heat detectors of approved types. For automatic deluge and pre-action systems, the discharge of water should be controlled by the fire detection system and the coverage area of the detection system sections should correspond to the area of the deluge sections. The detection system should provide an alarm upon activation of any single detector and discharge if two or more detectors activate. Automatically released systems should also be capable of manual operation (both opening and closing) of the section valves. Means of preventing the simultaneous release of multiple sections shall be provided. The automatic release may be disconnected during on- and off-loading operations, provided that this function is automatically reconnected after a pre-set time (appropriate period for the operations in question).

It is considered that a heat detection system probably is the most suitable system for activation of an automatic fire suppression system. A heat detection system is robust, relatively inexpensive, and the risk for detection of a fire outside the coverage area is small. A smoke or flame detection system may, however, be able to detect a smoldering (smoke) or a flaming (flame) fire earlier than a heat detection system. Therefore, the focus of the revised fire test procedures is on testing the performance of manual or automatic deluge systems that are controlled by a heat detection system.

Section 2.3.1.3 of the FSS Code requires that heat detectors shall be certified to operate before the temperature exceeds 78 °C, but not until the temperature exceeds 54 °C, when the temperature is raised to those limits at a rate less than 1 °C per minute. At higher rates of temperature rise, the heat detector shall operate within temperature limits to the satisfaction of the Administration having regard to the avoidance of detector insensitivity or oversensitivity.

Detectors shall be located for optimal performance. Positions near beams and ventilation ducts or other positions where patterns of air flow could adversely affect performance and positions where impact or physical damage is likely shall be avoided. Table 2 shows the maximum spacing of detectors given in the FSS Code.

Table 2. The maximum spacing of fire detectors given in the FSS Code.

Type of detector	Maximum floor area per detector	Maximum distance between centres	Maximum distance away from bulkheads
Heat	37 m^2	9 m	4,5 m
Smoke	74 m^2	11 m	5,5 m

There are two specific installation requirements for spot-type heat detectors in MSC.1/Circ.1430/Rev.2:

- Section 4.9: Where beams project more than 100 mm below the deck, the spacing of spot-type heat detectors at right angles to the direction of the beam travel should not be more than two thirds [i.e., no more than 6,0 m] of the spacing permitted under Chapter 9 of the FSS Code.
- Section 4.10: Where beams project more than 460 mm below the deck and are more than 2,4 m on centre, detectors should be installed in each bay formed by the beams.

As it is suggested (per the discussion in the previous section of this report) that a flat, smooth non-combustible ceiling should be used, the detector spacing should be at most 9 m.

The revised fire test procedures propose that a total of four Ø=0,5 mm wire thermocouples are installed at the ceiling, orthogonally at radius of 4,5 m from the point of fire ignition. The thermocouples should be positioned 75 mm below the ceiling surface to reflect a likely position in practice. When the temperature of at least two of these four thermocouples exceeds 78 °C, the time delay associated with the water travel time is applied and the system control valve is opened. It should be noted that testing of automatically and a manually operated deluge systems should be made in a similar way.

5 The moisture content of the wood pallets

Main author of the chapter: Magnus Arvidson, RISE.

5.1 General

The moisture content of the wood pallets is a key issue as this will influence the fire growth rate in the fire test scenarios. Section 3.2.1 in the Appendix of MSC.1/Circ.1430/Rev.2 says that “The primary fire source for both scenarios consist of EUR standard wood pallets (ISO 6780:2003), stored inside with the moisture content of 14±2 %.”

The requirements do not specify the number of wood pallets included in the measurements, the measurement equipment, if the moisture content limits apply to the tested samples or to all pallets used in the test, if it refers to an individual pallet or if it refers to an arithmetic mean value.

The wood pallets used in the benchmark tests documented in report D10.4 had a mean moisture content of 9,6 % (based on all tests), which is significantly lower than these limits. The pallets had been stored indoors prior the tests, initially weather protected in an unheated storage building and thereafter inside the heated fire test hall. In other words, the handling of the pallets fulfilled the qualitative requirements but not the quantitative requirements.

Fire test procedures often recommend that the material to be tested or the combustible material that is part of a fire test scenario is conditioned for several days in a controlled environment having a specified temperature and humidity. In this case, the large number of wood pallets that are required for a series of tests make conditioning under specific environmental conditions unrealistic from a practical perspective.

5.2 Standardized measurements of the moisture content of wood

Wood is a hygroscopic building material, which means that the material can absorb and release water vapor from the surrounding air. The moisture content in wood is constantly adapting to the surrounding climate. When, after a long time, the wood's moisture content has completely adapted to the surrounding climate, it is said to have reached its equilibrium moisture ratio, which is controlled by the relative humidity and the surrounding temperature, with the relative humidity having the greatest influence in the temperature range 0 - 20 °C. As the climate varies throughout the year, the moisture content of wood will also change. Indoors, wood will dry and shrink during the winter months, then absorb moisture and swell again during the summer. In heated Swedish homes in the centre of Sweden, the moisture content in wood throughout the year is on average 7,5 % and it is the highest during summer (7 - 12 %) and the lowest during winter (2 - 6 %). On average, it is drier in the north than in the south of Sweden [3].

The concept of a target moisture ratio describes the desired average moisture ratio for a lot of wood delivered from a sawmill, refer to EN 14298:2017, Sawn timber – Assessment of drying quality [4]. The sawmills dry the wood to different target moisture ratios depending on the intended use of the wood. When delivered from the sawmill, the moisture ratio must be adapted to accommodate further processing or the environment the product will ultimately be used in. The target moisture ratios of a lot of sawn timber are defined in the standard as well as the permitted variation in moisture ratio between individual pieces of wood in a lot. A lot is defined as a “whole of sawn timber pieces of the same species, same thickness and same specification.”

To comply with a drying specification, measures of the moisture content of a control sample shall satisfy two criteria:

- Criterion 1: The moisture content of each individual piece in a lot shall be between lower and upper limits. In the case of a standard drying quality, these limits are equal to 0,7 × target moisture ratio (lower limit) and 1,3 × target moisture ratio (upper limit). 93,5 % of the pieces of the control sample shall have an individual moisture content between the lower and upper limits.

- Criterion 2: The average moisture content of the controlled pieces taken from the lot shall be within a given range relative to the target moisture content. In the case of a standard drying quality, it is appropriate to refer to Table 1 of the standard.

The number of control samples in a lot that contains between 100 and 150 individual pieces is 20 and the sample size increases with the size of the lot. Some examples of the allowed variation of the average moisture content of a lot and the allowed moisture content of individual pieces within that lot are given in Table 3.

Table 3. Examples of the allowed variation of the average moisture content of a lot and the allowed moisture content of individual pieces within that lot based on the requirements in EN 14298:2017.

Target moisture ratio of a lot (%)	Allowable range of the average moisture content of a lot around the target moisture content (%)			Allowable moisture content of each individual piece (%)	
	Allowed variation (from Table 1 of EN 14298:2017)	Lower limit (%)	Upper limit (%)	Lower limit* (%)	Upper limit** (%)
8	-1/+1	8,0	9,0	5,6	10,4
10	-1,5/+1,5	8,5	11,5	7,0	13,0
12	-1,5/+1,5	10,5	13,5	8,4	15,6
14	-2,0/+1,5	12,0	15,5	9,8	18,2
16	-2,5/+2,0	13,5	18,0	11,2	20,8

*) 0,7 × target moisture ratio.
**) 1,3 × target moisture ratio.

The method for determining the moisture content is crucial. For each of the sampled pieces the moisture content shall be estimated according to EN 13183-2 (Electrical resistance method) or, in the case of a dispute, EN 13183-1 (Oven-dry method) shall be used.

EN 13183-2, Moisture content of a piece of sawn timber – Part 2: Estimation by electrical resistance method [5], defines a non-destructive method for estimating the moisture content of a piece of sawn timber using an electrical resistance moisture meter. The standard applies to sawn timber, and timber which has been planed, or mechanically surfaced by other means. Measurements shall be made with an electrical resistance moisture meter equipped with insulated electrodes, graduated up to 30 % in units of maximum 1 % moisture content. The meter shall be equipped with settings or tables to correct for wood species and temperature. The standard also specifies where and how the measurements shall be undertaken. Because of the strong effects of surface moisture content and possible variations of moisture content in the cross section, insulated electrodes with undamaged insulation should be used.

In conclusion, it is judged that long-term indoor storage of wood pallets would result in a moisture content that is less than the currently required 14±2 %, especially when stored in the winter. It is suggested that the requirements related to the moisture content limits of the wood pallets and how the moisture content is determined are evaluated, where reference is given to the standards for sawn timber discussed above.

5.3 Measurements on two individual pallets

To test the suggested measurement methodology and the influence of the pre-storage and storage conditions on the moisture content, an experiment was conducted.

Two pallets were used in the experiment: one that had been stored inside an unheated storage building at RISE in Borås, Sweden and one that had been stored outdoors and exposed to rain. The pallets were denoted ‘dry’ and ‘wet’.

Both pallets were brought indoors beginning of April 2023 and stored inside one of the fire test halls, i.e., in a heated space. Moisture content measurements were thereafter undertaken by two operators once a week. The measurement points were on each of the five top deck boards, i.e., at five different measurement areas. The areas were selected to fulfil the requirements in EN 13183-2 and two readings were taken on each occasion. One reading was taken at a depth of 7 mm, which is in line with the requirements in the standard that the electrodes should penetrate to a depth of approximately 0.3 times the thickness of the board. The other reading was taken at a penetration depth of 2 mm. Figures 7 and 8, respectively, show the results for the dry and wet pallets. The minimum range of the electrical resistance moisture meter used in the experiment was 8 %, as indicated in the graphs. This limitation seems to have had a minor influence on the calculated mean value as both operators reported this value relatively consistently.

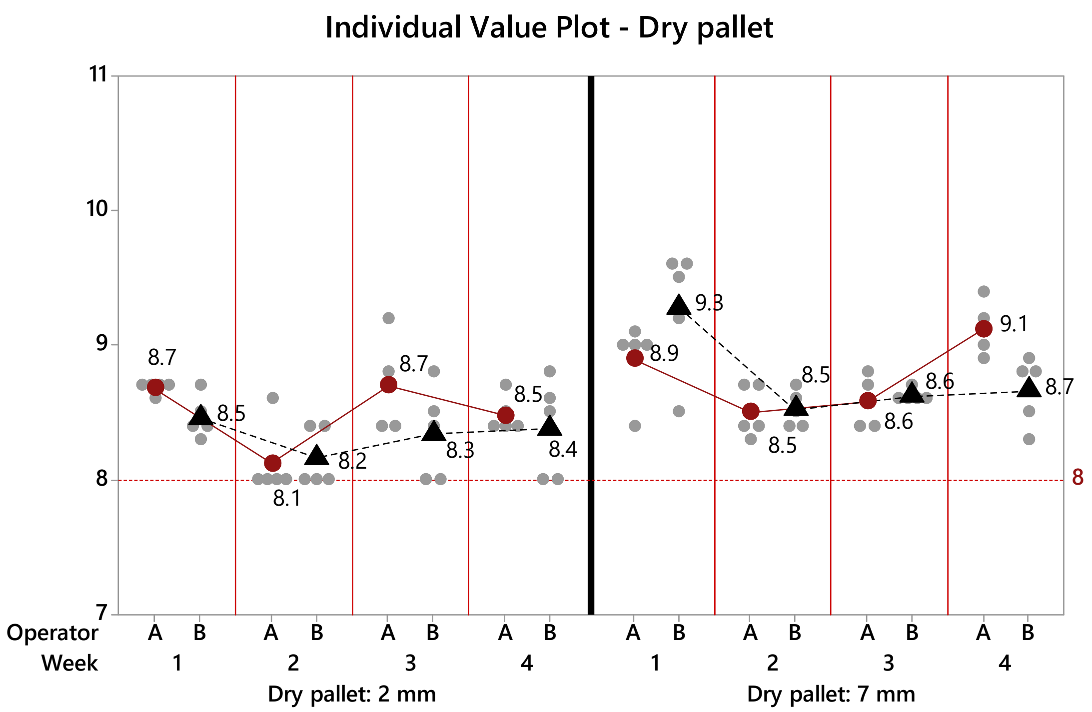


Figure 7. An individual value plot of the measured moisture content of the 'dry' pallet as determined by two operators (A and B) over a four-week period.

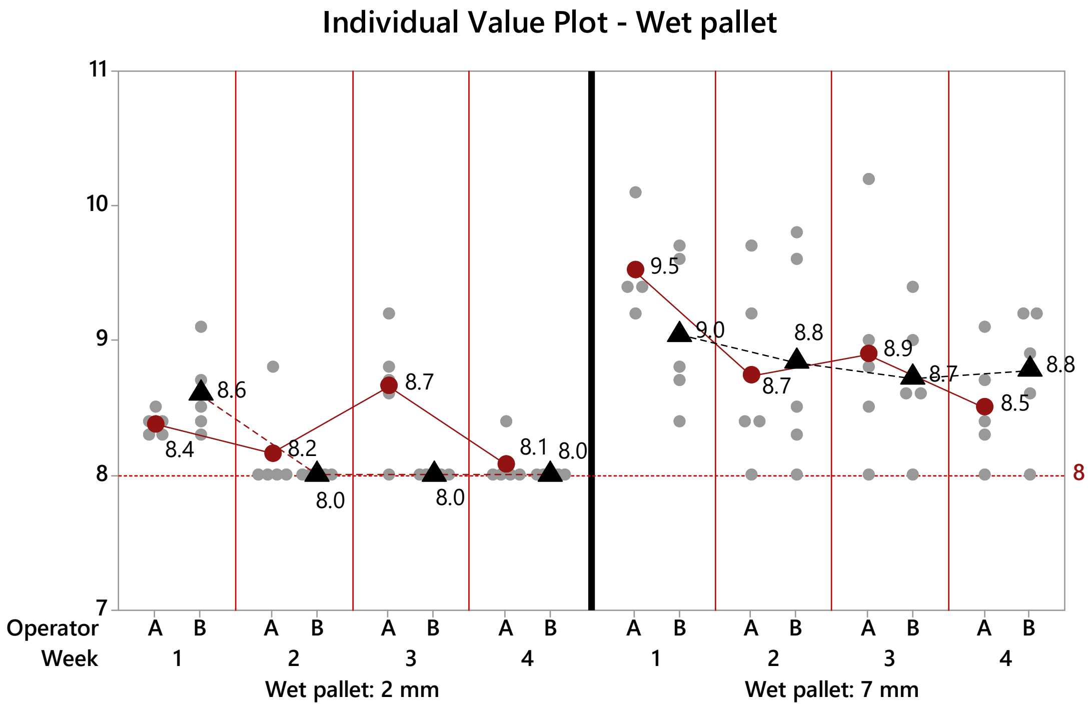


Figure 8. An individual value plot of the measured moisture content of the 'wet' pallet as determined by two operators (A and B) over a four-week period.

The initial mean moisture content of the 'dry' as compared with the 'wet' pallet was fairly similar, i.e., 8,6 % vs. 8,5 % at the 2 mm penetration depth and 9,1 % vs. 9,3 % at the 7 mm penetration depth. The fact that the 'wet' pallet had been exposed to outdoor conditions, including rain, seems to have had no influence on the moisture content at the two penetration depths. It may be that only the outer surface was wetted by the rain.

It is also noted that the initial mean moisture content was higher at the penetration depth of 7 mm. During the four-week measurement period, this was generally the case, with some exceptions.

For both the 'dry' and the 'wet' pallet, the reduction of the moisture content was the largest during the first week. Thereafter, the rate of decline was reduced, and the moisture content stabilized or even slightly increased.

The mean value determined for the individual operators did not significantly vary. The difference did not exceed 10 % of the measurement values. It can also be observed that the difference between the operators was not systematic, sometimes the mean value for operator A was higher than that of operator B, for other cases it was lower.

Another observation is that the moisture content of the five boards varied relatively much for some measurements and less for others. The largest variations appear for the 'wet' pallet at the 7 mm penetration depth.

5.4 The suggested new approach

The moisture measurement procedures for the suggested new approach are based on the requirements in EN 13183-2, but modified to measurements on wood pallets, and the assessment is based on EN 14298:2017.

It is suggested that the desired moisture content should be 10 %. For an individual pallet, moisture content in the control sample should be between 0,7 × the desired moisture content (lower limit) and 1,3 × the desired moisture content (upper limit). At least 93,5 % of the wood pallets of the control sample should have an individual moisture content between the lower and upper limits. Individual wood pallets not fulfilling these criteria should be replaced. These criteria are directly adopted from EN 14298:2017.

For criterion 2, the arithmetic mean of the control sample should be 10^{+2}_{-3} %. This suggested variation is slightly broader than that in EN 14298:2017, as the wood pallets are not dried as sawn timber. The lower limit for the arithmetic mean is similar to the lower limit of an individual pallet.

6 Discussion

Main author of the chapter: Magnus Arvidson, RISE.

6.1 The objective of the work

The overall objective of the work presented in this report and in report D10.4 was to establish a harmonized fire suppression performance level for prescriptive-based and performance-based fire protection systems for ro-ro cargo and special category spaces. For prescriptive-based systems, detailed design and installation criteria are given in MSC.1/Circ.1430, compliance with its Appendix is required for performance-based systems.

The fire test scenarios of the current fire test procedures were redesigned, such that they reflect the fire severity of modern vehicles. Thereafter, the fire suppression performance of two prescriptive-based systems was determined in large-scale benchmark fire suppression tests, as documented in report D10.4.

6.2 The redesign of the fire test scenarios

The fire test scenarios and the associated fire test mock-ups were redesigned. The designs in the current fire test procedures in the Appendix of MSC.1/Circ.1430/Rev.2 were used as the starting point for the work. For the passenger car fire test scenario, the intent was to provide a peak heat release rate on the order of 6 MW. As per the current design, part of the fire is shielded from direct application of water from overhead sprinklers or nozzles. Pool fire trays with heptane fuel underneath the passenger car mock-up were introduced to mimic a fire in either a fuel spill or a fire in a traction battery. The fire is started by igniting this fuel and allowing fire spread to the stacks of idle wood pallets through a hole in the platform. Tests were conducted (after the large-scale benchmark fire suppression tests) to confirm that the fuel spill fire was realistic, and that fire spread to the wood pallets occurred. As the number of idle wood pallets was reduced (from 36 pallets in the first proposal to 30 pallets in the final version), the inclusion of the fire trays would not have a significant influence on the overall fire severity.

For the freight truck trailer fire test scenario, a smaller number (96 instead of 112) of pallets are proposed. However, they are re-arranged in stacks that are 12 pallets high instead of the current seven pallet high stacks. Vertical wood supports shall improve stack stability. Half of the array is shielded under a roof, similar to the current approach. Even though the total fire load is less, the re-arrangement of the stacks of pallets will increase the peak heat release rate. Given that all pallets burn simultaneously, the theoretical peak approaches 20 MW. The fuel package is also arranged closer to the floor level in contrast to the raised fuel package of the current test scenario that was used for defining the design area in addition to evaluating the suppression performance.

6.3 New acceptance criteria

The fire suppression performance of an automatic sprinkler and deluge water spray system representing the prescriptive requirements in MSC.1/Circ.1430 was determined in large-scale benchmark fire suppression tests, as described in report D10.4. The data was used for the proposed new acceptance criteria, as described in this report.

The data generated during the tests was relatively variable, especially with respect to the location of the point of fire ignition relative to the sprinklers or nozzles at the ceiling. This meant that the proposed acceptance criteria are based on a certain degree of judgement. The results of the tests are simply not so clear-cut that it is possible to apply criteria without an assessment. For reasons of simplicity, it was also decided that the proposed acceptance criteria should be the same, regardless of the type of system (wet-pipe, dry-pipe, pre-action or deluge) being tested and the ceiling height during the tests. Additionally, it was decided that one set of requirements should apply for a single test, but that the two tests at a specific ceiling height should also meet a set of criteria based on the overall performance in two tests. The latter approach is needed to reflect that the performance of a system could be significantly different due to the position of fire ignition relative to the ceiling nozzles.

No fire tests were conducted to verify the practical use of the proposed fire test procedures when testing water mist systems. This was not part of the project.

6.4 Fire suppression tests using actual vehicles

No data in the literature was found relating to the fire suppression performance of automatic sprinkler systems or deluge water spray systems installed on board ships and designed per MSC.1/Circ.1430. However, a series of deluge water spray fire tests were conducted to compare the fire suppression performance of a deluge water spray for fires involving gasoline-powered and battery electric vehicles under test conditions that were as equivalent as possible. These tests are described in report D10.4. The tests simulated a ro-ro space having a ceiling height of about 5 m and the system design in terms of water discharge densities corresponded to the design recommendations in MSC.1/Circ.1430/Rev.2. The tests indicate that a fire in a battery electric vehicle is not more challenging than a fire in a gasoline-powered vehicle for the drencher system design given in MSC.1/Circ.1430/Rev.2. This experience indicates that no immediate change of the water discharge densities for prescriptive-based systems is required due to the introduction of battery electric vehicles in the market.

6.5 Revised testing procedures

The major change relates to the establishment of procedures for testing of dry-pipe and deluge systems, where a delay time is used measured from the activation of the automatic sprinklers in a dry-pipe system or the operation of simulated heat detectors of an automatic deluge system prior water discharge. A fixed vertical sprinkler/nozzle-to-ceiling distance is also recommended.

7 Conclusion

Main author of the chapter: Magnus Arvidson, RISE.

The work documented in this report and in report D10.4, “Large-scale validation of the new fire test standard for alternative fixed fire-fighting systems”, forms a basis for the revision of the current fire test procedures in the Appendix of MSC.1/Circ.1430/Rev.2.

A revision of the fire test procedures in MSC.1/Circ.1430/Rev.2 will require a submittal to the IMO Sub-Committee on Ship Systems and Equipment (SSE), that can further discuss a proposal for revision.

No water mist fire suppression tests were conducted, as the performance criteria in the revised method is based on the performance of prescriptive systems, hench not included in the project budget. Such tests could be valuable to provide input to verify the practical use of the fire test procedures. In particular, verifying the validity of the benchmark tests done at 5 m up to 6,5 m for water mist systems that rely partially on 3-dimensional fire-fighting mechanisms would be of interest. Also, additional benchmark fire tests using ceiling heights in excess of 6,5 m could provide input to the suitability of the suggested fire test procedures at excessive heights in general.

8 References

1 D10.4, “Large-scale validation of the new fire test standard for alternative fixed fire-fighting systems”, February 2022, The LASH FIRE Consortium

2 IMO Resolution A.800(19) adopted on 23 November 1995, “Revised guidelines for approval of sprinkler systems equivalent to that referred to in SOLAS Regulation II-2/12”, International Maritime Organisation, London, UK, December 14, 1995

3 “Fuktkvot (Moisture ratio)”, https://www.svenskttra.se/trafakta/allmant-om-tra/tra-och-fukt/ (accessed 2023-01-12)

4 EN 14298:2017, “Sawn timber – Assessment of drying quality”, Approved: 2017-11-17, Published: 2017-11-17, Edition: 2

5 EN 13183-2, “Moisture content of a piece of sawn timber – Part 2: Estimation by electrical resistance method”, Approved 2003-04-11, edition 1

9 Indexes

9.1 Index of tables

9.2 Index of figures

10 ANNEX A

WATER-BASED FIRE-FIGHTING SYSTEMS FOR RO-RO SPACES AND SPECIAL CATEGORY SPACES

[Decimal points used in the document as in MSC.1/Circ.1430]

1 Scope

This test fire test method is intended for evaluating the fire control capabilities of fixed performance-based water-based fire-fighting systems to be installed in ro-ro spaces and special category spaces with deck heights up to and including 2.5 m and 6.5 m, respectively, with optional testing in spaces exceeding 6.5 m.

The test method includes two different fire test scenarios: a scenario simulating a passenger car fire and a scenario simulating a fire in the cargo of a freight truck trailer.

The objective of the fire test programme is to establish the maximum nozzle spacing and minimum system operating pressure of the tested nozzles. The test results should be valid up to and including the ceiling height used in the tests. Unique nozzle characteristics and installation criteria for different ceiling heights are allowed, but the same operating pressure should be used. Systems successfully completing the fire test programme for a certain ceiling height are suitable for use with the same system specifications for a lower ceiling height.

The fire test method covers testing of wet-, dry- and pre-action systems utilizing automatic nozzles as well as deluge systems using open nozzles.

No specific fire tests to determine the area of operation for wet-, dry- and pre-action systems are given. The area of operation specified in MSC.1/Circ.1430/Rev.2 for prescriptive-based systems should be used.

2 General requirements

2.1 Sampling

The nozzles and other components to be tested should be supplied by the manufacturer together with design and installation criteria, operational instructions, drawings, and technical data sufficient for the identification of the components.

2.2 Tolerances

Unless otherwise stated, the following tolerances should apply:

.1 Length: ±2 % of value.

.2 Volume: ±5 % of value.

.3 Pressure: ±3 % of value.

.4 Temperature: ±2 % of value.

2.3 Observations

The following observations should be made during and after each test:

.1 Time of ignition.

.2 Activation time of the first automatic nozzle or the exceeding of the temperature threshold of the thermocouples mimicking spot-type heat detectors. This time is defined as the activation time of the tested system.

.3 Time when water flows out through the first nozzle(s).

.4 Time when water flow is shut off.

.5 Time when the test is terminated.

.6 Total number of activated nozzles (where applicable).

2.4 Test hall and environmental conditions

The test hall where the tests are conducted should have a minimum floor area of 300 m^2 and a ceiling height in excess of 8 m. The test hall may be equipped with a forced ventilation system, or be natural ventilated, in order to ensure that there is no restriction in air supply during a test.

Prior to each test, the test area should be dried and all water from previous testing should be removed. There should be no visible water on the floor or ceiling. The air in the test area should be conditioned to an ambient temperature of 20 °C ±10 °C as measured at thermocouples located below the ceiling.

The tests should be conducted under a flat, smooth, non-combustible ceiling of at least 100 m^2. There should be at least a 1 m horizontal distance between the perimeters of the ceiling and any wall of the test hall. The ceiling height is defined as the minimum vertical distance from the floor to the underside of the ceiling.

2.5 Combustibles

The primary fire source for both scenarios consist of stacks of single-deck EUR 1 wood pallets (per ISO 6780:2003), sized nominally 1200 mm (L) by 800 mm (W) by 144 mm (H).

Commercial heptane should be used in the fire trays.

3 Instrumentation and measurements

3.1 Ceiling gas temperatures

Ceiling gas temperatures should be measured above the fire. A total of five thermocouples should be installed. One thermocouple should be positioned directly above the point of fire ignition and four additional thermocouples should be positioned at an orthogonal angle, at a 1.5 m radius from the centremost thermocouple. The thermocouples should be installed 75 mm below the ceiling.

Sheathed, nominally 1 mm thick Type K thermocouples should be used.

3.2 Temperatures of simulated spot-type heat detectors

For deluge system tests, ceiling gas temperatures should be measured, with the intent to simulate the temperature of spot-type heat detectors. Four thermocouples should be installed at an orthogonal angle, at a 4.5 m radius from the point of fire ignition. The thermocouples should be installed 75 mm below the ceiling.

Sheathed, nominally 0.5 mm thick Type K thermocouples should be used.

3.3 Surface temperatures of the target steel sheet screens

The surface temperature of the target steel sheet screens should be measured at the positions described in Sections 4 and 5, respectively.

Wire-type, nominally 0.5 mm thick Type K thermocouples should be spot-welded to the backside of the steel sheet.

3.4 System operating pressure

System operating pressure should be measured by using suitable equipment. The measurement should be made at the end of a branch line of the system pipe-work, with limited height difference between the pressure transducer and the nozzles.

3.5 System flow rate

The system flow rate should be determined by a direct measurement using a flow meter or indirectly by using the system operating pressure data and the "K-factor" of the nozzles.

3.6 Recording of measurements

The measurements in sections 3.1 to 3.5 should be recorded at intervals not exceeding one second using a computerized data acquisition system. Measurements should begin and end at least three minutes prior to fire ignition and after the termination of the tests. All instrumentation should be calibrated prior the series of tests or be part of a periodical calibration program.

3.7 Moisture content measurements of wood pallets prior a test

3.7.1 General

The moisture measurement procedures are based on the requirements in EN 13183-2 but modified to measurements on wood pallets.

The assessment of the drying characteristics is based on EN 14298:2017.

3.7.2 Moisture measurement apparatus

An electrical resistance moisture meter equipped with insulated electrodes, graduated up to 30 %

in units of maximum 1 % moisture content should be used. The meter should be equipped with settings or tables to correct for wood species and temperature.

Prior being used, the electrical resistance moisture meter should be verified according to the instructions provided by the supplier of the instrument.

3.7.3 Moisture measurement procedures

Use the following procedure for estimating the moisture content of an individual wood pallet intended to be used in the test.

Correct the electrical resistance moisture meter reading to take into consideration the temperature and species of the wood being measured. Take the measurement in the direction of the grain, in one of the outside top deck boards.

Drive the electrodes into the face of the board, at a point at least 300 mm from either end of the board and at a distance of 0.3 times the width from one edge, so that the tips of the electrodes penetrate to a depth of approximately 0.3 times the thickness of the board, i.e., 7 mm. The measurement area should be free from resin wood and features such as bark, knots, and resin pockets. If such features exist, take the measurement at the nearest clear area towards the centre of the board.

Take the reading after it has been displayed for 2 s to 3 s.

3.7.4 Control sample

For the passenger car fire test scenario, the control sample should include at least 10 wood pallets intended to be used in the test.

For the freight truck trailer fire test scenario, the control sample should include at least 20 wood pallets intended to be used in the test.

3.7.5 Moisture content requirements

The desired moisture content should be 10 % and the following criteria should be fulfilled:

Criterion 1: The moisture content of an individual wood pallet in the control sample should be between 0.7 × the desired moisture content (lower limit) and 1.3 × the desired moisture content (upper limit). At least 93.5 % of the wood pallets of the control sample should have an individual moisture content between the lower and upper limits. Individual wood pallets not fulfilling these criteria should be replaced.

Criterion 2: The arithmetic mean of the control sample should be 10^{+2}_{-3} %.

4 Simulated passenger car fire test scenario

4.1 General

The passenger car fire test scenario simulates a fire that involves a flammable liquid fuel spill fire (commercial heptane is used to simulate gasoline) or traction battery fire that spread to other combustibles of a car, as the tires and the passenger compartment.

The fire in a fuel spill underneath a car or in a traction battery generates flames from the lower parts of the long side of a car and the fire is completely shielded from direct application of water from overhead nozzles.

The fire in ordinary combustibles of a passenger car is simulated by an array of wood pallets that is partly shielded from direct application of water from overhead nozzles by a roof.

4.2 Combustible material and their arrangement

4.2.1 Array of wood pallets

The passenger car fire test scenario should involve 30 EUR wood pallets in an array that is 2 pallets (wide) by 5 pallets (high) by 3 pallets (long). Half of the array should be shielded from direct application of water from overhead nozzles by a horizontal steel sheet plate. The other half is fully exposed to the water spray.

In the longitudinal direction, the stacks of wood pallets should be abutted together, long-side-to-long side. In the transversal direction, each stack should be separated by a nominally 150 mm horizontal distance.

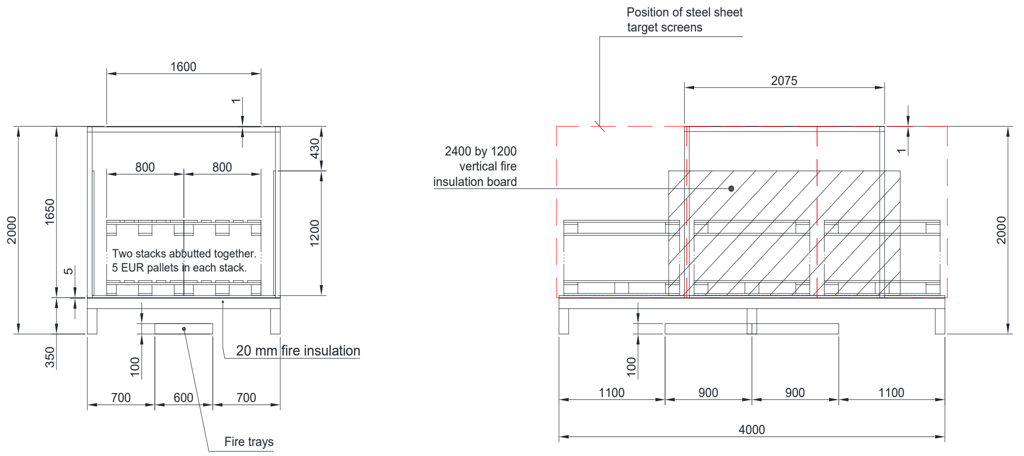
The array should be positioned on a rectangular platform sized 2.0 m (wide) by 4.0 m (long), made from nominally 5 mm steel sheets, supported by a steel construction made from nominally 100 mm by 100 mm square iron. The vertical distance from the top of the platform and the floor should be

0.35 m. Vertical supports should be arranged at each corner of the platform and at the mid-point of the long sides.

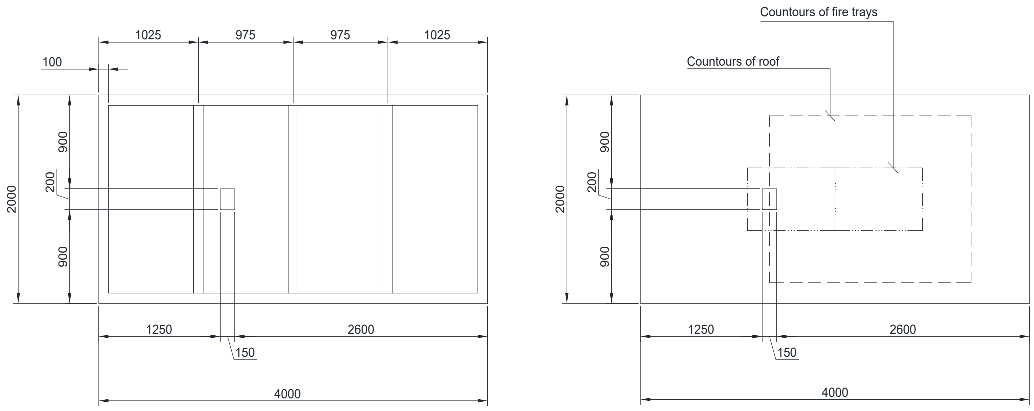
The top of the platform should be protected by nominally 20 mm fire insulation boards positioned underneath the stacks of wood pallets. These fire insulation boards should be replaced after each test.

The platform deck and the insulation board should be fitted with an opening sized 150 mm (L) by 200 mm (W). The 150 mm measure equals the separation distance between stacks of pallets in the longitudinal direction. The intent of the opening is to allow flames from the fire trays positioned underneath the platform to ignite the wood pallets.

Part of the of stacks of wood pallets should be shielded from the long side by nominally 20 mm fire insulation boards, nominally sized 2.4 m by 1.2 m. These fire insulation boards should be replaced after each test.



Design of the passenger car mock-up.



Design of the platform and the position of the floor opening.

Half of the of stacks of wood pallets should be shielded from direct application of water from overhead nozzles by a horizontal steel sheet plate, simulating the roof of a car. This roof should be sized 1.6 m (W) by 2.075 m (L) and be nominally 1 mm thick. The width of the roof correlates with the width of the array of wood pallets. The top of the roof should be 2.0 m above the floor.

4.2.2 Heptane fire trays

Two fire trays individually sized 600 mm (W) by 900 mm (L) by 100 mm (H) should be arranged short-side to short-side to provide a 600 mm (W) by 1800 mm (L) fire tray area. The trays should be constructed from nominally 1 mm thick steel sheets.

The fire trays should be symmetrically positioned underneath the mock-up and each tray should be filled with 7 litre on 7 litre of water bead prior a test.

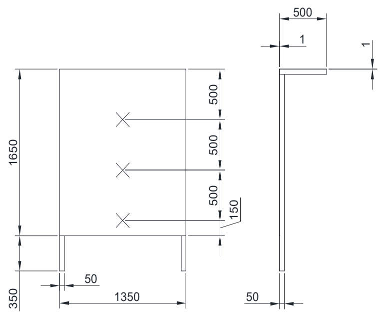
4.3 Fire ignition arrangement

The fire should be initiated by the ignition of the fire trays below the mock-up with a torch.

4.4 Target steel sheet screens

A total of six target steel sheet screens (three on each side) should be positioned along the long sides of the mock-up, at a horizontal distance of 0.5 m.

Each screen should be sized 1.35 m (W) by 1.65 m (H) and be made from nominally 1 mm thick steel sheets. A 0.5 m wide horizontal overhang at the top of the screen should be fitted to prevent the steel sheet screen from being wetted on its backside from the tested nozzles. The screens should be supported by 0.3 m high vertical supports.



Steel sheet screen (6 pcs) with the positions of the spot-welded thermocouples.

Thermocouples should be spot-welded to the backside of each steel sheet screen along its vertical centreline, such that they are aligned towards the vertical centreline of the stacks of wood pallets. A total of three thermocouples should be used on each screen, vertically separated 500 mm with the topmost thermocouple positioned 500 mm below the top of the screen.

5 Simulated freight truck trailer fire

5.1 General

The freight truck trailer fire test scenario simulates a fire the cargo of a freight truck trailer.

The amount of fuel used in the tests represents a total energy of almost 34 GJ.

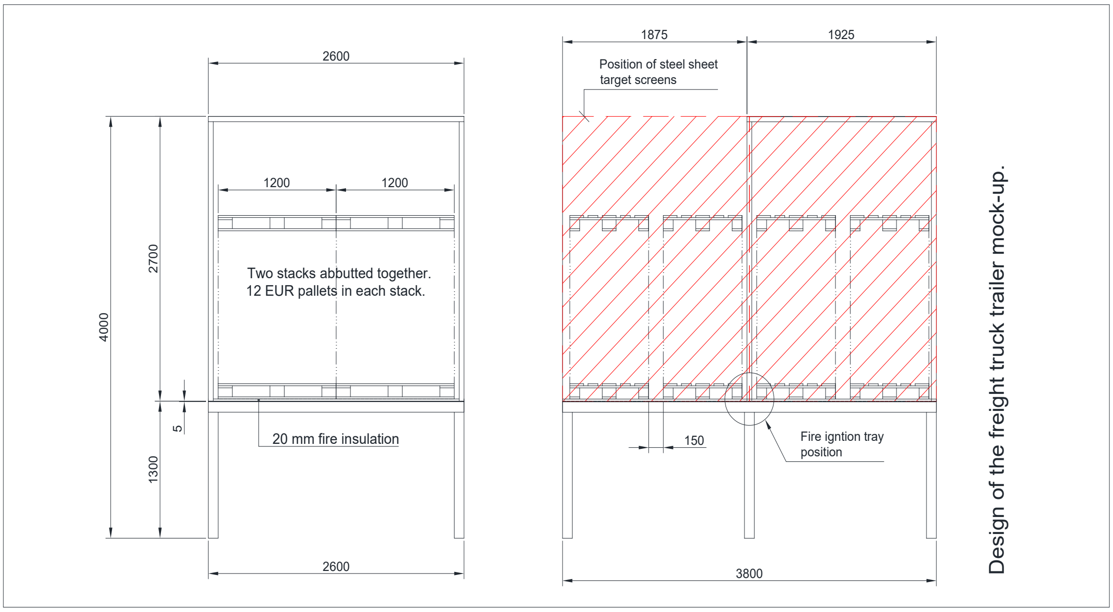
5.2 Combustible material and their arrangement

The freight truck trailer fire test scenario should involve 96 EUR wood pallets in an array that is 2 pallets (wide) by 12 pallets (high) by 4 pallets (long). Half of the array should be shielded from direct application of water from overhead nozzles by a horizontal steel sheet plate. The other half is fully exposed to the water spray.

In the longitudinal direction, the stacks of wood pallets should be abutted together, short-side-to-short side. In the transversal direction, each stack should be separated by a nominally 150 mm horizontal distance.

The long sides of each stack and the outer short side should be supported by vertical 45 mm by 90 mm wood studs, going from the bottom to the top of the stack. The wood studs should be attached by nominally 6.0 mm × 120 mm wood screws. Four screws should be attached at the bottom, top and mid-height of the stack, respectively.

The array should be positioned on a rectangular platform sized 2.6 m (wide) by 3.8 m (long), made from nominally 5 mm steel sheets, supported by a steel construction made from nominally 100 mm by 100 mm square iron. The vertical distance from the floor and the top of the platform should be 1.3 m. Vertical supports should be arranged at each corner of the platform and at the mid-points of the long sides.



The top of the platform should be protected by nominally 20 mm fire insulation boards positioned underneath the stacks of wood pallets. These fire insulation boards should be replaced after each test.

Part of the of wood pallets should be shielded from direct application of water from overhead nozzles by a horizontal steel sheet plate. This roof should be sized 2.6 m (W) by 1.925 m (L) and be nominally 1 mm thick. The width of the roof correlates with the width of the platform. Lengthwise, the roof should cover half of the length of the array. The top of the roof should be 4.0 m above the floor.

5.3 Fire ignition arrangement

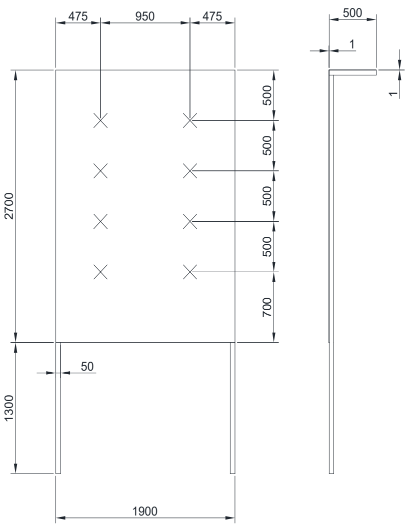
The fire should be initiated using a fire tray sized 600 mm (L) by 150 mm (W) by 150 mm (H) filled with 20 mm (1,8 litres) of heptane on a 50 mm water bead (4.5 litres) that is ignited by a torch.

The fire tray should be symmetrically positioned between the centremost stacks of wood pallets, i.e., at the border line between the exposed and shielded part of the array.

5.4 Target steel sheet screens

A total of four target steel sheet screens (two on each side) should be positioned along the long sides of the mock-up, at a horizontal distance of 0.5 m.

Each screen should be sized 1.9 m (W) by 2.7 m (H) and be made from nominally 1 mm thick steel sheets. A 0.5 m wide horizontal overhang at the top of the screen should be fitted to prevent the steel sheet screen from being wetted on its backside from the tested nozzles. The screens should be supported by 1.3 m high vertical supports.



Steel sheet screen (4 pcs in total) with the positions of the spot-welded thermocouples.

Thermocouples should be spot-welded to the backside of each steel sheet screen. Two vertical columns, each having four thermocouples should be symmetrically arranged around the vertical centreline of the screen, such that they are aligned towards the vertical centreline of the stacks of wood pallets. The thermocouples should be vertically separated 500 mm with the topmost thermocouples positioned 500 mm below the top of the screen.

6 Fire test procedures

6.1 Test programme

The following four tests should be conducted:

Ceiling height	Fire test scenario	Point of fire ignition
2.5 m	Simulated passenger car fire	Directly under one nozzle
	Simulated passenger car fire	Between four nozzles
6.5 m	Simulated freight truck trailer fire	Directly under one nozzle
	Simulated freight truck trailer fire	Between four nozzles
In excess of 6.5 m, to the discretion of the manufacturer	Simulated freight truck trailer fire	Directly under one nozzle
	Simulated freight truck trailer fire	Between four nozzles

Tests using higher ceiling heights than 6.5 m may be conducted to the discretion of the manufacturer.

The tests at each of the ceiling heights may be conducted using unique nozzle characteristics and installation criteria but should be conducted using the same nominal system operating pressure.

6.2 Nozzle positioning

Nozzles should be installed at the ceiling at the maximum horizontal nozzle spacing specified in the manufacturer's design and installation recommendations.

The nozzles should be installed either upright or pendent. For testing of dry- or pre-action systems, nozzles should be installed pendent.

The vertical distance from the underside of the ceiling to the deflector or the tip of a nozzle should be nominally 150 mm, irrespective if upright or pendent nozzles are used.

Tests should be repeated with two different relative locations between the nozzle array and the fire test scenario: a) with the point of fire ignition directly under one nozzle and b) with the centre of ignition symmetrically between four nozzles. For the passenger car fire test scenario, the hole in the platform should be the regarded as the point of fire ignition.

For the fire ignition location per a), at least five nozzles and per b), at least four nozzles should be installed.

6.3 System preparation and system control procedures

6.3.1 Wet-pipe systems

The system pipe-work should be connected to a pump.

The minimum system operating pressure specified in the manufacturer's design and installation recommendations should be set flowing four open nozzles. Thereafter, the pump should be stopped, and the nozzles replaced with automatic nozzles having an identical K-factor.

The system pipe-work should thereafter be pressurized with water to the minimum stand-by pressure specified in the manufacturer's design and installation recommendations.

During the test, automatic nozzles are allowed to operate by the heat from the fire and a delay time of at least 15 s should be applied from the recording of the pressure drop in the system piping until the water pump is started. If more than four automatic nozzles operate during the test, the system operating pressure should be adjusted accordingly, to maintain the minimum specified value.

If requested by the manufacturer, and at the sole discretion of the classification society, the tests may be conducted with automatic nozzles having the highest nominal temperature rating. Such test condition is intended to enable evaluation of multiple nominal temperature ratings at once.

6.3.2 Dry-pipe and pre-action systems

The system pipe-work should be connected to a system control valve and a pump.

The minimum system operating pressure specified in the manufacturer's design and installation recommendations should be set flowing four open nozzles. Thereafter, the pump should be stopped, the control valve closed, the pipe-work drained, and the nozzles replaced with automatic nozzles having an identical K-factor.

The system pipe-work should thereafter be pressurized with compressed air to the minimum stand-by pressure specified in the manufacturer's design and installation recommendations.

During the test, automatic nozzles are allowed to operate by the heat from the fire. A delay time of at least 45 s should be applied from the recording of the pressure drop in the system piping until the system control valve is manually opened and the water pump is started.

If more than four automatic nozzles operate during the test, the system operating pressure should be adjusted accordingly, to maintain the minimum specified value.

6.3.3 Deluge systems (manual and automatic operation)

The system pipe-work should be connected to a pump.

The minimum system operating pressure specified in the manufacturer's design and installation recommendations should be set flowing all installed open nozzles. Thereafter, the pump should be stopped.

When at least two of the thermocouples mimicking spot-type heat detectors have reached the fire detection temperature threshold of 78 °C, the pump should be started after a delay time of at least 45 s.

6.4 Testing procedures

Prior to the start of each test, the moisture content of the desired number of EUR wood pallets should be measured and the results should be reported.

The actual test procedure for all tests is as follows:

.1 The heptane fire tray(s) should be filled with heptane on a water base using the amount previously described.

.2 The measurements are started.

.3 The flammable heptane fire tray should be lit by means of a torch or a match.

.5 The test is continued for 30 minutes after system activation.

.6 Any remaining fire should be manually extinguished.

.7 The test is terminated.

7 Acceptance criteria

7.1 Ceiling gas temperatures

The average gas temperature of the five ceiling gas measurement points above the fire should be calculated, and thereafter a five-minute average gas temperature based on this reading.

The peak of the five-minute average gas temperature, as determined during the period from two minutes after the start of water application until the termination of water application, should not exceed 600 °C in any of the tests.

The mean gas temperature calculated based on the peak of the five-minute average gas temperature determined from each of the two tests (fire ignition directly under one nozzle and fire ignition below four nozzles, respectively), should not exceed 450 °C. *Example: If the peak of the five-minute average gas temperature in the first test is 600 °C, the peak of the five-minute average gas temperature in the second test is not allowed to be more than 300 °C.*

7.2 Surface temperature of target steel sheet screens

The mean surface temperature of all measurement points of the steel sheet screens on both sides should be calculated, and thereafter a five-minute average surface temperature based on this reading.

The peak of the five-minute average surface temperature, as determined during the period from two minutes after the start of water application until the termination of water application, should not exceed 150 °C in any of the tests.

The mean surface temperature calculated based on the peak of the five-minute average surface temperature determined from each of the two tests (fire ignition directly under one nozzle and fire ignition below four nozzles, respectively), should not exceed 100 °C. *Example: If the peak of the five-minute average surface temperature in the first test is 150 °C, the peak of the five-minute average surface temperature in the second test is not allowed to be more than 50 °C.*

8 Test report

The test report should, as a minimum, include the following information:

.1 Name and address of the test laboratory.

.2 Date of issue and identification number of the test report.

.3 Name and address of applicant.

.4 Name and address of manufacturer or supplier of the tested nozzles.

.5 Test method and purpose.

.6 Nozzle identification.

.7 Description of the tested nozzles and system performance.

.8 Detailed description of the test set-up including drawings and photos of the fire test scenarios before and after the tests.

.9 Date of tests.

.10 Measured nozzle pressure and flow characteristics.

9 Guidance on the positioning of automatic sprinklers or nozzles

Section 4.5 of MSC.1/Circ.1430/Rev.2, that is valid for prescriptive-based systems states that sprinklers or nozzles should be positioned such that 1) they are not exposed to damage by cargo, 2) undisturbed spray is ensured and 3) water is distributed over and between all vehicles or cargo in the area being protected. Automatic sprinklers or nozzles should be positioned and located so as to provide satisfactory performance with respect to both activation time and water distribution.

This section provides recommendations on positioning of automatic sprinklers or nozzles that are valid for both prescriptive-based and performance-based systems. For nozzles not having an external deflector, the reference point should be the tip of the nozzle.

.1 Automatic sprinklers or nozzles should be positioned and orientated to provide satisfactory performance with respect to both activation time and distribution of water. An object located at or near ceiling level that extends downward into the area located below the discharge pattern is considered an obstruction to the pattern, except under the following conditions; i) the object located at or near ceiling level is a structure member or similar that is at least 70% open, or ii) the object located at or near ceiling level is no wider than 75 mm in its least dimension and is separated from other objects by a minimum of 300 mm.

.2 For ceiling constructions having structural ceiling members less than 300 mm in depth, install automatic sprinklers or nozzles with the deflector a minimum of 50 mm and a maximum of 150 mm (for upright sprinklers/nozzles) or a maximum of 300 mm (for pendent sprinklers/nozzles) vertically below the underside of the ceiling.

.3 For a ceiling construction having transversal primary structural ceiling members deeper than 300 mm that are forming channels where more than one sprinkler branch line can be installed (ensuring that hot gases produced during a fire can reach the nearest four ceiling-level sprinklers anywhere within a single channel), install automatic sprinklers or nozzles with the deflector a minimum of 50 mm and a maximum of 150 mm (for upright sprinklers/nozzles) or a maximum of 300 mm (for pendent sprinklers/nozzles) vertically below the underside of the ceiling.

.4 For a ceiling construction having transversal primary structural ceiling members deeper than 300 mm that are forming channels where no more than one sprinkler branch line can be installed, automatic sprinklers or nozzles should be positioned as follows:

i) in every channel bay formed by these members, with the deflector a minimum of 50 mm and a maximum of 150 mm (upright sprinklers/nozzles) or a maximum of 300 mm (pendent sprinklers/nozzles) below the underside of the ceiling, or,

ii) in every channel bay formed by these members, with the deflector vertically aligned with, or, no more than 150 mm higher than, the bottom edge of the members. For this alternative, vertical barriers made from sheet metal should be installed in every channel to reduce the length of the channels formed by the beams. The barriers should extend from the ceiling to the bottom edge of the members and the maximum channel length should include no more than three sprinklers on a branch line. Note: Secondary structural ceiling members that is either solid or no more than 10% open serves the purpose of the barriers.

iii) in every other channel bay formed by these members, given that the centre-to-centre distance between the members is less than or equal to 1.8 m. Install the sprinklers per section 9.4 i) or ii) with steel sheet barriers per section 9.4 ii) in every channel.

.5 As an alternative irrespective of the ceiling construction, install a smooth, solid continuous, non-combustible, sub-ceiling that is positioned aligned parallel to the floor at a given vertical distance below the primary ceiling and install automatic sprinklers per section 9.2.

.6 Position additional sprinklers under any flat or non-flat, continuous, solid objects that are positioned below the sprinklers and are more than 600 mm wide.

10 References

ISO 6780:2003, “Flat pallets for intercontinental materials handling - Principal dimensions and tolerances”, 2003

EN 13183-2, “Moisture content of a piece of sawn timber – Part 2: Estimation by electrical resistance method”, May 2003

EN 14298:2017, “Sawn timber – Assessment of drying quality”, October 2017