Engineering analysis report - Eco-Island ferry

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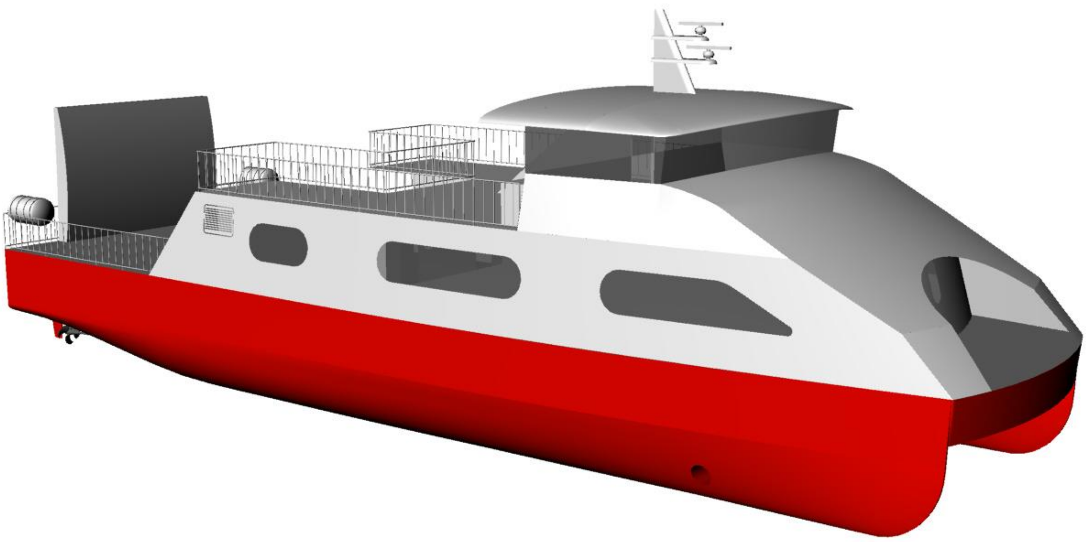

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SP Fire Research
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Abstract

This report contains the engineering analysis in accordance with SOLAS chapter II-2 regulation 17 for the fictitious ship called the Eco-Island ferry; it is a small ro-ro ship fully built in FRP composite, designed to replace an existing steel ferry with space for about 6 cars and 200 passengers. It was shown to pose a number of deviations to prescriptive requirements. The deviations particularly concern the fact that FRP composite is combustible. This although has effects on several prescriptive requirements, functional requirements and also on implicit requirements in SOLAS. In the quantitative assessment a number of identified potential fire hazards were managed independently whilst others were incorporated in fire scenarios involving the representative space groups. Different combinations of risk control measures, forming 21 trial alternative designs, were also quantified. In conclusion, the base design was shown to pose a risk more than four times as high as the prescriptive design. A performance criterion with a safety factor of 50% provided three acceptable trial alternative designs. By assigning distributions to all quantified probabilities and consequences to manage uncertainties, safety estimations could be made with better confidence. Assuming a confidence of 90% gave the same results as the safety margin above.

Key words: regulation 17, alternative design, FRP composite, fire safety

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Content

Summary

This report contains the engineering analysis as described by the IMO/Circ.1002 for the fictitious ship called the Eco-Island ferry; it is a small ro-ro ship fully built in FRP composite, designed to replace an existing steel ferry with space for about 6 cars and 200 passengers. A risk-approach to performance-based design involved a fire hazard identification process based on workshops held by a designated design team of 8 persons, covering critical aspects and knowledge necessary for the task. This illuminated a number of potential risks associated with use of FRP composite in load-bearing structures. In particular fire development on deck and fire spread through openings and vertically along the outboard sides of the ship were identified as fire scenarios where differences in fire safety would be significant. Furthermore, 8 space groups with similar conditions for fire scenarios were identified to manage the potential fire scenarios on board.

A base design was defined, where steel structures had simply been replaced by the intended FRP composite construction. It was shown to pose a number of deviations to prescriptive requirements. The deviations particularly concern the fact that FRP composite is combustible. This although has effects on several prescriptive requirements, functional requirements and also on implicit requirements in SOLAS.

In the quantitative assessment a number of identified potential fire hazards were managed independently whilst others were incorporated in fire scenarios involving the representative space groups. Different combinations of risk control measures, forming 21 trial alternative designs, were also quantified.

In conclusion, the base design was shown to pose a risk more than four times as high as the prescriptive design. A performance criterion with a safety factor of 50% provided three acceptable trial alternative designs. All of these design solutions include an extinguishing system for the ro-ro deck and a redundant supply unit for that extinguishing system as well as for the internal sprinkler system. There is also an additional longitudinal bulkhead dividing the accommodation space in two. In addition to this, for the ship to be sufficiently safe it was required to contain at least surfaces of low-flame spread characteristics on the forward bulkhead on ro-ro deck.

By assigning distributions to all quantified probabilities and consequences to manage uncertainties, the risk estimations of sufficient safety could be made with better confidence. Assuming a confidence of 90% gave the same results as the safety margin above.

1. Scope of the analysis

This report documents an evaluation of fire safety for the Eco-Island ferry, which is part of the research project "Øko-Ø-færge" (Danish for Eco-Island ferry). The scope of the current analysis is given subsequently, commencing with a background to the research project and why the ship has become a case for evaluation of alternative fire safety design and arrangements. Thereafter follows an introduction to the regulation for alternative fire safety design and arrangements and the analysis procedure necessary when making claim to this regulation for such a case.

1.1. The Øko-Ø-færge project

It was after a kick off meeting in the EU project MARKIS in 2010 with the headline "Light Weight Marine structures" that an industrial group in North Jutland, Denmark and SP Technical Research Institute of Sweden started to discuss displacement ferries with reduced environmental footprint. This led to a Swedish-Danish consortium with the objective to open up for the construction of this type of ferry in the Swedish and Danish region. The project was given the name "Øko-Ø-færge" (Eco-Island ferry) and a project group was formed consisting of naval architects from Sweden and Denmark, university and shipyard representatives as well as specialists from research institutes. A project plan was drawn up for the project, where a full fire safety assessment according to SOLAS chapter II-2 Regulation 17 as well as LCC and LCA assessments were planned for the new *eco*logical and *eco*nomical island ferry.

A preliminary study [1] was carried out by SP Technical Research Institute of Sweden which was financed by Västra Götalandsregionen, Sweden, and supported by the rest of the consortia. It included investigations of national, European and international regulations as well as studies of the financial potential and potential market for lightweight island ferries in the region. The preliminary study also included search for further funding, which was allocated by The Danish Maritime Fund (Den Danske Maritime Fond), and development of the lightweight "Eco-Island ferry". This new ferry is meant to illustrate how an island ferry can be replaced by a more ecological and economic alternative. It was set out to replace the old Tun island ferry (Tunøfærgen), which has a route between the Hov and the island Tunö in Denmark. A prerequisite for the ship was to keep the same capacity as the Tun island ferry with 200 passengers and six cars (alternatively four cars and a truck). Using Fibre Reinforced Polymer (FRP) composite as shipbuilding material it is possible to reach a weight reduction of up to 60% [2], which would have significant positive effects on operational costs and environmental footprint. A ro-ro passenger ship with load-bearing structures in combustible FRP composite instead of in steel does although not comply with prescriptive fire safety requirements in the European passenger directive [3]. However, there is an opening for alternative fire safety design and arrangements in the EU directive which refers to Part F of the revised Chapter II-2 of SOLAS 1974 [4]. An evaluation of alternative design and arrangements may seem risky for a ship owner, both from a financial and a time perspective. The objective of this report is thus to show on the feasibility in reaching approval of an island ferry made in FRP composite.

1.2. Regulation 17

SOLAS (Safety of Life At Sea) is one of the most important directives for merchant ships on international waters, adopted in 1929. The convention was latest revised in 1974 and is with its updates and amendments still the regulation of practice. SOLAS consists of twelve chapters comprising issues such as construction, life-saving appliances, safety of navigation and other measures for maritime safety [5]. Fire safety has always been of great concern on merchant ships and for these matters chapter II-2 of the SOLAS convention is essential. To obtain sufficient fire safety according to SOLAS the fire safety objectives and functional requirements found in Regulation 2 need to be met, either by fulfilment of the prescriptive requirements specified in parts B, C, D, E and G or by demonstrating that an alternative design and arrangements is at least as safe as if it would have been designed according to prescriptive requirements. The fire safety objectives and functional requirements are hence considered met if an evaluation of fire safety of the design and arrangements is reviewed and approved by the Flag. The latter option is described in SOLAS Chapter II-2, Regulation 17 (part F), hereafter referred to as Regulation 17. Corresponding openings for alternative design exist also in other parts of SOLAS (e.g. for life-saving appliances, machinery and electrical installations) and is a step towards future Goal-Based Standards.

Prescriptive fire safety requirements stipulate structural decks and bulkheads to be made in non-combustible material but FRP composite is combustible. In line with Regulation 17, this could be treated as a deviation to prescriptive fire safety requirements and the Eco-Island ferry is hence an alternative fire safety design and arrangements.

1.3. Regulation 17 and the EU passenger directive

Performing a fire safety analysis according to Regulation 17 (part F) in SOLAS is in line also with the amended EU directive, as mentioned above. According to the EU directive the stipulated fire safety objectives and functional requirements can be achieved if the ship's design and arrangements, as a whole, comply with the relevant prescriptive requirements in the directive or if the ship's design and arrangements, as a whole, have been reviewed and approved in accordance with part F of the revised chapter II-2 in SOLAS 1974, which applies to ships constructed on or after 1 January 2003.

It was concluded in the preliminary study of the Eco-Island ferry project [1] that it would be more relevant to base a fire safety assessment, also according to the EU directive, on fire safety regulations as they are structured in SOLAS. In SOLAS the fire safety requirements have been rearranged to illuminate the objectives and functions of regulations, a structure adapted to allow for alternative performance-based design. Since the EU directive is based on and updated according to SOLAS, all prescriptive requirements in the EU directive are also found in SOLAS [1]. There should therefore not be any hindrance to use the prescriptive requirements in SOLAS, even when evaluating an alternative design and arrangements according to the EU directive.

Due to incomplete updates of the EU directive there is although a hindrance to use the EU directive for this ship. From the unchanged Article 3 it is apparent that the EU directive does not apply to ships not made in steel or equivalent material. Even though the design and arrangements on the Eco-Island ferry will be adapted to provide safety equivalent to a steel construction and even though the ship will travel only in national waters, it has to become a SOLAS vessel to even be considered by the Flag.

1.4. Required procedure

When laying claim to Regulation 17, an engineering analysis is required which follows a method summarized in SOLAS [5] and described in more detail in MSC/Circ.1002 [6] (hereafter referred to as Circular 1002). These guidelines open up for using performance-based methods of fire safety engineering to verify that the fire safety of an alternative design is equivalent to the fire safety stipulated by prescriptive regulations, a concept often referred to as the "equivalence principle". Briefly, the procedure can be described as a two-step deterministic risk assessment carried out by a design team. The two major parts to be performed are:

(1) the preliminary analysis in qualitative terms; and
(2) the quantitative analysis.

In the first part, the design team is to define the scope of the analysis, identify hazards and from these develop design fire scenarios as well as trial alternative designs. The different components of the preliminary analysis in qualitative terms are documented in a preliminary analysis report which needs an approval by the design team before it is sent to the Administration for a formal approval. With the Administration's approval, the preliminary analysis report documents what goes into to the next step of the Regulation 17 assessment, the quantitative analysis. Now the design fire scenarios are quantified and, since there are no explicit criteria for the required level of fire safety, outcomes are compared between the trial alternative designs and a prescriptive design (complying with applicable prescriptive requirements). Accordingly, the prescriptive design is referred to as a reference design, complying with all the prescriptive fire safety requirements. The documented level of fire safety of the alternative design is therefore not absolute, but relative to the implicit fire safety of a traditional design, which is likewise a product of the implicit fire safety level in prescriptive regulations. Accounting for uncertainties when comparing levels of fire safety, the final documentation of the engineering analysis based on Regulation 17 (hereafter referred to as "Regulation 17 assessment") should with reasonable confidence demonstrate that the fire safety of the alternative design and arrangements is at least equivalent to that of a prescriptive design, which is the purpose of the report at hand.

1.5. Revised approach

Regulation 17 was developed to undertake innovative design solutions, typically high atriums and long shopping promenades on cruise vessels, without compromising with fire safety. The regulation is in that sense employed to make safety more attractive, but it can also be used to make fire safety more cost-efficient, i.e. to accomplish the same level of fire safety at a lower cost or to increase fire safety at the same cost. In the present case, all steel divisions have been redesigned in FRP composite. Above all, the material is combustible and the fire integrity will be fundamentally affected, which implies significant effects on fire safety. Laying claim to Regulation 17, an evaluation of the alternative fire safety design should be based on Circular 1002, which describes a "plausible worst-case" type of risk assessment [7]. However, in order to establish whether the fire safety of a ship with FRP composite can be regarded at least as safe as prescriptive requirements, it has been judged that the risk assessment may need to be more elaborated than what is outlined in Circular 1002 [7], depending on the scope at hand.

It is namely not evident how fire risks in a truly novel design should be assessed to adequately display effects on fire safety. For one thing, all fire safety requirements are made up around steel designs, leaving many implicit requirements unwritten. To further complicate the comparison of safety levels, prescriptive requirements have unclear connections with the purpose statements of their regulations and also with the fire safety objectives and functional requirements of the fire safety chapter, which are supposed to define "fire safety". A Regulation 17 assessment involving FRP composite should, as any risk assessment, hence not only comply with what is stipulated in Circular 1002, but must also be of sufficient sophistication to describe the introduced novelty in terms of fire safety. This is why the more general term "Regulation 17 assessment" is preferred, since the term "engineering analysis" refers to a risk assessment of certain sophistication.

A more elaborated risk assessment was developed which comprises all the instructions in Circular 1002 but brings the estimation and evaluation of fire risks to a higher level [8]. The method of the preliminary analysis in qualitative terms is succinctly delineated throughout the analysis process and general explanations are also given in *Appendix A. The revised approach*. The approach could advantageously be used also for other areas of SOLAS where corresponding analyses are made to evaluate alternative designs.

2. Description of the alternative design and arrangements

The aim for a Regulation 17 assessment is to find a final trial alternative design and arrangements which includes certain desired novel features and arrangements and still provides a sufficient level of safety. This chapter describes the current ship and the scope of the alternative design and arrangements, which involves FRP composite instead of steel in load-bearing structures. Such constructions are novel in merchant ships and are therefore given general descriptions below, primarily from a fire safety point of view. Finally, more detailed definitions are made of the prescriptive design and the foundational design and arrangements for the trial alternative designs (called a base design).

2.1. Scope of the alternative design and arrangements

The Eco-Island ferry has been designed with the same capacity as the Tun island ferry (free translation of the actual Danish name Tunøfærgen), a reference ship. It is a Ro-pax ferry class D from 1993, designed to carry about 6 cars and 200 passengers (IMO# 9107875). The new ship was designed with the same capacity as the reference ship and approximately with the same dimensions (LxBxD = 30.7x10x3.2 m). The two ferries are shown in Figure 2.1 below.

Figure 2.1. The present Tun island ferry to the left (photo: Ulrich Streich) and the Eco-Island ferry to the right.

The Tun island ferry has an ~1 h route between Hov and Tunø in Denmark and the number of passengers using the ship each year is approximately 50 000. It is a displacement ferry with a speed of 9.5 knots and the Eco-Island ferry is designed to keep the same speed. This is possible at a significantly lower engine power (220 kW compared to 590 kW) since structures are designed in FRP composite instead of in steel. Making the Eco-Island ferry in FRP composite instead of in steel, as the Tun island ferry, gives a displacement as specified in

Table 2.1 and a draft of 1.4 m. The number of crew of the Tun island ferry varies over the seasons but the Eco-Island ferry has been designed with 3 crew members on board.

Table 2.1. Weight specifications for the reference object, the Tun island ferry, and the Eco-Island ferry

Weight item	*Tun island ferry [kg]*	*Eco-Island ferry [kg]*
Lightweight	250 000	72 000
Ballast	33 900	0
Fuel & water	18 800	8 000
Stores	1 000	1 000
Passengers	15 000	15 000
Crew	225	225
Luggage	2 000	2 000
Cars	16 000	16 000
Deck cargo	3 075	3 075
Displacement	**340 000**	**117 300**

The scope of the alternative design and arrangements is hence an island ferry with the same capacity as the Tun island ferry but where all steel structures have been replaced by FRP composite. The prescriptive design (with steel structures) and the foundational arrangements for all alternative designs (the base design) are further described below. The general arrangement for the Eco-Island ferry is presented in *Appendix B. General arrangement*.

2.2. Definition of the prescriptive design and the base design

In a Regulation 17 assessment a number of trial alternative designs are defined and analysed to find out which are sufficiently safe. The starting point for the trial alternative designs is a base design, which is defined by the design and arrangements certain to be included in any trial alternative design. Applying different combinations of risk control measures (RCMs) to the base design makes up different trial alternative designs. The fire safety of these designs will be compared to that of a reference design which complies with all relevant prescriptive fire safety requirements, a prescriptive design. In the end it may prove that the base design provides sufficient safety on its own, due to existing safety measures installed beyond applicable prescriptive requirements. In that case the base design forms an acceptable trial alternative design. However, the normal case is that the base design needs additional RCMs in order to provide sufficient safety. Identified RCMs and distinguished trial alternative designs are further described in chapter 4 of this report whilst the prescriptive design and the base design are further defined subsequently. This is initiated by descriptions of the ship layout.

2.2.1. Layout of the Eco-Island ferry

The Eco-Island ferry consists of a main deck and an upper deck on two pontoons. Between the pontoons there is also a wet deck, consisting of shallow void spaces. For the sake of simplicity in this report, the levels of the ship will although be referred to as deck 1, deck 2 and deck 3, starting from the floor of the pontoons. The wet deck will be referred to as deck 1.5. The notations are illustrated in Figure 2.2 which also provides an overview of the layout of the ship.

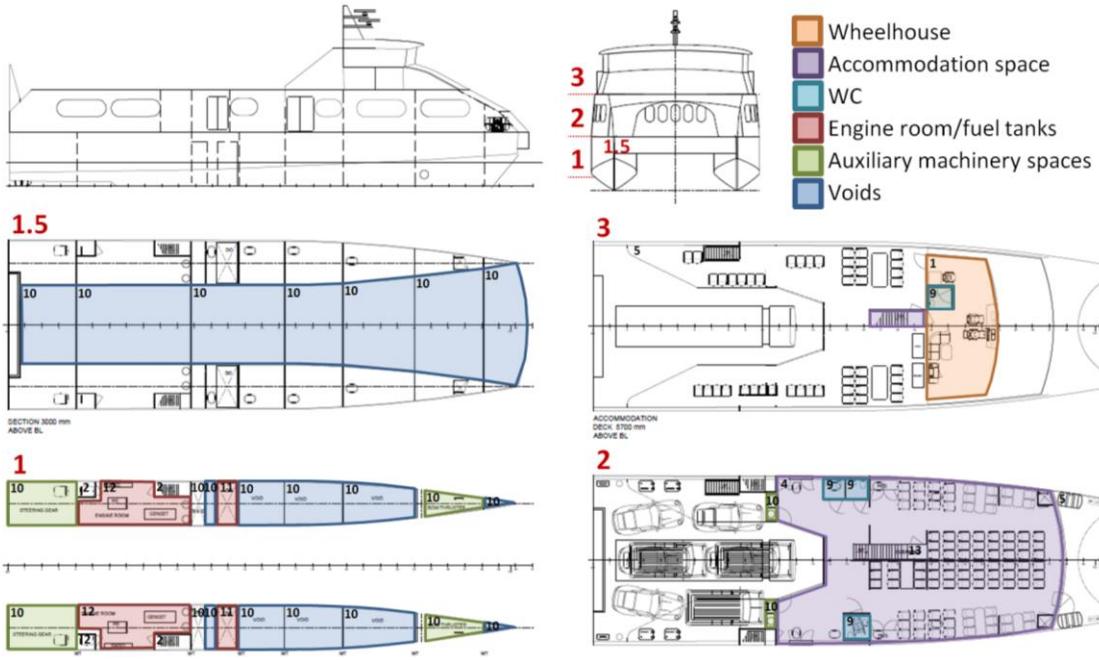

Figure 2.2. Overview of the ship where some spaces are coloured for guidance and space classifications according to SOLAS II-2/9 are provided.

Starting from deck 1, the two pontoons are principally mirrored, starting with steering gear spaces (10; space category according to SOLAS II-2/9 for passenger ships carrying more than 36 passengers are given in parentheses) in the aft. These spaces are reached from the ro-ro deck through hatches which are generally locked. Thereafter follow the engine rooms (12) which each has two exits (unmarked in Figure 2.2). One exit leads to a protected enclosure (2) with a ladder and a hatch to ro-ro deck. The other exit leads to a stairway (2) to the accommodation space on deck 2. Forward of the engine rooms is a fresh water tank (10) on starboard side and a black & grey water tank (10) on port side (unmarked in Figure 2.2). After a small void space (10) follow the fuel tanks (11) on each side. Forward follow a number of void spaces (10), except the spaces with bow thruster equipment (10), marked green in Figure 2.2.

Deck 1.5 consists of void spaces (10) made up from the transverse bulkheads and deck reinforcing the hull girder. The height of these spaces is approximately 1 m and they will only contain limited electrical equipment necessary for inspection and possibly pipe and cable penetrations.

Deck 2 (the main deck) mainly consists of a ro-ro deck in the aft and an accommodation area in the fore. The ro-ro deck is clearly classified as an "*Open ro-ro space*" according to SOLAS II-2/3.35, since it has an opening at one end and is provided with adequate natural ventilation in the sides and from above. Specific kinds of open deck spaces are not distinguished for passenger ships in SOLAS II-2/9; they simply fall under category (5) *Open deck spaces*. However, SOLAS II-2/20.5 specifies special requirements for ro-ro spaces on passenger ships carrying more than 36 passengers. On the Eco-Island ferry the ro-ro deck provides space for six cars or four cars and a truck (typically transporting garbage or delivering supplies or heating oil for apartments on the island). Between the ro-ro deck and the accommodation space there are small compartments containing fire rated ventilation ducts (10) to and from the engine room (this is better illustrated in Figure 2.3). The accommodation space includes a boarding area and a seating area. In the boarding area there are three toilets (9) and exits to shore, ro-ro deck and to stairways (2) leading down to the engine rooms on each side. There is also a staircase leading to deck 3, considered to be a part of the accommodation space. The seating area contains upholstered chairs for 100 passengers (including disabled), a cleaning cabinet (13) placed under the stairs to deck 3 and MES stations on port and starboard side (note that the cleaning cabinet is not marked in figure 2.2). The whole accommodation space is hence an assembly station and falls under category (4), but it is still referred to as the accommodation space. Forward the accommodation space exits to the foredeck (5) where there are life rafts and a deck space for management of the forward mooring arrangements.

Deck 3 contains an open deck space (5) with ~100 seats amidships and the wheelhouse (1) in the front. A passage from the wheelhouse to the exterior staircase on port side is an external escape route.

2.2.2. The prescriptive design

In the prescriptive design of the ship the hull, superstructure, structural bulkheads, decks, deckhouses and all other structures which are required to be made A-class are assumed constructed according to prescriptive requirements, i.e. in steel or other non-combustible material. As a result of the space classifications outlined above, a number of fire safety requirements apply. As for passive fire protection, depicted in Figure 2.3, 60 minutes of thermal insulation must be fitted in the ceiling of the engine rooms and also in the ceiling of the spaces with fuel tanks. In the engine rooms A-30 is required towards the staircases. Since all divisions on decks 1 and 1.5 are generally made in bare or painted steel, there are no relevant surface requirements. However, surfaces in all spaces on decks 2 and 3 must achieve low flame-spread characteristics. Furthermore, since the accommodation space is classified as an evacuation station, 60 minutes of thermal insulation is required towards the fore deck, ro-ro deck and enclosing the cleaning cabinet. The division of the accommodation space is one way to achieve the requirements to have redundant evacuation stations. It is since the life rafts on the fore deck are included in this evacuation plan that it must be thermally separated from the accommodation space. The division between the accommodation deck and the ro-ro basically forms a main vertical zone and divides the ship in two main fire zones.

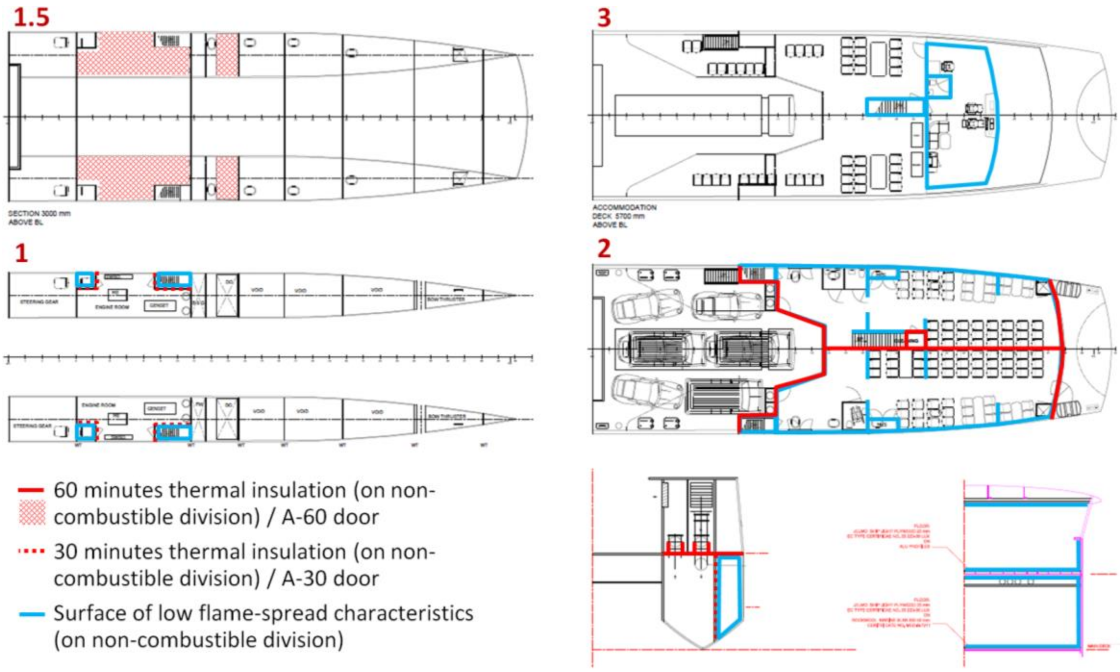

Figure 2.3. Overview of the passive fire protection of the prescriptive design.

The requirements regarding active fire protection includes detection systems, hydrants, fire hoses, portable extinguishers, sprinkler systems etc. All internal spaces of the ship are fitted with smoke detection systems, all except voids and tanks etc. Additional to the smoke detection systems there are visual fire (flame) detectors installed in the engine room and on ro-ro deck. The prescriptive design also includes different extinguishing systems, in accordance with the prescriptive SOLAS requirements as well as requirements of the Fire Safety Systems Code [7]. Internal spaces on deck 2 and deck 3 are protected with a high pressure water mist extinguishing system. The spaces on deck 1 (except engine room and stairs), deck 1.5 as well as casings from the engine room are not covered by sprinkler systems but reached manually from the fire main. The engine room is fitted with a water mist fire-extinguishing system.

2.2.3. General construction of the base design

The decks and bulkheads which otherwise are made in steel or equivalent material were designed in carbon fibre reinforced polymer (FRP), a material composition which is further described below. This construction material is, however, not intended for other structures prescribed to be made in “steel or equivalent material”, such as ladders or doors. Below follow descriptions of the FRP composite constructions intended for the Eco-Island ferry and the most important fire performance features of FRP composite. Together with some implemented additional safety arrangements, described in the following section, this defines the base design of the ship.

2.2.3.1. FRP composite and the intended construction materials

A FRP composite panel essentially consists of a lightweight core separating two stiff and strong fibre reinforced polymer laminates, as is illustrated in Figure 2.4. In maritime applications the core material generally consists of PVC (polyvinyl chloride) foam or balsa wood and the face sheets are generally made by carbon or glass fibre reinforced polymer. When these laminates are bonded on the core, the composition altogether makes up a lightweight construction material with very strong and rigid qualities, which is further described in *Appendix C. FRP composite panels and fire performance*.

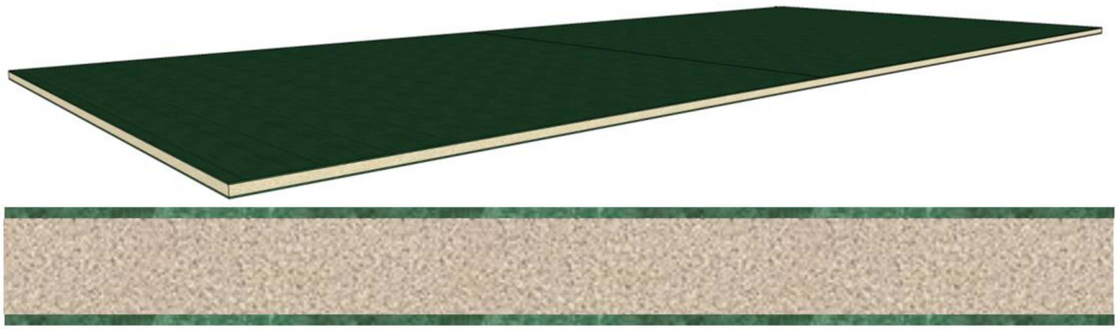

Figure 2.4. Illustration of an FRP composite panel (top) and a close-up on the lightweight core and the rigid and strong fibre reinforced laminates (bottom).

A typical FRP composite set-up is a 50 mm PVC foam core (80 kg/m^3) surrounded by two 1.5 mm carbon fibre reinforced polymer laminates (approximately 2,100 kg/m^3). The total weight of such FRP composite is ~10.5 kg/m^2. This composite could replace a 7 mm steel plate which weighs 55 kg/m^2. Even if additional fire safety measures will add weight, the weight-loss is substantial when using FRP composite instead of steel. The strong and rigid characteristics, in conjunction with the weight-effectiveness, makes FRP composite a cost-effective alternative construction material for ships.

The Eco-Island ferry is intended to be built in a FRP composite consisting of carbon fibre reinforced laminates (Vinyl ester matrix and T300 fibres) on a PVC core (Divinycell). The used thickness and properties of laminates and cores depend on the required strength in different places of the ship. For example, the hull is generally designed with a 40 mm H100 core and laminates of 2.7 and 1.5 mm. Where ice reinforcement is necessary a higher density core (H200) and thicker laminates are used whilst the top sides above the water line are made with lower density core (H80) and a thinner laminates. In the superstructure bulkheads thin laminates are used in combination with a thicker core (60 mm H80) to provide for better acoustic and thermal comfort. The decks work as lateral stiffeners and are therefore generally of a more rigid construction (2,5 to 2,7 mm laminates on a 60 mm H130 core). Furthermore, a thin glass fibre laminate is applied to most exterior surfaces of the hull and superstructure to provide a rub layer.

2.2.3.2. Fire performance of FRP composite

The general material construction replacing steel in the ship is a sandwich construction with a lightweight core separating two laminates. In summary, the performance of such a construction when exposed to fire varies with the composition, mainly depending on three conditions:

- thickness of face sheets: a thinner laminate gives a worse performing panel;
- density of core material: a lighter material gives a negative effect on the performance;
- type of plastic: a polymer with lower softening temperature gives less fire resistance.

As long as the core is intact and well adhered to both laminates, the structural strength of the material is not affected. The critical part of the construction regarding resistance to fire is hence the bonding between the core material and the laminate. The bonding softens and the structural performance deteriorates when the temperature in the bonding becomes critical; typically at 130-140ºC for a vinyl ester (and ~200ºC for a phenolic polymer matrix). Tests in the small-scale testing device called the Cone calorimeter (ref, ISO 5660) have shown that such critical temperature could be reached typically within one minute if the FRP composite is directly exposed to fire [9]. In addition, Figure 2.5 shows that the material *ignites* very quickly when exposed to 50 kW/m^2 irradiation in the Cone calorimeter, an irradiance level typical of a large fire. Theoretically, a short period of such fire exposure might thus be critical for unprotected FRP composites, both from a structural strength perspective as well as from a fire perspective. However, large scale fire tests have shown that FRP composite structures may last much longer [2, 10, 11], both when exposed to local fire and fully developed fire. Further descriptions of the fire performance of FRP composite constructions are found in *Appendix C. FRP composite panels and fire performance*.

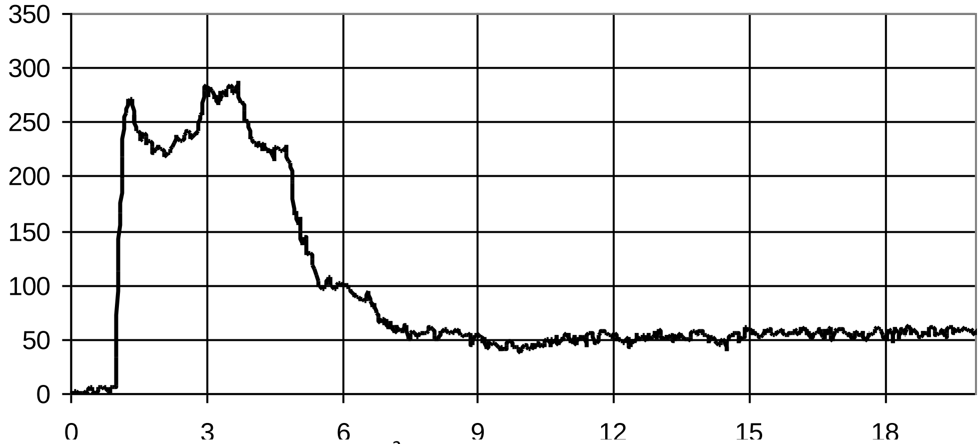

Figure 2.5. Heat release rate (kW/m^2) on the y-axis vs. time (minutes) on the x-axis, from FRP composite material when exposed to an irradiation of 50 kW/m^2 in the Cone calorimeter.

2.2.3.3. Insulation as a measure to achieve fire resistance

The structures replaced by FRP composite are generally required to achieve A-class standard. According to SOLAS II-2/3.2 this implies a “non-combustible” construction that will resist a 60 minute fire (represented by a temperature rise in a large furnace according to the standard temperature-time curve as defined by ISO [12]) without letting hot gas or flames pass to the side unexposed to fire, in accordance with IMO Resolution A.754(18) [12]. Depending on the following number, “A-X” (X = 0, 15, 30 or 60) requires a temperature rise less than 140°C after X minutes on the side of the construction that is unexposed to fire. To achieve this, steel structures are generally thermally insulated. FRP composite is a good thermal barrier on its own and the fundamental condition to achieve A-class standard is hence not so much the temperature requirement on the unexposed side but that structural resistance is maintained for 60 minutes. It has been demonstrated that a FRP composite construction can be designed to contain fire and achieve structural resistance on its own [2, 10, 11], e.g. by stiffeners, double panels, or pillars. A simpler and many times lighter way to achieve this is by insulating the FRP composite divisions sufficiently to not deteriorate from the prescribed 60 minute fire. Such construction is illustrated in Figure 2.6. However, the requirement on non-combustible construction material would still be deviated.

In the International Code of Safety for High-Speed Crafts [13] (HSC Code) there is no restriction to make load-bearing structures only in non-combustible materials. Instead of A-class divisions the HSC Code correspondingly requires Fire Resisting Divisions (FRD). The fire test required for an FRD in a High Speed Craft (HSC) is defined by IMO Resolution MSC.45(65) [14] and is almost equivalent to the test required for A-class divisions in SOLAS ships, except for an additional load-bearing requirement. This requirement implies that FRD decks and bulkheads shall withstand the standard fire test while subject to transverse and in-plane loading, respectively. This additional requirement was implemented for the test to apply to constructions which do not have the same ability to withstand high temperatures before strength deterioration. The HSC Code is although not applicable due to the restricted speed of the Eco-Island ferry, which would have to be >15.9 knots.

Even if a FRD60 construction does not achieve the requirement on non-combustibility it will fulfil the SOLAS requirements on fire resistance for an A-60 division. Furthermore, from the above discussion on critical temperature for softening of the FRP laminate-core interface, it is clear that the temperature on the unexposed side will, down to the high insulation capacity of the composite, be virtually at room temperature even after 60 minutes of fire. The heat from a fire will therefore to a larger extent stay in the fire enclosure and not so easily be transmitted to adjacent spaces.

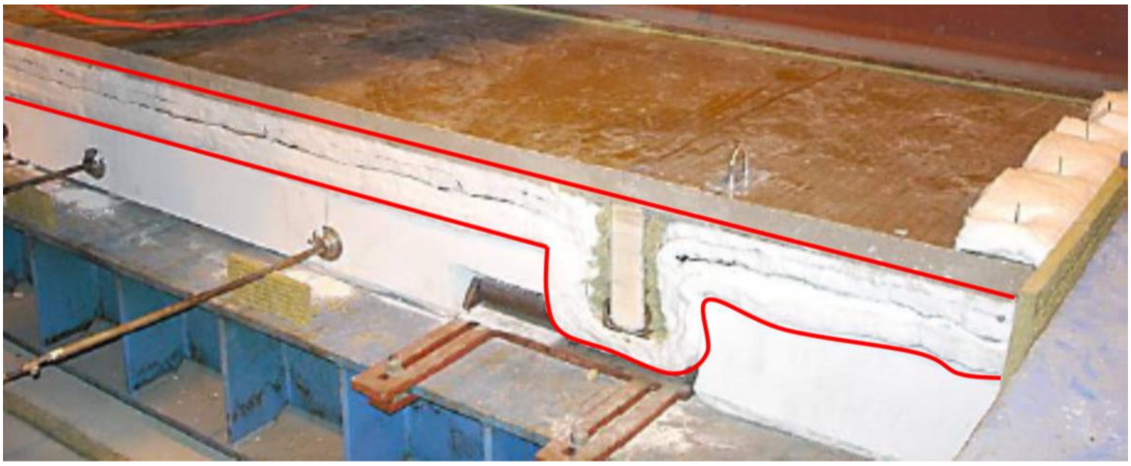

Figure 2.6. FRP composite deck with 60 minutes of thermal insulation, marked red, to be tested according to MSC.45 (65) [14].

Use of thermal insulation is one example of how the FRP composite could be protected to reach sufficient structural and integrity properties. The FRP composite could also be protected by combinations of passive and active risk control measures (RCMs) which altogether provides a solution with sufficient safety, e.g. surface treatment (achieving low flame-spread characteristics according to the FTP code [15]), limited insulation and sprinkler redundancy. The particular fire safety measures which are intended in the base design are further described below whilst potential additional RCMs are presented in section *3.2 Description of the trial alternative designs being evaluated*.

2.2.4. Fire protection of the base design

The base design is founded on the above general descriptions of the ship, with its layout and constructions intended in FRP composite. Except from making load-bearing structures in a combustible material, certain fire safety measures were implemented on a general basis. The ship was designed to fulfil applicable prescriptive requirements regarding the fire safety organization and fire fighting routines. As for the active and passive fire protection systems and equipment they were based on the prescriptive requirements but with the ambition to establish a base design which contains only those safety measures which are certain to be included in the final design. Hence, a minimum level of safety was sought to provide for flexibility in the selection of additional safety measures. Such a base design was defined in the preliminary analysis report. However, because of the predominant benefits in risk reduction compared to cost, a number of additional RCMs (not required prescriptively) were included on a general basis. The additional RCMs which were thus certain to be included in all trial alterative designs are the following:

- RCM e: Fog nail for use as a fire fighting tool, at least available on deck 2 and also for use towards deck 1.
- RCMs h1, h2 and h3: Encapsulated electrical equipment in void spaces and auxiliary machinery spaces.
- RCM k: Improved floor construction in accommodation space and wheelhouse.
- RCM l1: Non-combustible surface covering the ro-ro deck
- RCM p: Door closing devices on WCs
- RCMs t1, t3 and t4: Smoking forbidden and hazard minimization by clear “no smoking” throughout the ship, TV information screens and spoken information through speakers given before each voyage.

- RCMs u1, u2, u3 and u4: New routines consisting of:
    - maximum 25 passengers on board when oil tank truck is transported;
    - no passengers on board during bunkering;
    - redundant manual extinguishing equipment ready during bunkering; and
    - manual extinguishing equipment brought down to the auxiliary machinery spaces in case of repair (portable extinguisher or hydrant from above).

In the preliminary analysis report these and a number of other RCMs were included in all RCOs. However, **in this report the above RCMs were incorporated as part of the base design** whilst combinations with other RCMs may be evaluated in the quantitative assessment. The (new) base design is further described below with regards to active and passive safety measures. Hence, the following analyses of the base design assume the addition of the above RCMs. Further RCMs identified to have a potential and the considered trial alternative designs are described in the next chapter, along with other results of the preliminary analysis in qualitative terms.

2.2.4.1. Active fire protection of the base design

The base design of the ship fulfils applicable prescriptive requirements regarding the active fire protection systems and equipment. Detection system, hydrants, fire hoses, portable extinguishers, sprinkler systems etc. comply with prescriptive requirements. All internal spaces of the ship therefore have smoke detection systems installed, all except voids having no source of ignition. Additional to the smoke detection systems there are also visual fire (flame) detectors installed in the engine room and on ro-ro deck. The base design also includes different extinguishing systems, all complying with the prescriptive SOLAS requirements as well as requirements of the Fire Safety Systems Code [7]. Internal spaces on deck 2 and deck 3 are protected with a high pressure water mist extinguishing system but spaces on deck 1 (except engine room and stairs), deck 1.5 as well as casings from the engine room are not covered by sprinkler systems. These spaces are reached manually from the fire main, except from the engine room which is fitted with a water mist fire-extinguishing system.

Except from the above prescriptive active measures, door closing devices are installed on doors to WCs and fog nail is added as a fire fighting tool. New routines are also implemented with regards to manual extinguishing tools in auxiliary machinery spaces and during bunkering.

2.2.4.2. Passive fire protection of the base design

Regarding passive fire protection, Figure 2.7 illustrates how the base design was designed in general. Starting from deck 1, none of the spaces are designed with added passive fire protection except from the engine rooms and the stairways leading to them. Between the engine room and the adjacent compartments (steering gear, voids, stairways and water tank) in each pontoon there are A-class requirements (A-0, A-0, A-30 and A-0, respectively). In the base design the engine room will be fitted with 60 minutes of thermal insulation from the inside to provide 60 minutes of structural integrity in case of an engine room fire. It will hence also give 60 minutes of protection against fire spread, which is otherwise only required against ro-ro deck (A-60). As in a prescriptive ship, the bulkheads will only be fitted with insulation down to 300 mm below the water line. The area below this level is covered with a surface of low flame-spread characteristics in accordance with the relaxed requirements for Aluminium hulls. However, this may need further attention since the FRP composite is not cooled by sea water and furthermore is combustible. For uniformity reasons the doors to the stairways and to the protected enclosures aft of the engine rooms will also be of A-60 category (A-30 required).

However, the bulkheads are not thermally insulated from the stairways and protected enclosure sides. The passive fire protection in the stairways are surfaces of low flame-spread characteristics. Spaces classified in category (10) *Tanks, voids and auxiliary machinery spaces having little or no fire risk* were left with unprotected FRP composite in the base design (A-0 required in ceiling and bulkheads), which needs further attention. The spaces with fuel tanks are left without any passive fire protection in the base design even though A-60 is required towards the accommodation space above and A-0 toward the surrounding void spaces. The actual tanks occupy approximately one third of the spaces.

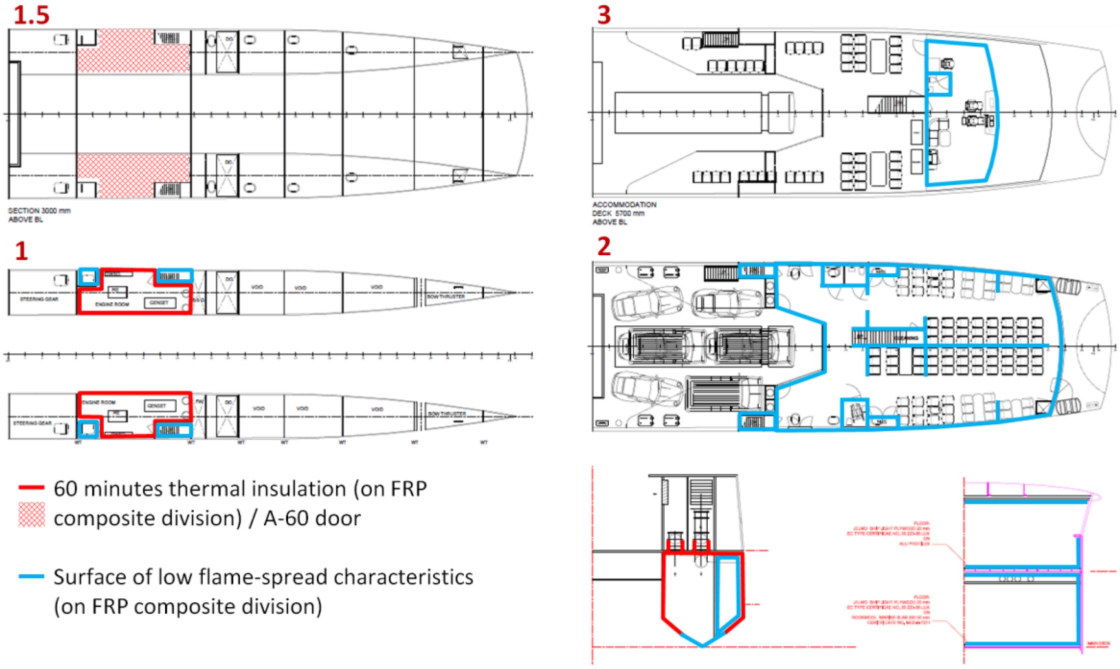

Figure 2.7. Passive fire protection of the base design.

Moving up there is a non-combustible deck plating covering ro-ro deck in the new base design. This will hinder the FRP composite deck from being directly exposed to a fire and could be argued to account to the fire resistance of the division. However, requirements in SOLAS II-2/20.5 for ro-ro decks state that the boundary bulkheads and deck of ro-ro spaces shall be insulated to A-0 or A-60 class standard, depending on the adjacent space. This means that the forward bulkhead towards the accommodation space and the deck towards voids, engine room and steering gear need to achieve fire resistance for 60 minutes and also that the divisions towards the accommodation space, engine room and the steering gear also need to achieve 60 minutes of thermal insulation. On a steel ship this is generally managed by insulating the inside of the steel decks and bulkheads. Thermal insulation providing fire protection for 60 minutes was provided on the inside of the divisions in the engine rooms in order to hinder fire spread in case of a large fire in these spaces. However, insulating the inside will not provide 60 minutes of structural integrity in case of a large fire on ro-ro deck. Except from provision of thermal insulation in engine rooms, the deviated A-60 requirements could be addressed by different means in the trial alternative designs. In the base design the surrounding spaces were therefore left non-insulated in the base design. The combination of safety measures will have to be evaluated further based on the fire scenarios in the different spaces. The design also deviates from prescriptive requirements by not separating the cleaning closet with A-60 divisions. The same applies to the division between the accommodation space and the foredeck, which is only made in FRP composite. Furthermore, the accommodation space is supposed to be separated from the wheelhouse by an A-0 deck, which is also only FRP composite.

On deck 3 the wheelhouse is supposed to be separated from the open deck space by A-0 divisions but this is only protected by FRP composite divisions with surfaces of low flame-spread characteristics on the inside. The toilet in the wheelhouse is also supposed to be enclosed by A-0 divisions but is only protected by FRP composite divisions with surfaces of low flame-spread characteristics. The floor construction in the wheelhouse, and also in the accommodation area, consists of 20 mm Rockwool (high density) plates covered by a carbon FRP laminate (achieving fire resisting material according to [13]).

With regards to doors, these were designed to fulfil A-0 standard unless the division was made FRD60; the A-60 doors are used. In the accommodation space the toilets may be separated with B-0 divisions according to SOLAS II-2/9.2.2.3.2.2, since they are fully enclosed in the space. These divisions are although designed as the rest of the accommodation space, with FRP composite and surfaces of low flame-spread characteristics. They will although have regular B-class doors.

A number of deviations from prescriptive regulations have already been identified above. These mainly concern internal surfaces but also exterior surfaces may need further attention. Furthermore, collapse due to fire must be kept in mind in case of a prolonged fire, not only to protect passengers but also to provide safety for fire fighting crew in and around a fire in a FRP composite structure. Challenges against prescriptive requirements are further investigated in the following section. Additional safety measures are required to achieve sufficient safety but the suitability of combinations of risk control measures needs to be further evaluated.

3. Results of the preliminary analysis in qualitative terms

In the preliminary analysis in qualitative terms a design team was firstly formed. Thereafter the SOLAS fire safety regulations were investigated to understand and document differences in fire safety between the base design and a prescriptive design, which establishes the needs for verification. The effects from the differences in fire safety are to be incorporated in fire scenarios in the quantitative analysis. These fire scenarios were developed by a process which firstly consisted of identifying and tabulating fire hazards. The fire hazards were then enumerated and rated in different ways to form the basis for a selection, which formed basis for fire scenarios in different kinds of spaces on the ship. These processes and their results are further described below, along with risk control measures found to be suitable to form trial alternative designs.

3.1. Members of the design team

The guidelines in Circular 1002 prescribe to form a design team to be responsible for the analysis and for co-ordinating the activities with regards to Regulation 17. The design team should mirror the complexity of the task in the sense that the members should together possess all the necessary competence to perform the assessment of fire safety. The persons selected for the design team in this project and their main expertise are presented in Table 3.1.

Table 3.1. The design team selected to contribute to the assessment of fire safety of the Eco-Island ferry

Name	*Organisation*	*Profession / Competence*	*Role / responsibility*
Jens Otto Sørensen	Danish Yachts A/S	Mechanical Engineer, manufacture and ship design in FRP composite	Project leader of the Eco-Island ferry project, ship yard representative, ship design
Niels Kyhn Hjørnet	Yacht Design & Composite Engineering	Naval architect, ship design in FRP composite	Ship design
Mats Hjortberg	Coriolis AB	Naval architect, ship design in FRP composite, regulations, alternative design	Ship design, fire safety design
Henrik Johansson	Kockums	Naval architect, manufacture and ship design in FRP composite, fire safety	Ship design, fire safety design
Franz Evegren	SP	Research scientist, risk management, fire safety	Primary contact person, co-ordinator of Regulation 17 assessment, fire safety design
Malika Piku Amen	SP	Project manager, FRP composite, fire safety	Co-ordination, Regulation 17 assessment, fire safety design
Michael Rahm	SP	Project manager, fire safety, mechanics, risk assessment	Regulation 17 assessment, fire safety design
Tommy Hertzberg	SP	Senior research scientist, fire safety, risk assessment, FRP composite	Regulation 17 assessment, fire safety design, quality assurance

3.2. Description of the trial alternative designs being evaluated

As mentioned in section *2.2. Definition of the prescriptive design and the base design*, a base design usually needs additional risk control measures (RCMs) for the ship to provide sufficient safety[1]. A combination of risk control measures makes up a risk control option (RCO), which is applied to the base design in order to improve safety. Together with the base design, different RCOs make up trial alternative designs, as illustrated in Figure 3.1.

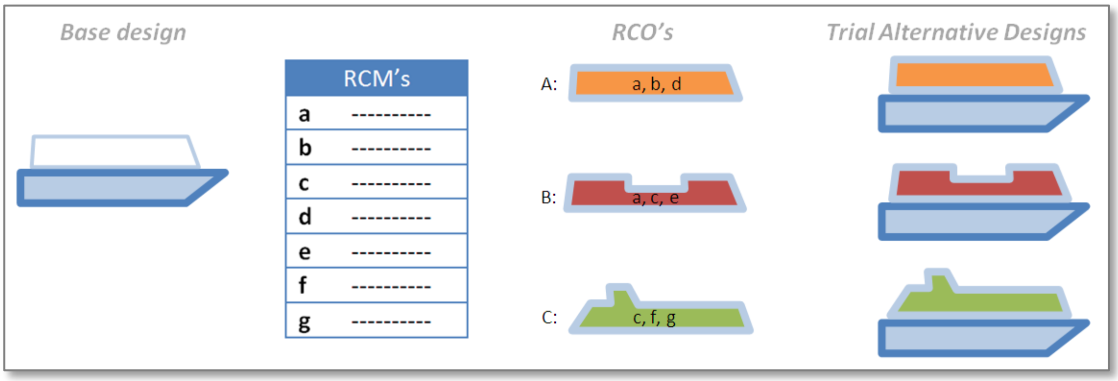

Figure 3.1. Illustration of the relation between the base design, RCMs, RCOs and trial alternative designs.

The ship in FRP composite imposes new risks. It is therefore essential that suitable risk control options are found to manage these risk. Since it is not constructive to eliminate risk control measures or combinations of such at an early stage, no risk control options were firmly defined in the preliminary analysis report. Suggested RCMs were tabulated (see *Appendix D. Identified risk control measures*) and all of those were said to be able to form risk control options, individually or in combination with others. The risk control options were kept open since the impact of individual or combinations of RCMs is not possible to fully comprehend until the effects are established in the quantitative analysis.

Except from the safety measures of the base design (some RCMs were certain to be included in all trial alternative designs and were therefore incorporated in the base design in the quantitative analysis, as described in paragraph *2.2.4. Fire protection of the base design*) a number of RCMs were considered particularly suitable, namely:

- RCMs a1 and a3: Redundant supply unit for extinguishing system in stairways, accommodation space (including the void space above the ceiling in the accommodation space if extinguishing system is installed there), wheelhouse as well as in the engine rooms;
- RCM a2: Fully redundant interior sprinkler system;
- RCM a4: Ro-ro deck extinguishing system with redundant supply unit;
- RCM a5: Fully redundant ro-ro deck extinguishing system;
- RCM c1 and c3: Drenchers covering the outside of the bulkhead separating the accommodation space from the ro-ro deck as well as the sides and front of the ship from deck 3 and down;
- RCM c2: Drencher system covering the whole ro-ro deck;
- RCM d: Extinguishing system on ro-ro deck with pop-up nozzles;

[1] In the end the base design may prove to provide sufficient safety on its own, due to safety measures implemented beyond applicable prescriptive requirements. In that case the base design forms an acceptable trial alternative design. However, the normal case is that the base design needs additional RCMs in order to provide sufficient safety.

- RCM g: Smoke detectors in void spaces;
- RCM i4 or i5: Low flame-spread characteristics on FRP composite surface facing ro-ro deck (on bulkhead between ro-ro deck and accommodation space) or on all FRP composite surfaces facing ro-ro deck;
- RCMs j1, j2, j3, j4 and j7: Fire Resisting Material covering FRP composite surfaces in accommodation space, toilets, stairways, auxiliary machinery spaces, wheelhouse and cleaning closet;
- RCM n3: Improved structural fire resistance by added thermal insulation on the accommodation space side of the boundary bulkhead between accommodation space and ro-ro deck;
- RCMs n1, n2, n3 and n5: Improved structural fire resistance to achieve FRD60 in the whole of the accommodation space;
- RCM n6: Improved structural fire resistance to achieve FRD60 on wheelhouse side of the boundary bulkhead between wheelhouse and open deck space;
- RCM n11: Thermal insulation encapsulating fuel tanks (made in steel or equivalent material);
- RCM n12: Structural redundancy of accommodation space/ro-ro deck bulkhead;
- RCM o1: Additional structural division of FRD60 dividing the accommodation space longitudinally;
- RCM q1 or q2: Fire resistant windows on the sides of the wheelhouse or in the whole wheelhouse; and
- RCMs r1, r2, r3 and r4: Alarm on openings to WCs, voids, auxiliary machinery spaces and engine rooms.

Some of the above RCMs originate the trial alternative designs which were primarily considered. All combinations of RCMs can although still be included in the analysis, where the most advantageous risk control options are sought. The combinations of RCMs which were primarily considered in case safety would need to be improved further are the following:

- a1, c1 and o1;
- a1, n12 and o1;
- a1, d, a4, i4 and o1;
- a1, d, a4, i5 and o1; and
- a1, d, a4, i5, n12, o1.

3.3. Discussion of affected SOLAS chapter II-2 regulations and their functional requirements

By not complying with the prescriptive requirements, the base design does not achieve the same level of safety as is provided by a prescriptive design. It is therefore crucial to identify all deviations and how these may have an effect on safety. This determines the approval basis (or the needs for verification). This investigation is presented subsequently, commencing with a background to and overview of the same. As part of the revised approach, the achievement of purpose statements was also judged independently (without regard to deviated prescriptive requirements), which is included in the discussions below. Some further evaluations were also made which are presented in *Appendix F. Additional regulation and fire safety evaluations*. These evaluations were added since use of FRP composite in shipbuilding is still relatively new and has limited field history regarding effects on fire safety and due to the rather large scope of the design and the deviations. The results from these additional investigations are summarized at the end of this section.

3.3.1. Background to investigation of affected regulations

The fire safety chapter in SOLAS is structured as illustrated in Figure 3.2. The goals of the chapter are defined through stated fire safety objectives at the beginning of the chapter. For these to be achieved, a number of stated functional requirements are embodied in the following regulations of the chapter. Hence, the fire safety objectives and functional requirements are achieved by compliance with the prescriptive requirements. It is although stated that the fire safety objectives and functional requirements should also be considered achieved if the ship has been reviewed and approved in accordance with Regulation 17. Note that compliance with prescriptive requirements thus only is one way to achieve the fire safety objectives and functional requirements of the fire safety chapter.

After the introductory regulations follow regulations with prescriptive requirements covering different areas of fire safety, e.g. ignition, containment or fighting of fire. The particular area of fire safety is defined by a purpose statement at the beginning of each regulation. The purpose statement consists of a regulation objective and the functional requirements to be achieved by that regulation[2]. Thereafter follow prescriptive requirements.

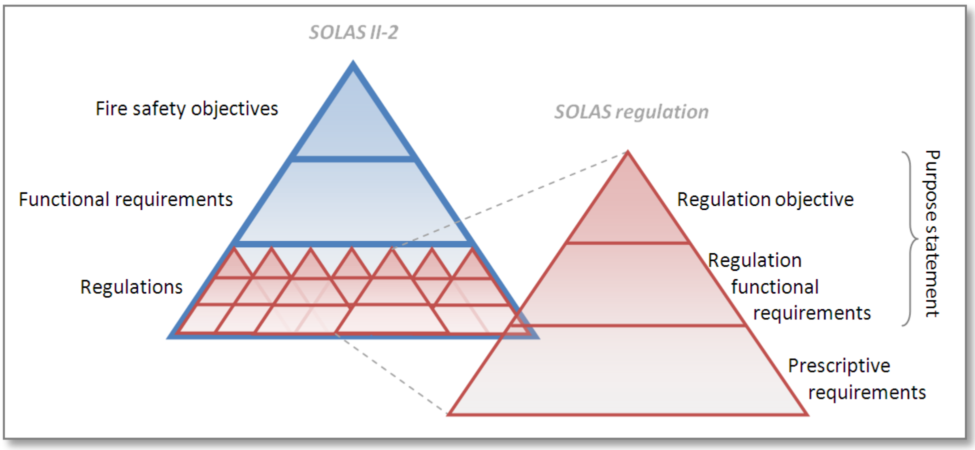

Figure 3.2. Each regulation in SOLAS II-2 consists of a purpose statement and prescriptive requirements. The purpose statements comprise regulation functional requirements and an individual regulation objective which sets out the objective of the functional requirements.

The fire safety objectives and functional requirements of the fire safety chapter can be said to define fire safety, which hence also defines how safety is viewed and measured. This is further defined through the functional requirements in the regulations, in light of the regulation objectives. Therefore it is highly important to identify which functional

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[2] For example, Regulation 5 in SOLAS II-2 has a purpose statement specified in SOLAS II-2/5.1. The first sentence expresses the regulations' objective: "...to limit the fire growth potential in every space of the ship." Thereafter follow three functional requirements in SOLAS II-2/5.1.1-3, that shall be achieved in order to realize the objective of this regulation. In the same way, Regulation 6 in SOLAS II-2 has a regulation objective expressed in the first sentence in SOLAS II-2/6.1: "...to reduce the hazard to life from smoke and toxic products generated during a fire in spaces where persons normally work or live." Thereafter follow the functional requirements (however in this case only one) specific for this regulation: "...the quantity of smoke and toxic products released from combustible materials, including surface finishes, during fire shall be limited." Each regulation in SOLAS II-2 has a similar purpose statement, where the regulation objective (RO) is defined and followed by regulation functional requirements (RFR) that shall be achieved in order to accomplish the objective.

requirements the base design may affect the achievement of. This is done by identifying deviations from prescriptive requirements and clarifying their purposes by recognizing the associated functional requirements. The functional requirements of the deviated prescriptive requirements can thereafter be used (along with the fire safety objectives) to define performance criteria. How well the performance criteria must be achieved is determined by how well a reference design, complying with applicable prescriptive requirements, performs. Thereby it is possible to determine how deviations to regulations affect safety.

If effects on safety from deviations can be managed within the scope of each regulation separately this is recommendable, since it simplifies the evaluation process. However, if the scope of deviations is great, as in this case, the ship may not achieve the functional requirements of each deviated regulation as well as a prescriptive design. It may then be necessary to account for better performance in other areas to compensate for such deficiencies. In this case it has been judged necessary to take this broader approach to assess safety.

2.3.1 Overview of investigation of affected regulations

A scrutiny of the fire safety regulations in SOLAS II-2 was carried out where the regulations were divided according to Figure 3.2 above and where deficiencies of the base design were determined. As part of the revised approach, not only deviations to prescriptive requirements were identified but also effects on the achievement of purpose statements. The main identified deficiencies are summarized in

Table 3.2 along with associated regulation functional requirements and regulation objectives. The regulations are thereafter discussed in the following paragraphs. These are excerpts from the full scrutiny of all regulations which is lain out in *Appendix E. Evaluation of prescriptive requirements and associated functional requirements*.

Table 3.2 A summary of the challenged SOLAS II-2 regulations and a comment on how the base design challenges prescriptive requirements and purpose statements

SOLAS II-2	***Regulation Objective (RO)***	***Regulation Functional Requirements (RFR)***	***Comment on how the regulation affects the base design***
Part B	**Prevention of fire and explosion**		
Reg. 5 Fire growth potential	Limit the fire growth potential in every space of the ship.	(1) Control the air supply to the space; (2) Control flammable liquids in the space; (3) Restrict the use of combustible materials.	Unprotected and sparsely protected FRP composite surfaces could be a fire risk, even if specific **deviations are lacking**. If open deck is considered a space, unprotected external surfaces challenge RFR 3.
Reg. 6 Smoke generation potential and toxicity	Reduce the hazard to life from smoke and toxic products generated during a fire in spaces where persons normally work or live.	Limit the quantity of smoke and toxic products released from combustible materials, including surface finishes, during fire.	Unprotected interior FRP composite surfaces in voids and auxiliary machinery spaces **may be argued to challenge Reg. 6.2.1**, even if the surfaces are without finish.
Part C	**Suppression of fire**		
Reg. 9 Contain-ment of fire	Contain a fire in the space of origin	(1) Subdivide the ship by thermal and structural boundaries; (2) Boundaries shall have thermal insulation of due regard to the fire risk of the space and adjacent spaces; (3) The fire integrity of the divisions shall be maintained at openings and penetrations.	Load-bearing bulkheads, decks, and internal bulkheads made in combustible material **deviates from the A and B class definitions**. Insufficient thermal insulation is provided in several places whilst improved thermal insulation is provided in other places.
Reg. 11 Structural integrity	Maintain structural integrity of the ship, preventing partial or whole collapse of the ship structures due to strength deterio-ration by heat.	Materials used in the ships' structure shall ensure that the structural integrity is not degraded due to fire.	**Reg. 11.2 is deviated** as it states structures to be constructed in "steel or other equivalent material", which is defined as non-combustible in Reg. 3.43.
Part D	**Escape**		
Reg. 13 Means of escape	Provide means of escape so that persons on board can safely and swiftly escape to the lifeboat and liferaft embarkation deck	(1) Provide safe escape routes; (2) Maintain escape routes in a safe conditions, clear of obstacles; (3) Provide additional aids for escape, as necessary to ensure accessibility, clear marking, and adequate design for emergency situations.	Reg. 13.5.1 requires thermal insulation separating ro-ro deck from spaces below, **which is deviated towards steering gear**. From SOLAS III it is implied that two alternative evacuation stations should be provided, which is not fulfilled.

Part G	Special requirements		
Reg. 20 Protection of vehicle, special category and ro-ro spaces	Provide additional safety measures in order to address the fire safety objectives of this chapter for ships fitted with vehicle, special category and ro-ro spaces	(1) Provide fire protection systems to adequately protect the ship from the fire hazards associated with vehicle, special category and ro-ro spaces; (2) Separate ignition sources from vehicle, special category and ro-ro spaces; (3) Adequately ventilate vehicle, special category and ro-ro spaces.	The structural fire protection required by **Reg. 20.5 is deviated** in the base design; partly since the FRP composite does not fulfil A class standard and partly due to lack of thermal insulation towards the accommodation space, overhang and engine rooms.

3.3.2. Regulation 5: Fire growth potential

This regulation oversees materials in spaces with the intention to limit the fire growth potential. In the prescriptive requirements, use of non-combustible and combustible materials is primarily managed in paragraph 3. Except interiors and furnishings the requirements concern linings, grounds, draught stops, ceilings, faces, mouldings, decorations, veneers, insulation materials, partial bulkheads etc. These are also the materials that will govern the growth face of a fire, together with e.g. luggage, furniture and fittings. In general, all surfaces and linings in accommodation and service spaces must fulfil requirements of a maximum calorific value of 45 MJ/m^2, a maximum volume of combustible material and have low flame-spread characteristics according to the FTP code. This is why the accommodation space, stairways and wheelhouse are designed with such surface material. For other spaces these requirements do not apply, which is the reason why tanks, voids and auxiliary machinery spaces were left without such a protective surface in the base design. However, these uncovered divisions are normally made of non-combustible material. Similarly, constructions with surfaces of low flame-spread characteristics are normally not constructed with a combustible FRP composite just underneath. Since these fire hazards could affect fire growth and the first stages of a fire (which is covered by this regulation) they must be addressed appropriately. The revised base design includes some relevant additional safety measures but particularly the auxiliary machinery spaces have been identified to may need further attention. The presented RCOs are meant to address these hazards further.

Even if all prescriptive requirements of regulation 5 considering enclosures could be argued complied with, the design in FRP composite will still have implications for the fire growth potential. Looking at the functional requirements, neither of the first two is affected by use of FRP composite in ship constructions. The third regulation functional requirement (Regulation 5.1.3) could although be claimed challenged as it states that the use of combustible materials shall be restricted. The regulation objective sets the focus on spaces and, except from what is discussed above, the base design will not add to the fire growth potential in spaces. However, if open deck is considered a space, the unprotected combustible external surfaces could give reason to assert deviation from the regulation functional requirement. Intrinsically the consequences of affecting the fire growth potential on exterior surfaces are not as problematic since smoke management is not critical.

3.3.3. Regulation 6: Smoke generation potential and toxicity

Similar to Regulation 5, the scope of Regulation 6 is also enclosures and the first stages of a fire, which is primarily when people could be exposed to toxic smoke. All materials involved in a fire will contribute to the production of toxic smoke but during the first stages of a fire it is mainly the exposed surface that will contribute to the generation and toxicity of smoke. This regulation therefore generally controls exposed surface finishes (with the exception of primary deck coverings which are also required not to give rise to smoke or toxic or explosive hazards at elevated temperatures).

In order to reduce the hazard to life, only approved linings, floors, surface materials etc. are used in the base design. However, in the spaces where the FRP composite is left unprotected, Regulation 6.2.1 may be claimed challenged. Even if this regulation only applies to surface finishes it may be argued that a non-combustible material is implied underneath. The generation and toxicity of smoke may therefore not be limited to the same extent as in a prescriptive design in these spaces. Reflecting in what spaces such deviation would be relevant, exterior spaces should not be considered since smoke management is not critical outside. Furthermore, the aim of the regulation is spaces where people work or live, which excludes void spaces. The only spaces left without such a surface are the steering gear and the bow thruster spaces, if those are considered as spaces where people work.

In the engine room, thermal insulation will be used in internal divisions to protect the combustible FRP composite surfaces from becoming involved in a fire. For the time that the construction is thermally protected, the FRP composite will not add to the generation or toxicity of the produced smoke.

3.3.4. Regulation 9: Containment of fire

This regulation prescribes main vertical and horizontal zones and, where necessary, internal bulkheads to be made up by A-class divisions, which implies steel or other equivalent material should be used. SOLAS II-2/3.43 defines “steel or other equivalent material” as a non-combustible material which, by itself or down to insulation provided, has structural and integrity properties equivalent to steel **at the end of the standard fire test** (as a result of this definition doors, pipes, windows etc. are also generally required to be made in metal when penetrating A class divisions).

To fulfil the A class requirement some of the FRP composite divisions and penetrations have been fitted with 60 minutes of protective thermal insulation. Some FRP composite divisions in the base design are although not insulated even though such requirements apply (see *2.2.4.2. Passive fire protection of the base design*) according to tables 9.1 and 9.2 in Regulation 9. For example most boundary bulkheads facing the ro-ro deck need to be insulated to A-60 class standard according to Regulation 9.6.6.1, which is not fulfilled by the base design (the same requirement is found in SOLAS II-2/20, where it is further commented). The fore deck needs to be protected from a fire in the accommodation space by A-60, which is neither fulfilled. Towards open deck from the accommodation space and the wheel house A-0 requirements apply but simple FRP composite is provided.

In case of an engine room fire, the base design achieves equal structural properties to A-60 and the added thermal insulation in divisions and penetrations makes it exceed the requirements on integrity by all means. Especially where only A-0 divisions are required and there is no obligation to insulate divisions or to use fire rated penetrations. Thanks to improved thermal insulation, the engine room in the base design will contain a fire in its origin better than the reference design. However, it is a deviation that the divisions surrounding the engine room are only protective one way, i.e. the division doesn’t function equally if a fire starts in the surrounding compartments. Furthermore, even if structural and integrity properties in divisions are achieved by thermal insulation, using combustible FRP composite in A-class divisions pose deviations since the material is combustible.

In addition, Regulation 9.7 further describes that ventilation ducts have to be of non-combustible material. As the ducts in the base design are made of FRP composite, this prescriptive requirement is also deviated. There is also a requirement to protect the spaces with fuel tanks with A-60 divisions which is although not considered constructive since the tanks are not in connection with the division.

3.3.5. Regulation 11: Structural integrity

This regulation intends to ensure that structural integrity is maintained in case of fire. After the purpose statement of the regulation follows a foundational requirement (Regulation 11.2) which prescribes structures to be constructed in steel or other equivalent material. That refers to any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the standard fire test (MSC.45(65)). The structural and integrity properties equivalent to steel may be achieved at the end of the applicable exposure to the standard fire test if the FRP composite is sufficiently insulated. However, unlike the requirements on structural and integrity properties, the requirement for non-combustibility is not time-limited and cannot be achieved by a FRP composite construction.

All materials lose their structural strength when exposed to a large fire. Steel structural integrity due to heat transfer, which may cause potential for fire spread to adjacent compartments. FRP composite although loses structural integrity due to strength deterioration when bonding is lost between the core and the exposed laminate. There are hence different reasons to use thermal insulation for FRP composite and steel divisions.

The structural integrity in case of fire should not be worse in a construction with FRD60 divisions compared to one with A-60 divisions during the first 60 minutes. They both pass the 60 minute standard test for A-60 bulkheads and decks according to MSC.45(65) [15]. However, in some cases in the base design FRD60 is used instead of A-0, which has no restrictions regarding the temperature rise at the unexposed side. There are also cases where unprotected FRP composite is used instead of FRD60. This hazard has been addressed partly by redundancy in the sprinkler system. In any case the fact that FRP composite constructions are combustible may not be overlooked, both for unprotected and protected divisions.

3.3.6. Regulation 13: Means of escape

This regulation aims to provide means for persons to safely and swiftly escape a fire, assemble and proceed to their evacuation station (embarkation deck). In order to achieve safe escape routes Regulation 13 requires fire integrity and insulation in several places, referring to values in SOLAS II-2/9 (tables 9.1 to 9.4). Since it is only referred to fire integrity and insulation values and not to the class of the divisions it could be argued that a sufficiently insulated FRP composite division achieves such requirements. These appear in Regulation 13.5.1 which requires escape routes from ro-ro deck to be thermally protected from fire on the decks below; in this case by A-0 divisions against the void spaces and by A-60 divisions against the steering gear and the engine room. The separations against steering gear do not fulfil these requirements, which although the void spaces and engine rooms do (not considering the requirement on non-combustibility).

The life rafts on foredeck must be protected from a fire in the accommodation space, which requires 60 minutes of fire protection by thermal insulation. This is not achieved by the simple FRP composite division in the base design. Furthermore, from SOLAS III it is apparent that two alternative evacuation stations must be provided. This is not fulfilled by the base design since it consists of only one large evacuation station, i.e. the accommodation space. A suggested RCM is to manage this by adding an additional

FRD60 division dividing the accommodation space longitudinally and thereby achieve evacuation station redundancy.

3.3.7. Regulation 20: Protection of vehicle, special category and ro-ro spaces

This regulation describes requirements for ventilation, alarm and detection systems, fire extinguishing equipment and structural requirements for spaces with vehicles. In Regulation 20.5 it is stated that in passenger ships carrying more than 36 passengers, the boundary bulkheads and decks of a vehicle space must achieve A-60. The structural fire protection can although be reduced to A-0 where the adjacent spaces are of category 5, 9 or 10, i.e. against overhangs (the open deck space above parts of the ro-ro deck), steering gear and void spaces. Except from not fulfilling A-class standard the base design does not achieve 60 minutes of thermal insulation as required towards the engine rooms and the accommodation space. In order to address the risk of fire spread to surrounding spaces the deck has although been covered by a non-combustible plate in the revised base design.

3.3.8. Further regulation and fire safety investigations

The preceding evaluation of the base design has been delineated to document affected regulations with a starting point in prescriptive requirements and associated purpose statements. In particular the requirements on “non-combustible” and “steel or equivalent material” cannot be achieved by the novel material, even if the accomplished safety may be sufficient. It was also found that the current steel-based regulations are not fully applicable for this kind of design as they do not consider combustible exterior surfaces. Missing regulations and the high level of innovation in the present design case invokes further evaluations of how the base design affects the implicit level of fire safety in the regulations [7]. For this reason, investigations have been performed revealing effects on the general fire safety objectives and functional requirements stated in SOLAS II-2/2, which are significant as they set out the safety targets for the whole chapter. In addition, effects on the structure of the fire safety prescribed in regulations and effects on different properties represented in current requirements have been scrutinized. This way innate effects on the implicit level of fire safety in regulations have been identified. The above analyses were complimented with a general evaluation of how the novel structural material may affect different stages of a fire development in the base design. These additional regulation and fire analyses are documented in *Appendix F. Additional regulation and fire safety evaluations* and summarized below.

3.3.9. Summary of additional regulation and fire safety investigations

The additionally performed analyses revealed several important effects on the implicit level of fire safety that need to be verified. When it comes to the fire safety objectives in SOLAS II-2, the base design may fulfil some of the objectives superior to a traditional design down to its improved thermal insulation. The focus on safety of human life in the fire safety objectives makes it topical to address, not only the safety of passengers, but also the safety of fire fighters and crew. Investigating the functional requirements for the whole fire safety chapter in SOLAS especially indicated that the risk when adding combustible materials needs to be accounted for.

Effects on the fire safety structure mainly concerned the exposure and effect parts of the fire protection strategy and invoke thorough verification since the changes will affect many protection chains. The following analysis of fire safety properties showed that in particular human intervention, complexity in the fire protection strategy, reliability and vulnerability will be affected. The implications for safety may, however, not be very significant for all of these properties.

When the revealed differences were put in the context of fire dynamics it was established that the ignition and first stages of a fire in an enclosure will be unaffected by a change to FRP composite if it is insulated or at least protected. In case the circumstances allow a fire to progress, it will reasonably be better contained in the structure within the first 60 minutes in a FRD60 compartment. In case of fire that ability could e.g. give the advantage of an increased time for escape as the temperature in the staircases and escape routes would be significantly lower. If FRP composite surfaces are only protected with low flame-spread characteristics and there is fuel available they may provide fuel to an already on-going fire. The conditions in the base design if a fire develops past 60 minutes may although be worsened, in comparison with a traditional design. Fire safety will also be negatively affected in case a fire includes external surfaces, which go from being non-combustible in a steel design to combustible but protected in the base design.

3.4. Fire hazard identification

Fire hazards were identified in a Hazid workshop held at Kockums in Malmö 7 February 2012. A Hazid, or hazard identification, is a systematic brainstorming session where the fire safety of each concerned space is thoroughly investigated to identify fire hazards, i.e. what could give rise to fire and burn in different stages of a fire in in each space of the concerned spaces. Critical objects and conditions significant in different stages of a fire development were also identified. The processes were carried out by the multidisciplinary design team selected for this specific design case. and resulted in a tabulation of fire hazards, as presented in *Appendix G. Data from fire hazard identification*.

3.5. Enumeration of fire hazard

According to Circular 1002 the identified fire hazards should be grouped into one of the three incident classes localized, major or catastrophic. These incident classes are meant to signify the effect zone of the fire hazards, i.e. if the fire is confined in an area, ship or spreading outside of the boundaries of a ship. The instruction to tabulate fire hazards into these incident classes can, however, seem quite illogical with the standard definitions of hazard and incident within risk management, see e.g. [16]. A hazard is namely merely a source of danger whilst the incident classes represent degrees of consequences, which will depend on the existence and function of safeguards. With this perspective, the hazards do not have to be related with the possible outcomes. To shed some light on the issue, the ocean can be said to be a hazard and attempting to cross it we undergo risk. If the means of transportation is a row boat the risk will be significantly greater than if the Queen Elisabeth was used as a safeguard. In the example the possible consequences could be seen as rather clear; when crossing the ocean you will either die or live. However, the severity of the consequences, the number of fatalities, will be of significantly different probabilities. The difference in risk depends on how the safeguards affect the probability of a hazard converging into actual damage or loss [16]. Hence, it is rather the probability of functioning safeguards and the potential consequences which together constitute the possible outcomes, i.e. what is generally referred to as risk.

3.5.1. Enumeration into incident classes

If fire hazards identified in the concerned spaces after all are to be enumerated in the above specified incident classes, which is instructed by Circular 1002, one could claim that the first three columns in *Appendix G. Data from fire hazard identification* (ignition sources, initial fuels and secondary fuels) are localized fire hazards and that the extension potentials are major fire hazards. However, since the judgement is based only on identified fire hazards within spaces and extension potentials (i.e. propagation of fire to adjacent spaces), truly major or catastrophic incidents will not be identified. Catastrophic, or at least major, fire hazards were therefore identified in the 5th and last matrix in *Appendix G. Data from the second hazard identification,* where fire hazards posed to the ship as a whole were identified. This tabulation, hence, provides an enumeration of the identified fire hazards as required.

3.5.2. Deterministic fire risk rating

What Circular 1002 could be aiming at when stipulating an enumeration into incident classes, and what is more useful, is to rather identify and categorize the plausibly worst fire developments in the spaces, based on the identified fire hazards. It can be said to constitute some form of fire hazard rating of the concerned spaces, since only plausibly worst consequences are considered and probability thereby is included to a very limited extent. Despite this, and although it is founded on value judgement, it provides an indication of the fire risks as perceived by the design team. The ratings of the plausibly worst fire developments were divided in the two categories (A) Amount of combustibles and (P) Potential fire growth rate. The ratings were made from 1 to 5 for each space in the base design, based on the performed identification of fire hazards. The fire hazard ratings are listed in Table 3.3 below.

Table 3.3. Fire hazard ratings for the spaces in the base design

Deck 1	*A*	*P*	*Deck 1.5*	*A*	*P*	*Deck 2*	*A*	*P*	*Deck 3*	*A*	*P*
Steering gear space	2	2	Voids	2	2	Ro-ro deck	5	4	Wheelhouse	3	3
Engine rooms	4	5				WCs	2	2	Open deck space	4	2
Water tanks	1	1				Ventilation casings	2	3	WC	2	2
Fuel tanks	5	2				Accommodation space	4	4			
Void spaces	2	2				Fore deck	4	2			
Bow thruster spaces	2	2									
Stairways	2	2									

(A) Amount of combustibles
(P) Potential fire growth rate

The rating of fire hazards given in Table 3.3 most likely serves the purpose of the prescribed enumeration of fire hazards in Circular 1002. It is useful when selecting fire hazards to form design fires and event trees, which will define the fire scenarios. The table describes the conditions for a fire starting in the concerned spaces. However, in the Hazid there were also fire hazards identified with regards to fire spread, which influenced the selection of fire hazards.

3.5.3. Collection and rating in Procon list

The different investigations documented in this report have revealed much information regarding differences in fire safety between the base design and a prescriptive design. In order to get a better picture of all discovered pros and cons (or hazards if you will) from a fire safety perspective they were all collected and summarized in a procon list (see *Appendix H. Procon list*).The potential differences in risk implied by the design changes were also rated in this list. This provides the most concluding and useful enumeration and rating in the preliminary analysis in qualitative terms since it will give support on differences in fire safety when selecting fire hazards, which is the focus in a Regulation 17 assessment.

From the procon list it could be concluded that, generally speaking, one of the main fire hazard induced by the use of FRP composites is related to the exposure of combustible surfaces. This is particularly critical on open deck and outboard sides of the ship. A fire in the accommodation space might produce an intense flashover fire due to used standard combustible materials [17] in combination with a possibly high degree of ventilation through a door or broken window. Consequently, the possibility of having well-ventilated fires connected with the exterior will allow for fire spread between fire zones which induces a significant fire hazard. There are also other outdoor areas accessible for people and thereby for fire ignition by accident or arson, that could be hazardous in case of fire.

Another important fire hazard concerns the differences in structural integrity (see *Appendix H. Procon list*). Even if a fire in a prescriptive design is uncontrolled and lasts for hours or days, the structure might still remain more or less intact whilst sinking. The combustible materials in the FRP composite could take part in a fire soon after it is established (or after 60 minutes provided that FRD60 is used) and even if it would only fuel an already developing fire, it would lead to strength deterioration and loss of structural integrity. A long-lasting fire could thus bring about a major collapse which could affect great parts of the ship. Before the time until such collapse (10 minutes or half a day?) has been proven, this risk will be considered significant.

The above fire hazards constitute some of the most significant changes in fire safety when comparing the base design with a prescriptive design (all of which can be found in *Appendix H. Procon list*) which should be given priority in the selection of fire hazards.

3.6. Selection of fire hazards

All of the previously identified fire hazards (*Appendix G. Data from hazard identification*) were reviewed with help from the Procon list (*Appendix H. Procon list*) to distinguish the fire hazards differing between the designs and the ones with great potential to affect a fire development. Based on the identified differences in fire safety, a number of hazards were distinguished by the design team. These hazards were judged to need further evaluation and quantification in order to assure fire safety of the alternative design and arrangements. The selection was also influenced by the structure of the SOLAS fire safety regulations and is further commented in the Procon list (see *Appendix H. Procon list*).

It was reckoned possible to verify safety in some areas independently whilst other hazards would be necessary to include in overall fire scenarios for the whole ship, according to the revised approach.

The distinguished hazards and possible ways to manage these hazards are elaborated in the following subsections and the quantification needs are thereafter summarized.

3.6.1. Ignitability of surfaces

More combustible materials will be visible on external surfaces. In some internal spaces FRP composite is directly exposed in the base design and in other spaces simply protected by a surface of low flame-spread characteristics. What is prescribed in a functional requirement with regards to ignition is that combustible materials should have restricted ignitability, i.e. a material characteristic. Two possible ways forward were distinguished: (1) require surfaces to have as restricted ignitability as painted steel surfaces, or (2) require external combustible surfaces to have restricted ignitability. The latter is what is required by regulations and the most sensible since there are already many surfaces on deck on passenger ships with worse ignitability than painted steel; FRP composites divisions do not stand out. It would nevertheless be good if the ignitability of FRP composite surfaces was established. It was therefore suggested that the ignitability of FRP composite is determined by a test according to a building standard since no such standardized test exists within the IMO.

3.6.2. Smoke generation and toxicity

"Smoke production" and "smoke generation potential and toxicity" imply different things. They have to do with quantity and quality (or rather severity) of the smoke. The former is covered in regulation 5 (fire growth potential) whilst the latter mainly has to do with the individual material characteristics, covered by regulation 6. In regulation 5 it is managed that an unrestricted amount of kilos of combustible materials does not catch on fire and in regulation 6 the potential of each kilo is managed.

For internal surfaces the additional production of smoke may affect people in an escape situation/evacuation in the accommodation space depending on the behaviour of the surface with low-flame spread characteristics. Furthermore, in the spaces without any protective surface there may be an increased production of toxic smoke. Considering both passenger and crew safety it should be most important to improve conditions in the earlier stages of a fire, rather than at the latter stages when evacuation has already taken place. If 60 minutes of thermal insulation is provided (as in the engine room) the FRP composite construction only starts contributing to production of toxic gases in the later stages of a worst-case fire scenario when the fire has been combated for a long time. Any crew coming into contact with smoke should long since have been using breathing apparatus. Nevertheless, the increased amount of fuel behind the insulation may fuel an uncontrolled fire after 60 minutes. This could prolong and help develop the fire further. The consequences of this may be limited but should be accounted for in the overall fire scenarios for the whole ship.

Open deck spaces and vertical external surfaces contain a lot of combustible materials. Some materials generate more and more toxic smoke than others and the core material of the FRP composite in the base design particularly contains PVC, which produces very toxic smoke containing HCl. Smoke is what causes most fatalities in a fire and smoke management is not a problem in case of an external fire. It may nevertheless be argued that an unrestricted amount of smoke with unrestricted toxicity shall not be allowed. However, as was claimed above, FRP composite surfaces are not likely to be ignited by an ignition source as a first fuel but it rather adds as a potential secondary fuel on open deck and on the exteriors of the hull. A fire is in other words already on-going, e.g. in combustibles on open deck or in a space spreading to vertical FRP composite surfaces. In case the initiating fire is situated on open deck it is important to remember that the deck on a prescriptive ship is generally not a stripped painted steel deck. On the contrary, on passenger ship decks there are often plastic chairs, sunbeds and matrasses, upholstered furniture, wooden deck or polymeric teak deck imitations, FRP composite pool, rails and other structures which could produce the same toxic gases as the FRP composite surfaces.

As for fire spread from an interior space, large scale fire tests [17] were conducted in which a standard cabin was burnt out, which showed that the gases produced by certified furnishings and interiors are very toxic. For instance, the amount of CO produced by one cabin in 15 minutes was estimated to be sufficient to make an area of 2 100 m^2 on board inescapable due to incapacitation. The HCl production peaked after 5 minutes and was measured to almost 20.000 ppm, which is over 60 times the 300ppm limit for incapacitation when inhaled (average production throughout the test was 6600 ppm).

Hence, the gases produced from combustion of FRP composite might just as well be produced from combustion of adjacent materials in the prescriptive design. The additional smoke production in case of fire is therefore claimed to be more or less proportional to the additional probability of fire growth (due to the increased amount of combustible material). Any increase in smoke production or increase in toxicity of the produced smoke due to combustion of exterior FRP composite surfaces is not taken into account in the proceeding analysis.

3.6.3. Containment of fire

With regards to containment of fire there is a potential benefit in the base design engine room which is protected against fire for 60 minutes. Containment is equal or better thanks to the increased insulation necessary to keep temperatures down in the FRP composite and thanks to insulation provided by the FRP composite itself. Containment of fire is in the case of FRP composite structures although all about building decks and bulkheads with sufficient fire resistance. In the case with FRD60 divisions in the engine room the ship does not comply with the definition of an A-60 division since FRP composite is combustible (all RFR's are however complied with). Combustible materials will not give fire growth potential in enclosures until after 60 minutes but will then give the fire ability to consume the bulkhead. Just as fire is not contained by an A-60 (steel) division after 60 minutes due to extensive heat, an FRD60 division will not contain the fire after 60 minutes due to possible collapse. The benefits of better containment because of improved thermal insulation could be useful to account for but since the division nevertheless may collapse after 60 minutes such benefits were ignored (structural integrity is evaluated separately).

In most spaces containment of fire is although significantly worsened in comparison with prescriptive requirements. In general A-60 or A-30 has been replaced with FRP composite structures without any significant fire resistance. Most of these cases should be evaluated in the overall fire scenarios. In toilets FRP although replace B-0 division and this may be possible to manage independently.

3.6.4. Fire growth

Regarding fire growth it is essential to first establish that the use of combustible materials is restricted, as required by SOLAS II-2/5.1.3. This could for example be done by comparing the areal addition of combustible surfaces on the exteriors and maybe even comparing their inherent energy contents. It could thereby be stated that combustible surfaces are restricted based on the above comparisons.

Moving on and looking at fire growth it is relevant to realize that the most dangerous part of fire growth from a life safety perspective is smoke production. For external surfaces the smoke production will be increased, in comparison with a prescriptive ship, if exterior FRP composite surfaces are involved in a fire. This may however will be a less significant addition if the fire origin is an already large fire e.g. a cabin fire. Neither is the problem on open deck lack of oxygen nor visibility. Hence, fires involving exterior surfaces are not as significant as enclosure fires from a life safety perspective. Fire scenarios which include vertical exterior surfaces or surfaces on open deck although need to be managed in order to assure safety. Since such a scenario may stem from a fire anywhere on open deck or a space with an opening towards the exteriors this hazard should be included in the overall fire scenarios for the whole ship.

Considering potential fire spread on external combustible surfaces invoked to evaluate whether fire growth is more probable in the alternative design and arrangements than on a prescriptive ship. Two fire scenarios were distinguished where this may be evaluated: (1)

Outboard fire spread (e.g. accommodation fire leads to fire spread on outboard combustible external surfaces), and (2) fire growth on open deck (how much more likely for fire growth because of the larger areas of combustible external surfaces). These disadvantages should also be included in the overall fire scenarios for the whole ship.

For internal spaces there are some conditions in different spaces which could affect fire growth. In some spaces FRP composite surfaces are simply covered by surfaces with low flame-spread characteristics. The effect on fire development should be further assessed in order to quantify effects on safety in fire scenarios. Spaces with surfaces without any protection should also be investigated in order to evaluate the potential effects on safety.

3.6.5. Structural integrity

According to SOLAS II-2/11.2 structures shall be constructed in steel or equivalent material (i.e. any non-combustible material) which, by themself or due to insulation provided, have structural and integrity properties equivalent to steel at the end of the standard fire test (MSC.45(65)). For the engine room, the non-combustibility requirement cannot be achieved by the FRD60 construction. However, the structural and integrity properties equivalent to steel may be achieved at the end of the applicable exposure to the standard fire test. An A-60 steel construction per definition also loses structural integrity after 60 minutes; not due to strength deterioration by heat but due to heat transfer and thereby fire spread to adjacent compartments. For an FRD60 construction, structural integrity is maintained until the end of the applicable fire test and it thereby fulfils the structural integrity requirement. The general knowledge is however that a steel structure, even if not classified fire resistant, may stand far longer than an hour.

Strength deterioration is not the requirement by regulations but non-combustibility is. An A-60 Aluminium structure will not only loose structural integrity due to heat transfer after 60 minutes but will also be deteriorated by heat and may collapse after 60 minutes (at the end of the applicable exposure to the standard fire test). Containment and collapse may in other words fail at the same time, after 60 minutes. Except for the obligation of being non-combustible, that is also what regulations require from a FRD60 division; 60 minutes of fire resistance. Hence, FRD60 constructions achieve sufficient structural integrity, as required by regulations.

Regulations are however made up for steel designs, and Aluminium structures can be said to be an exception. Divisions are implicitly meant to stand longer and not collapse for a longer time than the applicable time in the furnace test. This needs to be accounted for when comparing safety levels. It was thereby assumed that steel structures have a lower probability of collapse than the exposed combustible FRD60 structures after 60 minutes, even if RCM's could be provided to improve the probability of collapse in the new structure.

For unprotected FRP composite structures there are no arguments that the construction would have better structural integrity than steel structures. It is although necessary to determine if the construction with different protective solutions provide load-bearing capacity for 5 minutes or 45 minutes. The risk of collapse therefore needs to be quantified in many different ways. Furthermore, a long-lasting fire could bring about a major collapse which could affect great parts of the ship. The consequences associated with this risk also need to be accounted for in the overall fire scenarios for the ship as a whole.

Looking at exterior surfaces, the FRP composite is also worse than both steel and Aluminium. FRP composite bulkheads are load-bearing and unprotected and a fire could lead to structural collapse well before 60 minutes have passed. Two scenarios have been identified where it is relevant to evaluate the probability of collapse: (1) Vertical surface fire which could spread and cause collapse (e.g. accommodation space fire spreading to exteriors), and (2) A fire on open deck which could spread and cause collapse (e.g. for deck or deck house). These scenarios should be included in the overall fire scenarios for the whole ship.

3.6.6. Fire-fighting routines

No need for boundary cooling, new fire-fighting tools, parts of the ship built in FRD60 and others in steel and some further changes in the fire-fighting routines imply that the probability of successful fire-fighting may be affected. A qualitative evaluation was performed in a related research project from which it was assessed possible to draw conclusions regarding probability of failure of manual extinguishment is evaluated.

Fire-fighting may furthermore be affected through the risk of collapse. Fire-fighters in a space below or next to the fire origin may be unaware of the time to collapse due to the well-contained fire. A damaged division could furthermore bring about an unexpected early collapse. This should be evaluated, e.g. through assessing the probability of fire-fighting fatality on the ship.

3.6.7. Evacuation

Potentially worsened conditions in case of fire could affect evacuation. Furthermore, there is no redundancy with regards to evacuation station in the base design. It was therefore suggested to evaluate whether it is less likely with fatalities associated with evacuation in case of a fire on the novel ship. This should be evaluated in the overall fire scenarios for the whole ship. It may be necessary to find RCMs which do not allow major collapse before ship has been abandoned. It may also be necessary to consider that the decision to initiate evacuation may be affected by the inherent risks associated with FRP composite and that the evacuation process could be hazardous on its own.

3.6.8. Summary of quantification needs

In conclusion the following quantification needs were identified which were judged to be possible to manage independently:

- To establish whether the actual FRP composite material considered for exterior surfaces can be considered to have restricted ignitability.
- To establish whether the introduced use of FRP composite implies that combustible materials are still restricted.
- To establish how the probability of successful fire-fighting is affected by usage of the new material.
- To establish how the personal risks for fire-fighters are affected by the alternative design and arrangements.
- To establish how the fire risks are affected by use of FRP instead of A-60 in divisions towards the fuel tanks.

The following matters were identified necessary to quantify but to be necessary to be included in the overall fire scenarios for the whole ship:

- To establish how fire growth is affected by usage of FRP composite surfaces with and without low flame-spread characteristics as opposed to in a prescriptive design.
- To establish how the consequences are increased due to the increased amount of fuel which is made available to an uncontrolled fire in a space with FRD60 divisions.

- To establish how the probability of exterior fire development is affected due to the combustible exterior surfaces.
- To establish how the risks associated with an uncontrolled fire is affected by usage of FRP composite surfaces with and without low flame-spread characteristics with regards to the potential for collapse.
- To establish how much the consequences of an uncontrolled fire in outboard sides are increased due to the risk of collapse.
- To establish how much the consequences of a fire on deck are increased due to the risk of collapse.
- To account for the consequences associated with evacuation, which may be more likely in the alternative design and arrangements.

3.7. Description of fire scenario groups

In this step of the procedure to develop fire scenarios according to the revised approach, different conditions and characteristics are described in order to define for example design fires and event trees. A design fire is a description of the development and spread of fire for use in a fire scenario. An event tree describes different courses of development with failure modes and probabilities. Together with a design fire, failure modes will make up fire scenarios, from which design fire scenarios could be chosen to cover all fire scenarios, in accordance with Circular 1002. In the present case the ambition was although to quantify a larger range of fire scenarios and thereby attain a deeper and more sophisticated assessment.

The above selection of fire hazards was made based on the differences in fire safety between the prescriptive design and the base design. Primarily conditions and characteristics affected by these fire hazards need to be considered in the design fires and amongst the failure modes. Thereafter the priority is to include fire hazards that significantly will affect the fire development. Finally it should be a general goal to include as many of the identified fire hazards as possible and, hence, not only the fire hazards plausibly resulting in the most severe consequences. It results in not only one or a few design fire scenarios, but a distribution of fire scenarios with varying consequence and probability.

In order to include the above aspects, all of the previously identified fire hazards were reviewed with help from the Procon list (*Appendix H. Procon list*) to distinguish the fire hazards differing between the designs and the ones with great potential to affect a fire development. This process also worked as an input to the fire hazard rating in table 3.1. Concurrently, fire hazards affecting failure modes were recognized for all spaces along with their number of exits and whether the space is an evacuation route. A summary of the results is presented in

Table 3.4. As in the previous process, priority was to distinguish fire hazards differing between the base design and the reference design.

Table 3.4. Summary of whether the spaces are evacuation routes and their number of exits, along with target locations affecting failure modes

	Evac.	***Exits***	***Aut. ext.***	***Door***	***Win.***	***Det.***
Deck 1						
Steering gear spaces	No	1	No	No*	No	Yes
Engine room	No	2	Yes	Yes	No	Yes
Water tanks	No	N/A	No	No	No	No
Fuel tanks	No	N/A	No	No	No	No
Bow thruster spaces	No	1	No	No*	No	Yes
Void spaces	No	N/A	No	No	No	No
Stairways	Yes	2	No	Yes	No	Yes
Deck 1.5						
Voids	No	N/A	No	No	No	No
Deck 2						
Ro-ro deck	Yes	2	Yes	N/A	N/A	Yes
WCs	No	1	Yes	Yes	No	Yes
Ventilation casings	No	N/A	No	No	No	No
Accommodation space	Yes	2	Yes	Yes	Yes	Yes
Fore deck	No	1	No	N/A	N/A	No
Deck 3						
Wheelhouse	No	2	Yes	Yes	Yes	Yes
Open deck space	No	1	No	N/A	N/A	No
WC	No	1	Yes	Yes	No	Yes

*** Compartment is accessed through a hatch from the deck above**

Table 3.4 shows differences between the spaces involved in the base design and the reference design. However, as mentioned above, the main priority in the preceding processes has been to identify differences between the base design and the reference design. The most significant differences to consider when forming design fire scenarios is obviously the fact that divisions include combustible materials. This is the same for all involved spaces and was included in the previous fire hazard rating. Differences to consider when forming the event trees are particularly fire hazards represented amongst the target locations which affect failure modes. A difference which may be significant in a fire scenario is for example the fact that there in many cases are non-insulated combustible divisions in the base design where A-class divisions are required in prescriptive requirements.

The next action in the process of selecting fire hazards is to group spaces with similar characteristics to narrow down the number of design fire scenarios and simplify the following quantitative analysis. Design fires will be developed for the groups of spaces with similar fire characteristics. However, dissimilarities may appear in e.g. heat release rate, depending on diverging floor areas. Simplifications and constructive (preferably conservative) assumptions are therefore necessary in order to simplify the proceeding analysis. With the revised approach (see *Appendix A. The revised approach*) all spaces on the ship should be arranged in groups of spaces with similar fire hazards (even if spaces with the least foreseen differences in fire safety may not be necessary to prioritise). Following this selection process and based on the previous tables, seven groups of spaces were distinguished:

1. Accommodation space
2. Engine rooms
3. Auxiliary machinery spaces
4. Void spaces
5. Wheelhouse
6. Ro-ro deck
7. Stairways
8. Open deck

These groups have similar conditions for fire scenarios, as further specified below, and each group can be said to be represented by a fictitious representative space. Each representative space is assigned a relevant and plausibly worst-case uncontrolled design fire as well as failure modes affecting the fire development. The design fire for each representative space was selected based on the largest amount of combustibles with the highest potential fire growth rate amongst the spaces in each category, as specified in table 3.1. Considerations were also made to include potential effects from fire spread from other areas, which could affect the fire development. Furthermore, conservative assumptions were made regarding target locations in order to select influencing failure modes, and regarding the size of the compartment. The relation to evacuation routes and the size of the floor area also worked as input to the above categorization

The most relevant failure modes for each space will characterize the fire developments in that space. Examples of failure modes are the following:

- Failure of sprinkler system (cannot control fire or fails to function)
- Failure of fire damper
- Failure of detection (failure in detector or in communication with crew)
- Failure of smoke management
- Failure of first aid
- Failure of manual extinguishment by fire crew
- Failure of fire alarm
- Failure of structural integrity (propagation of fire through boundary or penetration weakness)

- Failure of window (braking window)
- Failure of evacuation
- Failure of closing door
- Failure of additional RCM
- …

In combination with a worst-case fire (specified by e.g. fire load density, HRR, smoke production), the failure modes will define a whole distribution of fire scenarios (not only the worst-case fire scenarios).

In the revised approach, a distribution of fire scenarios will be used in the quantitative analysis based on the identified fire hazards. A range of representative fires and failure modes have been identified to define this distribution. As specified in Circular 1002, the fire scenarios will be characterized in more detail during the quantitative part of the assessment. However, characteristics and conditions of each space category are as further described below.

3.8. Description of design fire scenarios

As a result of the revised approach, not only a few design fire scenarios will be specified. Instead the conditions and characteristics defining a large range of the possible fire scenarios in the above selected groups of spaces will be specified. As described above, each group of spaces is tied to a representative space which is assigned the worst selection of fire hazards from the spaces. Hence, when it comes to implementing further active and passive risk control measures, all spaces in each category will be treated equally (as if they contained the worst fire hazards).

A design fire can be said to be the fire one can expect when all safety measures are eliminated, or the fire in a certain environment that the design should be able to manage with the implemented safety measures. Based on the defined design fire it is possible to identify suitable passive and active risk control measures for each space. It is also possible to evaluate effects on life safety, e.g. through evacuation analysis. Hence, in the task of gaining sufficient safety by implementing alternative risk control measures, the definition of design fires is central. At this stage of the Regulation 17 assessment the design fires are qualitatively defined by what could ignite and burn in different stages of a fire development. The potential fuels in each space group were therefore recognized and specified below. Likewise, the failure modes and conditions that could affect the progressing fire and that determine the range of fire scenarios were recognized from each space group. Subsequently, the following potential fuels and conditions were recognized for each representative space:

1. ignition sources: potential ignition sources, i.e. high temperatures and other energy sources in contact with potential fuels are of interest as well as exposure time and area;
2. initial fuels: potential initial fuels, their state (solid, liquid, gas, vapour, spray), amount etc. are of interest;
3. secondary fuels: potential secondary fuels, their state, proximity to initial fuels, amount, distribution etc. are of interest;
4. extension potential: structures and areas to where fire might spread beyond the compartment of fire origin;
5. target locations: target items or areas associated with the listed critical factors, e.g. if oxygen supply through a door or the door integrity is crucial for the fire development, the door should be identified as a target location; and

6. critical factors: important factor associated with the fire development and its effects on human safety, such as ventilation, extinguishing system, time of day etc.

These and some further descriptions necessary to define a design fire quantitatively are specified for the representative spaces below.

3.8.1. Accommodation space fire scenarios

The characteristics of the accommodation space is unique and it therefore represents itself. It is a large public space on deck 2 which has a water mist extinguishment system, detection system as well as two exits towards the ro-ro deck, one to the deck above and one to the fore deck. The compartment is also used as an assembly station and embarkation station. The compartment has several windows and also two doors leading to the engine rooms (via stairways). This space surrounds three WCs, a stairway up to deck 3 and also contains void spaces above the ceiling. Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in Table 3.5.

Table 3.5. Fire hazards that define fire scenarios in the accommodation space

Fire hazard	***Findings***
Ignition sources	Electrical failure in equipment or cables, fire spread from surrounding areas, arson, human error (smoking, lighter, match etc.)
Initial fuels	Textiles (e.g. surface of seats, curtains and clothes), plastics in electrical equipment, trash/dust, newspapers, magazines, books, tissues, etc.
Secondary fuels	Textiles: Surface of seats and curtains, flammable liquids spilled by passengers such as alcohol, lighter fluid etc., FRP composite underneath protective surface layer, luggage, baggage, upholstered furniture (certified), trash cans
Extension potentials	Void spaces, ro-ro deck, open deck space above, wheelhouse, WCs, fore deck, cleaning cabinet, staircases, engine room, ventilation, fuel tanks, bow thruster spaces and water tanks.
Target locations	Doors: all doors to the accommodation space are generally closed (have automatic closing devices) and only doors to toilets and to open deck (via stairs) are possible to open for passengers. Windows: not possible to open. Combustible products, such as walls, furniture, luggage, ceiling and other secondary fuels (all surfaces have LFS characteristics and upholstered chairs are certified). Quality of FRP composite divisions, no thermal insulation provided. Surfaces, furniture and luggage (all surfaces have LFS characteristics and upholstered chairs are certified Res. A.652(16)). Information (smoking signs could probably be more visible, information given in speakers?). Water mist extinguishment system. Smoke detectors. Portable fire extinguishers (available).
Critical factors	Oxygen supply, heat release rate, structural fire resistance, reaction to fire properties, restriction of ignition sources, evacuation, automatic extinguishment, detectors, manual extinguishment

3.8.2. Engine room fire scenarios

The ship has two identical engine rooms which make up and represent the engine room space group. The engine rooms are equipped with a water mist extinguishment system and both smoke and heat detectors. The engine rooms have two exits; one staircase and one enclosed ladder. All composite surfaces in the engine rooms except in the bilge are insulated (FRD60) and the surfaces have low flame-spread characteristics. Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in

Table 3.6.

Table 3.6. Fire hazards that define fire scenarios in the engine room

Fire hazard	***Findings***
Ignition sources	Hot surfaces (normally insulated), electrical equipment causing statistic electricity or overheating (generator, lighting, main switchboard, enclosed battery system, heat fan, engine room fan, bearings, etc.), fire spread from surrounding areas, arson (two doors separating from passengers)
Initial fuels	Grease/hydraulic oil, fuel (diesel), cabling, plastic covers/electronics, fuel/oil spray, paper/trash (very limited), rags (very limited)
Secondary fuels	Grease/hydraulic oil pool and spray, fuel (diesel pool and spray), cabling, hoses, clothes, plastic covers, electronics, switchboard, fuse box etc.
Extension potentials	Steering gear (FRD60), void space on deck 1.5 (FRD60), cargo deck (FRD60), water tanks (FRD60), staircase (FRD60)
Target locations	Door closers A-60/FRD60 doors, ventilation system routine in case of fire, fire dampers, non-insulated surfaces below insulation (only LFS). FRD60 down to 300 mm below summer waterline, quality of insulation (FRD60), smoke and heat detectors, water mist extinguishment system, portable fire extinguishers, hydrants on cargo deck, insulation of hot surfaces, water mist extinguishing system.
Critical factors	Oxygen supply to fire, reaction to fire properties of surface materials, manual extinguishment, automatic extinguishment, detection, fire growth rate, evacuation.

3.8.3. Worst-case auxiliary machinery space fire scenarios

The auxiliary machinery space group include the steering gear rooms (SB and PS) and the bow thruster rooms (SB and PS). The auxiliary machinery spaces are equipped with smoke detectors but not with any automatic extinguishment systems. The representative worst-case auxiliary machinery space has one exit, a ladder to open deck. All surfaces in the space are of unprotected FRP composite (hence not achieving low flame-spread characteristics). Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in Table 3.7.

Table 3.7. Fire hazards that define fire scenarios in the worst-case auxiliary machinery space

Fire hazard	***Findings***
Ignition sources	Arson (not easily accessible, only by crew since hatch is locked, possible to open from below), human error during inspection and repair (unmanned during operation), electrical failure or overheating (generator, lightning, very limited amount of electrical equipment, mainly lights), static electricity, fire spread from surrounding areas, hot surfaces (normally insulated), mechanical failure or overheating
Initial fuels	Paper/trash (very limited), grease/hydraulic oil pool or spray, cabling, plastic covers/electronics, rags (very limited)
Secondary fuels	Grease/hydraulic oil, structural FRP composite material, cabling (limited amount), tubing (limited amount
Extension potentials	Engine room (insulation in engine room), adjacent void spaces, ro-ro

	deck, accommodation space
Target locations	Door/hatch (normally closed except in case of inspection, otherwise only an approx. 100 mm diam. ventilation penetration is provided). Surface material, unprotected in base design provides fuel to potential fire without restrictions. Quality of FRP composite divisions. No means for manual extinguishment are provided, e.g. portable extinguishers. Smoke detectors. No automatic fire extinguishment system (e.g. sprinkler system).
Critical factors	Oxygen supply to fire, reaction to fire properties, structural fire resistance, manual extinguishment, detection, automatic extinguishment, possible fire growth rate and heat release.

3.8.4. Worst-case void space fire scenarios

Void spaces are normally closed volumes (no large ventilation openings) and are, of course, never populated. All void spaces on the ship are included in this group (except void spaces above ceiling in accommodation space). They do not have automatic extinguishment system or detection system. The potential for fire development is represented by the worst-case design fire amongst the spaces in this category, i.e. the largest space with the most combustible materials and the largest ventilation openings. Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in

Table 3.8.

Table 3.8. Fire hazards that define fire scenarios in the worst-case void space

Fire hazard	***Findings***
Ignition sources	Electrical failure (e.g. overheating, shortcut), fire spread from surrounding areas
Initial fuels	Dust, trash, grease, oils, cabling etc.
Secondary fuels	Structural FRP composite material, cabling, combustible piping and insulation, plastics in electronics.
Extension potentials	Fuel tank, adjacent void spaces, stairway, water tanks, bow thruster space, accommodation space, ro-ro deck, steering gear, engine rooms
Target locations	Door/hatch (normally closed except in case of inspection, otherwise only an approx. 50 mm diam. ventilation penetration is provided). Surface material, unprotected in base design provides fuel to potential fire without restrictions. Quality of FRP composite divisions. Smoke detectors are not available. No means for manual extinguishment are provided, e.g. portable extinguishers. No automatic fire extinguishment system (e.g. sprinkler system)
Critical factors	Oxygen supply to fire, reaction to fire properties, structural fire resistance, detection, manual extinguishment, automatic extinguishment, possible fire growth rate and heat release.

3.8.5. Wheelhouse fire scenarios

The wheelhouse is also unique on the ship and represents itself. It is equipped with extinguishing system and detection system. The extinguishment system is manually activated in the wheelhouse. The wheelhouse is always populated while at sea and there are more than one exit from the compartment. The wheelhouse has windows and the potential for fire development is represented by the actual conditions in this space. Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in Table 3.9.

Table 3.9. Fire hazards that define fire scenarios in the wheelhouse

Fire hazard	***Findings***
Ignition sources	Electrical failure in equipment or cables, fire spread from surrounding areas, human error (smoking, lighter, match), pyrotechnical equipment (emergency flares etc.)
Initial fuels	Newspapers, magazines, books, tissues, clothes, textiles (e.g. surface of seats, curtains and clothes), plastics in electrical equipment, trash, dust
Secondary fuels	Upholstered and wood furniture and consoles, FRP composite underneath protective surface layer, suitcase/baggage, binders, books, structural composite material, cables, control panel and plastics in electronics.
Extension potentials	WC, accommodation space, open deck space, exterior surfaces.
Target locations	Space volume (medium sized). Doors: generally closed (have automatic closing devices), none of which are possible to open for passengers. Windows: possible to open and often used for ventilation. Division surfaces, furniture and seats (all surfaces have LFS characteristics and upholstered chairs are certified Res. A.652(16)). Quality of FRP composite divisions, no thermal insulation provided. Smoke detectors available. Water mist system installed. Portable fire extinguishers available.
Critical factors	Oxygen supply, reaction to fire properties, structural fire resistance, detection, automatic extinguishment, manual extinguishment, critical factors, oxygen supply to fire, reaction to fire properties, fire resistance, detection, automatic extinguishment, manual extinguishment, structural fire resistance.

3.8.6. Ro-ro deck fire scenarios

The ro-ro deck is unique on the ship as well and represents its own group. The fire scenarios in this group differs from the other fire scenarios since this space is not enclosed. Oxygen supply to such a fire is unlimited and the fuel load on the cargo deck is potentially very large with cars, trucks and other cargo. Dangerous goods will although not be transported with more than 25 passengers on board. Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in Table 3.10.

Table 3.10. Fire hazards that define fire scenarios on the ro-ro deck

Fire hazard	***Findings***
Ignition sources	Human error (smoking etc.), arson, car fire due to any failure, electrical failure, bunkering, fire spread from other areas
Initial fuels	Hydrocarbon fuel, burning car, deck equipment, trash cans, plastics/rubber on deck, lighter fluids
Secondary fuels	Dangerous goods, vehicles (tires, plastic bumpers), composite structural materials, lighter fluid or other flammable liquid or fuel, deck equipment.
Extension potentials	Surrounding exteriors, open deck space on deck above, accommodation space.
Target locations	Impossible to limit ventilation (large open area with unlimited access to oxygen). Trash cans. Flammable oils. FRP composite surfaces. Surface material, unprotected in base design provides fuel to potential fire without restrictions. Quality of FRP composite divisions, no insulation. Ignition sources, such as engines in vehicles and smoking. Portable extinguishers and fire hoses. Flame detectors. Evacuation routes. Surface material, unprotected in base design provides fuel to potential fire without restrictions.
Critical factors	Oxygen supply, amount of initial fuels, amount of secondary fuels, reaction to fire properties, fire resistance, ignition sources, automatic extinguishment, manual extinguishment, detection, evacuation, risk of fire spread to exteriors and particularly under overhang.

3.8.7. Worst-case stairway fire scenarios

Except from the staircase included in the accommodation space, the ship has two kinds of stairways which make up this space group. Both stairways are connected to the engine room. One leads forward from the engine rooms and contains regular stairs. The other one is located in the aft part of the engine rooms and contains a ladder up to ro-ro deck. Both stairways are evacuation routes from the engine rooms and contain detection system but no automatic extinguishment system. The largest stairway with the most potential for combustible materials will be used as representative worst-case stairway for this group. The passengers will not have access to any of the stair cases (for crew only). Furthermore, the fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in

Table 3.11.

Table 3.11. Fire hazards that define fire scenarios in the worst-case stairway

Fire hazard	***Findings***
Ignition sources	Electrical failure in equipment or cables, fire spread from surrounding areas, arson, human error (smoking?)
Initial fuels	Cables, dust/trash, wall decorations, garbage bags
Secondary fuels	Ceiling and bulkheads (LFS), furnishing (not allowed), garbage bags (not allowed)
Extension potentials	Engine room, accommodation space, void space, ro-ro deck, engine room, ventilation casings.
Target locations	Doors: all normally closed. Ventilation: sparse natural ventilation from accommodation space. Walls, floors and other surfaces (fulfil low flame-spread characteristics). Quality of FRP composite divisions. Smoke detectors. Water mist extinguishing system.
Critical factors	Oxygen supply to fire, reaction to fire properties, structural fire resistance, manual extinguishment, detection, automatic extinguishment

3.8.8. Open deck

The open deck space behind the Wheelhouse on deck 3 is unique on the ship as well and represents its own group. The fire scenarios in this group differs from the other fire scenarios since this space is not enclosed. Oxygen supply to such a fire is unlimited but the fuel load on the open deck is rather limited except from the combustible FRP composite surfaces. The fire hazards providing conditions and characteristics for the fire scenarios in this space group are listed in Table 3.12.

Table 3.12. Fire hazards that define fire scenarios on open deck

Fire hazard	***Findings***
Ignition sources	Human error (smoking etc.), arson, electrical failure, bunkering, fire spread from other areas, over-heating, electrical failure or mechanical failure in HVAC/Em.gen.
Initial fuels	Plastics/rubber on deck, deck equipment, garbage bags, flammable liquid, diesel from Em.gen.
Secondary fuels	Composite structural materials, deck equipment, life rafts, plastic seats and tables, luggage.
Extension potentials	Wheelhouse, Ro-ro deck, WC, Accommodation space, Stairways to engine rooms, engine room ventilation.
Target locations	Impossible to limit ventilation (large open area with unlimited access to oxygen). Trash cans. FRP composite surfaces. Surface material, unprotected in base design provides fuel to potential fire without restrictions. Quality of FRP composite divisions, no insulation. Ignition sources, such as smoking. No extinguishing system provided. Portable extinguishers and fire hoses. No detection. Manual fire extinguishers.
Critical factors	Oxygen supply, reaction to fire properties, fire resistance, ignition sources, automatic extinguishment, manual extinguishment, detection, evacuation, risk of fire spread to Wheelhouse and cut off of evacuation.

3.8.9. Fire spread

The above groups of fire scenarios describe the conditions for a fire starting in the concerned spaces. Note that fire hazards were identified with regards to fire spread, which needs to be taken into account. The accommodation space and particularly the ro-ro deck were recognized to have high probability of fire spread to other spaces via exterior combustible surfaces. The greatest fire risk was reckoned on ro-ro deck, where hydro carbon fires are likely to occur and where dangerous goods may be stowed.

Another fire hazard which was identified when considering fire spread was blockage of the assembly station. If a significant fire is more likely in the accommodation space on the Eco-Island ferry, then it is also more likely that an accommodation space fire cannot be managed (in the base design). An uncontrolled fire in the accommodation space could potentially make the entire embarkation station inaccessible. Such a scenario could lead to catastrophic consequences and should be taken into account in the quantitative analysis, preferably as part of the accommodation space fire. Hence, this could occur also in the prescriptive design but, depending on how risk control measures are directed it could be suitably avoided in the Eco-Island ferry.

4. Results of quantitative analysis

The quantification of differences in fire safety between the prescriptive design and alternative design and arrangements was divided in two parts; one part where some potential fire hazards were investigated individually and one part where the rest of the proposed fire hazards were quantified. Thereafter these differences in fire safety were incorporated in fire scenarios for the ship superstructure.

With regards to fire scenarios Circular 1002 stipulates to describe critical assumptions, amount and composition of fire load, engineering judgements, calculation procedures, test data, sensitivity analysis and time-lines. A list of this information, as may be implied, does not seem to provide much value. Critical assumptions and engineering judgements were made and those are illuminated throughout the process; for transparency they are although also be reprinted in a summarized list. Amount and composition of fire load were described when using a design fire (many difference in fire safety are although well beyond a traditional fire safety engineering approach, ASET-RSET). Calculation procedures are described in this chapter where appropriate. Available and carried out test data is also described where appropriate. Except to support certain estimations made in the quantification process, sensitivity analyses were carried out during the evaluation of trial alternative designs against performance criteria.

After the quantification of fire scenarios, the different risk control measures were quantified. Thereafter the resulting risk posed by the trial alternative designs was compared with the risk associated with the prescriptive design.

4.1. Fire hazards managed independently

Some of the identified fire safety hazards were estimated not to be likely to have a significant effect on safety but nevertheless necessary to be managed. Other hazards were too uncertain to manage quantitatively. In other cases the hazard could easily be managed in a delimited area or safety could be proven by a simple test. Such fire safety hazards were more rational to manage independently, i.e. to assure safety in those particular areas individually and delimit the rest of the fire scenarios from these hazards. Some fire safety hazards were initially intended to be included in the overall fire scenarios but were individually managed after they had been shown to have an insignificant or uncertain but likely positive effect on safety. These fire safety hazards are accounted for in the subsequent subsections.

4.1.1. Ignitability of surfaces

- To establish whether the actual FRP composite material considered for exterior surfaces can be considered to have restricted ignitability.

Even though restricted ignitability is what is required by regulations there is no IMO certifying test to show this. On land in Europe there is although a corresponding test method called EN ISO 11925-2, Reaction to fire tests - Ignitability of building products subjected to direct impingement of flame - Part 2: Single-flame source test. This is a test method which measures the ignitability of building products when exposed to a small flame.

Based on the numerous fire tests conducted at SP Fire Technology with various FRP composite materials it was judged very likely that the exposed surface of an untreated FRP composite (i.e. the laminate) would pass such a test. This can also be distinguished from the Con Calorimeter test data in Figure 2.5. The graph does hence not only show that the FRP composite may become involved in a significant fire but also that it resists the rather significant irradiation of 50 kW/m^2 for at least one minute before becoming involved in a large fire. For reference, 15-20 kW/m^2 towards the floor is often referred to as a criteria for when flashover is determined in an enclosure fire. Furthermore, in the aforementioned test method for ignitability of building products, the material is exposed to a flame in the size of a match for 15 or 30 seconds. It can thereby be concluded that FRP composite surfaces generally have restricted ignitability and that what could rather be a problem is fire spread if the surface is exposed to an already established fire.

Because of the certainty in this issue, the simplicity in testing in a real case and due to the insignificance of the result in case a decision is made to add surface treatment, a test was not prioritized within the project. For the sake of the forthcoming quantitative analysis it is although assumed that the restricted ignitability of the external FRP composite surfaces is proven, e.g. though test according to EN ISO 11925-2.

4.1.2. Restricted amount of combustible materials

- To establish whether the introduced use of FRP composite implies that combustible materials are still restricted.

Regarding fire growth it is essential to first establish that the use of combustible materials is restricted, as required by SOLAS II-2/5.1.3. With regards to exterior surfaces it is important to remember that surfaces in connection to open deck areas on a passenger ship are generally not a stripped steel. There are some areas on open deck where the surfaces replaced by FRP composite may be considered quite limited in comparison with all the other combustible materials, e.g. the ro-ro deck full of cars. However, in other areas on open deck the replacement of steel with FRP composite will provide one of few combustible materials available, e.g. the deck space on deck 3. At least if not considering the many layers of paint on steel surfaces. With regards to interior spaces there are numerous upholstered chairs, lining materials, electronics etc. which may have restricted ignitability of even low flame-spread characteristics but which are nevertheless combustible. In addition there are no restrictions on how much luggage people can bring on board. Altogether the replacement of steel by FRP composite surfaces was estimated to potentially increase the amount of combustible materials by a maximum of 200% in interior spaces, comparing with what potentially already exists on a prescriptive ship. For exterior spaces this figure may be significantly smaller, considering cars, hydro carbon fuels etc. An increase by more than 50% was therefore not judged realistic. These figures are not regarded as out of proportion or as an unlimited amount. Thereby it is considered established that the use of FRP composite is not unrestricted. The added potential fuels although imply an increased fire risk which must be managed in a proper way, hence the current fire risk assessment.

4.1.3. Fire-fighting

- To establish how the probability of successful fire-fighting is affected by usage of the new material.
- To establish how the personal risks for fire-fighters are affected by the alternative design and arrangements.

No need for boundary cooling, new fire-fighting tools and some further changes in the fire-fighting routines imply that the probability of successful fire-fighting may be affected. Furthermore, the risks for fire-fighters could also be affected due to the risk of collapse after. These issues were investigated for a different design case though a dissertation supervised by SP Technical Research Institute of Sweden. A student concluding his fire safety engineering degree at Lund University carried out the study

[18] which is summarized in *Appendix I. Fire-fighting in large FRP composite passenger ships*.

The conclusions of the study on fire-fighting effectiveness and efficiency as well as personal risks for fire-fighters [18] shows that it is possible to fight fires as safe and as efficient in ships with FRP composite structures as in a prescriptive design if suitable measures are taken. There are although a number of limitations of the applicability of study must although be taken into account. In order to make any assessment regarding the implications for fire-fighting on the Eco-Island ferry the applicable hazards on the ship were evaluated, consideration e.g. structural failure, added smoke production and toxicity, added fuel, current and improved fire-fighting strategies, techniques and equipment, fire-fighting operations' effectiveness and efficiency, the complexity and robustness of fire-fighting performance as well as the fire-fighters' personal risks. This knowledge was concretized in what fire scenarios a fire-fighter could be exposed to.

On the Eco-Island ferry the fire-fighting efforts that can be carried out may be quite limited due to the limited crew. They may namely need to prioritize to get the passengers in safety. In case of a fire scenario there may be although be attempts to manually extinguish the fire by passengers (by portable extinguishers) or by crew. At this stage the crew is counted as passengers when assessing their risks. If passengers are able to get to a safe place, so are they. If passengers are exposed to smoke, so are they. Thereafter, when a safe place is reached, crew may focus on fighting the fire. Then they are although assumed to take proper action with regards to use of breathing apparatus and other safety equipment. Hence, from a smoke and toxic gases point of view there was judged to be no differences between the prescriptive design and the base design except from those that will be quantified for passengers in a fire scenario from this perspective.

In case of an internal fire, the possibility of structural collapses must be regarded as a great threat to both the safety of the crew as well as to the effectiveness of the fire-fighting efforts. Efforts may be made to combat the fire by traditional means (smoke diving with breathing apparatus and equipped with a fire hose). The potential for collapse may although reduce the time available for fire-fighting and this kind of attempt may not be possible. Fire-fighters and in particular commanders must be aware of the fact that the structure is susceptible to collapses and that the time for fire-fighting is limited. Due to the risk of collapse, this kind of fire-fighting efforts are judged to be improbable. Even on a prescriptive ship where the risk of collapse is not immediate the focus in fire-fighting will be on getting passengers into safety and to restrict the potential for fire spread. If fire-fighting by smoke diving is difficult on the base design it is important to quickly apply hot gas cooling. Traditional boundary cooling is ineffective and should instead be replaced by this kind of cooling of hot smoke from an adjacent compartment. In order to improve these possibilities without entering the fire enclosure it was judged relevant to add the fog nail as a fire-fighting tool. The strategy is effective both for improving fire-fighters' working conditions by suppressing the fire prior to entering, as well as holding a boundary line since it will greatly reduce the structure's exposure to heat. Cooling of the hot smoke will not only lower temperatures and dampen the fire but will also protect the load-bearing structure from high thermal loads, increasing the chance of preventing collapse. With regards to how the ship should be constructed to ease the adaptation of the new fire-fighting techniques and equipment it was suggested to pre-install discreet holes or mark areas that are suitable for a fog nail to be inserted. This could be done discreetly and would decrease the risk of fire-fighters accidently damaging vital installations. It will also increase the chance of effective results and greatly ease deployment as pre-drilling of holes is not needed. With proper training and knowledge regarding the issues of collapse and with implementation of an extinguishing tool allowing to cool hot gases without entering the room the personal risks of fire-fighters were assessed to be at least as low as on a prescriptive ship.

With regards to the validity of the study it assumes that some kind of safety measure has been installed to protect the outboard spaces and the exterior of the hull. It is assumed that these surfaces are at least of low flame-spread characteristics or are protected by drencher system (outboard sprinkler). Note the importance of such a safety measure in the trial alternative design for the results of the study to have any validity. If such measure is installed it was estimated that fire fighting would have a greater chance of being successful. The consequences and probabilities of such scenarios although needs to be further evaluated in the fire scenarios. In any case, the probability of fire-fighters exposed to critical conditions was assessed to be equal to that of passengers if any of these measures is taken.

Another hazards of FRP composite is that after a severe fire has been successfully suppressed, it may tend to reignite locally for a longer time afterwards. Thus, the area needs to be monitored until temperatures in the structure have fallen to a safe level. Furthermore, the adjacent compartments will also need to be monitored to ensure no creeping fires are propagating slowly through the construction. With regards to hazards after the fire is extinguished it is also important to remember that FRP composite materials that have been subjected to severe fire may produce harmful particles that require extra caution when working in, or decontaminating, a fire-exposed area.

With the introduction of the above new fire-fighting strategies and equipment, in combination with adequate training, it was assessed that fire-fighting efforts can be undertaken as safe in the Eco-Island ferry as in a prescriptive design of the ship. As for the probability of successful fire-fighting, a number of aspects affecting this on the Eco-Island ferry have been discussed above. The particular probability of fire-fighting in different scenarios will be further quantified below.

4.1.4. Fire integrity of fuel tanks

- To establish how the fire risks are affected by use of FRP instead of A-60 in divisions towards the fuel tanks.

The spaces with fuel tanks are left without any passive fire protection in the base design even though A-60 is required towards the accommodation space above and A-0 toward the surrounding void spaces. These requirements are relevant only to protect a fire from spreading to involve the fuel tanks, i.e. not to protect surrounding spaces from a fire in the fuel tanks. In the present case the tanks are although made as an independent volume inside each space. The actual tanks occupy approximately one third of the spaces and are incorporated in the design in such a way that they should not be able to be affected by a fire in an adjacent space. A hazardous scenario introduced with this design is although that a leakage could occur from the tank into the space, which could lead to fire exposure of both the fuel tank as well as of the surrounding divisions. Hence, fire protection would be necessary for both the fuel tanks as well as the divisions of the space to avoid further consequences.

In order to provide sufficient fire protection it was suggested that the diesel oil tanks are surrounded by void spaces, as illustrated in Figure 4.1. Thereby passive fire protection is provided.

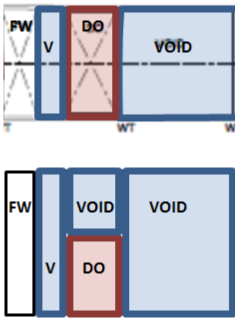

Figure 4.1. Top view (top) and side view (bottom) of the suggested design of spaces in order to provide passive fire protection around the fuel tanks.

However, as stated above, the required structural and integrity properties towards void spaces is A-0. This is neither achieved by the FRP composite divisions in the design illustrated above. The A-0 requirement although applies to all divisions from spaces towards void spaces. The divisions between voids and fuel tanks will therefore be treated in the same was as is concluded necessary for other A-0 divisions for void spaces, based on the forthcoming assessment.

4.2. Quantification of fire hazards affecting the risk assessment

Most of the identified differences in fire safety between the base design and the prescriptive design were distinguished necessary account for in the overall fire risk assessment. Some fire safety hazards which were initially intended to be managed independently also had to be accounted for after considering them more thoroughly above. The most significant differences in fire safety were investigated and quantified subsequently whilst less significant differences which may only apply to certain spaces were investigated when considering the fire scenarios in each space.

4.2.1. Fire development in internal spaces with FRP composite divisions

- To establish how fire growth is affected by usage of FRP composite surfaces with and without low flame-spread characteristics as opposed to in a prescriptive design.
- To establish how the risks associated with an uncontrolled fire is affected by usage of FRP composite surfaces with and without low flame-spread characteristics with regards to the potential for collapse, increase amount of fuel and production of smoke.
- To establish how the consequences are increased due to the increased amount of fuel which is made available to an uncontrolled fire in a space with FRD60 divisions.

Many of the internal divisions of the base design consist FRP composite which is unprotected or protected with surfaces of low flame-spread characteristics. This can make a significant difference in the beginning of a fire scenario and can also lead to early collapse where prescriptive requirements otherwise require 60 minutes of passive fire protection. When identifying quantification needs it was decided to evaluate how probabilities and consequences were affected with regards to the bullets listed above. In the subsequent paragraphs this is investigated in different stages corresponding to the stages predicted in a fire scenario.

4.2.1.1. Fire growth on FRP composite surfaces in internal spaces

The potential for fire development is affected in interior spaces where unprotected FRP composite is used and where the FRP composite surfaces simply have low flame-spread characteristics. It is affected since prescriptive requirements imply that a non-combustible division, i.e. not FRP composite, is found behind the unprotected surfaces and surfaces of low flame-spread characteristics.

To assess the differences this could implicate in case a fire develops in an internal space, the potential fire growth in a prescriptively built accommodation space was first defined. In doing this, reference was made to the full scale cabin fire tests performed at SP Fire Technology in 2007 [17]. It was assumed that the fuels in this cabin fire can also represent the fuels in a worst-case accommodation space. In the uninterrupted fire test where a wood crib according to BS 5852:Part 2 [19] was used as ignition source. This gave an incipient phase of 4 minutes. It was estimated likely to get a shorter incipient phase in the accommodation space and therefore 2 minutes was assumed for the design fire.

Thereafter follows the actual growth phase. A fire development in the growth phase is commonly described as a "t-squared fire" [20] where the heat release is expressed as:

$$\dot{Q} = \alpha \cdot t^2.$$

Based on the large scale cabin fire tests the following values were estimated for the prescriptive accommodation space design fire, as illustrated in Figure 4.2:

- Incipient phase: 2 minutes, α = 0,00347, resulting in a 50 kW fire after 120 seconds, this fire growth rate approximately corresponds to a "slow" fire growth rate.
- Growth phase: α = 0,047 (generally denominated "fast").

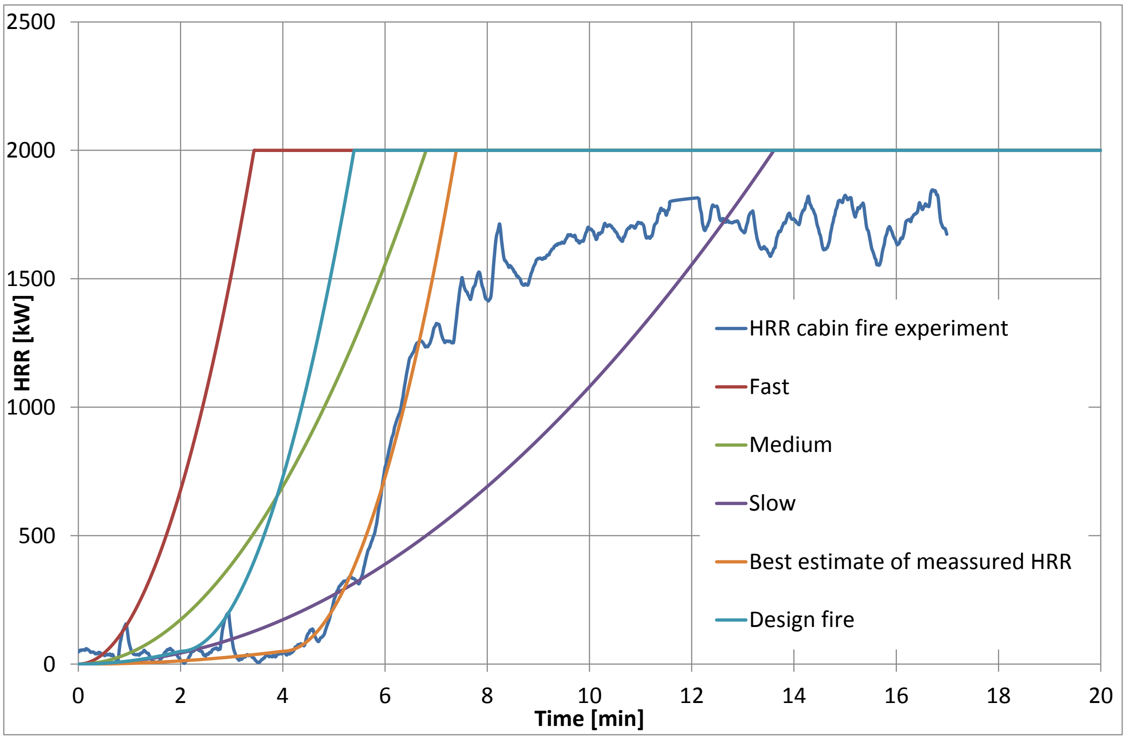

Figure 4.2. Heat Release Rate curve in the large scale cabin fire test, commonly used fire growth rates and the design fire for the worst-case accommodation space fire.

Large scale fire tests have also been carried out at SP Fire Technology which show that an unprotected FRP composite panel is susceptible to quick flame spread along its surface when ignited and exposed to a fully developed fire. In fact, after being exposed to a large (approximately 1.2 MW) fire for a couple of minutes, the fire growth rate on a large exposed vertical FRP composite surface may be faster than what in Fire Safety Engineering is denominated Ultrafast, i.e. where $\alpha = 0.19$. However, based on the tests this will have an effect after 2 minutes of significant fire exposure which implies that the fire will reach at least two minutes after the incipient phase in Figure 4.2. Hence the fire will already be ventilation controlled. This will need to be verified in fire simulations of the corresponding fire in the relevant spaces. However, the likely conclusion is thus that the maximum heat release rate will already be reached by the time that the unprotected FRP composite surfaces make a difference to fire growth. An exposure time of 2 minutes before unprotected FRP composite surfaces are ignited was also confirmed by tests where external surfaces were exposed through a window opening in [17], which are further described below.

Performed tests have also showed that a sprinkler system is very effective for preventing fire development on unprotected FRP composite surfaces as well as for extinguishing an already established fire on these surfaces [17].

In the accommodation space the divisions with surfaces achieving low flame-spread characteristic will hence neither make a difference during the fire growth phase of an internal fire.

4.2.1.2. Time until local collapse

In order to make any accurate claims regarding structural fire resistance of the FRP composite panels implied for the Eco-Island ferry these would need to be tested in furnace tests according to paragraph 8.3.1 in IMO Resolution A.754 [12]. This test for structural resistance to fire consists in exposing the panel to a well-defined temperature that varies over time. Typical standardized time-temperature curves are used as reference for the temperature in the furnace as depicted in Figure 4.3. The test sample is normally not subjected to any loading if designing a ship according to SOLAS, since the implied steel structures are known to have sufficient properties in this respect. However, when building ships according to the HSC Code [13] the divisions must be tested according to the FTP Code [15]. The corresponding tests for structural resistance in case of fire are the same as when complying with SOLAS except that the sample is also subjected to a static or dynamic nominal load during the test.

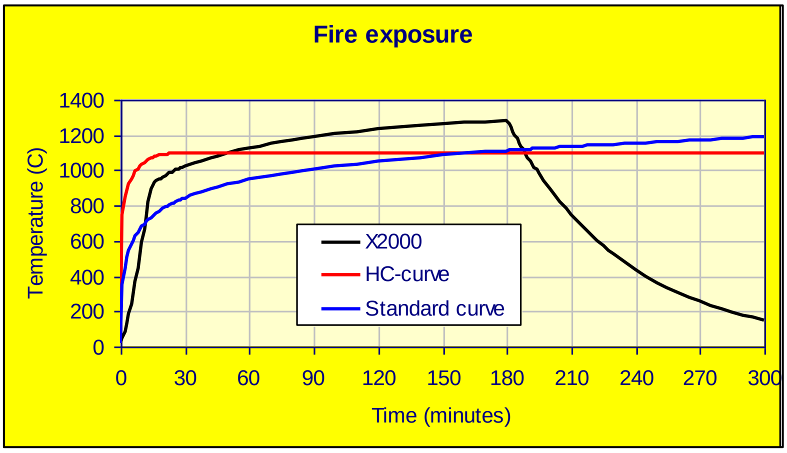

Figure 4.3. Time-temperature curves used for testing of structural resistance.

The applicable time for fire exposure in the fire test is 60 minutes, which all relevant (A-0) structures on the Eco-Island ferry should pass with regards to strength deterioration according to regulations. Comparing this with what is achieved by a FRP composite structure with or without surfaces of low flame-spread characteristics there is a significant difference. The particular FRP composite sandwich panels that are intended for the base design have although not been put on trial in fire resistance tests. Claims regarding their properties can therefore not be made with any accuracy in this respect. However, tests conducted at SP Fire Technology on FRP composite panels designed with thin glass fibre reinforced laminates and low-density core (in order to give conservative results) indicate that the load-bearing capacity may be affected well before the materials take part in the fire. Ignition generally occurred above 300°C whilst loss of structural resistance occurs due to delamination, at significantly lower temperatures. The relationship between these temperatures is illustrated in Figure 4.4.

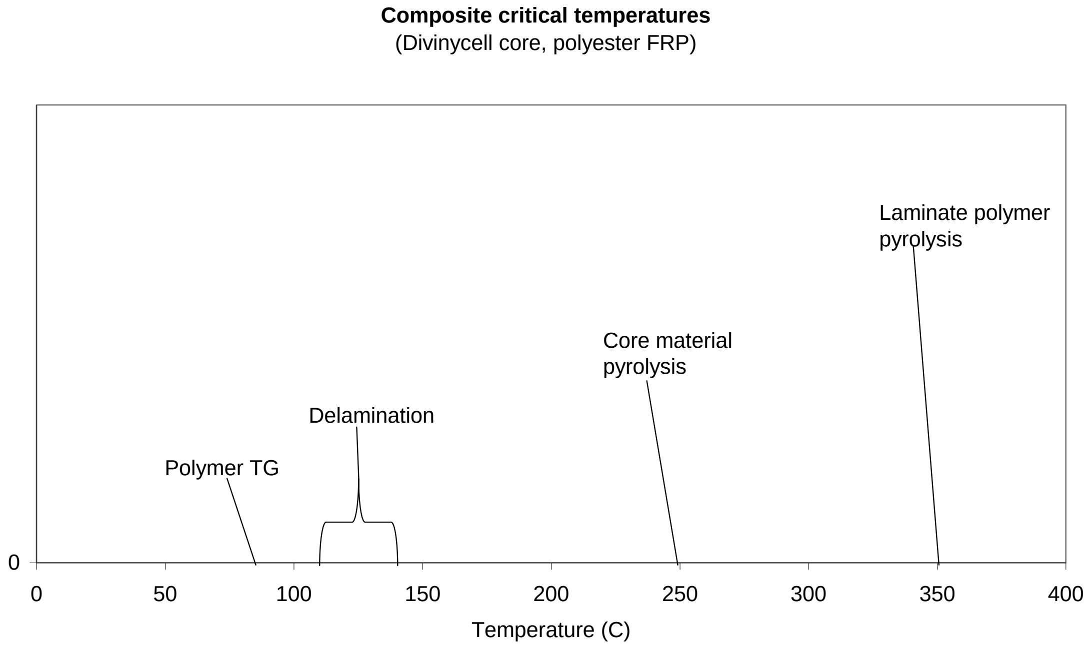

Figure 4.4. Relationship between critical temperatures of a GFRP composite panel.

It is nevertheless justified to claim that the unprotected FRP composite panels on the Eco-Island ferry will withstand at least a couple minutes of significant fire exposure before local collapse occurs.

With regards to potential local of major collapse it should be noted that in actuality it may be conservative to assume sudden collapse due to the following reasons:

- Normally there is an additional thermal barrier between the fire seat and the load-bearing structure. Inner ceiling and walls separate most interior spaces from the structure via void spaces that are used for wiring, ventilation, plumbing etc. These inner ceilings and walls are likely to withstand the initial flashover phase and the first ten minutes or so of fully developed fire, which reduces the thermal load to the load-bearing construction.
- If comparing with the furnace test, these worst-case temperatures are achieved in an "oven" for 60 minutes. In reality it is likely to take longer to achieve these temperatures, if they may be achieved at all. Probable limited supply of fuel or air in an actual fire scenario may lead to lower or less sustained temperatures.

The above reasoning is based upon the results from full scale cabin fire tests at SP Fire Technology [17] as well as the incident report from Star Princess [21] and lessons learned from the fire on HMS Ledbury [10, 22].

Furthermore, when a division is tested for structural resistance in the aforementioned test it is done with no support from surrounding structures. Unpublished global FEM-studies have previously been performed to evaluate small and medium sized FRP composite compartments. It showed that even if the structural integrity was lost in all divisions surrounding a compartment there will be no global collapse until the next divisions in all directions are lost. This would be the next logical step if fire is spread to surrounding compartments and the divisions surrounding those compartments loose structural integrity.

The above are good arguments for a longer time until collapse than what was shown in the unprotected FRP composite tests carried out on a weak GFRP composite panel. At this time passengers will not be present in the same space as the fire (unless already incapacitated) but the main risks are posed to fire-fighters and potentially to evacuating passengers, if consequences spread that far. The potential additional time until collapse could give more time to get to a safe place with the ship or to successfully finish evacuation. The potential extra time until collapse will although not be accounted for in the proceeding analysis. Hence, local collapse as a result of lost load-bearing capacity in structures exposed to fire is assumed to occur within 5 minutes from when the fire was ignited. The probability and consequences of local collapse were assessed depending on the fire scenarios in the different spaces in quantifications below. With regards to spaces where surfaces are treated to achieve low-flame spread characteristics tests have been carried out which show that this can prevent fire spread and additional heat release from the FRP composite panel for a few minutes. On the Eco-Island ferry this was assumed to give another couple of minutes before the strength of the panel is deteriorated.

4.2.1.3. Escalating fire scenarios

When it comes to evaluating the consequences of structural collapses, all on-board fires will be different and the hazards they imply will vary from case to case. For instance, a weakened bulkhead in the bottom of the ship may compromise all the decks above. A fire that affects a horizontal deck in a similar fashion should be less likely to cause major collapses and should only affect the adjacent decks in a close vicinity to the fire seat.

In any case, it is difficult to estimate the effects an internal collapse can have for people's lives with any precision. From the several tests carried out on loaded deck and bulkheads as well as the full scale tests with FRP composite structures and accidents which have occurred in FRP composite ships, all mentioned in the discussions above, it was assessed as likely that there will initially be a local loss of load-bearing performance when the FRP composite becomes heated sufficiently. This will lead to a local collapse in these areas, the consequences of which will be further assessed for each particular space category below.

After a local collapse, as the fire spreads to involve more of the FRP composite structures and possibly also adjacent spaces, a collapse propagation may occur and cause a major or global collapse in the ship structures. The time frame from local collapse until a global collapse may occur is case dependant and hard to estimate. The conservative figure would be to say after 5-10 minutes of fire ignition, but even local collapse may be unlikely to occur at this time based on the discussions above.

The potential for collapse and added fuel to the fire as well as difficulties in extinguishing a large fire established in FRP composite will make it harder to get a fire in a FRP composite superstructure under control than a fire in a prescriptive superstructure. Together with the aforementioned potential consequences for some areas of disembarkation this may have an effect on the decision to abandon ship. If knowing that a fire will not likely get under control within 5-10 minutes, a decision to abandon ship may come earlier if structures are in FRP composite. Hence, a decreased likelihood of getting the fire under control and increased risks in case abandonment is delayed may cause indirect risks on a ship with a FRP composite superstructure. In a prescriptive ship there may instead be a possibility to go to a harbour, await further fire-fighting efforts or to avoid abandoning ship in bad weather.

4.2.2. Fire development on exterior surfaces in FRP composite

- To establish how the probability of exterior fire development is affected due to the combustible exterior surfaces.
- To establish how much the consequences of an uncontrolled fire in outboard sides are increased due to the risk of collapse.
- To establish how much the consequences of a fire on deck are increased due to the risk of collapse.

The exteriors of the base design contain large areas of combustible material. This is particularly significant since these areas are not protected in the base design. When identifying quantification needs it was decided to evaluate how probabilities and consequences associated with fire development on exterior surfaces of the ship are affected when using FRP composite instead of a conventional materials. An on-going fire which is large enough to develop on exterior surfaces is assumed from previous events and particularly involve fires on ro-ro deck, open deck as well as in the accommodation space and in the wheelhouse. The events leading up to such a scenario are elaborated for each space in separate paragraphs below. Here consideration was made to effects from use of combustible FRP composite on exterior surfaces in the base design when presuming a fire which is self-fuelled and which is large enough to affect exterior surfaces. Depending on where the fire was established there are different conditions to promote a fire development which leads to local structural collapse and eventually a major fire involving great parts of the ship if left unhindered. For the base design, FRP composite structures were assumed whilst Aluminium structures were assumed in the prescriptive design. Aluminium is a commonly used material in conventional ship superstructures. Different stages of such fires involving external areas are elaborated below.

4.2.2.1. Fire development on FRP composite structures

There are a number of considerations to be made with regards to fire development on FRP composite surfaces. Since conditions are rather different in open deck fires and fires caused by internal fire spread, these two scenarios were investigated separately below. Thereafter some consideration is made to less idealized weather conditions than in some performed tests.

Fire development on outboard sides

Looking at areas on outboard sides, the most relevant surfaces are those above the accommodation space windows. As can be seen in Figure 2.1 these areas are although quite limited. The maximum height from the accommodation space windows to the wheelhouse windows is less than 2 m (thereafter follows the wheelhouse roof). The limited areas in FRP composite which in the real case application can be exposed to heat from an internal fire significantly reduces the likely involvement of the FRP composite surfaces. Furthermore, the size of the windows are not as large as the fully open side in the tests referred to above. Based on this it was therefore considered useful to also refer to some of the tests carried out on fire spread from a cabin window [17] when trying to appreciate how much the added combustible exterior vertical surfaces may affect the potential for fire growth. A representative fire exposure when a fully developed cabin fire spreads through a window is illustrated in Figure 4.5. Note that no addition is given from combustible surfaces in this case since the surfaces are drenched with water.

Figure 4.5. Representative fire exposure to outboard surfaces when a cabin fire spreads through a window [17] (exterior surfaces are not involved).

It was shown in the tests that when this fire, representing a fully developed cabin fire, exposes a vertical surface through a window, fire spread is fast in the vertical direction whilst lateral fire spread if rather slow (in idealized conditions), as illustrated in Figure 4.6.

Figure 4.6. FRP composite surface which has been exposed to flames from a fully developed fire through a window opening for 4.5-5 minutes.

The fire growth rate on the vertical FRP composite surface above the window was between those denominated Medium and Fast in Fire Safety Engineering. This is illustrated in Figure 4.7, where the heat release rate is depicted from when the FRP composite ignited until the fire was extinguished. The fire source established at the beginning of this time interval (before the FRP composite surface was involved) is hence assumed to be at a constant level of approximately 250 kW. Prior to the ignition of the

FRP composite, the surfaces had been exposed to significant flames (touching the outboard side and blackening the FRP composite surfaces) for 2-2.5 minutes.

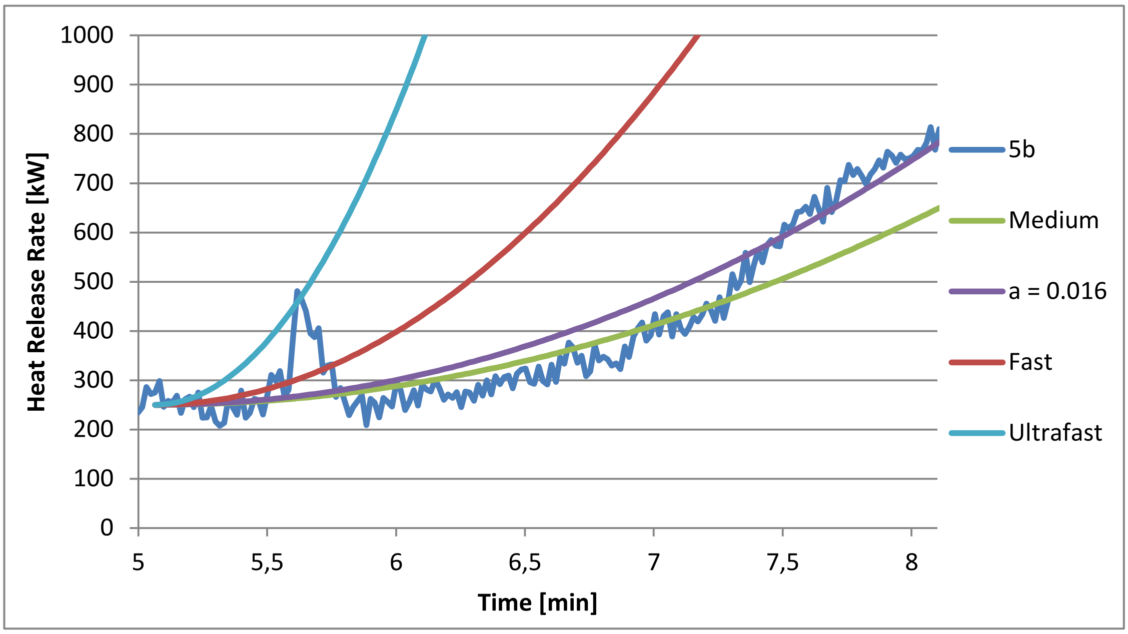

Figure 4.7. Heat release rate from fire growth on a vertical unprotected FRP composite surface (5b) when exposed to a fully developed fire through a window (from when the surface ignited), in comparison with other denominated fire growths.

The windows on the Eco-Island ferry are larger than those in the tests and would allow more flames out of the potential opening. Based on Figure 4.5 and the larger size of windows it can be concluded that fire spread to the wheelhouse from an accommodation space fire could occur also in the prescriptive design. The addition of 2 m of combustible material above the openings will nevertheless make a significant difference. In the current assessment, outcomes affecting the probability of spread to difference spaces will not be accounted for as affecting the probability of an initiated fire in the space but is accounted for as consequences in the proceeding scenarios. What can also be concluded is that the potential fire growth on exterior surfaces when exposed to fire through an accommodation space window would likely be less than that denominated Fast and hence significantly less than Ultrafast.

In addition to the results on fire growth it was shown when inspecting the materials after the tests that load-bearing capacity may be lost in the burning areas in FRP composite a couple of minutes after the surface ignites when exposed to a large fire.

Fire development on deck

With regards to fire development when FRP composite surfaces are fully exposed to a large fire for a few minutes it was concluded above, in paragraph *4.2.1.Fire development in internal spaces with FRP composite divisions*, that fire growth may be very rapid. On the open deck space the probability for such a scenario is very limited, since the potential initial fuels are very limited. Such a large fire is therefore unlikely. If a large fire nevertheless establishes, it could be promoted particularly by the FRP composite bulkhead towards the wheelhouse in the base design. On ro-ro deck the probability of a fire which could involve the FRP composite surfaces is significantly larger and the fire with rapid fire growth referred to above is more applicable.

Less idealized wind conditions

Furthermore, as it is often windy at sea it is necessary to consider less idealized conditions in all of the scenarios which could involve fire spread on exterior surfaces. When there is a fire on an outboard side of a ship, fire development may be either assisted or hindered by the weather. A fire scenario where large areas of FRP composite could be involved is then not hard to imagine. For example if an accommodation space fire spreads through a window in the forward part, an unfortunate wind from the aft could lead to a fire scenario where large parts of the front of the ship becomes involved. A ro-ro deck fire could also be easily affected by the wind, even if some of the sides are covered to some extent. A fire on open deck could be less affected by the wind, even if involvement of the wheelhouse could be more rapid. The above effects would all be due to the fact that the surfaces are combustible. On the Star Princess, a strong wind hastened fire spread, until the captain altered the ship's course to minimize winds on the port side where the fire had broken out [21]. This is an advisable approach, as concluded in the evaluation of fire-fighting routines, as well as to attack the fire from the upwind side if possible [18]. Accounting for the effects on fire development from the wind makes it clear that fire spread on the combustible surfaces in the lateral direction must also be considered. The likelihood for winds which would promote fire spread affected by the FRP composite surfaces extending laterally was given the probability of 80%.

4.2.2.2. Prevention of an exterior fire to grow sufficiently to cause local collapse

There are a number of considerations to be made with regards to mitigation of a fire before it causes local collapse, both in the alternative design and the prescriptive design. In particular the potential for fire growth on FRP composite surfaces must be accounted for, as described above. When assessing the probability of fire development affecting exterior surfaces above, the presumed scenario was a fire which is self-fuelled and which is large enough to expose exterior surfaces sufficiently to eventually lead to structural collapse if left unhindered. This event could although be hindered by fire-fighting efforts. The potential for successful fire-fighting will differ between the base design and the prescriptive design and will also depend on the conditions for the fire. Below this is evaluated with starting point in whether the fire was initiated on open deck or if it spread from an interior fire. The relevant spaces were considered with respect to previous discussions on potential for fire growth and fire spread and with consideration to the potential to grow to a large fire, which would affect the structural integrity, particularly in the base design. These evaluations were made assuming that that Aluminium structures were used in the prescriptive design of the ship, which is a commonly used material in ship superstructures. Furthermore, in the discussions above, no account was taken to the fact that the surfaces on a prescriptive ship generally have layers of combustible paint. However, no tests have yet been performed in comparison with painted non-combustible surfaces.

Pre-local collapse fire-fighting on outboard sides

In case a large fire has developed in the accommodation space and exposes outboard sides of the ship, the fire development on outboard sides would be promoted by rapid fire growth on FRP composite surfaces. Fire growth on outboard sides could occur also in the prescriptive design, taking account to the combustible paint and that flames can spread fire to the next deck. In the base design it was shown that local structural collapse could occur as soon as after five minutes of exposure to a large fire [17]. This could be hindered by fire-fighting but there are some circumstances which reduce the probability of successful efforts:

1. Fire-fighters may be preoccupied with the internal fire;
2. It may be hard to reach the fire on the side with a fire hose, particularly in case of unfortunate winds; and
3. Structural integrity may be jeopardized soon after a fire develops on exterior surfaces, which will limit the possibilities for fire-fighting;

It is rather necessary, with regards to the third point, to protect the exterior surfaces since structural integrity may be lost a few minutes after a FRP composite surface ignites when exposed to a significant fire. It would thus be almost impossible to assemble crew for an external fire-fighting effort before structural integrity may be compromised. The probability for successful fire-fighting before a first local collapse on outboard sides when exposed to a large fire was, based on the above discussion, therefore assumed to be very low in the base design of the ship. In case of no wind it was estimated to 20% and if windy to 2 %, i.e. a total failure rate of 94%. In a prescriptive design the corresponding total failure rate was estimated to 50%, based on a significantly longer time until a local collapse and lessons learned from the Star Princess fire [21]. Hence, more importantly, the probability of successful fire-fighting before local collapse is almost ten times higher in the prescriptive design. Note that such a scenario in the prescriptive design therefore is associated with considerably lower consequences.

There are although ways to manage outboard fires in FRP composite surfaces in a safer way. The tests discussed above [17] also showed that a drencher system is very effective for preventing fire development on a FRP composite surface as well as for extinguishing an already established fire on these surfaces. When an internal fire spreads there may not be a problem to activate such a system in time but if the fire is initiated outdoors detection may be a problem. As mentioned, the system could although also extinguish an already established fire, e.g. if activated “too late”. Exterior detection, e.g. with use of flame detectors, could also provide for early activation of the system if fire is initiated e.g. on ro-ro deck. Furthermore, it has also been shown that FRP composite surfaces treated to achieve low-flame spread characteristics may manage to prevent fire development and additional heat release from the FRP composite panel for the first 10 minutes of exposure. Such a treatment could hence be very useful as it provides additional time for the fire-fighting crew to arrange and perform suitable efforts. One of these risk control measures are hence likely necessary to achieve sufficient safety. The effect of these risk control measures on the probability for extinguishing such a fire before significant fire development are evaluated further in section *4.12. Quantification of risk control measures*.

Pre-local collapse fire-fighting on ro-ro deck

On ro-ro deck it is not hard to imagine a large fire which leads to deterioration of structures, both in the prescriptive design and particularly not in the base design. The conditions to prevent the fire from reaching such consequences are significantly different on ro-ro deck in comparison with fire spread on outboard sides of the ship. The layout of the deck area, being outdoors and mostly open, gives a significantly larger variety of fire-fighting strategies. It was shown in [17] and further discussed in [18] that a fire on FRP composite surfaces may be relatively simple to extinguish if suitable efforts are possible. Hence, the above speaks in favour of the likelihood of a rather swift and effective fire-fighting effort.

Potential late detection and quick fire spread on FRP composite surfaces may reduce the probability of successful fire-fighting. On ro-ro deck there are not supposed to be any passengers during a voyage and automatic detection is not included in the base or prescriptive design. Furthermore, as fire growth may be rapid, e.g. in case of a hydrocarbon fire, the likelihood of organizing fire-fighting efforts before the fire deteriorates FRP composite structures seems unlikely in the base design. Furthermore, the development of a ro-ro deck fire was estimated to be less depend on wind conditions.

Based on the above discussions the probability for successful fire-fighting before a first local collapse in structures surrounding ro-ro deck when exposed to a large fire was assumed to be 15% in case of no wind and 10% in case of windy conditions in the base design, i.e. a total failure rate of 89%. In the prescriptive design the time until the load-bearing capacity is compromised was assessed longer and hence gives more time for fire-fighting. The corresponding total failure rate was estimated to 40%. Hence, the probability of successful fire-fighting before local collapse is almost six times higher in the prescriptive design. Such a scenario in the prescriptive design is therefore associated with considerably lower consequences.

Pre-local collapse fire fighting on open deck

On open deck it is unlikely that a large fire is established when people are not around (except e.g. in case of arson) and manual detection is therefore plausible. Fire-fighting efforts should therefore be possible to organize rather quickly. Furthermore, the potential fuels on open deck do generally not provide very fast fire growth, which also speaks for the possibilities to organize fire-fighting efforts fast enough.

The layout of the open deck area is open and has many access routes, which gives a variety of fire-fighting strategies. As previously mentioned, a fire involving FRP composite surfaces may then be relatively simple to extinguish. Hence, effective fire-fighting efforts are probable if provided swiftly. Windy conditions are estimated to moderately affect the potential for successful fire-fighting on open deck.

Based on the above discussions the probability for successful fire-fighting before a first local collapse in structures surrounding open deck when exposed to a large fire was assumed to be 65% in case of no wind and 40% in case of windy conditions in the base design, i.e. a total failure rate of 60%. In the prescriptive design the time until the load-bearing capacity is compromised was assessed longer and hence gives more time for fire-fighting. The corresponding total failure rate was estimated to 25%. Hence, the probability of successful fire-fighting before local collapse is almost six times higher in the prescriptive design. Such a scenario in the prescriptive design is therefore associated with considerably lower consequences.

4.2.2.3. Consequences of a local exterior fire

In case fire development affecting exterior surfaces is not hindered it was established above that the fire could spread to other parts of the ship and that it could cause collapse of structures. This accounts for both the base design and the prescriptive design, with reference to what happened on the Star Princess where structures were mainly made in Aluminium [21]. The potential consequences from external fire development are although be larger in the base design as a result of using load-bearing FRP composite structures which are unprotected from the outside. The time until collapse of an Aluminium structure exposed to fire was assumed to take a lot longer, which affects the outcomes. The potential consequences are elaborated subsequently. As for the probabilities, this was done in three scenario branches: (1) Outboard fire development, (2) Fire development on open deck, and (3) Fire development on open deck.

Consequences of the first stages of a fire on outboard sides

In case outboard sides of the base design of the ship are exposed to a large fire development, structures may eventually collapse and smoke and fire may spread to adjacent spaces and cause inhabitable conditions. Large scale tests carried out at SP Fire Technology have showed that an unprotected FRP composite panel is susceptible to quick flame spread along its surface when exposed to such a fire. In *4.2.2.1. Fire development on FRP composite structures* it was concluded that the FRP composite surfaces in the base design are although quite limited above the windows of the accommodation space. Nevertheless, the combustible surfaces were assessed to promote fire development and could increase the production of toxic smoke. An unhindered large fire on outboard sides in the base design is assumed to spread quickly in the vertical direction and also in the lateral direction, depending on the influence of wind. As a result passengers on the open deck and in the wheelhouse may be exposed to smoke in a worst-case scenario. Furthermore, the greater potential for increased smoke production as a result of faster fire spread and the properties of FRP composite will have consequences as well. However, this will only have an effect if people are occupying the area, i.e. on open deck in particular in the high season.

Furthermore, the tests showed that after the FRP composite panel ignited a few minutes into the fire exposure, it only took about 2 minutes until structural integrity was lost in large areas, which was assessed from the area where delamination had occurred between the core and the surface laminate. This area had almost the same width as the opening and covering the full height of the panel. Loss of structural integrity would be local in the early stages but in a worst-case scenario the sides of the ship could collapse locally rather soon and in other words result in direct consequences for evacuating and hesitating passengers.

In all it was assessed that the consequences of more and more toxic smoke causes critical conditions for 4 persons in case of high season and otherwise for 1 person in the base design. Furthermore, the same number of casualties are assumed due to local structural collapse. When it comes to consequences on the prescriptive ship at this stage of the fire scenario, the smoke affecting the passengers and crew will be almost the same, a total of 3 persons were assumed are caused in the high season and none otherwise.

Consequences of a local collapse on ro-ro deck

It was shown above that the load-bearing capacity of a FRP composite panel may be lost a couple of minutes after the surface ignites when exposed to a large fire. In the tests a heptane pool fire was used. It is likely that a fire in materials on ro-ro deck will have a similar fire growth potential as there are sources of hydrocarbon. The time from the fire is initiated until load-bearing capacity is lost may therefore be as short as 5 minutes. This is above especially relevant in the case with FRP composite structures but also in the prescriptive design is assuming Aluminium structures.

In case a local collapse occurs on ro-ro deck it is likely that no one is present in the actual space, since people are not allowed during voyage. People inside the accommodation space may although be unaware of the raging fire, particularly if the fire alarm system has not yet been activated or if structures deteriorate quickly, which is mainly relevant in the case with FRP composite structures. Furthermore, the accommodation space is the only place of evacuation; note the need for protection of this bulkhead. In case a collapse comes sudden, curious bystanders or fire-fighters too close to the fire may also be caused e.g. on open deck. Comparing with the consequences from a local collapse on outboard sides of the ship, the casualties from this scenario are assumed to be larger since deterioration of structures affecting the overhangs or the accommodation space could imply serious outcomes. Based on the above discussions the assessed number of persons affected by critical conditions from smoke in this scenario in the base design was 6 in case of high season and 2 otherwise. Another 8 persons were estimated affected by the collapse at this stage in case of high season and 2 persons otherwise. In the prescriptive design 2 persons were assumed affected by critical conditions due to smoke and 4 persons due to the collapse at this stage in case of high season. Otherwise a total of 1 person was assumed affected.

Consequences of a local collapse on open deck

It was shown above that the load-bearing capacity may be lost a couple of minutes after a FRP composite surface ignites when exposed to a large fire. In the tests a heptane pool fire was used. It is likely that a fire in materials on open deck will have less growth potential. The time until load-bearing capacity is lost sufficient to result in a local collapse may therefore take longer in the base design than in the experiments.

People inside an adjacent space may although be The above effects may especially be relevant in the case with FRP composite structures.

In case a local collapse occurs on open deck it is likely that most people in the close vicinity of the fire have already moved away, i.e. also away from the effect zone of a local collapse. People inside the wheelhouse or in the accommodation space may although be unaware of the raging fire, particularly if the fire alarm system has not yet been activated or if structures deteriorate quickly, which is mainly relevant in the case with FRP composite structures. Furthermore, in case a collapse comes sudden, curious bystanders or fire-fighters too close to the fire may be caused. Comparing with the consequences from a local collapse on outboard sides of the ship, the casualties from this scenario are assumed to be in the same magnitude even if slightly lower since a fire on open deck will generally not affect as many load-bearing bulkheads and spaces above the fire. Based on the above discussions the assessed number of persons affected by critical conditions from this scenario was 6 in case of high season and 1 otherwise in the base design. In the prescriptive design 1 person was assumed affected by critical conditions when local collapse occurs at high season and none otherwise.

4.2.2.4. Consequences of a major exterior fire

In case mitigation efforts fail, fire development involving exterior FRP composite surfaces could lead to a catastrophic fire involving large parts of the ship. Such a fire could eventually cause a major collapse and collapse propagation in the ship superstructure. Eventually the fire could develop similar to the scenario on the Indonesian navy ship Kri Klewang, built in unprotected FRP composite. This ship fire is illustrated in Figure 4.8. The potential of such a fire could not only cause inhabitable conditions due to collapse and smoke. Knowing that this is a possible scenario could also cause an earlier decision to disembark.

Figure 4.8. The Indonesian navy ship Kri Klewang had unprotected FRP composite surfaces on exteriors where a catastrophic fire established. (photo: skalanews.com)

The time frame from local collapse until a major collapse is case dependant and hard to estimate. It is therefore difficult to estimate the effects for people's lives from such a scenario with any precision. Since the general alarm may be delayed due to detection problems on exterior surfaces and the fire may spread quickly, the time frame for evacuation may be as low as 10-30 minutes. Hence, a major collapse is assumed to have significant consequences for evacuating or mustering passengers. It was assumed that a major collapse will occur at the beginning of the above time frame, potentially 15 minutes after ignition, which is also considered to be a major external fire.

In case a major collapse is not hindered, effects on evacuation must thus be taken into account, both for the prescriptive design and the base design. Smoke may cause inhabitable conditions on great parts of the ship and structural parts and other debris may fall down in the area of disembarkation or where people reside, which could have direct consequences for passengers. The effects will depend on how early or if a decision has been made to abandon ship before such consequences occur, which will be different in the prescriptive design and the base design. Increased risks in case abandonment is delayed may cause an earlier decision to abandon a ship in FRP composite. In a prescriptive ship there may instead be a possibility to go to a harbour, await further fire-fighting efforts or to avoid abandoning ship in bad weather. On the Star Princess, for example, it may be concluded that there would have been additional casualties in case there would have been a need to disembark the ship, particularly in case of bad weather. The consequences solely associated with the disembarkation of passengers are further quantified in paragraph *4.2.3. Evacuation* but consequences to people on board the ship before managing to evacuate are accounted for subsequently.

If a local collapse is unlikely to have any great effects on the passengers, a major external collapse due to an accommodation space fire will likely have large effects on the people on board. This scenario will not only entail structural parts collapsing in the area where people may reside but will also involve significant smoke production. At the time of a major collapse in the base design accommodation space, passengers should be assembled since long, either on ro-ro deck or in the other side of the accommodation space, if such measures have been added in a trial alternative design. In the current base design there are no possibilities to access life-rafts from the ro-ro deck but safe evacuation can only take place if shore is reached shortly, which is further quantified in *4.2.3. Evacuation*. Furthermore, being able to reside in a protected part of the accommodation space also provides further safety. The consequences for assembled or disembarking passengers hence depend on whether there is an alternative safe place except the ro-ro deck and also on how early or if a decision has been made to abandon ship. If the accommodation space is not divided and the fire continues uncontrolled and causes a major collapse in the accommodation space, 2, 4 or 80 persons were estimated exposed to critical conditions (see *Appendix J. Validation of yields*) depending on whether the occupancy was low, medium or high, respectively (i.e. 10.5, 33.6 or 204 persons on average, see *4.4.3.1. Persons present in accommodation space*). If the accommodation space is divided the number of persons exposed to critical conditions were estimated to 1, 2 or 40 depending on the occupancy.

The corresponding fire scenarios on a prescriptive ship would also be associated with casualties. However, the probabilities of reaching the same consequences are significantly smaller. A long-lasting major fire could although spread through the ship and cause collapse and heavy smoke production. The consequences on the prescriptive ship of a major fire which has been initiated in the accommodation space will not be associated with the same magnitude of casualties since the space is divided by A-60 divisions. Even if the fire causes local collapse on the side of the accommodation space where the fire was initiated there will still be a possibility for the passengers to stay in the other half of the accommodation space. If the fire spreads to involve the wheelhouse there may be a possibility for the fire to spread downwards again and into the other half of the accommodation space. However, at this time evacuation is assumed to have occurred. Nevertheless, people may still be exposed to critical conditions before fire spread, in particular due to smoke and heat radiation during evacuation. Therefore, in case the ship is running on full capacity, 20 persons were assumed exposed to critical conditions in case of full occupancy and otherwise none were assumed exposed.

If the major external fire was initiated on ro-ro deck there may be a possibility that some of the people are able to evacuate before inhabitable conditions are reached on the whole ship. In this case 2, 4, or 40 casualties were assumed, depending on the occupation on board.

A major fire on the prescriptive ship which was initiated on ro-ro deck could in particular affect the forward bulkhead towards the accommodation space. This bulkhead is assumed to be made in aluminium and protected thermally for 60 minutes of fire exposure from the inside. Fire exposure from the ro-ro deck would although eventually deteriorate its load-bearing capacity and cause collapse. This will have consequences for the people residing in the accommodation space (evacuation stations) since they could be exposed to falling debris, smoke and heat. The consequences of this scenario are although assumed to be lower than in the case with a an unprotected FRP composite bulkhead since it is assumed to stand longer before collapse. Hence there is more time to carry out an evacuation at sea or to reach shore. In all, such a scenario was assumed to cause inhabitable conditions for 1, 2 or 20 persons.

In case the initiating fire was on open deck it was first estimated possible to reside on ro-ro deck as an alternative potential safe place if the accommodation space becomes inhabitable. However, Figure 4.8 above shows that an unfortunate wind will definitely cause persons on ro-ro deck to be exposed to toxic smoke. Furthermore, calculations of the heat radiation levels of a large external fire developed on open deck, involving the wheelhouse, gave levels which are well beyond 2.5 kW/m^2 at a distance of 15 m. A fire scenario was nevertheless assumed to take a bit longer before causing inhabitable conditions in the accommodation space in comparison with a fire initiated on the ro-ro deck. Therefore, less casualties were assumed from a fire initiated open deck, namely 1, 5 or 80 persons depending on the number of persons on board.

In case a major fire initiated on open deck occurs in the prescriptive design, the conditions are similar to when fire was initiated in the accommodation space. The fire is mainly assumed to involve the wheelhouse, even if it would take longer and is significantly less likely. Fire protection towards the accommodation space (evacuation stations) is only A-0 and fire could therefore spread downwards and affect residing passengers. However, at this time evacuation is assumed to already have taken place. Nevertheless, people may still be exposed to critical conditions before fire spread, in particular due to smoke and heat radiation during evacuation, in particular at high occupancy. Therefore, in case the ship is running on full capacity 10 persons were assumed exposed to critical conditions and otherwise 1.

4.2.2.5. Prevention of a major exterior fire

The major fire scenarios discussed above could be limited if fire-fighting efforts are established and performed effectively. Considering the potential for early deterioration of structural integrity in FRP composite structures exposed to significant fire it may although be difficult to perform fire-fighting at this time in the base design. Since fire spread in the vertical and lateral directions are considered and fire hoses are primarily available on ro-ro deck it should be easier to manage a large fire in the forward part of the ship. However, in this case the possibilities for navigation would be very limited. A fire on ro-ro deck could be easier to reach for fire-fighting thanks to the layout but if the forward bulkhead is compromised and available fire-fighting equipment is limited by the fire the possibilities may be small. In all the probability of getting a fire under control was assumed the same all over the ship except on ro-ro deck. In the prescriptive design it was estimated successful in 60% of the cases for all fires except for those initiated on ro-ro deck for which the probability was estimated to 50%. The likelihood of getting the fire under control in the base design is although significantly lower due to the potential for collapse, added fuel to the fire and the potential difficulties in extinguishing a large fire established in FRP composite. Successful fire-fighting was therefore estimated to be possible in 15% of the cases, except for those fires initiated on ro-ro deck for which the probability was estimated to 10%.

4.2.3. Evacuation

- To establish the risks associated with evacuation, which may be more likely in the alternative design and arrangements.

The probability of fire scenarios which lead to abandonment of the ship may be increased in the base design and the trial alternative designs, which has not been managed so far. Risks associated with the abandonment process must thus be accounted for.

In [23], historical data from Lloyds Register and DNV covering the years 1990-2002 was investigated in order to assess the risk (to life) associated with evacuation as a result of fire. In this case evacuation includes to muster, assemble, disembark and abandon the ship. If a fire occurs on a cruise ship, a number of events were identified which affect the likelihood of a successful evacuation process, as illustrated in Figure 4.9. These and other events affecting abandonment of a cruise ship are further discussed below, particularly with regards to likelihood, potential outcomes and applicability for the small island ferry.

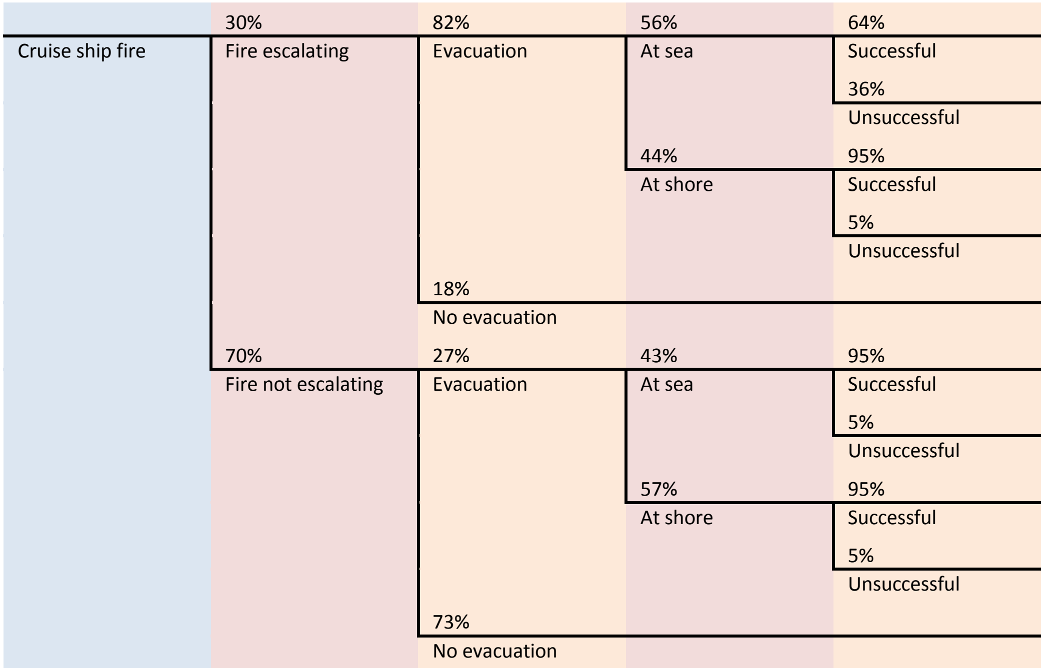

Figure 4.9. Event tree for cruise ship fires based on historical data, reproduced from [23].

4.2.3.1. Failure to reside on ship

According to [23], the probability for evacuation (abandonment of the ship) is linked to whether the fire is escalating or not. This is assumed to correspond to whether a fire in the risk model is contained or not and was hence taken from the current data in the event trees. If containment is not lost, abandonment will take place in 27% of the cases. The reason for this figure not being 0% is that a decision to abandon the ship many times has to be made before it is known whether the fire will later become under control. The current situation when a decision is made is hence related to whether a fire will later become under control or not but the following scenario may not be as expected. This uncertainty often leads to conservative decisions being made. If the fire is not contained, evacuation takes place in 82% of the cases in the model. Unsuccessful fire-fighting efforts for a long time will likely result in a decision to abandon ship. However, in some situations it may be assessed safer to stay and await the fire development on the ship. Hence this figure is not 100% in a prescriptive ship. Since these possibilities are more limited in the base design, due to the risk of collapse, this probability was assessed to be 97% in the base design. The corresponding probability in case of fire containment proves successful in the base design was in general assessed to be somewhat higher than in the prescriptive case due to the higher potential for consequences in case a decision is delayed, 38%.

In case of a fire on open deck or outboard sides of the ship, the fire-fighting efforts hindering a major fire are assumed to correspond to whether a fire is said to escalate or not in the data. Thus, if the fire is controlled the probability of abandonment is 27% and if containment fails the probability if 82%. For the base design the corresponding probabilities are 38% and 95%, respectively.

4.2.3.2. Events affecting the number of casualties in case of abandonment

In case a decision to abandon ship has been made, Figure 4.9 presents another event which affects the likelihood of a process without casualties, called successful evacuation. This event is whether abandonment of the ship takes place at sea or at shore. If the abandonment is a result of a fire which is escalating the probability to evacuate at sea is 56% and if the fire does not escalate the probability is 43% according to the aforementioned data. This has an effect on the probability for casualties. In case the abandonment was a result of an escalating fire and takes place at sea the scenario results in casualties in 36% of the cases and in all other scenarios only in 5% of the cases. This difference may be because of stress and direct effects on the possibilities for abandonment caused by the escalating fire. This seems valid also for the Eco-Island ferry but in the current model a new estimation was made with regards whether the evacuation takes place at shore or at sea for the base design. Considering the potentially short time until collapse in the base design and the approximately one hour crossing time it was estimated possible to reach shore in only 10% of the cases if the fire is escalating and otherwise in 30% of the cases.

4.2.3.3. Casualties in case of abandonment

People may be exposed to critical conditions, even if the ship is abandoned at shore. According to the statistics discussed above, this occurs in 5% of the occasions. Persons may e.g. have a heart attack due to a stressful situation, have a bad fall or be exposed to smoke when abandoning the ship. In these rare events where fatalities occur in the process of abandoning the ship at shore, 1 person was assumed to be caused, which gives an average outcome of 0,05 persons per evacuation at shore. In case of high season this figure was assumed doubled.

As for evacuations due to fire at sea, this was investigated in [23, 24]. In the records of fire accidents that were studied, solely six records of accidents where found where lives were lost due to unsuccessful evacuation; four were from accidents on RoPax ships and two from accidents on cruise ships, all significantly larger than the current island ferry. The authors assume that fatalities due to poor evacuation performance is similar for RoPax and cruise ships and that the likelihood of each accident is equal. In the six accidents 93%, 33%, 4%, 1%, 1% and <1% of the people on board were caused in the accident. The authors thus assume that the probability of each of these fatality rates is equal and representative for evacuations on both kinds of vessels. In actuality, however, only the two lowest records come from cruise ships.

In this report it was assumed the statistical data found in [23] was assumed to be valid. This assumption applies regardless of whether the fire is escalating or not since this is considered taken into account in the difference in probability for casualties. Hence, the expected number of fatalities in case of evacuation at sea was calculated to 22% and was assumed to apply to the persons on board who have not yet been exposed to critical conditions, both in the prescriptive design and the base design. The fact that the scenario may be more severe in the base design is namely already considered in the adjusted probability of casualties for such a scenario. The same applies to the difference between scenarios where the fire is escalating or not escalating.

4.3. Frequency of fire and probability distribution

In the hazard identification it is required to investigate whether there is relevant statistical data for frequency of ignition for the considered spaces. This was further looked into in the quantitative part of the assessment. Few sources of literature were found which present such data valid for different spaces on a passenger ship. The data which was found was nevertheless investigated quite thoroughly in order to determine the likely frequency of a fire occurring on the Eco-Island ferry and furthermore to determine a probability distribution for fire the different spaces.

4.3.1. Frequency of significant fire

As part of the FIRE-EXIT research project, historical data was investigated from Lloyd's Register (and supplemented with data from DNV and other sources) covering the years 1990-2002 [23]. In this study only cruise ships over 4 000 GRT were considered, which gave a statistical base of 3 185 ship years in the chosen time period. Ships undergoing repairs were omitted as well as fires categorized as non-serious. Based on this historical data it was shown that the number of large fires on a cruise vessel can be estimated to 0.012 per ship year. A more detailed study also showed that the probability distribution of a fire starting in different areas on board can be estimated according to Figure 4.10 based on the statistical data.

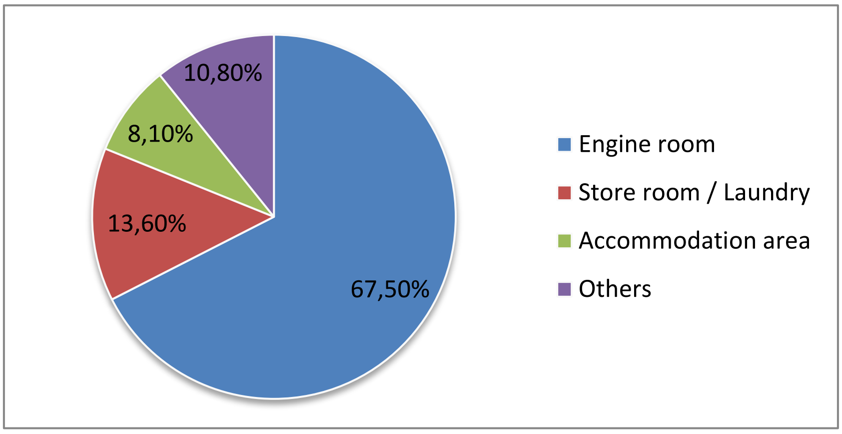

Figure 4.10. Origin of fires on cruise ships according to [23].

The data is not all the way applicable for the Eco-Island ferry since the data covers significantly larger ships with many more spaces etc. It was nevertheless estimated likely that fire in the engine room is the most likely also on the Eco-Island ferry and that frequency of a fire occurring may be significantly smaller. It was although also noted that 0.012 fires per ship year is already a quite low figure, which gives reason to believe that what is being considered as a fire in the investigated historical data is quite a major occurrence, as mentioned above. This figure is thus not very applicable to use as the frequency of a fire igniting but may rather correspond with the frequency of uncontrolled fires on cruise ships. The sought frequency should correspond to the number of fires occurring on a small passenger ferry which would be self-fuelled and continue to develop if left unhindered, referred to as a significant fire. This is not to mistake with a large fire since what is referred to as a significant fire must not be large in order to develop, if for example oxygen supply is unrestricted and no action is taken for extinguishment. It must only be self-fuelled and large enough to develop if left unhindered.

Further data was found in articles and project reports from the research projects SAFEDOR [25, 26] and Fireproof [27, 28]. In particular published data on fire frequencies per ship year for 51 different types of spaces on passenger ships were studied [28, 29]. The data stems from historical records of fire ignition in an incident database from different kinds (and sizes) of passenger ships. The database contains fire incident data (1 521 records) from a number of operators, corresponding to 463.13 ship-years. Note that fire incidents must be a lot smaller magnitude than the large fires implied in [23]. Accordingly the weighted average fire ignition frequency counts to 3.28 per ship-year. This figure would although probably be smaller for the Eco-Island ferry since the ship is very limited in size and number of passengers in comparison with the average cruise ship. However, the data is probably also associated with biases which should be accounted for, e.g. due to hidden statistics; since pure ignition of a fire may lead to a very limited fire if managed swiftly it may not find its way in to statistics. In all, half of the above figure (1.64) was assumed valid for the number of significant fires on the Eco-Island ferry per ship-year, mainly due to its restricted size in comparison with the considered average cruise ship (the size of which could be distinguished from the number and size of spaces in the data). Accounting for uncertainties in the statistical records, this was assumed to be a conservative figure, in particular in comparison with the data from Lloyd's Register.

This best estimate figure may be uncertain and could be derived in further detail. However, since the current fire risk assessment is relative between the prescriptive and alternative ship designs, and fires are assumed to occur as often on both ships, the actual value is irrelevant. It is just a way to link the assessment to risks from other activities in society.

4.3.2. Fire probability distribution for the different spaces

In order to find a probability distribution for fire in the different spaces in the considered superstructure, calculations were made in three ways. Firstly fire incident data from the Fireproof project was used as starting point to assess the relative likelihood of fire in the different spaces on the Eco-Island ferry based on the frequency of fire in each space according to the data. It accounts for fire frequencies in 51 different types of spaces on passenger ships, covering most spaces on the Eco-Island ferry. The spaces were identified in the data and multiplied with the number of spaces on the ship. In case a matching space was not found in the data, assumptions were made that the fire frequency was the same as in a space judged similar. The auxiliary machinery spaces were therefore assumed to correspond with the frequency of ignition in “electrical room”, which was hence multiplied by four since there are four such spaces. Neither was any data found for void spaces and these were therefore assumed to have a tenth of the ignition frequency of an auxiliary machinery space, which was multiplied by 17 void spaces. The ro-ro deck was assumed to count as 25% “engine / machinery space” and 75% “deck area (exterior)”. In other cases several spaces were considered to make up one space. For example the accommodation space was assumed to consist of a “public area (others)” as well as “restroom (public)”. Since it was assumed that what is considered a restroom in the data contains several facilities, only one of these were added to the accommodation space (and a third to the wheelhouse). Summing up the frequencies of the various spaces in each space group and dividing them by the total fire frequency for all spaces gave the relative ignition probability distribution presented as IPD1 in Table 2.1.

Traditionally in Fire Safety Engineering, the probability of ignition in a building is said to stand in relation to the floor area in that building or space (e.g. [30]). Hence, in this case the total floor area of the spaces in each space group divided by the total floor area of the superstructure could be said to represent the probability of a fire igniting in a space in that group. This is a quite vague model for probability of ignition founded some 40 years ago. The validity is questionable and the biases are obvious. In particular there is no account taken to the potential differences in fire risk in the spaces, e.g. depending on their use, who has access, amounts of initial fuels and especially ignition sources. Nevertheless, based on this theory the frequency data for each space in the ignition database used in the Fireproof project was therefore linked with corresponding floor areas, out of which minimum, maximum and average values were available [28, 29]. The obtained fire frequency per space and square meter was multiplied by the floor areas on the Eco-Island ferry which gave a second ignition probability distribution (IPD2 in Table 2.1) for the spaces groups on the ship. Whilst the former ignition probability distribution (IPD1) can be said to consider the ignition probability to stand in relation to each space as a function, this distribution (IPD2) also considers the ignition probability to depend on the area of each space. In some cases the data on associated floor area was uncertain or missing, which required some assumptions. For example, “open deck (exterior)” was not given any associated floor area and therefore data for "promenade deck" was used where appropriate.

A third distribution was also formed based on the performed hazard identification. Several Fire experts at SP Fire Technology made individual estimations based on the potential ignition sources and initial fuels available in the spaces in this particular design case. With the question "if a fire starts on the ship, how likely is it that it has occurred in space X", each space was given a value between 1 and 15. The figures were thereafter divided by the total sum to derive an ignition probability distribution. An average of these judgements rendered the ignition probability distribution referred to as IPD3 in Table 2.1.

Table 4.1. Ignition probability distributions [%] based on different data as well as an average distribution

Space group	*IPD1*	*IPD2*	*IPD3*	*IPDavg*
Accommodation spaces	6,0	24,0	17,6	15,8
Engine rooms	48,6	33,5	30,9	37,7
Auxiliary machinery spaces	10,0	0,8	6,2	5,7
Void spaces	4,3	0,6	2,1	2,3
Wheelhouse	3,9	5,4	10,3	6,5
Ro-ro deck	13,4	32,2	18,5	21,4
Stairways	4,0	3,0	4,1	3,7
Open deck space	9,8	0,4	10,3	6,8
Total	100,0	100,0	100,0	100,0

The three distributions formed as described above were summed up and averaged, which generated a final distribution, referred to as IPDavg in Table 4.1 an illustrated in Figure 4.11.

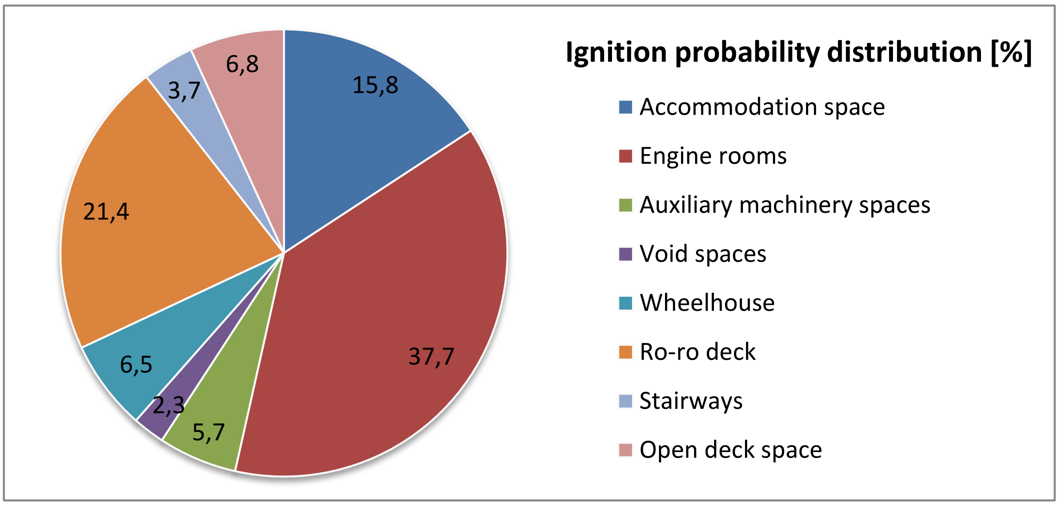

Figure 4.11. Ignition probability distribution derived for the different kinds of spaces on the Eco-Island ferry [%].

Comparing the derived distribution with the distribution presented in Figure 4.10, that data obviously presents a much more coarse distribution and the validity may be questioned when it comes to fire ignition (only large fires are considered) as well as the size of the considered ships. However, according to this data accommodation spaces are involved in about 8.1% of the fires, engine rooms in 67.5% and the rest of the spaces in 24.4%. In the derived distribution the corresponding relationship is rather 15.8%, 37.7% and 46.5%, which is not very close but at the same time not all the way different from the data from Lloyd's Register [23]. The derived distribution can also be compared with a distribution which should come from the same data but which is a bit more detailed, presented in [26]. It shows a distribution where engine room fires still have a similar representation but where the accommodation space category represents up to 15%, which is very similar to the derived distribution. Other, not all the way relevant spaces, represent the rest of the fires.

The derived distribution was also compared with internal company confidential data concerning origin of fires (also on cruise vessels) from DNV, presented in general terms in [26]. Some internal studies done by DNV based on statistics from 150 fire outbreaks for a major shipping company shows a distribution quite different from the one determined from Lloyd's Register. This distribution was adjusted by combining the categories referred to as "engine rooms, machinery spaces" and "incinerator", which were all seen as machinery spaces. The categories called "crew cabins", "pass. cabins" and "restaurants" were combined and called 'accommodation spaces'. Since "bridge" was referred to as one of four spaces in the "other spaces" category, a quarter of this fire probability was called 'Wheelhouse'. All other spaces were put in one last category called 'other'. This generated the distribution of fire origin presented in Figure 4.12.

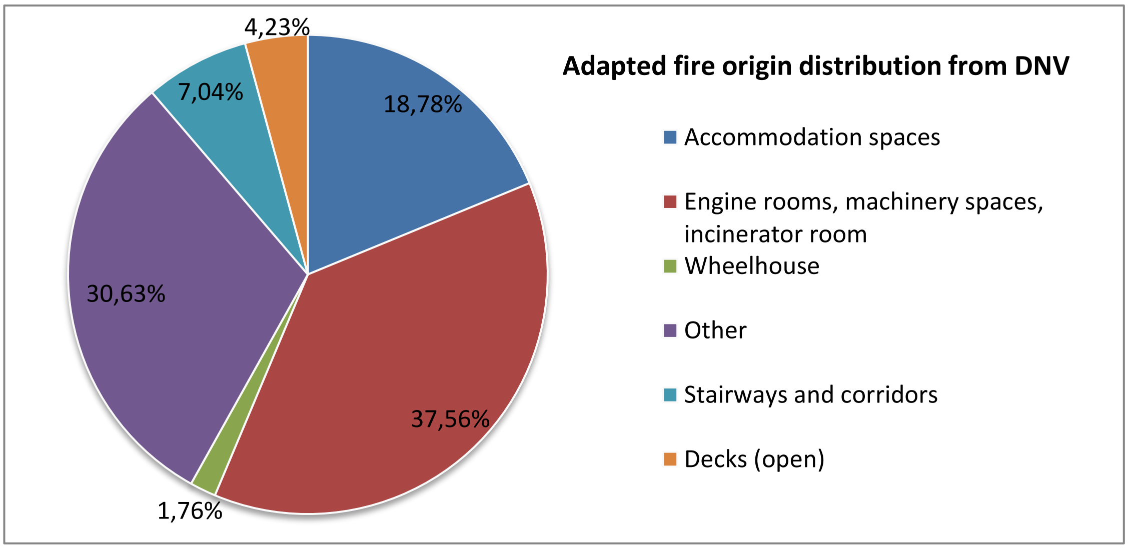

Figure 4.12. Fire origin distribution adapted based on internal data for cruise vessels from DNV [26].

Once again, the validity of this data can be questioned since it is derived from statistics for cruise vessels which have many more spaces, passengers etc. Nevertheless it shows a distribution which is similar to that derived for the Eco-Island ferry. The fires in accommodation spaces and engine rooms are in the same range and so are the fires in stairways and on open deck. The probability of a wheelhouse fire is significantly lower in the DNV data but this is considered reasonable since a wheelhouse on a cruise vessel may represent one of very many occupied spaces. The accuracy of all of these categories although depend on the magnitude of the 'other' category. Hence, for the values to be in the magnitude as presented in Figure 4.12, the 'other' category must be in the an accurate magnitude to represent the fires on ro-ro spaces and other spaces not represented in the other categories. However, it may still be concluded that the relative magnitude of all other spaces (i.e. excluding the spaces in the 'other' category) are in the same range in the adapted fire origin distribution and the ignition probability distribution derived for the Eco-Island ferry.

It should also be noted that when deriving the first two distributions based on ignition frequencies per space as well as per space and space area from the fire ignition database used in the Fireproof project, it was also possible to derive a total fire frequency for the ship. When the frequency was calculated without consideration to the floor areas, a total frequency of 0.85 fires/ship-year was derived for the Eco-Island ferry and when consideration was made to the (rather small) floor areas the corresponding figure was 0.42. These figures are approximately half and a quarter, respectively, of the assumed frequency of a significant fire on the Eco-Island ferry. This further argues for that the figure may be conservative.

Table 4.2. Ignition probability distribution for the different spaces combined with the estimated frequency of fire

	Probability of fire in space	Frequency [per ship-year]
1,64209	15,78%	0,25916
Significant fire	Accommodation spaces	
	37,73%	0,61956
	Engine rooms	
	5,68%	0,09335
	Auxiliary machinery spaces	
	2,32%	0,03817
	Void spaces	
	6,51%	0,10697
	Wheelhouse	
	21,41%	0,35152
	Ro-ro deck	
	3,72%	0,06109
	Stairways	
	6,84%	0,11228
	Open deck space	

The corresponding total fire frequencies for each space group are presented in Table 4.2. The derived frequency of fire ignition and the ignition probability distribution of fire origin were used as starting point in the event trees for the prescriptive and the trial alternative designs.

4.4. Accommodation space fire scenarios

The accommodation space category is representable of the large public space on deck 2. A representative design fire was developed for the space covered by this category, based on the fire hazards described above. The identified target locations and critical factors provide information on the possible scenarios, which lead to different fire developments. Hence the time to reach critical conditions will vary in the different fire scenarios, which together with the number of passengers will make evacuation more or less successful. This will determine the fire risk contribution from this space.

4.4.1. Accommodation space

In the base design the accommodation space has a longitudinal division along most of the space, which will affect the consequences of a developing fire and the possibilities for evacuation. As a whole, the accommodation space has average dimensions of (LxWxH) 16.8x9.5x2.4 m. In the aft there is are two exits towards the ro-ro deck and there are also stairs leading up to open deck and the wheelhouse. As illustrated in Figure 4.13 there are also an exit to the fore deck, even if this is not a safe place for more than a few people.

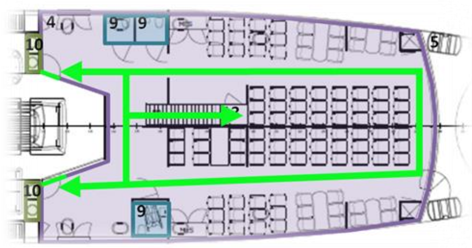

Figure 4.13. Geometries of the accommodation space and the evacuation routes in case of an accommodation space fire.

In case a fire alarm sounds, the evacuation plan is to gather people in the accommodation space, from where the ship should be disembarked. The accommodation space is hence classified as an assembly station. The life-saving arrangement with MES (Marine Evacuation Systems) stations in the accommodation space and spare life rafts in the fore is illustrated in Figure 4.14.

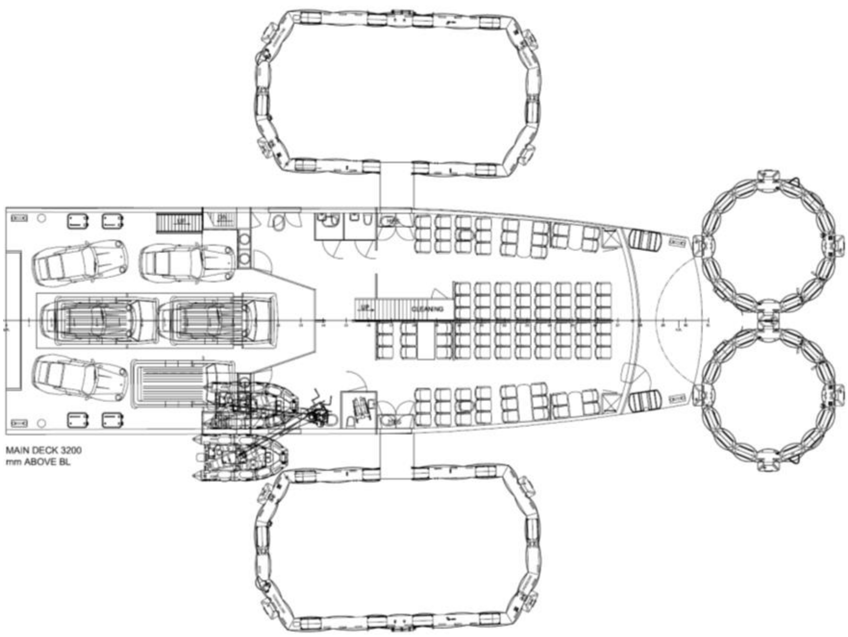

Figure 4.14. Life-saving arrangements on the Eco-Island ferry.

In case a fire occurs in the accommodation space the situation although becomes more complicated. In case the fire was initiated in one of the sides of the accommodation space in the prescriptive design, the people are safe on the other side if the doors between the sides close as intended. However, if the ship is fully occupied (or rather if more than 100 passengers are on board) all the people will not fit in one side of the accommodation space and there is hence a risk that queuing people are exposed to critical conditions. Therefore, in case a fire is detected in the accommodation space the evacuation plan consists in assembling passengers on ro-ro deck. This is also more reasonable in case a door fails between the sides of the accommodation space. In the base design where there is no division between the sides of the accommodation space it is also more reasonable to gather on the ro-ro deck in case of an accommodation space fire. Hence, note the arrows marking the evacuation routes from the accommodation space, of which the staircase to deck 3 would only be used in certain cases.

All of the doors from the accommodation space also represent plausible ventilation openings to provide oxygen for a fire along with the three large windows on each side. As for fuel, the main fuels are the seats, electronic equipment, clothes, magazines as well as passenger baggage and other materials, as described in *Appendix G. Data from fire hazard identification*.

4.4.2. Accommodation space design fire

The definition of a design fire in this space is that it must be able to grow from an incipient phase if it is not hindered. Such a fire was defined for the prescriptive ship in paragraph *4.2.1.1. Fire growth on FRP composite surfaces in internal spaces* based on [17]. It was also concluded that the fire growth will likely be the same up until the fire reaches flashover in the base design.

In order to determine the time available until untenable conditions are reached in the space it is also necessary to determine relevant yields produced by the fire. Yields for different subjects can be found in different literature but is generally quite uncertain. Since the most significant subjects were measured in the large scale cabin fire tests referred to when determining the design fire it was although possible to validate the estimations of yields. This is described in *Appendix J. Validation of yields*. The derived yields used for the accommodation space design fire are listed in Table 4.3.

Table 4.3. Yields for the worst-case accommodation space fire, validated against full scale cabin fire tests [17]

Subject	***Yields***
Energy yield (kJ/g)	12.4
Soot yield (g/g)	0.01
CO_2 yield (g/g)	2.5
CO yield pre-flashover (g/g)	0.15
CO yield post-flashover (g/g)	0.35

4.4.3. Development of accommodation space fire scenarios

The identified critical factors and the associated target locations in the accommodation space are safety functions which provide information on the different possible fire developments. Failure of such a safety function is generally called a failure mode. The most significant failure modes in an accommodation space fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of detection;
- Failure of manual extinguishment;
- Failure of sprinkler system;
- Failure of door;
- Failure of fire-fighting; and
- Failure of window.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.4.3.1. Persons present in accommodation space

The current Tun island ferry has a yearly schedule divided in winter and summer season. The winter season lasts from 1 October until 30 April. Then the ship has 3 crew and makes 2 return trips/day three days a week and otherwise 1 return trip/day. In the summer season on the other hand, the ship has 4 crew and makes 3 return trips/day 2 days a week and otherwise 2 return trips/day. Furthermore, in the winter time the maximum number of passengers is limited to the number of inside seats. On the Eco-Island ferry this number is 101 and in the summer season the allowed number of passengers is 200. These figures are very similar on the current Tun island ferry: 103 and 196 respectively. According to the shipping company the ship goes on full capacity basically throughout the whole high season, which lasts from mid-June until mid-August, when school children are on holiday. In the cold winter time, November-March the number of passengers is basically limited to serve the about 120 people living on the island, on average 5-10 per trip. In the spring (April – mid-June) and fall (mid-August – October) the ship is generally more occupied, with about 20-40 passengers on average. The number of passengers in these mid seasons is although very weather dependant. If the weather is nice the ship is often in need of its full capacity.

These values were used as input data to the quantitative analysis in order to create a realistic probability distribution of passengers. For the analysis it was assumed that on average 7.5 passengers travel with the ship in the winter season. It was further assumed that that the trips with full capacity in the spring and fall (in case of nice weather) can be represented by half a month going with full summer capacity each. One could then say that the ship runs with full capacity June-August and with about 30 passengers April-May and September-October. Considering the number of trips each month it adds up to 650 trips, where about a third are made with 7.5, 30 and 200 passengers respectively. The exact figures sum up to 49 985 passengers in a year. This corresponds very well with the approximate number of passengers in a year calculated by the shipping company (50 000).

Based on the figures above it was hence estimated that, including the crew, the total number of passengers on the ship is 10.5, 33.6 or 204 persons (during the same times as referred to above).

With regards to whether there is anyone present in the accommodation space it was assumed that people are always present in the accommodation space. This is reasonable since the assessment is delimited to when the ship is operating and the ship almost never travels empty. In the low season and mid seasons all of the 7.5 and 30 passengers, respectively, are assumed to occupy the accommodation space. In the high season when the ship is fully occupied the maximum number of passengers are assumed in the accommodation space, i.e. 101 persons. The occupancy probability distribution hence becomes 33.3% for 7.5 passengers, 34.7% for 30 passengers and 32.0% for 101 passengers.

4.4.3.2. Automatic detection and alarm system in the accommodation space

According to reports from the research project Fireproof and the OREDA handbook [31-33], the failure rate for fire and gas detectors can be set to $\lambda=0.43*10^{-6}$ per hour. Assuming that the detectors are replaced every ten years, the reliability can be calculated as $1\text{-}f(\lambda) = e^{-(\lambda*t)}$ to between 0.96-1.00. This close to one (1), it is a good approximation to consider the exponential function to be linear, i.e. an average failure rate of 2% could be used. However, this reliability data only covers the detector and not the connected alarm systems. When a fire is detected on board the ship, an alarm is activated in the accommodation space as well as on the bridge. It was estimated that the average failure rate for the whole system is twice as high. Thus, failure in the detection and alarm system (including both the alarm warning passengers in the accommodation space as well as the alarm on the bridge) are assumed in 4% of the fire scenarios. This figure could be further elaborated.

4.4.3.3. Manual extinguishment in accommodation space

In case a fire is established in the accommodation space, first aid may be given by a passenger close by the fire and slightly later there may also be initial attempts of manual fire extinguishment by passengers and crew. These occurrences were combined in one probability of manual extinguishment.

Both occupancy and function of the detection and alarm system were identified to affect the probability of such attempts. In the normal case when a fire is detected in the accommodation space an alarm is activated in the accommodation space. An alarm is also activated on the bridge and a crew member on call is commanded to investigate the alarm. According to routines the crew member is to call back to the bridge over the radio to report whether a fire is discovered or not. The crew member who called in the fire will also attempt to put out the fire and rescue persons in immediate danger. The order of the above events is obviously uncertain but first priority should be to call in the discovered fire to the bridge and second priority to relief endangered passengers.

In case the accommodation space is fully occupied, a person present in the accommodation space was estimated to provide first aid in 65% of the cases where a fire is ignited. There are first fuels which may be easy to extinguish in the early stages but in other cases proper fire extinguishing equipment may be necessary even this early. Furthermore, the fire may not be ignited where people reside, in particular if established by an arsonist, e.g. in a lavatory. If fire manages to establish, manual extinguishment by passengers or crew was assumed to be successful at an early stage in 15% of the cases when detection is functional. This figure takes into account that crew may be hindered to reach the fire due to the many evacuating passengers and were only estimated successful in 5% of the cases. Passengers attempting to extinguish the fire may also be hindered from extinguishing the fire due to the many evacuating passengers and were estimated to be successful in manual fire-fighting in 10% of the relevant cases. If detection is not functioning, these probabilities were in total reduced to 6%, based on that crew efforts may be too late and less passengers may realize the seriousness of the situation to take action. In all the probability of failure of manual extinguishment in case of full occupancy was derived to 29.8% in case detection is functional and to 32.9% in case detection fails.

In case the accommodation space is occupied by 30 passengers, the probability of first aid in case a fire is ignited was reduced to 45%. This was based on that less people will be present in the space but that they are still likely be in proximity of the fire in case it occurs in the seating area. If fire establishes, the probability of successful manual extinguishment by passengers or crew at this early stage was estimated to 35% in case detection is functional. This estimation is based on that crew is successful in extinguishing the fire in 25% of the cases, accounting for that one less crew member is available in 50% of the cases and that they may be occupied elsewhere. It furthermore assumes that passengers attempting to extinguish the fire are successful in 10% of the relevant cases. The latter probability is assumed to be only slightly affected by detection whilst the probability of successful fire-fighting by crew is significantly reduced. In total the probability of extinguishment by passengers or crew in case detection fails was estimated to 10%. In all the probability of failure of manual extinguishment in case occupied by 30 persons was derived to 35.8% in case detection is functional and to 49.5% in case detection fails.

In case the accommodation space is occupied only by 7.5 passengers (on average), the probability of first aid in case a fire is ignited was reduced to 25%. This was based on that significantly less people are present in the space. If fire establishes, the probability of successful manual extinguishment by passengers or crew at this early stage was estimated to 25% in case detection is functional. This estimation is based on that crew is successful in extinguishing the fire in 15% of the cases, accounting for that one less crew member is available and that they may be occupied elsewhere. It furthermore assumes that passengers attempting to extinguish the fire are successful in 10% of the relevant cases. The latter probability is assumed to be only slightly affected by detection whilst the probability of successful fire-fighting by crew is significantly reduced. In total the probability of extinguishment by passengers or crew in case detection fails was estimated to 8%. In all the probability of failure of manual extinguishment in case of full occupancy was derived to 56.3% in case detection is functional and to 69.0% in case detection fails.

4.4.3.4. Sprinkler system in accommodation space

According to reports from the research project Fireproof and the OREDA handbook [31-33], the failure rate for a sprinkler system can be set to λ=0.00036 per day. Assuming that the systems are tested and maintained on a yearly basis the reliability can be calculated as $1\text{-}f(\lambda) = e^{-(\lambda * t)}$ to between 0.88-1.00. This close to one (1), it is a good approximation to consider the exponential function to be linear. Hence the failure probability can be described as a uniform distribution between 0-0.12.

Furthermore, probabilities for sprinkler effectiveness was collected from statistics available in [34], showing a wet pipe sprinkler system performance reliability of 91%. The same statistics show that the probability for a wet pipe sprinkler system being functional is 93%.

In all, the probability of wet pipe sprinkler system failure was assumed to be 9%. The reason why the lower figure was selected was due to uncertainties in the time between functionality controls, even if this is supposed to be carried out on a yearly basis.

4.4.3.5. Doors open in the accommodation space

In case detection and alarm system fails to function, so will the connected door-closing devices for the doors put up on a magnet in the fore and in the aft part of the accommodation space. Someone may manually force the door closed, but for this to have a significant effect both doors must be closed this way which was considered to be unlikely. Moreover, in case the detection and alarm system functions could the door-closing devices fail independently. The door may stay open due to failure in the door mechanism, the door-closing device or due to it being put open, e.g. by personnel, a passengers luggage or an arsonist. The two doors were considered together; it is namely mainly the aft door which makes a significant difference in case of a fire scenario. No reliable data has been found on the reliability of door-closing devices, which although may stand for only a part of the failure probability of door closure. For this risk assessment it was assumed that the probability that the doors (or at least the aft door) is open in case a fire is detected in the accommodation space is 90%. However, the probability of the door being closed was also identified to be affected by the occupation in the space since this could affect the potential for luggage blocking the door etc. Therefore the probability of door failure in case of full occupancy was judged to be 15%. In the base design and trial alternative designs without added doors the probability of door failure is naturally 100%.

4.4.3.6. Fire-fighting in accommodation space

Swift fire-fighting efforts could hinder a so far uncontrolled accommodation space fire to develop further. In case the doors are open it was also identified necessary to account for local collapse. The time until local collapse in case of an accommodation space fire was discussed in paragraph *4.2.1.2. Time until local collapse* and estimated to possibly occur within 4-7 minutes from fire ignition. The possibilities for fire-fighting were discussed in *4.1.3. Fire-fighting* and [18], and based on these discussions it can be concluded that the time from detection of a fire until the first crewmember with fire-fighters outfit is at the scene should be less than 4 minutes. According to Figure 4.2, even a fire with a 4 minute incipient phase may reach flashover 5 minutes after detection. In combination with the probability of local collapse, this gives reason to believe that the potential for successful fire-fighting in the base design may be limited. The above discussions and references led to an estimation of the probability of successful fire-fighting before window breakage of 15% if the doors are closed in the alternative designs (which they are not in the base design). This includes account to the possibilities for safe access and other relief by new fire-fighting tools in the base design. The corresponding probability in the prescriptive design was estimated to 10%. In case the doors are open in an alternative design, the probability of successful fire-fighting before window breakage was estimated to 5%. This accounts for the reduced potential for fire-fighting due to the risk of collapse. In the prescriptive design the corresponding probability was estimated to 8% in case the doors are open. Note that fire-fighting efforts may also prove successful in later events, i.e. after potential window breakage.

In case fire-fighting fails at this stage, it was assumed that local collapse will occur in the base design. The consequences for people in case of a local collapse should not be substantial since evacuation of the space should already have taken place, based on *4.2.1.2 Time until local collapse* and the fire simulations presented in *Appendix L. Results of FDS simulations*. It is hence although possible that a local collapse has consequences for passengers assembled in an adjacent space. Such consequences were assessed small and to give fatalities in relation to the occupancy of the ship. It was assumed that local collapse due to fire would be associated with 5 fatalities in high season and otherwise with 1 fatality.

4.4.3.7. Window breakage in accommodation space

In order to estimate the likelihood of window breakage in case of a fire in the accommodation space, simulations were performed using the software Fire Dynamics Simulator [35], as further described below. The unhindered design fire derived above was used in the simulations where both half the accommodation space (port side) and the whole space were modelled. All relevant outputs are documented in *Appendix L. Results of FDS simulations*. The data most relevant for evaluating window breakage is the temperature by the windows. The locations where the temperature was measured in FDS are illustrated in Figure 4.15.

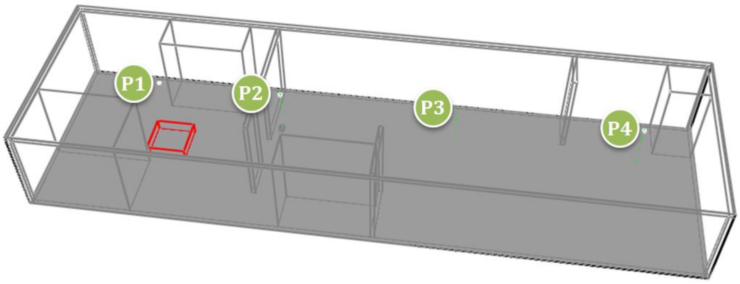

Figure 4.15. Illustration of the different measurement locations in the fire simulation model of the port side of the accommodation space.

To make estimations of the likelihood of window breakage, the temperatures at different heights were evaluated at locations P2 and P3 in the scenario where the port side of the accommodation space is closed from the starboard side (compare Figure 4.15 and Figure 4.18).

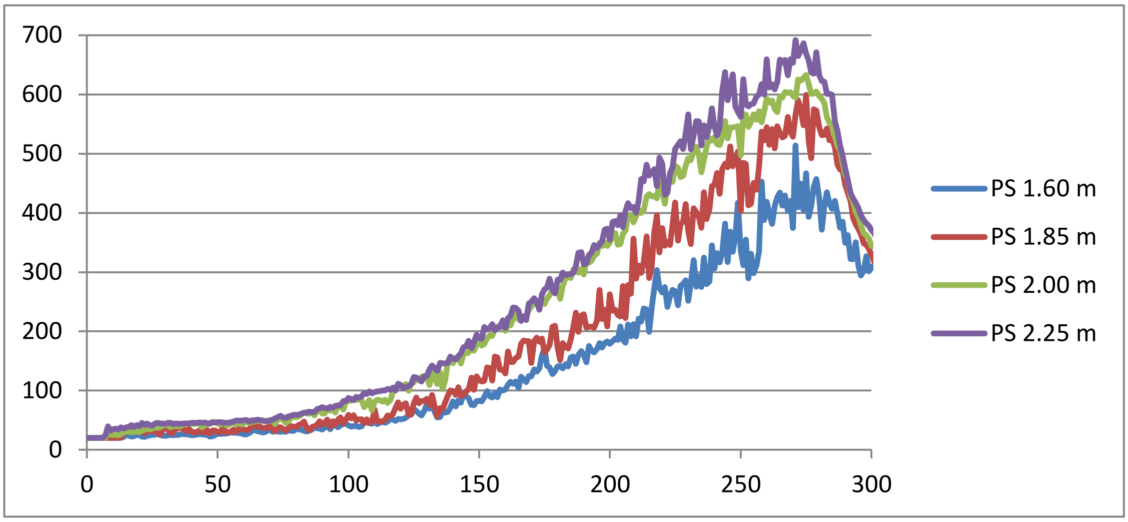

Figure 4.16. Gas temperature [°C] versus time [s] at different heights at location 2 on port side.

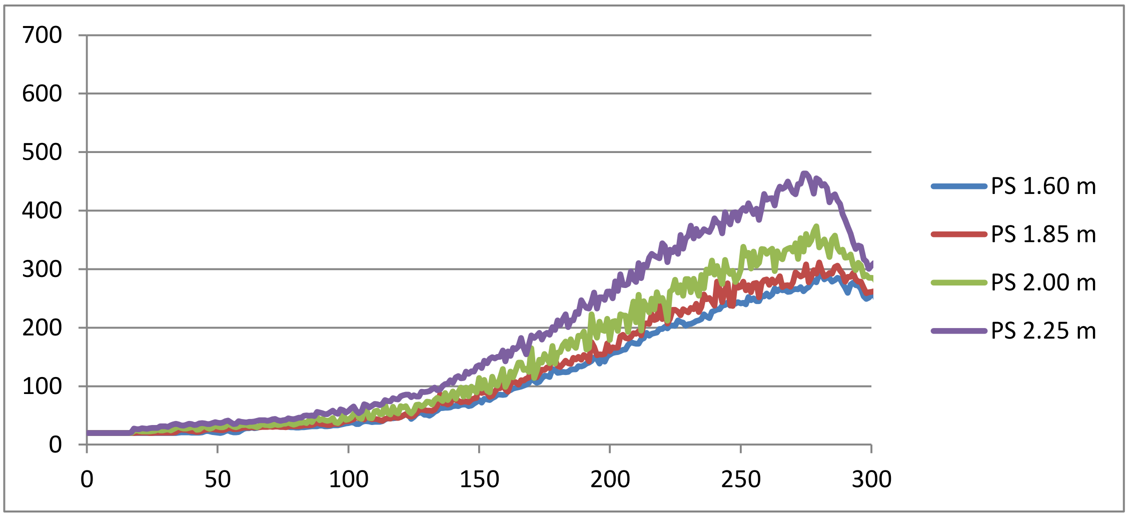

Figure 4.17. Gas temperature [°C] versus time [s] at different heights at location 3 on port side.

In [36] the published knowledge of window glass breakage in case of fire was summarized some years back. It shows that 3 mm single pane glass windows can be assumed to fall out at gas temperatures of about 310-410°C. Most of the data primarily deal with thin panes of annealed or tempered soda glass. Yet, there are also data showing that tempered 6 mm glasses fall out at 330-380°C and tempered 10 mm glasses fall out at about 470-590°C. Some 6 mm thick plate glass, used in many commercial buildings, were found to shatter after a significant time (7 min) of exposure to high radiation. It should although be noted that the key feature which causes windows to break is the temperature difference over the glass, which means that thicker glasses do not necessarily perform better than thin glasses. The glass frame and other conditions play a big part as well.

The windows in the accommodation space have a designed thickness of 8 mm or 10 mm and the top of the windows is situated about 0.2 m from the ceiling. In Figure 4.16 it is shown that temperatures 0.3 m from the ceiling (2.0 m above the floor) reach over 350°C after 200 s and that almost 600°C is reached at this height before the fire is self-extinguished. The temperatures in this location are although much higher than by the windows, which would likely be closer to the temperatures at location P3. In Figure 4.17 it is shown that the temperatures here are significantly lower and that 0.3 m from the ceiling the temperatures reach 350°C first at the end of the fire development. From the published data revised above, these temperature although seem sufficient for single pane single glass windows and tempered 6 mm glass windows to fall out. Since the temperatures by the windows may not be much higher than 350°C the probability of a window to break before a non-ventilated accommodation space fire self-extinguishes was estimated to 60%. Hence, if the fire is not extinguished by first aid, early manual extinguishment by passengers or crew or by the sprinkler system, then a window is assumed break in 60% of the cases. The temperatures reached very similar magnitudes in the scenario where the doors between the port and starboard parts of the accommodation space are open, as seen in Figure L13. However, the temperatures lasted significantly longer (approximately 100 s) before the fire self-extinguished. This was assumed to give a higher probability of window breakage, estimated to 85%.

The probabilities for window breakage estimated above also account for the probability that any door to the space was fixed open, which would provide ventilation to the fire and promote fire spread. The probability for this event alone was estimated to <5%. In case the doors are closed in the accommodation space and the windows stay intact the fire was assumed to self-extinguish without any significant consequences else than the burnt out space. In case the windows break the fire was assumed not to self-extinguish but to spread to other parts of the ship. Thus, the above derived probability corresponds with containment of the fire in the space of origin.

In case the fire spreads on external surfaces the consequences were assumed insignificant if fire-fighting efforts are provided swiftly, the probability of which was above estimated to 6% in the base design and to 50% in the prescriptive design (see *4.2.2.2. Prevention of an exterior fire to grow sufficiently to cause local collapse*). In the base design the resulting probability of a fire causing consequences outside the compartment of origin hence becomes 80% in case the doors between the parts of the accommodation space were closed and 87% in case they were open. In the prescriptive design the corresponding figures are 30% and 43% in case the doors were open or closed, respectively.

4.4.4. Consequences of accommodation space fire scenarios

In Fire Safety Engineering a common approach in performance-based evaluations of safety is to the use the so called ASET-RSET approach. It stands for available safe egress time – required safe egress time, which in other words means that the time required for evacuation is withdrawn from the available time for evacuation in order to determine whether the design achieves sufficient safety. In this case the approach was used in order to determine the potential consequences associated with different fire scenarios in the accommodation space during evacuation of the space. The time available for evacuation is determined in the subsequent paragraph whilst the time required for evacuation is determined in the following paragraph. Thereafter the resulting consequences of accommodation space fire scenarios are summarized.

4.4.4.1. Time until critical conditions are reached in the accommodation space

In determining the available time until critical conditions may be reached in the space, simulations were performed using the software Fire Dynamics Simulator [37]. In the simulations the dimensions of the accommodation space were simplified to approximately 16.6 x 9.8 x 2.3 m^3, as illustrated in Figure 4.18. Figure illustrating the FDS fire simulation model.. Apart from a number of obstructions this gives a volume of about 374 m^3.

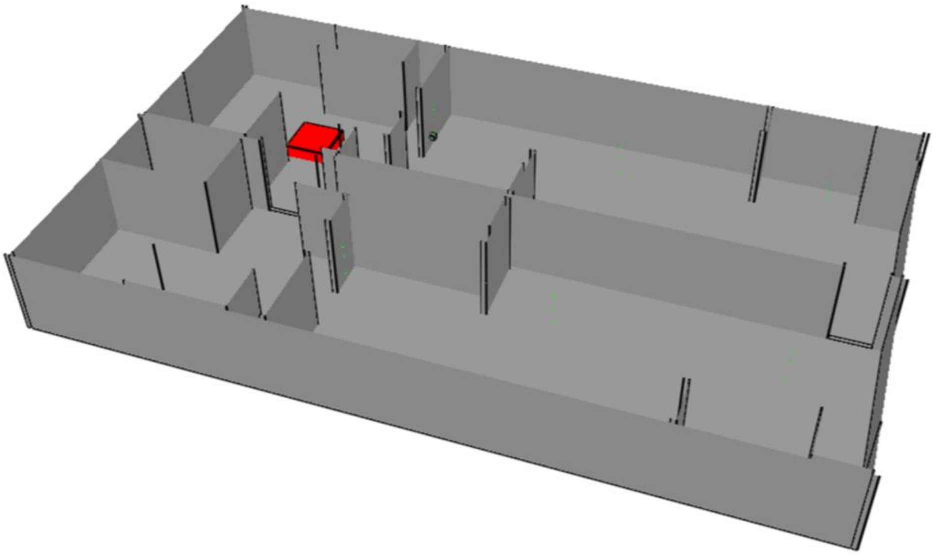

Figure 4.18. Figure illustrating the FDS fire simulation model.

The unhindered design fire as well as the yields determined above were used in the simulations. The fire was assumed located in the port/aft part of the accommodation space, by the toilets, so that the passengers would have to evacuate through the opening at the front of the space to be safe.

Two fundamentally different models were set up, one simulating the conditions in case the accommodation space is subdivided longitudinally (and all separating doors close properly) and one representing the case where there are openings between the port and starboard sides in the aft and the forward parts of the accommodation space. The following measurements were taken in the simulations:

- Heat release rate
- Temperature in heat detector
- Smoke obscuration in smoke detector
- Gas temperature
- Oxygen concentration
- Carbon dioxide concentration
- Smoke layer height
- Visibility

The measurements (except HRR) were mainly taken at four locations along the centre lines of the port side (P) and starboard side (S) of the accommodation space. These locations are referred to as P1-4 and S1-4 and are illustrated in Figure 4.19. The last five measurements in the list were taken at four different heights, 1.60, 1.85, 2.00 and 2.25 m above the floor.

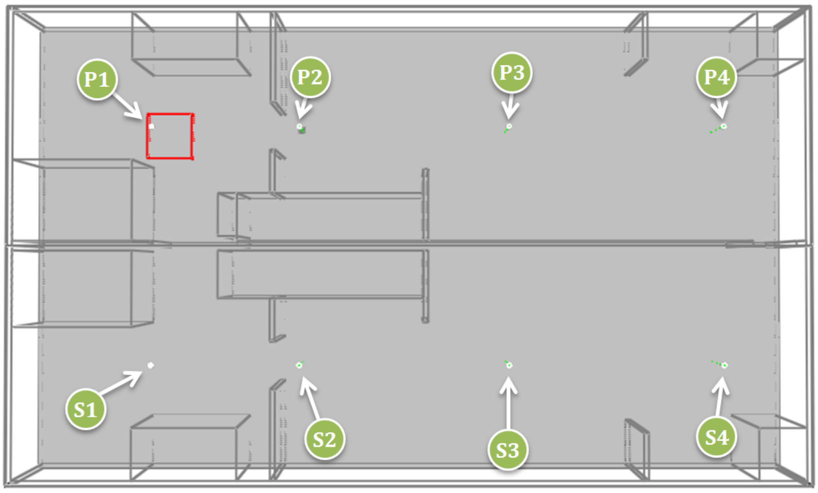

Figure 4.19. Illustration of the measurement locations in the FDS fire simulation model of the whole accommodation space.

Exact details for the measurements and estimations and other assumptions necessary for the simulations are documented in *Appendix K. FDS input files*. The criteria for critical life-safety conditions are established below and the associated results from the FDS simulations thereafter presented. All relevant outputs are documented in *Appendix L. Results of FDS simulations*.

Criteria for untenable conditions in the accommodation space

With regards to critical conditions, an amendment was proposed to Circular 1002 at MSC 90 [38] to incorporate uniform life-safety criteria. Conditions were suggested to be considered untenable when one of the life-safety criteria is reached, as described in Table 4.4. These are stated to be based on the NFPA Fire Protection Handbook, 20th edition, section 6, chapter 2, Variability of Human Responses to Fire Gases [39].

Table 4.4. Life-safety criteria as proposed by [38], all to be determined at 2 m above the deck surface

Condition	***Criteria***
Temperature	Max 60°C
Heat flux	Max 2,5 kW/m^2
Visibility	Minimum 10 m
Carbon dioxide concentration	Max 1400 ppm

With regards to these criteria, some comments are in place. In the proposed amendments it is stated that these criteria address survivability, which is not a suitable way to put it. Exceeding these criteria will not necessarily result in fatality but the limits should rather be seen as tenability limit; a level of exposure at which it is suggested to measure safety. For survivability of persons, the important aspects although have to do with what happens after exceeding these limits. Nevertheless, except from this unfitting description, the criteria may be compared with criteria used in building industries in different countries (e.g. Sweden, Norway, Denmark, United Kingdom, New Zeeland, Canada, NFPA, ISO…). The temperature criteria of 60°C (a recommendation which was by the way not found in NFPA) is in the lower range when comparing with corresponding criteria in most buildings standards. It is quoted in some publications that a temperature above only 60°C can cause thermal burns to the respiratory tract if the air is saturated with water vapour but a criteria of 80°C is more common. The heat flux is also a conservative measure but is the criteria found in most building standards (in some cases 2.0 kW/m^2 is used). In some cases it is although replaced by e.g. allowing a short exposure to a maximum of 10 kW/m^2 in combination with a maximum heat dose of 60 kJ/m^2 (excluding radiation below 1 kW/m^2). In some building standards this criterion is replaced by a criteria of a maximum temperature in the smoke layer of 200°C, which under certain conditions give a corresponding heat radiation. Furthermore, in some cases it may be necessary to determine exposure to heat radiation elsewhere than 2 m above the floor (e.g. if exposed to flames), which is instructed above. With regards to the visibility criteria of 10 m, this is used in most building standards. It is although commonly relaxed for small spaces for example by complementing it with a less conservative criteria of 5 m visibility in spaces less than 100 m^2. A less conservative criteria is in some cases also allowed around a queue if such is formed at an early stage. With regards to the carbon dioxide concentration criterion this must be a typo and reasonably refers to a critical level of carbon monoxide. A carbon monoxide level of 1 400 ppm is once again a quite conservative criteria, 2 000 ppm is more common. What are also commonly found in building standards are criteria for oxygen and carbon dioxide levels, which have although been omitted in the suggested amendment to Circular 1002.

In this fire risk assessment the above life-safety criteria were used, with a couple of exceptions. A visibility of 5 m was considered acceptable in spaces other than the accommodation space since they are very limited in size and 5 m is more than enough to see across the whole space (except in the wheelhouse where this criteria still was applied since it seems reasonable that the crew is very well aware of their surroundings in this space and will have no problem leaving if necessary for other reasons). Furthermore, criteria for oxygen and carbon dioxide were incorporated based on [40]. The used criteria in this fire risk assessment are summarized in Table 4.5.

Table 4.5. Life-safety criteria used in the fire risk assessment

Condition	*Criteria*
Temperature	Max 60°C
Heat flux	Max 200°C in the smoke layer
Visibility	Minimum 10 m in the accommodation space
	Minimum 5 m in other spaces
Toxicity	Carbon monoxide CO < 1 400 ppm
	Carbon dioxide CO_2 < 5 %
	Oxygen > 15 %

Simulated conditions in case doors dividing the accommodation space are closed

A simulation was first performed of only the port side of the accommodation space, which for example represents the conditions in the prescriptive design in case the detection and alarm system as well as the connected door-closing devices are functional. This set-up was mainly simulated to determine when untenable conditions are reached for evacuating passengers, when the fire will self-extinguish and whether the windows are likely to break before this happens.

The time until reaching untenable conditions in different ways is summarized in Table 4.6. As expected, the performed simulations show that the conservative temperature criteria of 60°C becomes critical first, after 130 s. This is approximately 30 seconds before any other criteria become critical.

Table 4.6. Time until critical conditions are reached in case of an unhindered fire in the port side of the accommodation space

Condition	*Time [s] until reaching condition at location P4*
Temperature > 60°C	**130**
Temperature > 80°C	150
Heat flux > 2,5 kW/m^2 (>200°C)	204
Visibility < 10 m	160
Carbon monoxide > 1 400 ppm	-
Carbon dioxide > 5 %	265
Oxygen < 15 %	160

The temperature distribution in the space after 130 s is illustrated in Figure 4.20.

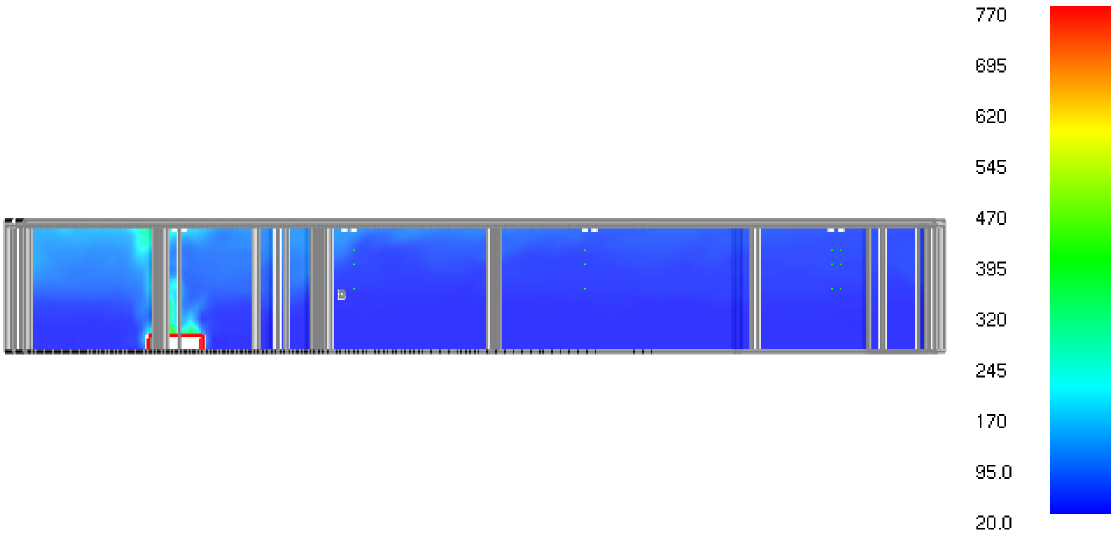

Figure 4.20. Temperature distribution in the closed port side of the accommodation space after 130 s.

The visibility distribution, which most often is the criteria which becomes critical first when referring to life-safety criteria in building standards, is illustrated in the space after 130 s in Figure 4.21.

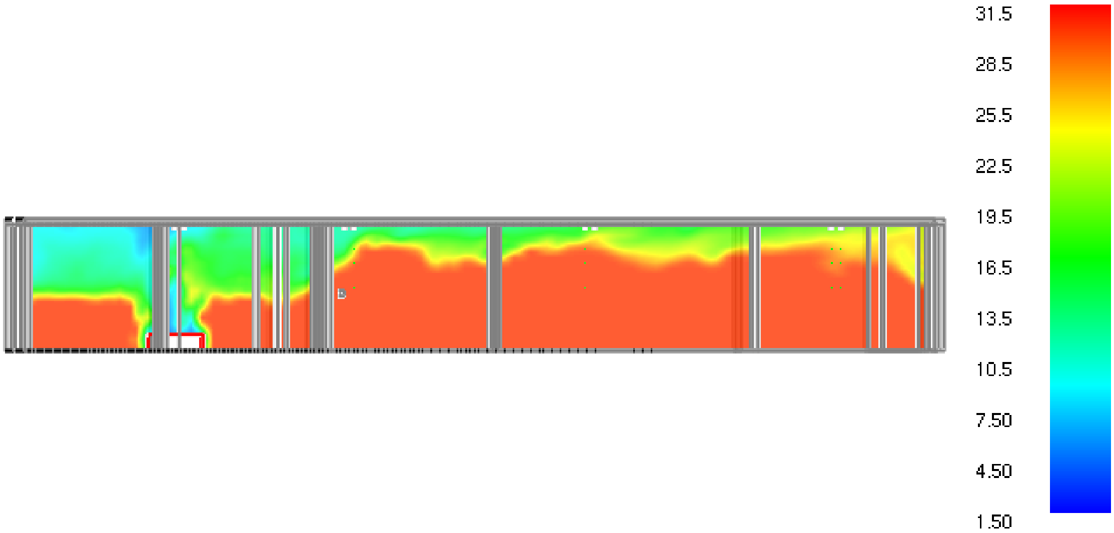

Figure 4.21. Visibility in the closed port side of the accommodation space after 130 s.

Simulated conditions in case doors between the accommodation space are open

The second simulation was performed of both sides of the accommodation space. This represents the conditions in the prescriptive design in case the detection and alarm system or the connected door-closing devices fail to function. It also represents the conditions in the base design. The purpose of the simulations was to determine when untenable conditions are reached for evacuating passengers the probability of windows breakage.

The time until reaching untenable conditions in different ways is summarized in Table 4.7. As expected, the performed simulations show that the conservative temperature criteria of 60°C becomes critical first, after 130 s. This is approximately 30 seconds before any other criteria become critical.

As summarized in Table 4.7 it could be shown through the simulations that the conservative temperature criteria of 60°C gives the first critical condition in the accommodation space, after 140 s.

Table 4.7. Time until critical conditions are reached in case of an unhindered fire in the whole accommodation space

Condition	*Time [s] until reaching condition*	
	at location P4	*at location S2*
Temperature > 60°C	**145**	**140**
Temperature > 80°C	165	160
Heat flux > 2,5 kW/m^2 (>200°C)	237	210
Visibility < 10 m	175	175
Carbon monoxide > 1 400 ppm	-	-
Carbon dioxide > 5 %	335	335
Oxygen < 15 %	280	280

The temperature and visibility distributions in the starboard side of the accommodation space after 140 s are illustrated in Figure 4.22 and Figure 4.23.

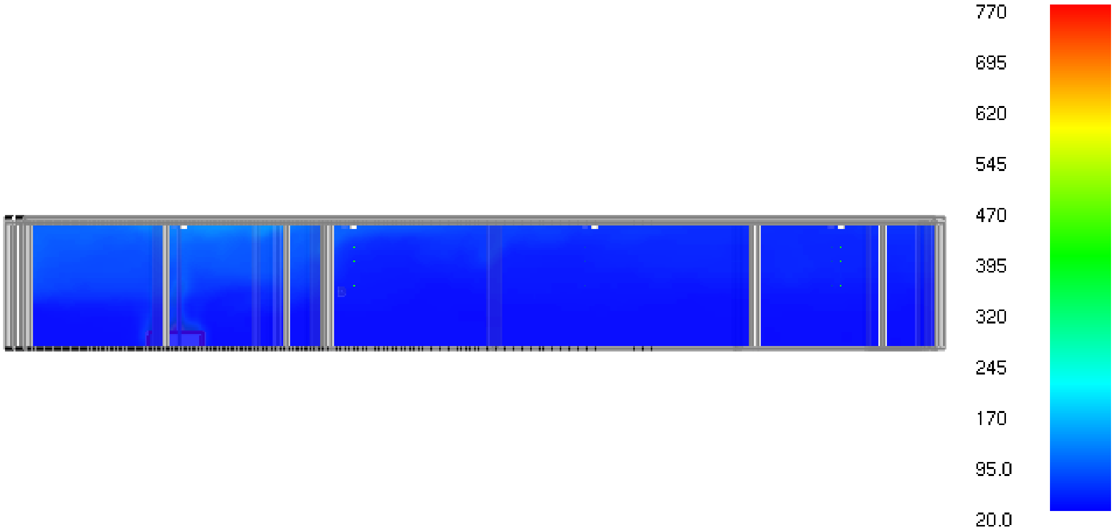

Figure 4.22. Temperature distribution in the starboard side of the accommodation space after 140 s.

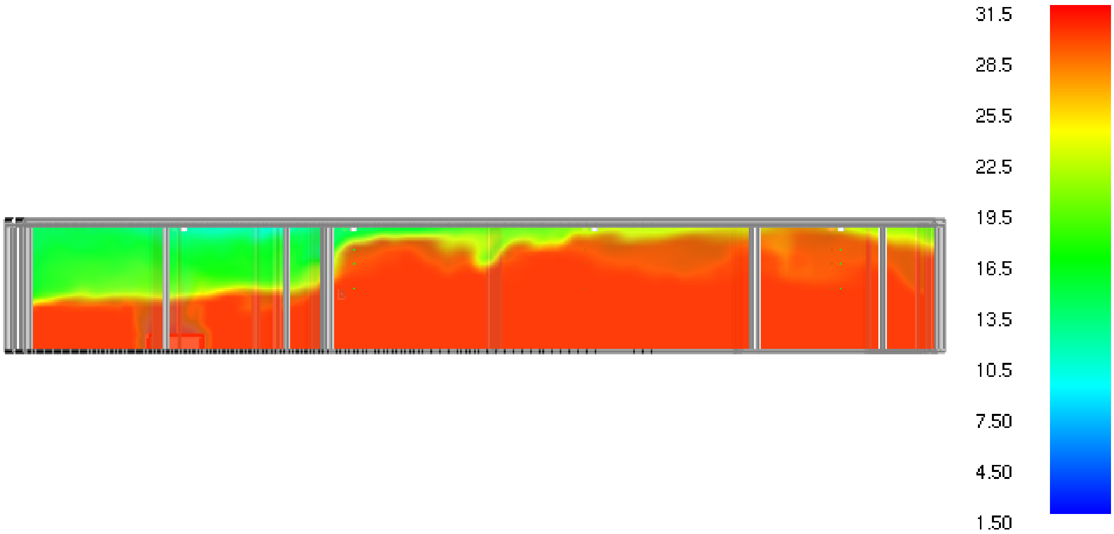

Figure 4.23. Visibility in the starboard side of the accommodation space after 140 s.

The temperature and visibility distributions in starboard side of the accommodation space after 160 s are illustrated in Figure 4.24 and Figure 4.25.

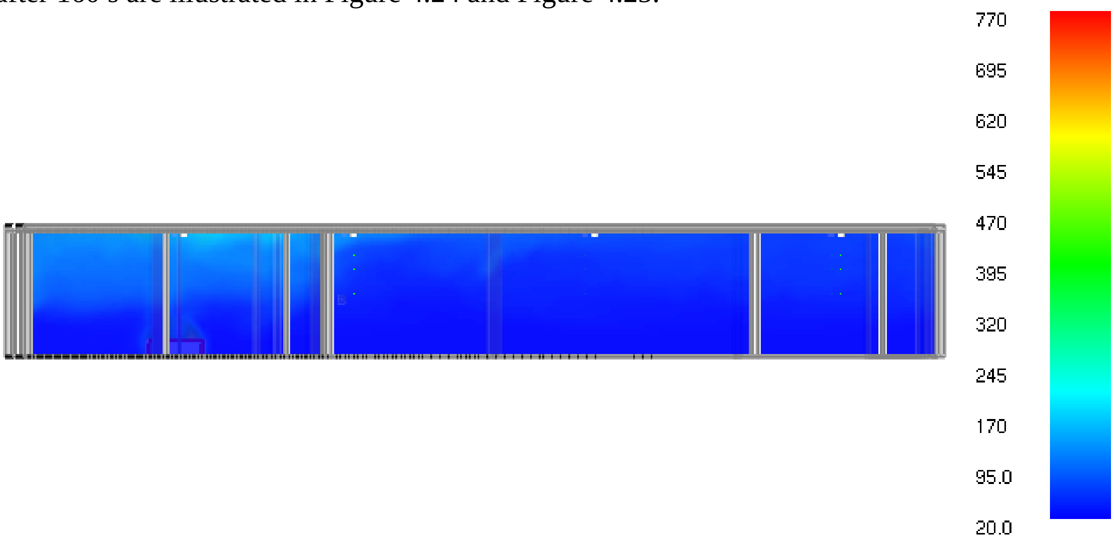

Figure 4.24. Temperature distribution in the starboard side of the accommodation space after 160 s.

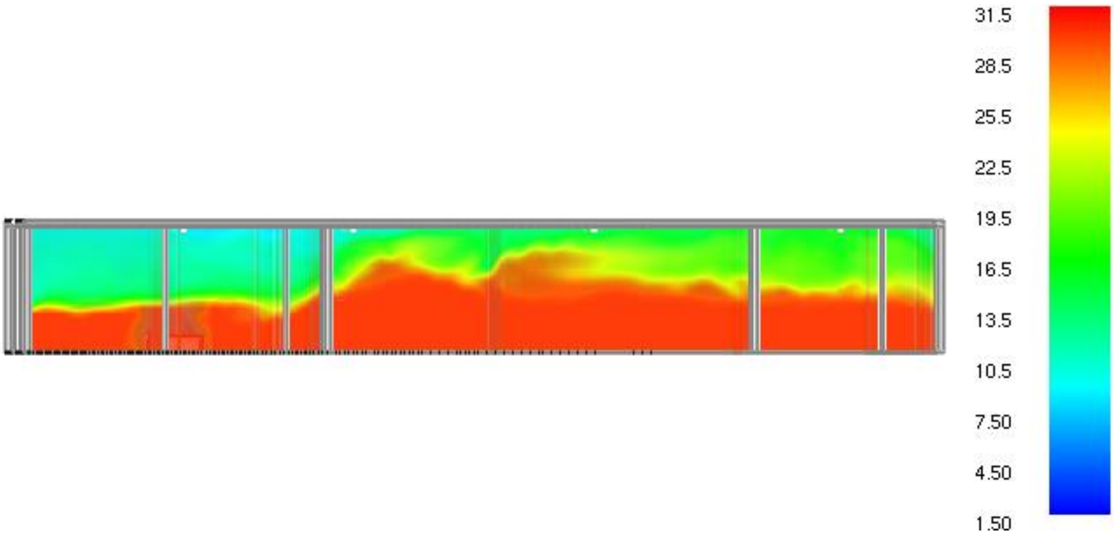

Figure 4.25. Visibility in the starboard side of the accommodation space after 160 s.

The temperature and visibility distributions in starboard side of the accommodation space after 210 s (when evacuation will be shown to be completed) are illustrated in Figure 4.26 and Figure 4.27.

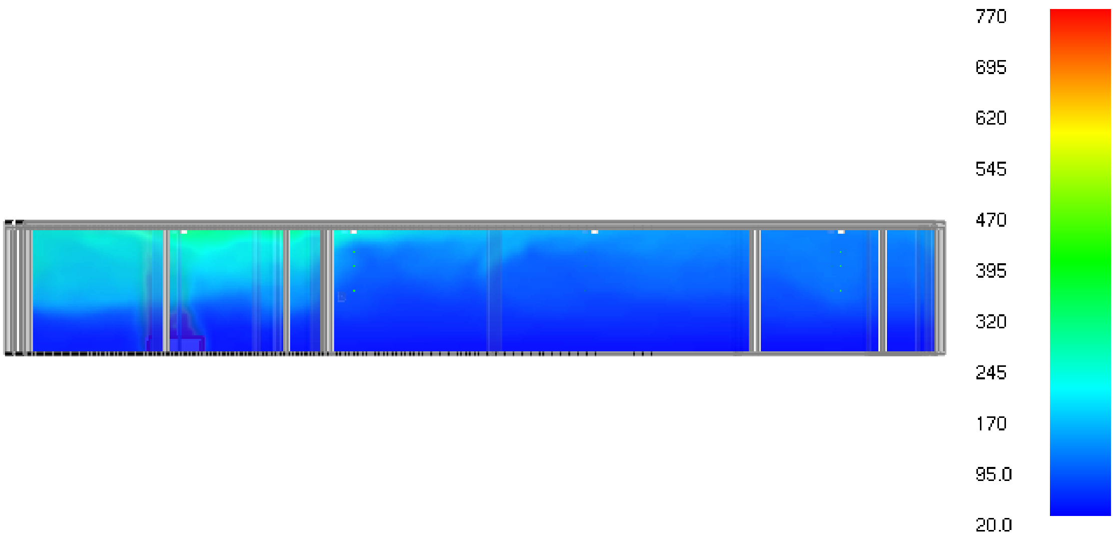

Figure 4.26. Temperature distribution in the starboard side of the accommodation space after 210 s.

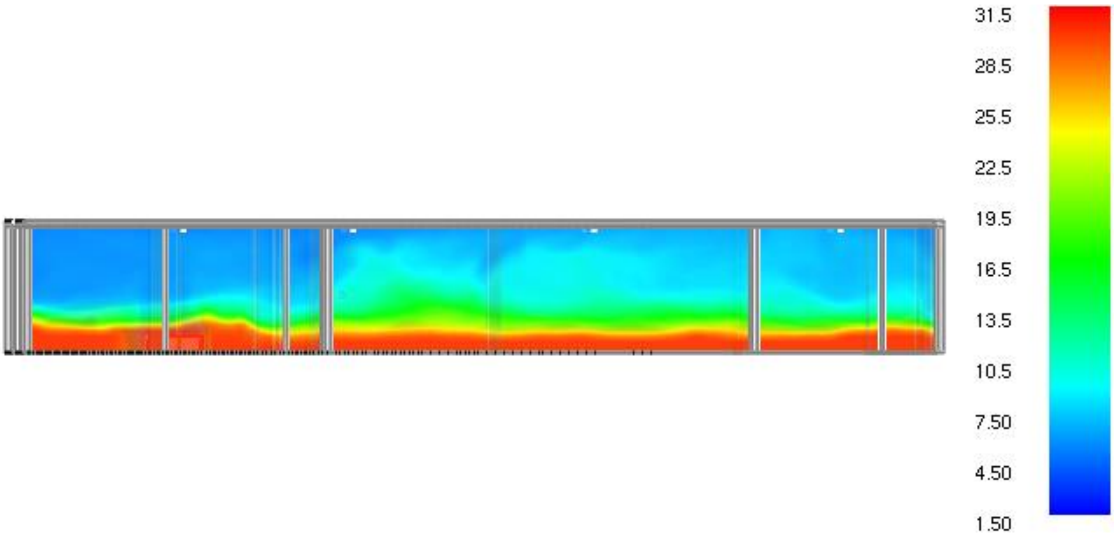

Figure 4.27. Temperature distribution in the starboard side of the accommodation space after 210 s.

The simulations also showed that the smoke detectors located in P1-4 were calculated to activate after 6 s, 10 s, 31 s and 52 s, respectively. The sprinkler system was calculated to activate after 93 s if a sprinkler head is located in the second position and after 120 s if located in the third position.

4.4.4.2. Required time for evacuation in the accommodation space

In fire evacuation theory [e.g. 41], the evacuation time is said to consist of:

$$evacuation\ time = recognition\ time + response\ time + movement\ time$$

The recognition and response times were determined based on theories of human behaviour in case of fire as well as the performed fire simulations. These times were used as input in evacuation simulations performed using the software Simulex [42]. Hence the movement time could be determined in conjunction with the total evacuation time.

Recognition time in the accommodation space in case of fire

With regards to recognition time, when a fire is detected in the accommodation space an alarm is activated. The time until activation of such alarm as determined by fire simulations below and was assumed to represent the recognition time if the detection and alarm system is functional. In these simulations, four smoke detectors were placed in each side of the accommodation space along the middle (from aft to forward) of that side, as illustrated in Figure 4.19. The first one (counting from the aft) on the port side (in location P1) was located almost straight above the fire and as seen in Figure L10 it activated very early in the simulations (after 6 seconds). However, also the one in the second location activated early, after 10 seconds. The next two smoke detectors in the seating part of the accommodation space activated after 31 and 52 seconds, as shown in Figure L10. For the evacuation simulations it was assumed that the alarm in the accommodation space sounds when the smoke detector in the middle of the seating part of the accommodation space activates, i.e. after 31 seconds. This was also the average time until activation of the three smoke detectors in this part of the space.

In case the system fails to function, the recognition time should although be based on when people can likely be assumed to have recognized the fire. In estimating the recognition time it must be recognized that passengers may be sleeping or pre-occupied in other business and that they may not wake up or be receptive to new information right away. The smell of smoke should although lead to a relatively fast recognition time and awake passengers were therefore assumed vigilant enough to recognize that there is a fire even if no alarm has not been activated or flames are visible. A sleeping passenger may also be notified of the fire by other persons recognizing the fire.

Again reference is made to the fire simulations performed above and the results presented in *Appendix L. Results of FDS simulations*. As shown in Figure L11, at 52 s after ignition the smoke layer has not only reached almost the whole seating area of the port side of the accommodation space and at locations 2 and 3 it has reached about 1.50 m and 1.75 m from the floor, respectively. This speaks for that smells associated with a fire will be detected in the space sufficiently to recognize that a fire may be developing.

When it comes to people on the starboard side of the accommodation space, these people should be warned by the an alarm which should go off also here if the smoke and alarm system is functional. The same recognition time was then assumed for them as for the persons on port side of the space. If it fails to work their recognition time may depend on whether the door between the sides in the aft fails to close. The door was although also assumed to depend on whether detection works, as this will likely activate a door-closing device. Hence, if the detection and alarm system fails, so will closure of the door and people on the starboard side of the accommodation space will be exposed to smells of smoke. Based on the fire simulations above, the same criteria as used above were reached after about 90 seconds. However, recognition of the on-going fire may also occur by notifications by the evacuating passengers from the port side. According to the subsequent evacuation simulations, a few (3-6) persons evacuating from the port side of the accommodation space have reached the starboard side about 80 seconds after the fire was ignited. A time of 80 seconds was therefore assumed as the recognition time for the passengers on the starboard side of the accommodation space. The smoke in the space along with manual notifications from other passengers were although assumed to reduce the pre-movement time for these passengers, as elaborated below.

Response time in the accommodation space in case of fire

In Simulex it is also possible to set a response time, i.e. the time from when a person has recognized that there may be a fire (by alarm, smoke etc.) until he or she actually starts moving out of the space. During this time passengers could e.g. look around to see how other passengers are acting or where the smoke is coming from, communicate with others, look out the window, put on their jackets, collect items (luggage in the accommodation space is assumed sparse) or simply decide to ignore the alarm (e.g. due to a belief that it is a false alarm or due to some other reason that makes it feel more reasonable to stay) [41, 43-46].

The response time varies much depending on the seriousness of the fire. People tend to adjust their preparative actions, such as getting dressed or packing belongings, depending on the present conditions. Furthermore, manual recognition (where the persons get aware of the fire by recognizing smoke themselves) can reduce the response time and so can notifications by evacuating passengers since this will better communicate the seriousness of the fire. It is hard to estimate the effects on the pre-movement time from passengers warning each other but due to the above reasons a slightly decreased response time was assumed in case the fire is recognized manually.

Something that was not considered when determining the recognition times above is that the recognition or response may vary over the populations. For example, the time until manual recognition will likely be more varied than when recognition is made through a fire alarm. The scatter in recognition and response times were incorporated in the response time estimations, based on the discussions above.

In all, the time from manually recognizing the signs of a fire (i.e. when the detection and alarm system has failed) until starting to move out of the space was estimated to 30±20 seconds . The time from when a fire alarm has activated until people start to move out of the port side of the accommodation space was estimated to 30±10 seconds. For the passengers on the starboard side of the accommodation space the response time was estimated to 20±15 in case the detection and alarm system fails and to 35±15 in case the system is functional. The difference between the latter time estimations mainly depends on the lack of smoke in the space in case the connected door-closing devices are functional. The distribution of the response times were set to be a so called “random distribution”, which gives a quite uniform distribution, in comparison with the other options “triangular distribution” and “normal distribution”.

Total evacuation time in the accommodation space in case of fire

In determining the time required for safely evacuating the passengers in case of an accommodation space fire scenario, the sum of the above determined recognition and response times was specified as the pre-movement time in evacuation simulations performed in the software Simulex [42]. Hence the total evacuation times in the different scenarios could be determined together with the simulated movement times.

In the simulation program a model was created where a fire was assumed in the aft, port part of the accommodation space, by the toilets, as illustrated in Figure 4.28. With regards to the evacuation route people would use in case of such a fire it has been shown that people normally move in patterns which are familiar, also in evacuation situations [47]. This means that people are generally prone to use the same way out as they used coming in. Based on this experience, in combination with a relatively short and simple evacuation route to the ro-ro deck [48], it seems reasonable to assume that there may be some hesitation as to what exit to use, since people may want not want to use the exit in the fore [49] but rather walk the short distance to where they entered, even if they have to pass through hazardous conditions in smoke [48]. Nevertheless, in the evacuation simulations it was assumed that everyone will try to use the safe exit to the starboard part of the accommodation space in the fore and not take the route by the fire. Furthermore, in the model the staircase up to deck 3 in the middle of the accommodation space was made available as an optional escape route. However, in the simulations none of the passengers selected this option as that route is slightly longer than simply leaving through the exit towards the ro-ro deck. Considering that the staircase volume probably would be smoke filled first, this although seems as a reasonable delimitation by the model. In conclusion, the evacuation route passengers would likely use to get to the ro-ro deck is illustrated in Figure 4.28.

Figure 4.28. The evacuation route passengers would have to use in order to not be directly affected by the fire or the smoke collected in the staircase.

In the simulations a population was selected with an occupant type which in Simulex was called IMO Ship Passenger. This consists of 10 different groups (with different gender, age, mobility impairments etc.) which is assumed to correlate with their size, walking speed etc. This complies with the requirements on selection of passenger population characteristics specified in MSC/Circ.1033 [50] and particularly affects the movement time of the passengers.

Simulations were performed for the scenarios where the detection and alarm system (and connected door-closing devices) fails and where it is functional, both the prescriptive and the base design. These conditions were namely above determined to affect the pre-movement times for the passengers in the different parts of the accommodation space and it also affects the spread of smoke, as determined by the above fire simulations. A summary of the pre-movement times used for the different scenarios in the simulations is illustrated in Figure 4.29.

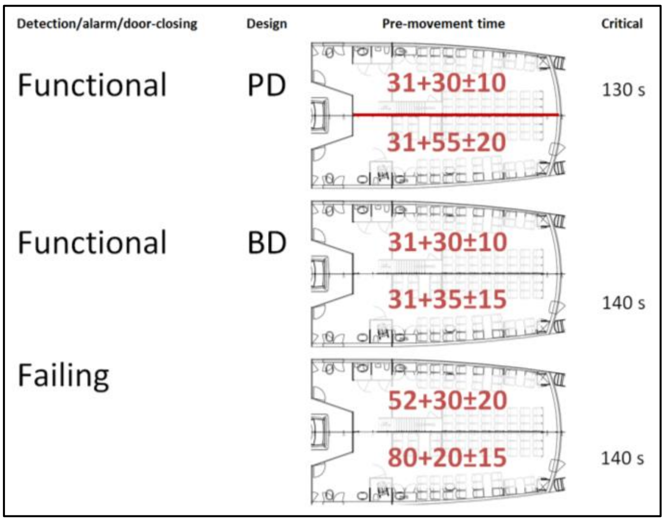

Figure 4.29. Summary of the estimated recognition and response (pre-movement) times in the prescriptive design (PD) and the base design (BD) depending on the function of the detection and alarm system (and the connected door-closing devices).

The result files of the simulations are documented in *Appendix M. Result files from Simulex simulations* and images of the results at different stages of the evacuation are illustrated in *Appendix N. Graphical results from Simulex simulations*.

In conclusion, the required time for evacuation in case smoke and alarm system functions in the prescriptive design was determined to 135 s. The evacuation situation after 130 s is illustrated in Figure 4.30.

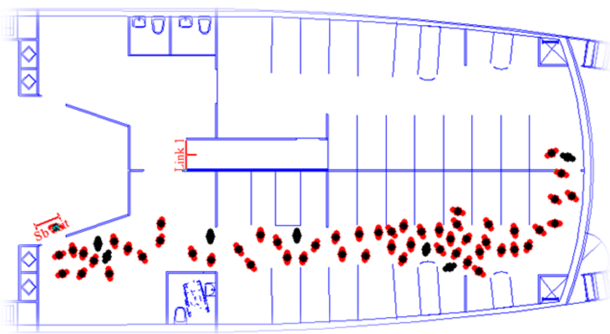

Figure 4.30. Evacuation situation after 130 s in case the smoke and alarm system and connected door-closing devices fail are functional in the prescriptive design.

The required time for evacuation in case the smoke and alarm system functions in the base design was determined to 204 s. The evacuation situation after 130 s is illustrated in Figure 4.31.

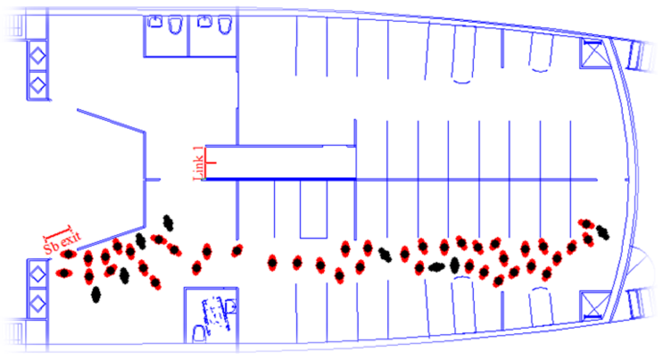

Figure 4.31. Evacuation situation after 140 s in case the smoke and alarm system and connected door-closing devices fail are functional in the base design.

The required time for evacuation in case smoke and alarm system fails was determined to 229 s. The evacuation situation after 140 s is illustrated in Figure 4.32.

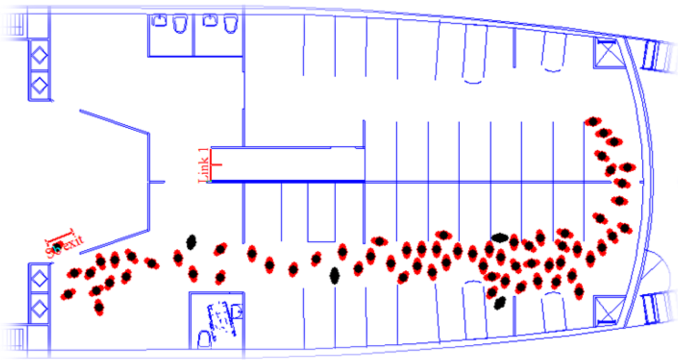

Figure 4.32. Evacuation situation after 140 s in case the detection and alarm system and connected door-closing devices fail.

4.4.4.3. Quantified consequences of accommodation space fire scenarios

The performed evacuation simulations do not only determine the time required for safely evacuating the passengers in case of an accommodation space fire scenario. Together with the performed fire simulations the evacuation simulations also answer how many persons may be affected by untenable conditions in case of the different fire scenarios.

In case the detection and alarm system (and connected door-closing devices) is functional in the prescriptive design there are 2 passengers left in the port side of the accommodation space after 130 s (see Figure 4.30), which is when conditions soon become inhabitable due to 60°C at 2.00 m at location P4. These persons are although very close to the opening whilst the measuring point (P4) is further up towards the longitudinal centre of the space (illustrated in Figure 4.19). Since the conditions likely become critical at the measuring point before along the sides of the space these persons were assumed unaffected by the critical conditions.

In case the detection and alarm system (and connected door-closing devices) is functional in the base design there are 50 passengers left in the accommodation space after 140 s, which is when conditions soon become inhabitable due to 60°C at 2.00 m at location S1.

Everyone passing this location will hence be exposed to untenable conditions. Some of the 50 persons have already passed this location but will nevertheless be exposed to untenable conditions in the aft part of the starboard side of the accommodation space. The persons closest to the exit were although assumed to be able to avoid the warm gases. Assuming that the smoke spreads symmetrically in this part of the space gives a safe zone at this time as illustrated in Figure 4.28. In this scenario there are 6 persons in this zone. Hence, 44 persons were assumed inhabitable in this scenario. This is also applicable for the prescriptive design in case the detection and alarm system works if a door closing device fails.

In case the detection and alarm system (and connected door-closing devices) fails there are 72 passengers left in the accommodation space after 140 s, which is when conditions soon become inhabitable due to 60°C at 2.00 m at location S1. Similar to above, 6 persons were estimated close enough to the exit to escape before being exposed to untenable conditions, which gives a total of 66 casualties in this scenario.

4.4.5. Fire escalation scenarios from the accommodation space

In case previously discussed failure modes have occurred, the fire will no longer be contained in the space of origin. In the base design this could lead to a major collapse in the compartment of origin and also to fire spread on exterior surfaces, as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*.

4.4.5.1. External fire spread from the accommodation space

In the current risk model it was assumed that all scenarios which have reached window breakage or where a door is open to the exteriors will lead to fire spread to the exteriors. With regards to the outboard sides there are not much combustible materials in the prescriptive design. They mainly consist of steel and glass and may therefore not be considered susceptible to fire spread. However, the fire on Star Princess [21] indeed showed that outboard fire spread must not be ignored, even on prescriptive ships. On the Eco-Island ferry the initial fire may not be initiated on a balcony, as on the Star Princess, but an accommodation space fire could for example lead to fire spread to the wheelhouse if the windows break. A fire in the base design will then also be fuelled by exterior combustible surfaces. Furthermore, based on that four out of six windows are situated under the wheelhouse and that it is likely that more than one window breaks in case of a continuing fire, it is likely that the fire will spread further. The fire scenarios that may occur as a result of an established exterior fire were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

4.4.5.2. Major collapse in the accommodation space

In case fire-fighting efforts are not shortly successful after the fire scenarios described above, the fire was assumed to result in a major collapse in the fire compartment in the current risk model. Based on what was previously discussed in *4.1.3. Fire-fighting* and *4.4.3.6. Fire-fighting in accommodation space*, the probability of controlling a ventilated accommodation space fire which has caused local collapse by fire-fighting efforts before a major collapse occurs was estimated to 5% in the base design. If the doors between the two sides of the accommodation space are open, the probability was although assessed lower, 2%. Due to the required passive fire protection, the corresponding scenarios were judged irrelevant in the prescriptive design. The fatalities in case of a major collapse in the accommodation space were quantified in *4.2.2.4. Consequences of a major exterior fire*. A major collapse can hence also occur in case external fire spread was not taken under control by fire-fighting measures, the probability of which was assessed to 10% in the base design and 60 % in the prescriptive design (see *4.2.2.5. Prevention of a major exterior* fire). Hence, loss of containment could eventually lead to the same major collapse scenario. This is only accounted for in the scenario branch where pre-major collapse fire fighting is successful in order to not account for the same scenarios twice. Hence, a major collapse can occur if fire-fighting efforts to avoid it fail either inside or outside the compartment. The resulting probability of failure of pre-major collapse fire-fighting is the sum of the probability of failed fire-fighting before major collapse in the space and the probability of failed fire-fighting before major collapse from the exterior fire spread minus the product of the two combined (in order to not account for the same scenarios twice).

4.4.6. Resulting event tree for accommodation space fire scenarios

The resulting event tree for the accommodation space fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.5. Engine room fire scenarios

The design fire in this space is naturally a hydro-carbon fire which is assumed to continuously be provided with fuel. The fire was assumed to take place during journey and no one was assumed present at the fire onset. In the prescriptive design the space is protected with A-60 thermal insulation in the ceiling whilst the base design has this protection also on the bulkheads, as illustrated in Figure 2.3 and Figure 2.7. The different possible fire scenarios and their probabilities and consequences are further elaborated below.

4.5.1. Development of engine room fire scenarios

The identified critical factors and the associated target locations in the engine room are safety functions which provide information on the different possible fire developments in the space by identification of failure modes. The most significant failure modes in an engine room fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of water mist system;
- Failure of door; and
- Failure of fire-fighting.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.5.1.1. Water mist system

The water mist systems in the engine rooms are assumed to consist of a high-pressure pump unit with cylinders, section valves, piping system and open nozzle heads. The system is activated by a detection system consisting of flame and smoke detectors. Water is supplied via a pump unit or cylinders depending on the system through different section valves operated either remotely or manually. For operation and monitoring there is also a control panel installed. It is assumed that the system can be activated both automatically and manually. This system configuration is according to [51, 52] and is illustrated in Figure 4.33.

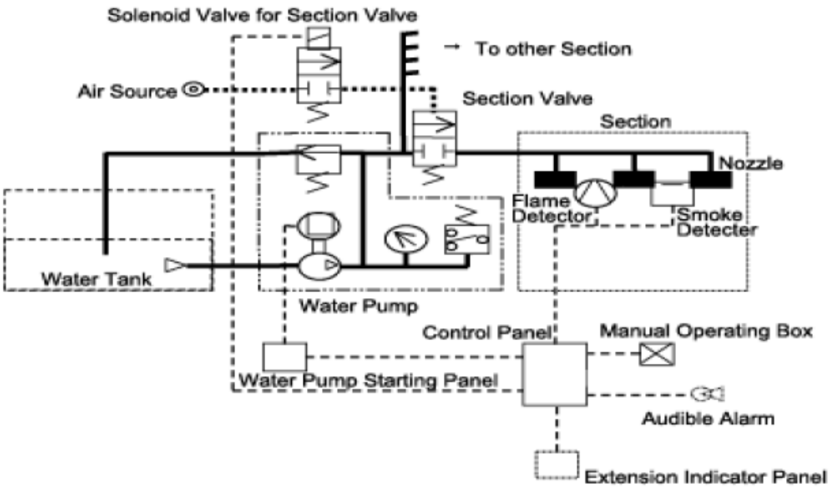

Figure 4.33. System configuration of a water mist system [31].

According to reports from the research project Fireproof and the OREDA handbook [31-33], the failure rate for a water mist system can, based on fault tree analysis, be set to λ=0.0024 per day. Assuming that the systems are tested and maintained on a yearly basis the reliability can be calculated as 1-f(λ) = $e^{-(\lambda*t)}$ to between 0.53-0.85. Even if this calculation includes the whole detection, alarm and extinguishing system, the figure seems rather low. According to the same references, a Hi-fog system on the other hand would give a reliability of 0.76-0.93 with yearly maintenance. Monthly maintenance would obviously give a higher reliability. Since the particular system for the Eco-Island ferry is not specified a figure between these values was considered representable. Approximating the exponential function to be linear, the average probability of failure of the water mist system was assumed to be 23%. This was combined with the reliability of a detection and alarm system (which was excluded in the figure derived above) and lead to a final reliability of 26%.

4.5.1.2. Doors open in the engine room

The doors to the engine room should always be closed, particularly during voyage. Even if the first door to the staircase is open it is unreasonable that also the next door is open, giving a clear passage to the accommodation space. If the all doors are they are closed or only the first door is open the fire will self-extinguish shortly, as was confirmed by simple two-zone simulations performed with Branzfire [53]. There is also a possibility that ventilation is provided through the emergency exit. However, then there are also two doors which need to be open. Even if it is unlikely that the doors are left open on accident there is a possibility that someone may manually put the doors open to give better ventilation or by arson. In this risk assessment it was assumed that the probability that the doors or other opening are opened sufficiently to provide oxygen to a fire is as small as 2%. In case the fire is not extinguished is was assumed to spread and cause a localized fire externally. The possibilities for fire fighting are further discussed below.

4.5.1.3. Fire fighting in engine room

In case a fire is established in the engine room, swift fire-fighting efforts could hinder a so far uncontrolled engine room fire to develop further. In the normal case a fire is detected in the engine room and an alarm is activated in the engine room and on the bridge. A crew member on call is commanded to investigate the alarm and according to routines the crew member is to call back to the bridge over the radio to report whether a fire is discovered or not. The crew member who called in the fire will also attempt to put out the fire but if the fire has already spread, which is likely, it would seem more reasonable to make a more planned attack with suitable outfits and equipment. The possibilities for fire-fighting in insulated compartments were further discussed in *4.1.3. Fire-fighting, 4.2.1. Fire development in internal spaces with FRP composite divisions* and [18]. The above discussions and references led to an estimation of the probability of successful fire-fighting before a local external fire of 30% in the base design and 20% in the prescriptive design. This includes account to the possibilities for safe access and other relief by new fire-fighting tools in the base design and possible increased risks for local collapse.

In case fire-fighting fails at this stage, it was assumed that local collapse will occur in the base design. The consequences for people in case of a local collapse should not be substantial since escape from spaces in danger should already have taken place, based on *4.2.1.2. Time until local collapse*. It is although possible that a local collapse has consequences for assembled passengers. Such consequences were assessed small and to give fatalities in relation to the occupancy of the ship and were assumed to stand in relation with the consequences from a fire on ro-ro deck, as quantified in *4.2.2.3. Consequences of a local exterior fire*. Furthermore, another fatality in case of low or mid seasons and 5 fatalities in case of high season are assumed due to stand in relation to the consequences which may occur due to the unprotected surfaces in the engine room in case fire fighting efforts fail at this stage.

4.5.2. Fire escalation scenarios from the engine room

In case previously discussed failure modes have occurred, the fire will no longer be contained in the space of origin. This could lead to a major exterior fire as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*. The proceeding fire scenario in the space of origin and the effects from use of FRP composite behind the thermal insulation is also discussed below.

4.5.2.1. External fire spread from engine room

In the current risk model it was assumed that all scenarios which are not extinguished by swift fire-fighting measures and where a door is open to the exteriors will lead to fire spread to the exteriors. With regards to the outboard surfaces there are not much combustible materials in the prescriptive design but a fire could still spread on various materials that exist on ro-ro deck and outboard sides. A fire in the base design will be fuelled by exterior combustible surfaces. The fire scenarios that may occur as a result of an established exterior fire were assumed to stand in relation to those on ro-ro deck, which were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

4.5.2.2. More fuel in spaces protected for 60 minutes

In the base design of the ship there is only one space which is designed with FRD60 divisions, i.e. the engine room. However, also divisions surrounding the accommodation space could be relevant to make accordingly if the results of the assessment show that this is necessary. As mentioned above, in spaces with FRD60 divisions additional fuel consisting of FRP composite structures may be contributed to an internal fire when the thermal insulation no longer works as fire protection after 60 minutes. Risks posed to fire-fighters associated with this issue were managed in *4.1.3. Fire-fighting*. It is neither likely to directly affect the passengers of the ship, whom should have escaped the fire-ravaged compartments long ago (e.g. in case divisions in the accommodation space are made

FRD60). Nevertheless, the increased amount of fuel behind the insulation may fuel an uncontrolled fire after 60 minutes. In the preliminary analysis report this was identified as a fire hazard since it could prolong and help develop the fire further. However, in the large scale tests reviewed above [17], in which two cabins and a corridor were enclosed in a FRP composite superstructure and a standard cabin was burnt out, all the combustible content was accounted for. It showed that the fuel represented by furnishings, interiors and internal divisions was very dominant. The fire went to flashover after a few minutes and high temperatures were maintained for over 90 minutes. Only minor parts of the FRP composite floor construction were involved in the fire and this was due to insignificant fire protection, which would be improved on the Eco-Island ferry if FRD60 is used. Furthermore, people should have been able to evacuate at shore long before 60 minutes have passed.

4.5.3. Resulting event tree for engine room fire scenarios

The resulting event tree for the engine room fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.6. Auxiliary machinery space fire scenarios

There are four spaces on the ship in this category, none of which are normally accessed during voyage, which is when a fire is assumed to take place. The spaces are not protected with any passive or active measures except from automatic detection. Despite the limited access and that there are very few combustibles in the spaces a fire could nevertheless occur. The different possible fire scenarios and their probabilities and consequences are further elaborated below.

4.6.1. Development of auxiliary machinery space fire scenarios

The identified critical factors and the associated target locations in the auxiliary machinery space are safety functions which provide information on the different possible fire developments in the space by identification of failure modes. The most significant failure modes in an auxiliary machinery space fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of hatch;
- Failure of detection and alarm; and
- Failure of fire-fighting.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.6.1.1. Hatch open in the auxiliary machinery space

The hatch to the auxiliary machinery spaces should always be closed, particularly during voyage. Two-zone fire simulations were performed in Branzfire [53] with the hatch open or closed. Since the fuel and fire growth is uncertain, simulations were performed both with slow and fast fire growth (see Figure 4.2). For the slow growing fires it was assumed that trash, plastic covers or FRP composite panels were the main fuel and the fast growing fire was assumed to be a hydrocarbon fire. The results of the simulations are presented in Table 4.8.

Table 4.8. Results of Branzfire simulations of worst-case auxiliary machinery space

Scenario	***Time to critical conditions (1.5 m above grating)***	***Time to critical conditions (2 m above grating)***	***Time to detec-tion***	***Time to self-extinguish-ment***	***Upper layer end temperature***
Closed hatch Slow fire growth Yield as Polyurethane	110s (visibility <5m)	110s (visibility <5m)	58s	330s	556°C
Closed hatch Fast fire growth Yield as JP-5	50s (visibility <5m and temp. >60°C)	50s (visibility <5m and temp. >60°C)	26s	140s	610°C
Open hatch Slow fire growth Yield as Polyurethane	100 s (visibility < 5 m)	100s (visibility <5m)	58s	-	620°C
Open hatch Fast fire growth Yield as JP-5	50s (visibility <5m and temp. >60°C)	50s (visibility <5m and temp. >60°C)	26s	-	600°C - 800°C

The fire simulations show that a fire in the space when the hatch is closed will not be critical if the fire growth is fast since it will give only a 140 s fire exposure. This applies both to the prescriptive design and the base design where the FRP composite surfaces are left unprotected. However, if it is a slow burning fire the exposure could be up to 330 s when the space is closed. Assuming hereafter that the steering gear spaces, which are the only auxiliary machinery spaces large enough to give such a long-lasting fire, are provided with surfaces of low flame spread characteristics it is safe to say that there will be no significant consequences if a fire occurs in an auxiliary machinery space with the hatch closed, based on the discussions in *4.2.1.2. Time until local collapse*.

There is although a possibility that the hatch is open. This is although unlikely during journey, particularly the bow thruster spaces which open up to the accommodation space. The auxiliary machinery spaces open up to the ro-ro deck where the hatch could be put open to provide ventilation or by arson. The probability of this occurring is although considered small, 4%. In case the fire is not extinguished is was assumed to spread and cause a localized fire externally on ro-ro deck. The possibilities for fire fighting depend in the reliability of the alarm system and are further discussed below.

4.6.1.2. Automatic detection and alarm system in the auxiliary machinery space

According to reports from the research project Fireproof and the OREDA handbook [31-33], the failure rate for fire and gas detectors can be set to $\lambda=0.43*10^{-6}$ per hour. Assuming that the detectors are replaced every ten years, the reliability can be calculated as $1-f(\lambda) = e^{-(\lambda*t)}$ to between 0.96-1.00. This close to one (1), it is a fair approximation to consider the exponential function to be linear, i.e. an average failure rate of 2% could be used. However, this reliability data only covers the detector and not the connected alarm systems. When a fire is detected on board the ship, an alarm is activated in the auxiliary machinery space as well as in the wheelhouse. It was estimated that the average failure rate for the whole system is twice as high. Thus, failure in the detection and alarm system (including both the detection and the alarm) are assumed in 4% of the fire scenarios. This figure could be further elaborated.

4.6.1.3. Fire fighting in auxiliary machinery space

In case a fire has established in the auxiliary machinery space, swift fire-fighting efforts could hinder a so far uncontrolled fire to develop further. In the normal case a fire is detected in the auxiliary machinery space and an alarm is activated. A crew member on call is commanded to investigate the alarm and according to routines the crew member is to call back to the bridge over the radio to report whether a fire is discovered or not. The crew member who called in the fire will also attempt to put out the fire which in this case would be as easy as closing the hatch. To further cool the space it would be very beneficial to make use of the new fire fighting tools in the base design. This would also be a useful strategy in case fire occurs when the hatch is closed. In the prescriptive design the hot smoke produced in the space could transfer through the unprotected steel divisions to adjacent spaces. This con of the prescriptive design, which also applies to other spaces on board, was not accounted for.

With regards to the risk of local collapse for the fire fighters this was discussed in *4.1.3. Fire-fighting*, *4.2.1. Fire development in internal spaces with FRP composite divisions* and [18]. In the auxiliary machinery space fire scenarios the results of the Branzfire simulations in Table 4.8 show that detection (and alarm) would occur within a minute after ignition. This gives the crew at least 4 minutes with a possibility to close the hatch before any risk of local collapse. Furthermore, in such a small space the consequences of local loss of load-bearing capacity would not give any significant effects (see *4.2.1. Fire development in internal spaces with FRP composite divisions*). Hence, if the detection and alarm system is functional the above discussions and references led to an estimation of the probability of successful fire-fighting before a local external fire of 70% in the base design and in the prescriptive design. This includes account to the possibilities for safe access and other relief by new fire-fighting tools in the base design and possible increased risks for local collapse. In case the detection and alarm system fails there is still a chance of manual detection and fire fighting, which would likely although occur later than if the detection and alarm system functioned. The probability of successful fire fighting in case the detection and alarm system fails was estimated to 50% in the prescriptive design and to 40% in the base design, accounting for the potential risk of local collapse at this stage.

In case fire-fighting fails at this stage, it was assumed that local collapse will occur in the base design. The consequences for people in case of a local collapse should not be substantial since escape from spaces in danger should already have taken place, based on *4.2.1.2. Time until local collapse*. It is although possible that a local collapse has consequences for assembled passengers. Such consequences were assessed small and to give fatalities in relation to the occupancy of the ship in relation to the consequences from a fire on ro-ro deck, as quantified in *4.2.2.3. Consequences of a local exterior fire*.

4.6.2. Fire escalation scenarios from the auxiliary machinery space

In case previously discussed failure modes have occurred, the fire will no longer be contained in the space of origin. This could lead to a major exterior fire as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*. The proceeding fire scenario in the space of origin and the effects from use of FRP composite in divisions is also discussed below.

4.6.2.1. External fire spread from auxiliary machinery space

In the current risk model it was assumed that all scenarios which are not extinguished by swift fire-fighting measures where a hatch is open to the exteriors will lead to fire spread to the ro-ro deck. There could be various combustibles on ro-ro deck and a fire in the base design will also be fuelled by exterior combustible surfaces. The fire scenarios that may occur as a result of an established ro-ro deck fire were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

4.6.2.2. A long-lasting fire in an auxiliary machinery space

In case a fire is not relatively swiftly extinguished in an auxiliary machinery space, fuel consisting of FRP composite structures may be contributed to the fire and a major collapse could occur. Risks posed to fire-fighters associated with this issue were managed in *4.1.3. Fire-fighting*. When it comes to consequences for passengers, who may be affected by the additional smoke or effects from collapse, a major collapse was assumed to give cause inhabitable conditions for 10 persons in case of high season and otherwise for 1 person, in addition to the consequences from the fire spreading on ro-ro deck. Since the combustibles in the space are more limited in the prescriptive design and there is no significant risk of collapse there were not assumed to be any additional consequences in the prescriptive design.

4.6.3. Resulting event tree for auxiliary machinery space fire scenarios

The resulting event tree for the auxiliary machinery space fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.7. Void space fire scenarios

There are a number of void spaces on the ship. None of the void spaces have proper openings, only inspection hatches which are always closed. They although have a small hole for pressure relief and ventilation. The ignition sources are minimal and the potential fuels are in the prescriptive design very sparse whilst the base design has unprotected FRP composite on divisions. The spaces are not protected with any passive or active measures and have no fire detection installed. Furthermore, the ventilation is very limited. Despite the limited access and that there are very few combustibles in the spaces a fire could nevertheless occur, as noted in the hazard identification. The different possible fire scenarios and their probabilities and consequences are further elaborated below.

4.7.1. Development of void space fire scenarios

The identified critical factors and the associated target locations in the void space are safety functions which provide information on the different possible fire developments in the space by identification of failure modes. The most significant failure modes in an void space fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of hatch;
- Failure of detection; and
- Failure of fire-fighting.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.7.1.1. Hatch open in the void space

The hatches to the void spaces are principally always be closed. It was considered such an extremely unlikely event that a void space was left with an open inspection hatch during voyage that it was ignored. Two-zone fire simulations were performed in Branzfire [53] with the hatch closed. In the prescriptive design the potential fuel in these spaces should be very sparse and in the base design basically only FRP composite. Two fire growth rates were although used in the simulations, slow and fast fire growth (see Figure 4.2). The results of the simulations are presented in Table 4.9.

Table 4.9. Results of Branzfire simulations of worst-case void space

Scenario	***Time until detection***	***Time until self-extinguishment***	***Upper layer end temperature***
0,01 m^2 vent *Slow fire growth* *Yield as Polyurethane foam*	9 s	200 s	390
0,01 m^2 vent *Fast fire growth* *Yield as Polyurethane foam*	8 s	130 s	468

The fire simulations show that a fire in the space when the hatch is closed will at a maximum last for 200 s before self-extinguishment. This is not a sufficient time for any significant consequences to occur in the base design, based on the discussions in *4.2.1.2. Time until local collapse*. The temperature in the space at extinguishment may not be above the ignition temperature of the FRP composite laminate, depending on the choice of material. The short exposure at this temperature makes it likely that the FRP composite will not take part in the fire if it was not the initial fuel. In the prescriptive design the hot smoke produced in the space could transfer the fire through the unprotected steel divisions to potential fuels with a lower ignition temperature in adjacent spaces. This con of the prescriptive design, which also applies to other spaces on board, was not accounted for.

4.7.1.2. Detection in the accommodation space

There is no automatic detection and alarm system, neither in the prescriptive design nor the base design. It is very uncertain to estimate the time until manual detection but it is unlikely that a response would be possible before the fire was already self-extinguished. The Branzfire simulation results in Table 4.9 show that if providing a detection and alarm system the fire would be detected very shortly after ignition, within 10 seconds in the largest of the void spaces.

4.7.1.3. Fire fighting in void space

Since a fire in the largest void space would only last for 3.5 minutes it is unlikely that this would have any effect since a fire fighting operation would likely not take place in this time. It is nevertheless good to know if a fire is taking place or has taken place in a void space, both in the prescriptive or the base design. The effects of this will although not be taken into account in the rest of this risk assessment.

A benefit in the base design is that the new fire fighting tools would make it possible to cool (and extinguish) the hot smoke produced in a space before making an entry. This is not accounted for in this risk assessment.

4.7.2. Fire escalation scenarios from the void space

Assuming that the hatches to void spaces are always closed, a fire in a void space will always self-extinguish before reaching any relevant consequences. Hence there are no escalating scenarios quantified in this risk assessment.

4.7.3. Resulting event tree for void space fire scenarios

The resulting event tree for the void space fire scenario for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.8. Wheelhouse fire scenarios

The wheelhouse category is representable only of the wheelhouse on deck 3. A representative design fire was developed for the space covered by this category, based on the identified fire hazards. The identified target locations and critical factors provide information on the possible scenarios, which lead to different fire developments. Hence the time to reach critical conditions will vary in the different fire scenarios, which together with the number of passengers will make evacuation more or less successful. This will determine the fire risk contribution from this space.

4.8.1. Wheelhouse

In the base design the wheelhouse has average dimensions of (LxWxH) 4.3x9.5x2.4 m and two evacuation routes, one on the port side and one in the middle, as illustrated in Figure 4.34. There are also windows all around the sides of the wheelhouse.

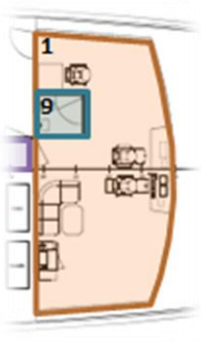

Figure 4.34. Layout of the wheelhouse.

As for fuel, the main fuels are the seats, cables, electronic equipment, upholstered furniture, clothes, books and other materials, as described in *Appendix G. Data from fire hazard identification*. The design fire in this space was assumed similar to the design fire in the accommodation space, developed paragraph *4.2.1.1. Fire growth on FRP composite surfaces in internal spaces* based on [17]. It was also concluded that the fire growth will likely be the same (fast) both in the prescriptive design and the base design up until the fire reaches flashover. The yields produced by the fire were also assumed to be the same as in the accommodation space fire (see *Appendix J. Validation of yields*) even though there may be more cables and plastic materials burning in the initial phases of a wheelhouse fire.

4.8.2. Development of wheelhouse fire scenarios

The identified critical factors and the associated target locations in the wheelhouse are safety functions which provide information on the different possible fire developments. The most significant of such a failure modes in a wheelhouse fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of detection;
- Failure of manual extinguishment;
- Failure of sprinkler system;
- Failure of door;
- Failure of fire-fighting; and
- Failure of window.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.8.2.1. Automatic detection and alarm system in the wheelhouse

The wheelhouse is fitted with a detection and alarm system for which the reliability was estimated to 4% in paragraph *4.6.1.2. Automatic detection and alarm system in the auxiliary machinery space*. However, since a fire is assumed to take place during a voyage at least one person is assumed to always be present in the wheelhouse when fire occurs. In case the detection and alarm system fails there is therefore likely that the fire will be detected manually. The probability for this to occur in case the detection and alarm system fails was estimated to 90%.

4.8.2.2. Manual extinguishment in wheelhouse

In case a fire establishes in the wheelhouse, first aid may be given by initial attempts of manual fire extinguishment by the present crew. Failure of detection was identified to affect the probability of such attempts which should under normal conditions take place very swiftly. If a fire manages to establish, manual extinguishment was assumed to be successful at an early stage in 95% of the cases when the fire was detected. Otherwise the fire was assumed proceed.

4.8.2.3. Sprinkler system in wheelhouse

The wheelhouse is equipped with a sprinkler system for which the 91% reliability estimated in paragraph *4.4.3.4. Sprinkler system in accommodation space* was considered valid.

4.8.2.4. Doors open in the wheelhouse

Some of the many windows or doors may be open sufficiently to provide ventilation for the fire to progress. In particular in case of high season when additional ventilation may be desired. Door closing devices on the doors to the wheelhouse should also make a small difference. In this risk assessment it was assumed that the probability that the doors or windows are open sufficiently to provide significant ventilation for the fire in the wheelhouse is 10% in case of high season and otherwise 1%.

4.8.2.5. Fire-fighting in wheelhouse

Fire-fighting efforts could hinder a so far uncontrolled wheelhouse fire to develop further. In case the fire is ventilated it was also identified necessary to account for local collapse. The time until local collapse in case of a wheelhouse fire was discussed in paragraph *4.2.1.2. Time until local collapse* and estimated to possibly occur within 4-7 minutes from fire ignition. The possibilities for fire-fighting were discussed in *4.1.3. Fire-fighting* and [18], and based on these discussions it can be concluded that the time from detection of a fire until the first crew member with fire-fighters outfit is at the scene should be less than 4 minutes. According to Figure 4.2, even a fire with a 4 minute incipient phase may reach flashover 5 minutes after detection. In combination with the probability of local collapse, this gives reason to believe that the potential for successful fire-fighting in the base design may be limited. The above discussions and references led to an estimation of the probability of successful fire-fighting before window breakage of 85% if potential ventilation openings are closed in the alternative designs. This includes account to the possibilities for safe access and other relief by new fire-fighting tools in the base design. The corresponding probability in the prescriptive design was estimated to 70%. In case the doors are open in an alternative design, the probability of successful fire-fighting before window breakage was estimated to 30%. This accounts for the reduced potential for fire-fighting due to the risk of collapse. In the prescriptive design the corresponding probability was estimated to 40% in case the doors are open. Note that fire-fighting efforts may also prove successful in later events, i.e. after potential window breakage.

In case fire-fighting fails at this stage, it was assumed that local collapse will occur in the base design. The consequences for people in case of a local collapse should not be substantial since nearby people should already have evacuated, based on *4.2.1.2 Time until local collapse*. It is hence although possible that a local collapse has consequences for passengers assembled in an adjacent space or that the increased smoke production will affect assembled passengers. Such consequences were assessed small and to give fatalities in relation to the occupancy of the ship. It was assumed that local collapse due to fire would be associated with 2 fatalities in high season and otherwise none.

4.8.2.6. Window breakage in wheelhouse

In order to assess the probability of window breakage in case of a fire, two-zone fire simulations were performed in the program Branzfire [53]. The variety over the height of the upper smoke layer cannot be determined with this program and the heat exposure is very dependable on the proximity of the fire to the windows. Based on uncertainties in the model and the discussions in paragraph *4.4.3.7. Window breakage in accommodation space* as well as the uncertainty in the performance of the windows in the wheelhouse when exposed to heat, approximations were made with regards to the probability of window breakage. In case of a non-ventilated fire, the probability of a window to break before a non-ventilated wheelhouse fire self-extinguishes was estimated to 30%. Hence, if the fire is not extinguished by first aid by crew or by the sprinkler system, then 70% of the fires will self-extinguish due to lack of oxygen. In case doors or windows are open, the fire is assumed to break windows and spread further in 90% of the cases.

In case the doors are closed in the wheelhouse and the windows stay intact the fire was assumed to self-extinguish without any significant consequences else than the burnt out space. In case the windows break the fire was assumed not to self-extinguish but to spread to other parts of the ship. Thus, the above derived probability corresponds with containment of the fire in the space of origin.

In case the fire progresses on adjacent external surfaces the consequences were assumed insignificant if fire-fighting efforts are provided swiftly, the probability of which was above estimated to 78% in the base design and to 90% in the prescriptive design (see *4.2.2.2. Prevention of an exterior fire to grow sufficiently to cause local collapse*). In the base design the resulting probability of a fire causing consequences outside the compartment of origin hence becomes 7% in case the fire is not initially ventilated and 20% in case there were ventilation openings. In the prescriptive design the corresponding figures are 3% and 9% in case the openings were open or closed, respectively.

4.8.3. Fire escalation scenarios from the wheelhouse

In case previously discussed failure modes have occurred, the fire will no longer be contained in the space of origin. This could lead to a major exterior fire as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*. The proceeding fire scenario in the space of origin and the effects from use of FRP composite in divisions is also discussed below.

4.8.3.1. External fire spread from wheelhouse

In the current risk model it was assumed that all scenarios which are not extinguished by swift fire-fighting measures where a window or door is open to the exteriors will lead to fire spread on open deck. There is quite sparse combustibles on the open deck but a fire in the base design could also be fuelled by exterior combustible surfaces. The fire scenarios that may occur as a result of an established open deck fire were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

4.8.3.2. A long-lasting fire in the wheelhouse

In case fire-fighting efforts are not shortly successful after the fire scenarios described above, the fire was assumed to result in a major collapse in the fire compartment in the current risk model. Based on what was previously discussed in *4.1.3. Fire-fighting* and *4.4.3.6. Fire-fighting in accommodation space*, the probability of controlling a ventilated wheelhouse fire which has caused local collapse by fire-fighting efforts before a major collapse occurs was estimated to 30% in the base design. In the prescriptive design the corresponding probability of successful fire fighting before a major collapse in the aluminium wheelhouse superstructure was assumed to 60%. In case the fire was ventilated to begin with the corresponding probabilities were estimated to 10% and 30% in the base design and the prescriptive design, respectively. In case of a major collapse in the wheelhouse the number of fatalities were assumed to be 1 in case of low or mid seasons and 10 in case of high season, both in the base design and the prescriptive design. A major collapse can hence also occur in case external fire spread was not taken under control by fire-fighting measures, the probability of which was assessed to 10% in the base design and 60 % in the prescriptive design (see *4.2.2.5. Prevention of a major exterior* fire). Hence, loss of containment could eventually lead to the same major collapse scenario. This is only accounted for in the scenario branch where pre-major collapse fire fighting is successful in order to not account for the same scenarios twice. Hence, a major collapse can occur if fire-fighting efforts to avoid it fail either inside or outside the compartment. The resulting probability of failure of pre-major collapse fire fighting is the sum of the probability of failed fire-fighting before major collapse in the space and the probability of failed fire-fighting before major collapse from the exterior fire spread minus the product of the two combined (in order to not account for the same scenarios twice).

4.8.4. Resulting event tree for wheelhouse fire scenarios

The resulting event tree for the wheelhouse fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.9. Ro-ro deck fire scenarios

The ro-ro deck category is representable only of the ro-ro deck on deck 2. A representative design fire was developed for the space covered by this category, based on the identified fire hazards. The identified target locations and critical factors provide information on the possible scenarios, which lead to different fire developments. Hence the magnitude of the critical conditions will vary in the different fire scenarios, which together with the number of passengers will make evacuation more or less successful. This will determine the fire risk contribution from this space.

4.9.1. Ro-ro deck

The ro-ro deck, illustrated in Figure 4.35, is not supposed to be occupied during journey. A fire could nevertheless occur. As for fuel, the main fuels are associated with the vehicles but there may also be combustible deck equipment and other materials, as described in *Appendix G. Data from fire hazard identification*. In the base design the surrounding FRP composite structures may naturally also take part in the fire.

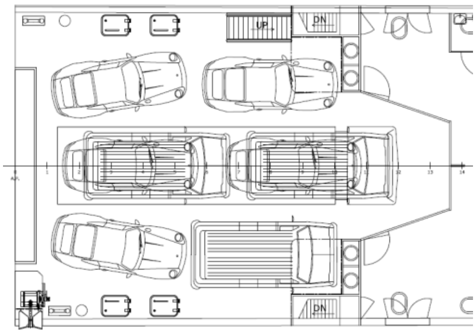

Figure 4.35. Layout of the ro-ro deck.

The design fire in this space would likely be fast or ultrafast in the initial stage, depending on the materials involved. It was concluded that the fire growth will likely be the same both in the prescriptive design and the base design up until a local fire has established.

4.9.2. Development of ro-ro deck fire scenarios

The identified critical factors and the associated target locations on the ro-ro deck are safety functions which provide information on the different possible fire developments. The most significant of such a failure modes in a ro-ro deck fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of detection;
- Failure of manual extinguishment; and
- Failure of fire-fighting.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.9.2.1. Automatic detection and alarm system on the ro-ro deck

The ro-ro deck is fitted with a visual fire (flame) flame detection and alarm system. It was assumed that the reliability for this system was the same as for a smoke detection and alarm system for which the reliability was estimated to 4% in paragraph *4.6.1.2. Automatic detection and alarm system in the auxiliary machinery space*.

4.9.2.2. Manual extinguishment on ro-ro deck

In case a fire establishes on the ro-ro deck, first aid may be given by initial attempts of manual fire extinguishment by the crew. Failure of detection was identified to affect the probability of such attempts which should under normal conditions take place very swiftly. If a fire manages to establish, manual extinguishment was assumed to be successful at an early stage in 35% of the cases when the fire was detected. If manual extinguishment is successful the fire was assumed to have insignificant consequences. Otherwise the fire was assumed proceed without any early manual extinguishment.

On ro-ro deck the amount of potential fuels in the prescriptive design is considerable, accounting for the cars and their fuel, tires and other contents as well as other equipment on deck. The probability of an established local fire affect surrounding structures was estimated based on the potential size of an established fire and the incident heat radiation as well as the potential locations of such a fire and the distance to surrounding structures. Based on these calculations and that a fire that other fires may affect structures if continuing to develop, the probability of a fire affecting external surfaces was fire was estimated to 83%. This will affect the possibilities for fighting the fire.

4.9.2.3. Fire-fighting on ro-ro deck

Swift fire-fighting efforts could hinder a so far uncontrolled ro-ro deck fire to develop further. In case the fire is affecting the surrounding structures in the base design it was also identified necessary to account for a possibly larger fire and the disadvantage associated with the risk of local collapse. The time until local collapse in case of a ro-ro deck fire was discussed in paragraph *4.2.1.2. Time until local collapse* and estimated to possibly occur within 4-7 minutes from fire ignition. The possibilities for fire-fighting were discussed in *4.1.3. Fire-fighting* and [18], and based on these discussions it can be concluded that the time from detection of a fire until the first crew member with fire-fighters outfit is at the scene should be less than 4 minutes. In combination with the probability of local collapse, this gives reason to believe that the potential for successful fire-fighting in the base design may be limited. The above discussions and references led to an estimation of the probability of successful fire-fighting in case surrounding structures are not affected by the fire to 65%, both in the base design and the prescriptive design. If adjacent structures are affected by the fire the probability of successful fire-fighting at this stage was estimated to 15% in the base design and to 45% in the prescriptive design. This accounts for the reduced potential for fire-fighting due to the risk of collapse. However, in case detection had failed, the probability of successful fire-fighting was assumed reduced by 50%. Note that fire-fighting efforts may also prove successful in later events, i.e. after potential window breakage.

In case fire-fighting fails at this stage, it was assumed that local collapse may occur. The consequences for people in case of a local collapse should not be substantial since nearby people should already have reached a safe place, based on *4.2.1.2. Time until local collapse*. It is although possible that a local collapse has consequences for passengers assembled in an adjacent space or that the increased smoke production will affect assembled passengers. Such consequences were assessed in relation to the occupancy of the ship in *4.2.2.3. Consequences of a local exterior fire*.

4.9.3. Fire escalation scenarios from the ro-ro deck

In case previously discussed failure modes have occurred, the fire will continue to spread. This could lead to a major exterior fire as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*. In the current risk model it was assumed that all scenarios which are not extinguished by swift fire-fighting measures will lead to fire spread on ro-ro deck, the probability and consequences of which were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

In case fire-fighting efforts are not shortly successful after the fire scenarios described above, a long-lasting fire on the ro-ro deck may occur which was assumed to result in a major collapse in the base design. Based on what was previously discussed in paragraphs *4.1.3. Fire-fighting*, *4.4.3.6. Fire-fighting in accommodation space* and *4.2.2.5. Prevention of a major exterior fire* the probability of controlling a ro-ro deck fire which has caused local collapse by fire-fighting efforts before a major collapse occurs was previously estimated to 10% in the base design. In the prescriptive design the corresponding probability of successful fire fighting before a major collapse in the aluminium ro-ro deck superstructure was assumed to 30%. In case of a major collapse on the ro-ro deck the number of fatalities were assumed to be 1 in case of low or mid seasons and 10 in case of high season, both in the base design and the prescriptive design.

4.9.4. Resulting event tree for ro-ro deck fire scenarios

The resulting event tree for the ro-ro deck fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.10. Stairway fire scenarios

The stairway category is representable only of the stairways leading from the engine rooms on deck 1 to the accommodation space on deck 2. There is one door in each direction and a window in each stairway. A number of fire hazards were identified for this space, as described in *Appendix G. Data from fire hazard identification*. The identified target locations and critical factors provide information on the possible scenarios, which lead to different fire developments. Hence the time to reach critical conditions will vary in the different fire scenarios, which together with the number of passengers will make evacuation more or less successful. This will determine the fire risk contribution from this space.

4.10.1. Development of stairway fire scenarios

The identified critical factors and the associated target locations in the stairways are safety functions which provide information on the different possible fire developments. The most significant of such a failure modes in a stairway fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of detection;
- Failure of manual extinguishment;
- Failure of sprinkler system;
- Failure of door; and
- Failure of fire-fighting.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.10.1.1. Automatic detection and alarm system in the stairway

The stairway is fitted with a detection and alarm system for which the reliability was estimated to 4% in paragraph *4.4.3.2. Automatic detection and alarm system in the accommodation space*. No person is assumed present in the actual staircase when the fire occurs.

4.10.1.2. Manual extinguishment in stairway

In case a fire establishes in the stairway, first aid may be given by initial attempts of manual fire extinguishment by the present crew. Failure of detection was identified to affect the probability of such attempts which should under normal conditions take place very swiftly. If a fire manages to establish, manual extinguishment was assumed to be successful at an early stage in 65% of the cases when the fire was detected. Otherwise the fire was assumed proceed.

4.10.1.3. Sprinkler system in stairway

The stairway is equipped with a sprinkler system for which the 91% reliability estimated in paragraph *4.4.3.4. Sprinkler system in accommodation space* was considered valid.

4.10.1.4. Doors open in the stairway

Both doors to the stairway should be fitted with door-closing devices and at least one of them should be locked from passengers. One of the two doors may nevertheless be left open, sufficiently to provide ventilation for the fire to progress. In this risk assessment it was assumed that the probability that one of the doors was opened sufficiently to provide significant ventilation in case of fire in the stairway is 5%.

The space contains very sparse combustibles and Branzfire simulations showed that in case the doors are closed the fire will self-extinguish within two minutes. Hence, a fire in the space will not be critical if the doors are closed, neither in the prescriptive design nor the base design. If one of the doors is open there is although a possibility for the fire to progress.

4.10.1.5. Fire-fighting in stairway

Fire-fighting efforts could hinder a so far uncontrolled stairway fire to develop further. In case the fire is ventilated it was also identified necessary to account for local collapse.

The time until local collapse in case of a stairway fire was discussed in paragraph *4.2.1.2. Time until local collapse* and estimated to possibly occur within 4-7 minutes from fire ignition. The possibilities for fire-fighting were discussed in *4.1.3. Fire-fighting* and [18], and based on these discussions it can be concluded that the time from detection of a fire until the first crew member with fire-fighters outfit is at the scene should be less than 4 minutes. The above discussions and references led to an estimation of the probability of successful fire-fighting before window breakage of 60% in the base design. This includes account to the possibilities for safe access and other relief by new fire-fighting tools and the reduced potential for fire-fighting due to the risk of collapse. The corresponding probability in the prescriptive design was estimated to 45%. Note that fire-fighting efforts may also prove successful in later events, i.e. after potential window breakage.

In case fire-fighting fails at this stage, it was assumed that local collapse will occur and that the fire spreads on exterior surfaces and results in an open deck fire. The consequences for people due to local collapse should not be substantial since nearby people should already have evacuated, based on *4.2.1.2 Time until local collapse*. It is hence although possible that a local collapse has consequences for passengers assembled in an adjacent space or that the increased smoke production will affect assembled passengers. Such consequences were assessed small and to give fatalities in relation to the occupancy of the ship. It was assumed that local collapse due to fire would be associated with 6 fatalities in the base design at high season and 3 fatalities in the prescriptive design at high season and otherwise none.

4.10.2. Fire escalation scenarios from the stairway

In case previously discussed failure modes have occurred, the fire will no longer be contained in the space of origin. This could lead to a major exterior fire as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*. The proceeding fire scenario in the space of origin and the effects from use of FRP composite in divisions is also discussed below.

4.10.2.1. External fire spread from stairway

In the current risk model it was assumed that all scenarios which are not extinguished by swift fire-fighting measures where a window or door is open to the exteriors will lead to fire spread on open deck. There is quite sparse combustibles on the open deck but a fire in the base design could also be fuelled by exterior combustible surfaces. The fire scenarios that may occur as a result of an established open deck fire were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

4.10.2.2. A long-lasting fire in the stairway

In case fire-fighting efforts are not shortly successful after the fire scenarios described above, the fire was assumed to result in a major collapse in the fire compartment in the current risk model. Based on what was discussed in *4.1.3. Fire-fighting* and *4.4.3.6. Fire-fighting in accommodation space*, the probability of controlling a ventilated stairway fire which has caused local collapse by fire-fighting efforts before a major collapse occurs was estimated to 45% in the base design. This is a relatively high probability since the new fire-fighting tools are very suitable for this scenario and give good possibilities for safe access. In the prescriptive design the corresponding probability of successful fire fighting before a major collapse in the aluminium stairway superstructure was assumed to 55%. In case of a major collapse in the stairway the number of fatalities were assumed to be 1 in case of low or mid seasons both in the base design and the prescriptive design. In case of high season 20 fatalities were assumed in the base design and 10 in the prescriptive design. A major collapse can hence also occur in case external fire spread was not taken under control by fire-fighting measures, the probability of which was assessed to 10% in the base design and 60 % in the prescriptive design (see *4.2.2.5. Prevention of a major exterior* fire). Hence, loss of containment could eventually lead to the same major collapse scenario. This is only accounted for in the scenario branch where pre-major collapse fire-fighting is successful in order to not account for the same scenarios twice. Hence, a major collapse can occur if fire-fighting efforts to avoid it fail either inside or outside the compartment. The resulting probability of failure of pre-major collapse fire fighting is the sum of the probability of failed fire-fighting before major collapse in the space and the probability of failed fire-fighting before major collapse from the exterior fire spread minus the product of the two combined (in order to not account for the same scenarios twice).

4.10.3. Resulting event tree for stairway fire scenarios

The resulting event tree for the stairway fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.11. Open deck fire scenarios

The open deck category is representable only of the open deck on deck 3. A representative design fire was developed for the space covered by this category, based on the identified fire hazards. The identified target locations and critical factors provide information on the possible scenarios, which lead to different fire developments. Hence the magnitude of the critical conditions will vary in the different fire scenarios, which together with the number of passengers will make evacuation more or less successful. This will determine the fire risk contribution from this space.

4.11.1. Open deck

The open deck, illustrated in Figure 4.36, is not supposed to be occupied during journey. A fire could nevertheless occur. As for fuel, the main fuels are associated with what people may bring to the deck as well as seats, deck equipment and other materials, as described in *Appendix G. Data from fire hazard identification*. In the base design the surrounding FRP composite structures may naturally also take part in the fire.

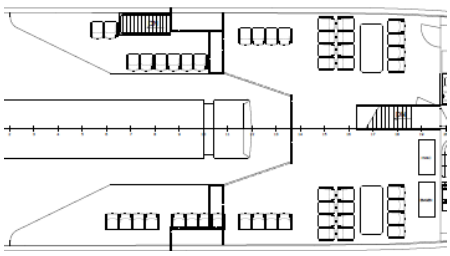

Figure 4.36. Layout of the open deck.

The design fire in this space would likely have an initial fire growth which is slow or medium but it could also be fast, e.g. if the fire was established by an arsonist or was associated with the fuel from the emergency generator. It was concluded that the fire growth will likely be the same both in the prescriptive design and the base design up until a local fire has established.

4.11.2. Development of open deck fire scenarios

The identified critical factors and the associated target locations on the open deck are safety functions which provide information on the different possible fire developments. The most significant of such a failure modes in an open deck fire have been used to identify the most relevant differences in fire scenarios between the prescriptive design and the trial alternative designs. The probabilities and consequences of these scenarios will determine the fire risk contribution from this space.

The failure modes which were identified as significant are:

- Failure of manual extinguishment; and
- Failure of fire-fighting.

The probabilities of the different failure modes will depend on the design and arrangements in the prescriptive design and the trial alternative designs. The argumentations behind the probabilities of failure modes and consequences associated with fire scenarios are further described subsequently and then summarized in an event tree.

4.11.2.1. Manual extinguishment on open deck

In case a fire establishes on the open deck, first aid may be given by initial attempts of manual fire extinguishment by the passengers or crew. The always occupied wheelhouse is located next to the open deck and has windows in that direction, which speaks for a possible swift manual extinguishment by crew. In case there are passengers nearby on open deck they may also make a first attempt to extinguish the fire or at least to inform the crew in the wheelhouse. Since the design fire is likely slow and the available combustible materials are sparse the total probability of successfully extinguishing the fire at an early stage was estimated to 30%.

On the open deck space the amount of combustible materials are quite restricted. There may however be combustible deck equipment, floor constructions, plastic chairs and other FRP composite structures, also on the prescriptive ship. The probability of an established local fire affect surrounding structures was estimated based on the potential size of an established fire and the incident heat radiation as well as the potential locations of such a fire and the distance to surrounding structures. Based on these calculations and that a fire that other fires may affect structures if continuing to develop, the probability of an established fire to affect external surfaces was fire was estimated to 48%.

4.11.2.2. Fire-fighting on open deck

Swift fire-fighting efforts could hinder a so far uncontrolled open deck fire to develop further. In case the fire is affecting the surrounding structures in the base design it was also identified necessary to account for a possibly larger fire and the disadvantage associated with the risk of local collapse. The time until local collapse in case of an open deck fire was discussed in paragraph *4.2.1.2. Time until local collapse* and estimated to possibly occur within 4-7 minutes from fire ignition. The possibilities for fire-fighting were discussed in *4.1.3. Fire-fighting* and [18], and based on these discussions it can be concluded that the time from detection of a fire until the first crew member with fire-fighters outfit is at the scene should be less than 4 minutes. In combination with the probability of local collapse and the possible effect from winds, this gives reason to believe that the potential for successful fire-fighting in the base design may be limited. The above discussions and references led to an estimation of the probability of successful fire-fighting in case surrounding structures are affected to 60% in the base design and to 75% in the prescriptive design (see paragraph *4.2.2.2. Prevention of an exterior fire to* *grow sufficiently to cause local collapse*). If adjacent structures are not affected by the fire the probability of successful fire-fighting at this stage was estimated to 85% in both the prescriptive design and the base design.

In case fire-fighting fails at this stage, it was assumed that local collapse may occur. The consequences for people in case of a local collapse should not be substantial since nearby people should already have reached a safe place, based on *4.2.1.2. Time until local collapse*. It is although possible that a local collapse has consequences for passengers assembled in an adjacent space or that the increased smoke production will affect assembled passengers. Such consequences were assessed in relation to the occupancy of the ship in *4.2.2.3. Consequences of a local exterior fire*.

4.11.3. Fire escalation scenarios from the open deck

In case previously discussed failure modes have occurred, the fire will continue to spread. This could lead to a major exterior fire as discussed in *4.2.1.3. Escalating fire scenarios* and *4.2.2. Fire development on exterior surfaces in FRP composite*. In the current risk model it was assumed that all scenarios which are not extinguished by swift fire-fighting measures will lead to fire spread on open deck, the probability and consequences of which were further elaborated in paragraph *4.2.2. Fire development on exterior surfaces in FRP composite* above.

In case fire-fighting efforts are not shortly successful after the fire scenarios described above, a long-lasting fire was assumed to result in a major collapse in the base design. Based on what was previously discussed in *4.1.3. Fire-fighting*, *4.4.3.6. Fire-fighting in accommodation space* and *4.2.2.5. Prevention of a major exterior fire* the probability of controlling an open deck fire which has caused local collapse by fire-fighting efforts before a major collapse occurs was previously estimated to 15% in the base design. In the prescriptive design the corresponding probability of successful fire fighting before a major collapse in the aluminium ro-ro deck superstructure was assumed to 60%. In case of a major collapse on the open deck the number of fatalities were assumed to be 1 in case of low or mid seasons and 10 in case of high season in the prescriptive design and in the base design the corresponding consequences were estimated to 1, 2 and 20, depending on the ship occupancy.

4.11.4. Resulting event tree for open deck fire scenarios

The resulting event tree for the open deck fire scenarios for the prescriptive design and the event tree for the base design are illustrated in *Appendix O. Event trees*.

4.12. Quantification of risk control measures

Risk control measures were considered in different combinations. Their effects on safety were assessed individually and in combination with other risk control measures, i.e. if effects were judged to be more or less significant in combination with others. Effects from different RCMs are assessed subsequently.

4.12.1. Redundant extinguishing system (a)

The RCM denoted “a” was considered in a few different set-ups which were estimated to give different effects:

RCM a1: Redundant supply unit for extinguishing system in stairways, accommodation space, wheelhouse and toilets was based on [31-33] estimated to give the extinguishing system a reliability of 60% in the cases where it would otherwise have failed in these spaces.

RCM a2: Fully redundant extinguishing system in stairways, accommodation space (including the void space above the ceiling in the accommodation space if extinguishing system is installed there, see RCM b), wheelhouse and toilets was based on [31-33] estimated to give the extinguishing system a reliability of 91% in the cases where it would otherwise have failed in these spaces.

RCM a3: Fully redundant extinguishing systems in engine room. The SB extinguishment system will protect the PS engine room and vice versa. This RCM was based on [31-33] estimated to give the extinguishing system a reliability of 77% in the cases where it would otherwise have failed in these spaces.

RCM a4: Redundant supply unit for extinguishing system on ro-ro deck was based on [31-33] estimated to give the extinguishing system a reliability of 55% in the cases where it would otherwise have failed in this spaces.

RCM a5: Fully redundant extinguishing system on ro-ro deck was based on [31-33] estimated to give the extinguishing system a reliability of 80% in the cases where it would otherwise have failed in this spaces.

4.12.2. Drencher on outboard sides (c)

The RCM denoted “c” was considered in a few different set-ups which were estimated to give different effects, as elaborated below.

This drencher system applies 3 l/(m^2 * min) according to [54] and activated at fire detection. Tests show that after 3-5 minutes of exposure to a large hydrocarbon fire on unprotected composite panels the fire has spread 6 meters vertically and severely damaged the composite panels (a 6 m high and 1-2 meter wide section where the outer laminate detaches from the core, resulting in almost total loss of strength). If there is no structural redundancy this damages is severe enough to cause a partial superstructure collapse. For a drencher system to be effective fast activation is crucial. Automatic fire detection system (flame detectors) detecting external fires is therefore considered in combination with this RCM when there is no structural redundancy. For a drencher system to be effective fast activation is crucial. Automatic fire detection system (flame detectors) detecting external fires is therefore considered in combination with this RCM. Automatic fire detection system detecting external fires to accomplish fast activation of external drencher could be flame detectors. Such a system would also be beneficial when the ship is at dockside and the system can be set on automatic activation. Based on [31-33] and available statistics in [34] a dry pipe extinguishing system reliability could be assessed to 79%. For this assessment it was assumed that the failure rate was somewhat improved so that the system together with flame detectors together have a reliability of 80%. Hence, this lower probability of failure is a requirement for this RCM which must be validated by using sufficient redundancies in the system design. In all this system was thereby assumed to decrease the probability of fire development by 80%.

RCM c1: Drencher system covering the outside of the bulkhead separating the accommodation space from the ro-ro deck was assumed to increase the probability pre-local collapse fire-fighting in case of fire development on ro-ro deck to 80% in case detection functions and to 65% in case detection fails. Furthermore, the probability of pre-major collapse fire-fighting was improved to by 50 %.

RCM c3: Drencher system covering the sides and front of the ship from deck 3and down (including c1) was assumed to also increase the probability pre-local collapse fire-fighting in case of fire development on outboard sides deck to 80%.

4.12.3. Extinguishing system on ro-ro deck (d)

The RCM denoted “d” was considered with pop-up nozzles and was estimated a reliability of 80% based on [31-33], which was included in the event tree for the ro-ro deck.

4.12.4. Surface with low-flame spread characteristics (i)

A surface with low flame-spread characteristics is based on [54, 55] assumed to limit fire-spread and the FRP composites’ contribution to the heat released. It also prolongs the time until the load-carrying capacity is affected and self-extinguishes when the original fire source has burnt out. There will hence be no fast fire growth in the composite. During the first ten minutes the composites will not be involved in the fire at all and in the later stages of the fire the contribution to the heat release by the FRP composite is small compared to the initial fire.

Due to the above the LEO system was assumed to have a number of effects, depending on the set-ups:

RCM i4: Low flame-spread characteristics on FRP composite surface facing ro-ro deck (on bulkhead between ro-ro deck and accommodation space) was assumed to increase the probability of pre-local collapse fire-fighting in case of fire development on ro-ro deck where structures are affected by 50% in comparison with a prescriptive design. This also applies to the probability of pre-major collapse fire-fighting. Furthermore, the increased fatalities from local collapse between the prescriptive design and the base design were reduced by 65%.

RCM i5: Low flame-spread characteristics on all FRP composite surfaces facing ro-ro deck was assumed to increase the probability of pre-local collapse fire-fighting in case of fire development on ro-ro deck where structures are affected by 65% in comparison with a prescriptive design. This also applies to the probability of pre-major collapse fire-fighting. Furthermore, the fatalities from local collapse were reduced to the same level as a prescriptive design in the base design and the increased fatalities from major collapse were reduced by 80%.

4.12.5. Fire resisting material on FRP composite surfaces (j)

The RCM denoted “j” consists of application of fire resisting material on top of FRP composite surfaces, which will affect the fire and smoke development in the initial stages of a fire. In later stages when the fire has reached a certain size, the covered combustible materials may still contribute to the fire. This was considered in a few different areas, out of which the relevant combinations were:

RCMs j1, j2, j3, and j7: Fire Resisting Material covering FRP composite surfaces in accommodation space, toilets, stairways and cleaning closet was assumed to affect the possibilities for pre-local collapse fire-fighting so that the probability is the same as on a prescriptive ship. Furthermore, the probability of pre-major collapse fire-fighting was assumed to be improved to 60% in case the doors are closed and to 30% in case the doors are open between the two parts of the accommodation space. The consequences in case of local collapse were also assumed reduced to the level in the prescriptive design and the increase in consequences in comparison with the prescriptive design in case of a major collapse were reduced by 50%.

RCM j5: Fire Resisting Material covering FRP composite surfaces in wheelhouse (including WC) was assumed to affect the possibilities for pre-local collapse fire-fighting so that the probability is the same as on a prescriptive ship. Furthermore, the reduced probability of pre-major collapse fire-fighting in the accommodation space was assumed to be improved by 75%. The consequences in case of local collapse were also assumed reduced to the level in the prescriptive.

4.12.6. Improved structural resistance (n)

The RCM denoted “n” consists of application of thermal insulation to achieve FRD60 in different areas, out of which the relevant combinations were:

RCMs n1, n2, n3, n5: FRD60 under deck 3 towards the accommodation space and WCs, on accommodation space side of the boundary bulkhead between the accommodation space and the open deck space on deck 3 (in the staircase), on accommodation space side of the boundary bulkhead between accommodation space and fore deck, on the accommodation space side of the boundary bulkhead between accommodation space and ro-ro deck. This was assumed to give the same probability of successful pre-local collapse fire-fighting, pre-major collapse fire-fighting and consequences if these occur as in the base design as in a prescriptive design.

RCM n12: Structural redundancy of the boundary bulkhead between accommodation space and ro-ro deck was assumed to increase the probability of pre-local collapse fire-fighting on ro-ro deck in case structures are affected to 85% or 75%, depending on whether detection was functional or not. The reduced probability of pre-major fire-fighting in case of a fire initiated on ro-ro deck was increased by 75% in comparison with a prescriptive design. The increase in consequences in comparison with the prescriptive design from local collapse were reduced by 50%.

4.12.7. Additional structural division (o)

The RCM denoted “o1” consists of installing an additional structural fire protection division dividing the accommodation space in two and fitting door-closing devices at interconnecting doors. This was assumed to give the passengers a safe place in one of the parts of the accommodation space in case a fire occurs in the other part and the door-closing devices function and was incorporated in the event trees.

4.12.8. Alarms (r)

The RCM denoted “n” consists of application of thermal insulation to achieve FRD60 in different areas, where a combination of RCMs r3 and r4 was quantified, i.e. alarms on openings to auxiliary machinery spaces and engine rooms. This was assumed to affect reduce the probability of a ventilated fire by 90%.

4.13. Summarized input data

All of the assumptions and quantifications made which work as input to the event trees and the fire risk model are for transparency listed in summary in *Appendix P. Summarized input data*.

4.14. Results and evaluation of trial alternative designs

The quantified outcomes from the event trees are now to be merged into risk measures. Estimations of risk are commonly presented in the risk measure “mean risk” or the expected number of fatalities in a year of operation. In risk management the “mean risk” is normally defined as the average number of people exposed to inhabitable conditions from possible accident scenarios in a year, commonly referred to as potential loss of life, PLL. This is a societal risk and concerns the total risk to human life in the areas affected by the possible fire scenarios. It is important to present risk in a combination of risk measures since all features of a risk cannot be displayed in one measure, particularly not in PLL. What is also notable concerning the expected number of fatalities is that is needs a fairly delimited context to make sense, which although is the case when comparing two designs of similar superstructures. In probabilistic risk analyses, societal risk is typically also expressed as or illustrated in an F-N diagram. Advantage with the F-N diagram are that it expressed the relation between accidents with small and large accidents and that it also provides a visual illustration of the potential risk. F-N comes from for “Frequency of accidents versus Number of fatalities” and the diagram displays the estimated cumulative frequency for a certain number of fatalities expected from incidents. Since the number of fatalities from different scenarios is plotted in order of magnitude against the cumulative frequency, the expected frequency of e.g. 10 or more fatalities can be deduced from the diagram. Note that an event with catastrophic consequences can be acceptable if the probability is sufficiently small.ABC DEH FGP IJN KLMO

The risk was presented in the above risk measures for the prescriptive design, the base design and the following trial alternative designs (TAD):

- TAD A: a1 (redundant supply unit for interior sprinkler system);
- TAD B: a2 (fully redundant interior sprinkler system);
- TAD C: a3 (fully redundant extinguishing system in engine rooms);
- TAD D: a4 (ro-ro deck extinguishing system with redundant supply unit);
- TAD E: a5 (fully redundant ro-ro deck extinguishing system);
- TAD F: c1 (drencher system covering the forward bulkhead on ro-ro deck);
- TAD G: c3 (drencher system around deck 3);
- TAD H: d (extinguishing system on ro-ro deck);
- TAD I: i4 (LFS on forward bulkhead on ro-ro deck);
- TAD J: i5 (LFS on all surfaces facing ro-ro deck);
- TAD K: j1, j2, j3, j7 (FRM in accommodation area);
- TAD L: j5 (FRM in wheelhouse);
- TAD M: n1, n2, n3, n5 (FRD60 in accommodation area);
- TAD N: n12 (structural redundancy of accommodation space/ro-ro deck bulkhead);
- TAD O: o1 (structural fire protection dividing the accommodation space);
- TAD P: r3, r4 (door and hatch alarms for auxiliary machinery spaces and engine rooms);
- TAD Q: a1, c1, o1 (redundant supply unit for interior sprinkler, drencher on fwd ro-ro deck bulkhead, structural fire protection division in acc);
- TAD R: a1, n12, o1 (redundant supply unit for interior sprinkler, structural fire protection division in acc, structural redundancy of acc/ro-ro bulkhead);
- TAD S: a1, d, a4, i4, o1 (redundant supply unit for interior sprinkler and ro-ro extinguishing system, LFS on forward bulkhead on ro-ro, structural fire protection division in acc);
- TAD T: a1, d, a4, i5, o1 (redundant supply unit for interior sprinkler and ro-ro extinguishing system, LFS on ass surfaces facing ro-ro, structural fire protection division in acc); and

- TAD U: a1, d, a4, i5, n12, o1 (redundant sypply unit for interior sprinkler and ro-ro extinguishing system, LFS on ass surfaces facing ro-ro, structural redundancy of accommodation space/ro-ro deck bulkhead, structural fire protection division in acc).

The risks estimated in these measures are presented below, followed by a sensitivity and uncertainty analyses and suggestions regarding acceptable final alternative designs.

4.14.1. F-N diagrams

The F-N curves for the prescriptive design, base design and the trial alternative designs with single RCMs affecting the internal extinguishing systems are presented in Figure 4.37.

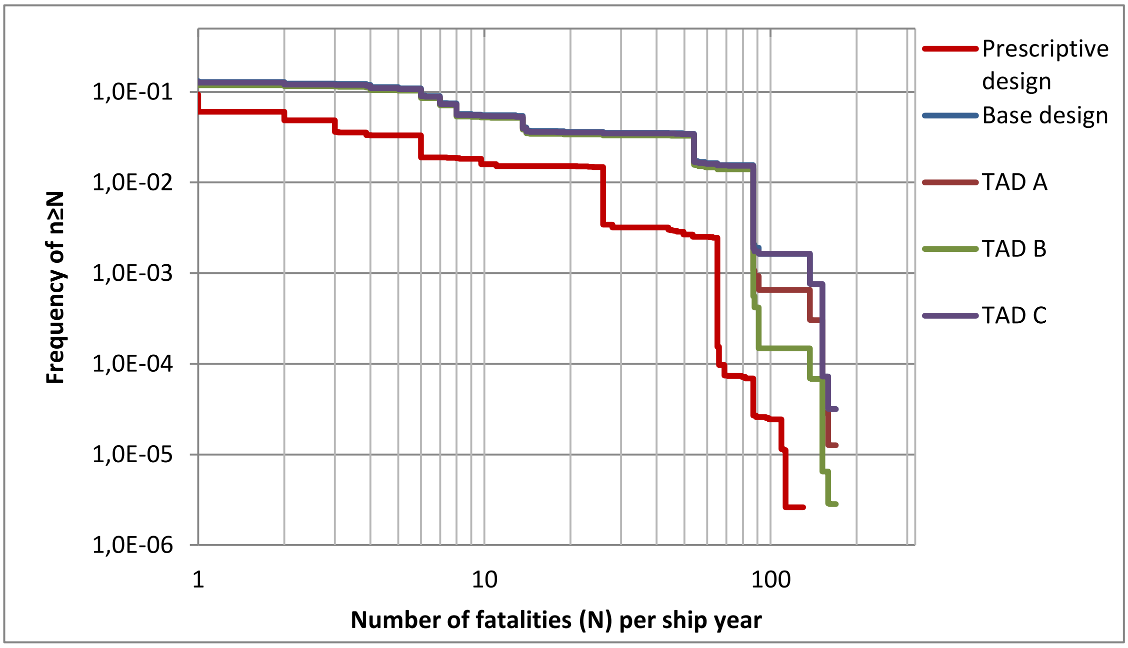

Figure 4.37. F-N diagram including single RCMs affecting the internal extinguishing systems.

The F-N curves for the prescriptive design, base design and the trial alternative designs with single RCMs affecting the an extinguishing systems on ro-ro deck are presented in Figure 4.38.

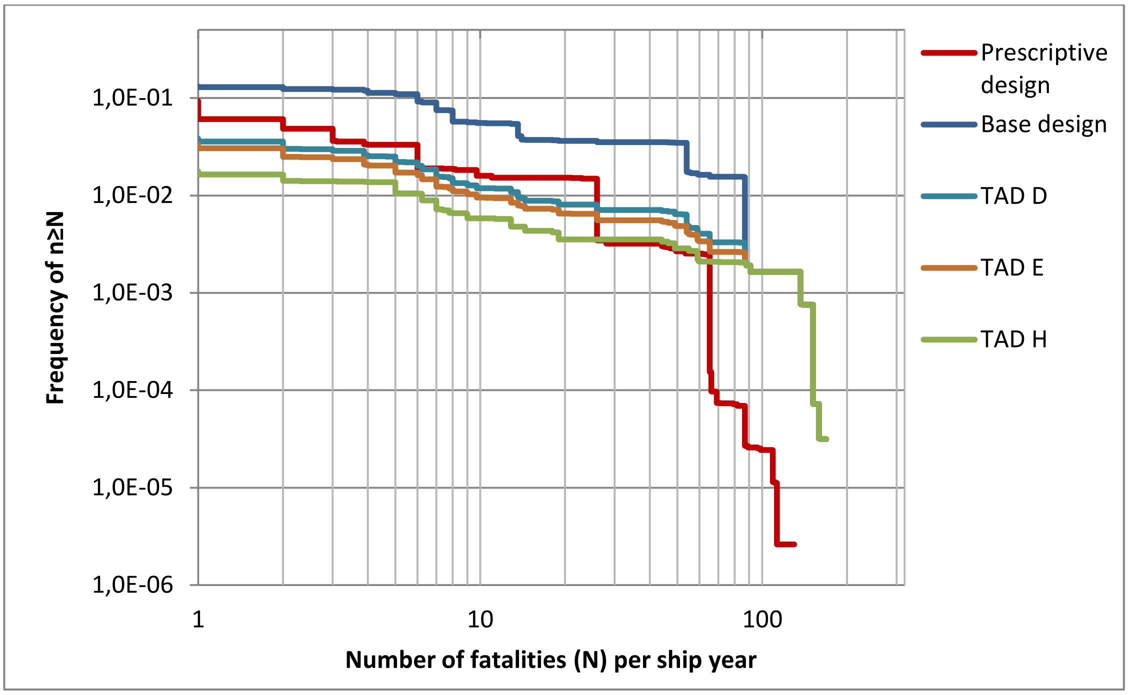

Figure 4.38. F-N diagram with different single RCMs affecting an extinguishing system on ro-ro deck.

The F-N curves for the prescriptive design, base design and the trial alternative designs with single RCMs affecting different set-ups of drencher systems as well as door and hatch alarms are presented in Figure 4.39.

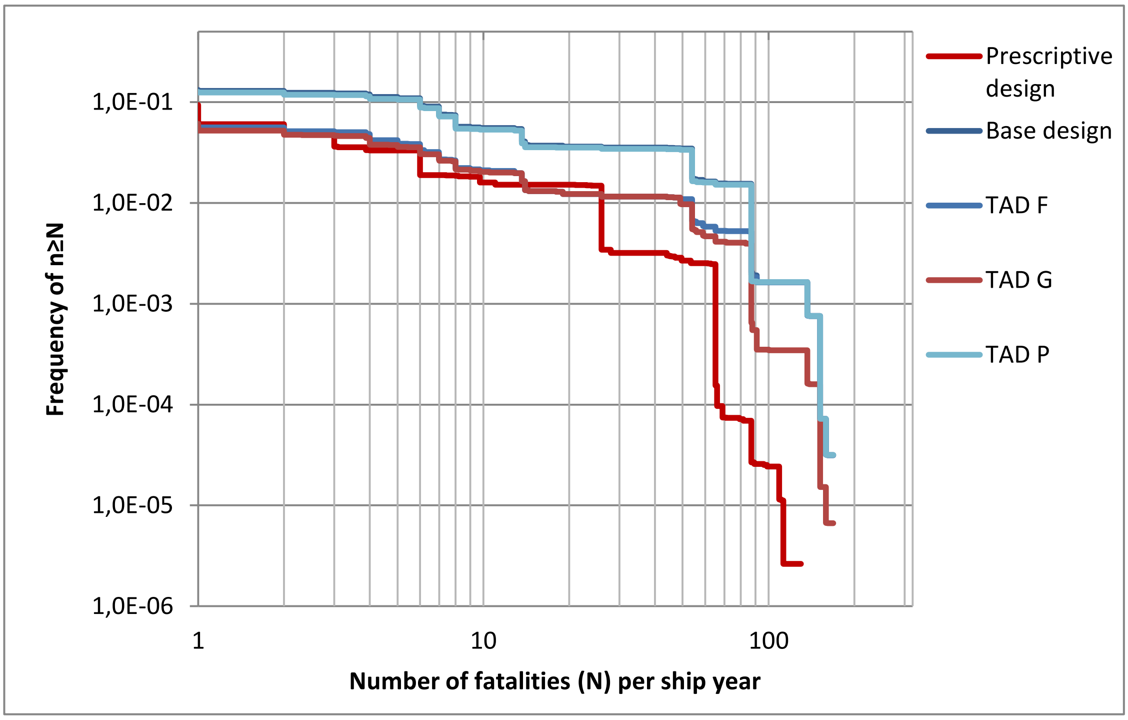

Figure 4.39. F-N diagram with different single RCMs affecting different set-ups of drencher systems as well as door and hatch alarms.

The F-N curves for the prescriptive design, base design and the trial alternative designs with single RCMs affecting the properties of the FRP composite surfaces on ro-ro deck as well as the structural fire resistance of the forward bulkhead are presented in Figure 4.40.

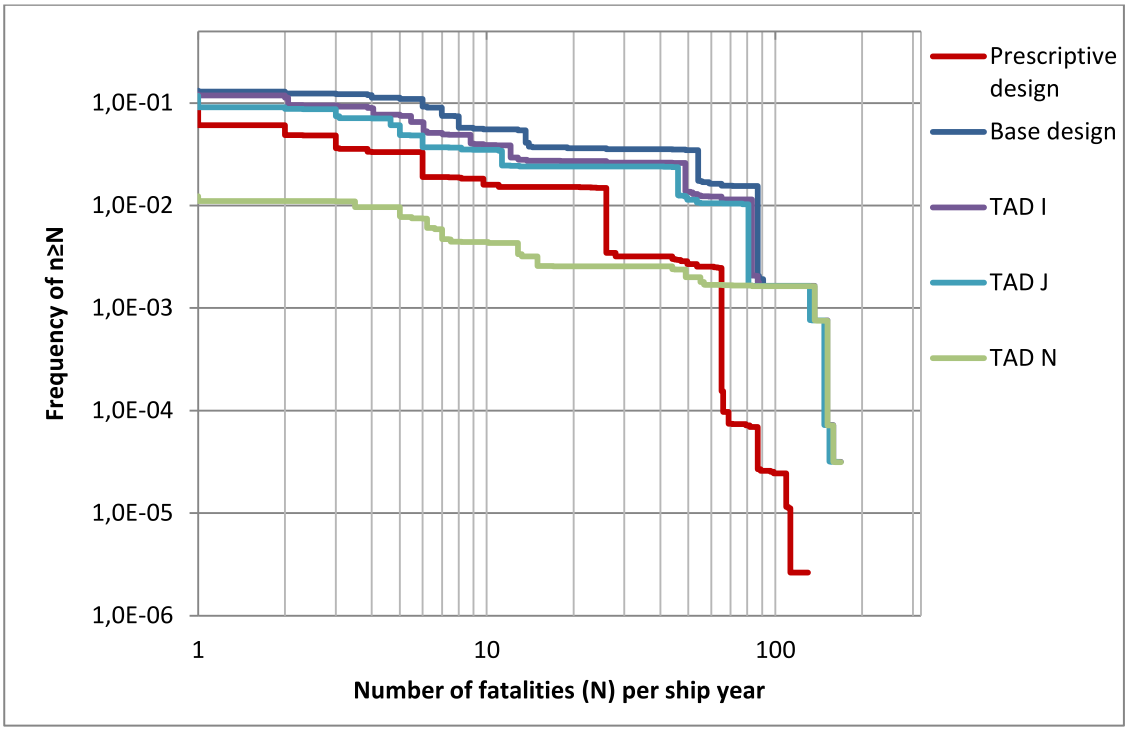

Figure 4.40. F-N diagram with different single RCMs affecting the properties of the FRP composite surfaces on ro-ro deck as well as the structural fire resistance of the forward bulkhead.

The F-N curves for the prescriptive design, base design and the trial alternative designs with single RCMs affecting the properties of the reaction to fire properties as well as fire resistance of the divisions in the accommodation space are presented in Figure 4.41.

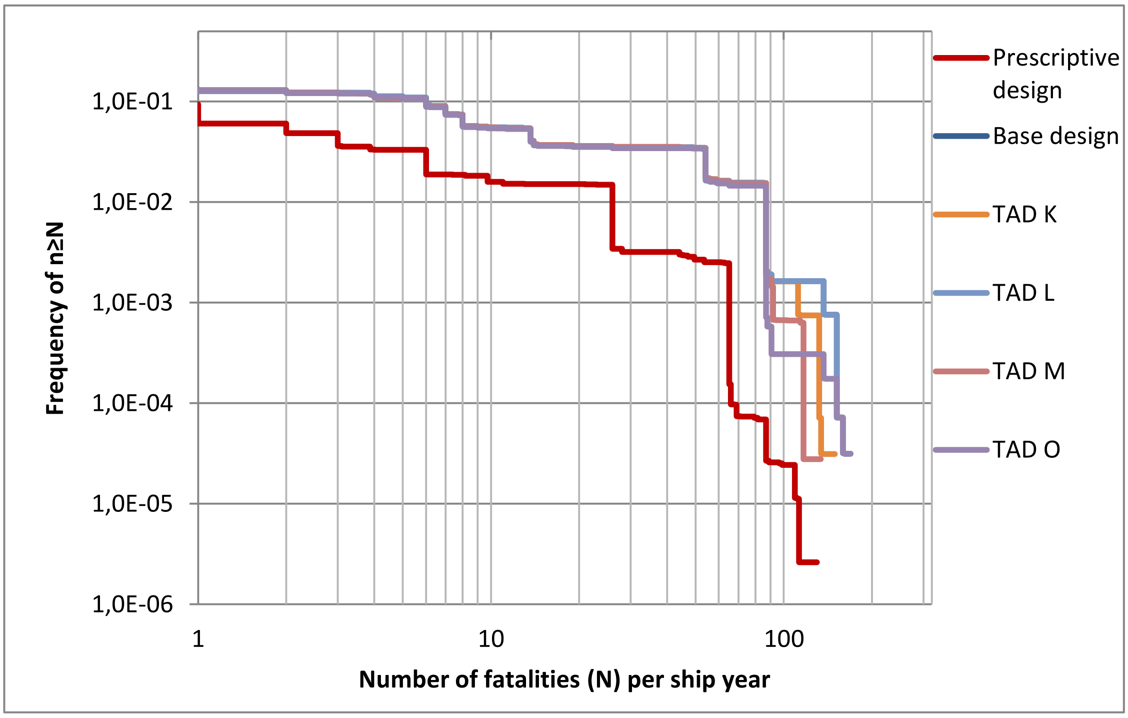

Figure 4.41. F-N diagram with different single RCMs affecting the properties of the reaction to fire properties as well as fire resistance of the divisions in the accommodation space.

The previous figures show that no single RCM is sufficient to improve safety to the level of the prescriptive design. The F-N curves for the prescriptive design and the trial alternative designs with combinations of RCMs, affecting different parts of the fire protection, are presented in Figure 4.42.

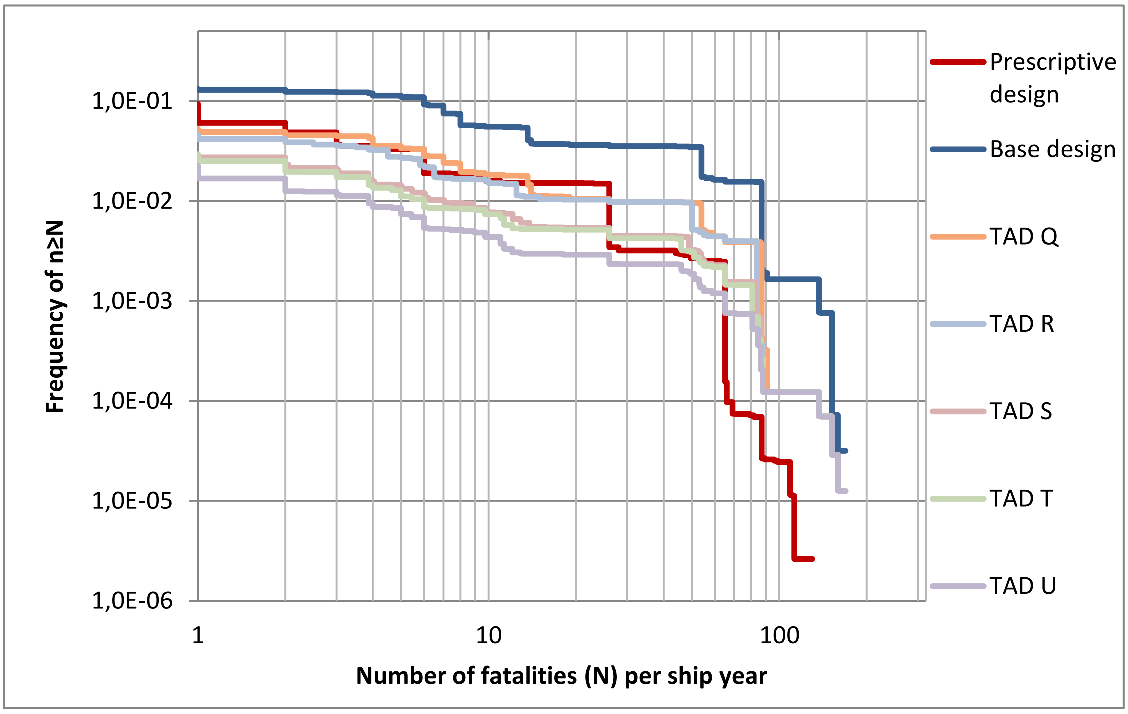

Figure 4.42. F-N diagram with different RCOs involving different combinations of RCMs.

4.14.2. Mean risk

The above F-N diagrams characterize the risks associated with different trial alternative designs. This gives a lot of information of the risks. However, a much more simple risk measure is PLL, or the mean risk, which provides an easier comparison with the prescriptive design. The mean risks for the prescriptive design, base design and the trial alternative designs are summarized in

Table 4.10.

Table 4.10. Potential loss of life, associated with different designs of the ship [PLL], in relation with the prescriptive design [PLL/PD] and the confidence of a design safer than the prescriptive design [C(PLL/PD > 1)]

Design	PLL	PLL/PD	C(PLL/PD > 1)
PD = Prescriptive design	0,74	1,00	-
BD = Base design	3,27	4,43	-
TAD A = BD + RCO A(red. int. sprinkler supply)	3,07	4,16	-
TAD B = BD + RCO B(fully red. int. sprinkler)	2,96	4,02	-
TAD C = BD + RCO C(fully red. ext. in engine)	3,21	4,36	-
TAD D = BD + RCO D(ro-ro deck ext. w red. supply)	0,80	1,08	-
TAD E = BD + RCO E (fully red. ro-ro deck ext.)	0,66	0,90	0.668
TAD F = BD + RCO F(dr. on ro-ro fwd bh)	1,23	1,67	-
TAD G = BD + RCO G(dr. around deck 3)	1,09	1,48	-
TAD H = BD + RCO H(ext. on ro-ro deck)	1,09	1,48	-
TAD I = BD + RCO I(LFS on fwd ro-ro bh)	2,33	3,17	-
TAD J = BD + RCO J(LFS on all ro-ro surfaces)	1,98	2,68	-
TAD K = BD + RCO K(FRM in acc.)	3,22	4,37	-
TAD L = BD + RCO L(FRM in wheelhouse)	3,26	4,42	-
TAD M = BD + RCO M(FRD60 in acc.)	3,17	4,31	-
TAD N = BD + RCO N(structural red. ro-ro fwd bh)	1,10	1,49	-
TAD O = BD + RCO O(structural div. in acc.)	3,10	4,21	-
TAD P = BD + RCO P(door and hatch alarms)	3,16	4,29	-
TAD Q = BD + RCO Q(red. int. spr. supply, dr. on ro-ro fwd bh, str. div. in acc.)	0,97	1,31	-
TAD R = BD + RCO R(red. int. spr. supply, str. div. in acc., SR ro-ro fwd bh)	0,85	1,15	-
TAD S = BD + RCO S(red. supply for int. spr. and ro-ro ext., LFS on ro-ro fwd bh, str. div. in acc.)	0,44	0,59	0.965
TAD T = BD + RCO T(red. supply for int. spr. and ro-ro ext., LFS on ro-ro surf., str. div. in acc.)	0,40	0,54	0.976
TAD U = BD + RCO U(red. supply for int. spr. and ro-ro ext., LFS on ro-ro surf., SR ro-ro fwd bh, str. div. in acc.)	0,24	0,33	0.997

The overall performance criteria is for the final alternative design to be at least as safe as the prescriptive design. Prior to the sensitivity analysis it was considered reasonable to require a safety margin of at least 50%. Hence, based on

Table 4.10, there would be only three trial alternative designs which achieve this performance criteria, namely TAD S, TAD T and TAD U. What these trial alternative designs have in common are an extinguishing system for the ro-ro deck and a redundant supply unit for that extinguishing system as well as for the internal sprinkler system and also an additional longitudinal bulkhead dividing the accommodation space in two. In addition to this, for the ship to be sufficiently safe it was required to contain at least surfaces of low-flame spread characteristics on the forward bulkhead on ro-ro deck (TAD S).

4.14.3. Uncertainty and sensitivity analysis

All estimated probabilities and consequences summarized in *Appendix P. Summarized input data* were assigned probability distributions based on the discussions in the quantifications of fire safety above. These distributions are presented in *Appendix Q. Uncertainty and sensitivity analysis*. Thereby the uncertainties of the estimations and assumptions made in the quantification processes were accounted for. With these distributions as input, Monte Carlo simulations were performed in the software @RISK (Palisade Decision Tools). The input distributions were also correlated so that input parameters which are related had connection. The simulations gave results of the mean risk with confidence intervals as presented in rightmost column in

Table 4.10 and the full results are presented in *Appendix Q. Uncertainty and sensitivity analysis*. This shows that the first requirement of a 50% safety margin was reasonable.

Assuming that a confidence of 90% is sufficient to show that an alternative design is at least as safe as a prescriptive design (i.e. that the alternative design is at least as safe as the prescriptive design in 90% of the simulation iterations) gives the same result as previously.

The sensitivity analysis is presented for the relevant trial alternative designs in *Appendix Q. Uncertainty and sensitivity analysis*. It could be concluded that the risk assessment was not very sensitive to any input parameter.

5. Summary and conclusions

This report contains the engineering analysis as described by the IMO/Circ.1002 for the fictitious ship called the Eco-Island ferry; it is a small ro-ro ship fully built in FRP composite, designed to replace an existing steel ferry with space for about 6 cars and 200 passengers. A risk-approach to performance-based design involved a fire hazard identification process based on workshops held by a designated design team of 8 persons, covering critical aspects and knowledge necessary for the task. This illuminated a number of potential risks associated with use of FRP composite in load-bearing structures. In particular fire development on deck and fire spread through openings and vertically along the outboard sides of the ship were identified as fire scenarios where differences in fire safety would be significant. Furthermore, 8 space groups with similar conditions for fire scenarios were identified to manage the potential fire scenarios on board.

A base design was defined, where steel structures had simply been replaced by the intended FRP composite construction. It was shown to pose a number of deviations to prescriptive requirements. The deviations particularly concern the fact that FRP composite is combustible. This although has effects on several prescriptive requirements, functional requirements and also on implicit requirements in SOLAS.

In the quantitative assessment a number of identified potential fire hazards were managed independently whilst others were incorporated in fire scenarios involving the representative space groups. Different combinations of risk control measures, forming 21 trial alternative designs, were also quantified.

In conclusion, the base design was shown to pose a risk more than four times as high as the prescriptive design. A performance criterion with a safety factor of 50% provided three acceptable trial alternative designs. All of these design solutions include an extinguishing system for the ro-ro deck and a redundant supply unit for that extinguishing system as well as for the internal sprinkler system. There is also an additional longitudinal bulkhead dividing the accommodation space in two. In addition to this, for the ship to be sufficiently safe it was required to contain at least surfaces of low-flame spread characteristics on the forward bulkhead on ro-ro deck.

By assigning distributions to all quantified probabilities and consequences to manage uncertainties, the risk estimations of sufficient safety could be made with better confidence. Assuming a confidence of 90% gave the same results as the safety margin above.

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Appendices

The revised approach

This appendix presents a method to assess fire safety in maritime FRP composite constructions based on [8].

Isolation at sea has made fire risks a major concern in shipping and this is also the key issue when considering ship structures in FRP composite. The main introduced difference in fire safety is that the material is combustible, as opposed to steel which by definition is non-combustible. The international code regulating safety of life at sea, SOLAS [5], does not allow making load-bearing structures in combustible material, according to prescriptive requirements. However, Regulation 17 came into force 2002 and provided an opening for alternative construction solutions if fire safety can be proven at least equivalent to that of a conventionally built ship. It is thus not an exception but an alternative way to fulfil the fire safety requirements of SOLAS. As part of the LASS-C project [56], a method to assess fire safety when making claim to Regulation 17 was developed which embraces the novelty of FRP composite. It was applied to a FRP composite redesign of the Panamax cruise vessel the Norwegian Gem, as further delineated below, and resulted in a preliminary analysis report documented by SP [57] and submitted to the Swedish Transport Agency for approval in principle.

Method to assess fire safety in FRP composite constructions

For FRP composite to become a viable maritime construction material, effects on fire safety from using the material need to be revealed, additional safety measures may be required and an analysis demonstrating and documenting sufficient fire safety is necessary. In Regulation 17, descriptions are summarized for how such analysis should be carried out and more detailed guidelines are found in MSC/Circ.1002 [6] (referred to as Circular 1002). They stipulate that the analysis (referred to as “Regulation 17 assessment”) should be performed by a design team selected to mirror the complexity of the task. The procedure of the analysis can be described as a two-step deterministic risk assessment using performance-based methods of fire safety engineering to compare the fire safety of the alternative design with the level of fire safety obtained by prescriptive requirements [7].The two major steps to be performed are (1) the preliminary analysis in qualitative terms and (2) the quantitative analysis. In the first step, the design team is to define the scope of the analysis, identify hazards and from these develop design fire scenarios as well as develop trial alternative designs. The different components of the preliminary analysis in qualitative terms are documented in a preliminary analysis report which needs an approval by the design team before it is sent to the Administration for a formal approval. With the Administration’s approval, the preliminary analysis report documents the inputs to the next step of the Regulation 17 assessment, the quantitative analysis. Now the design fire scenarios are quantified and, since there are no explicit criteria for the required level of fire safety, outcomes are compared between the trial alternative designs and a prescriptive design. Accordingly, the prescriptive design is a reference design, complying with all the prescriptive fire safety requirements. The documented level of fire safety of the alternative design is therefore not absolute, but relative to the implicit fire safety of a traditional design, which is likewise a product of the implicit fire safety level in prescriptive regulations. Accounting for uncertainties when comparing fire safety levels, the final documentation of the Regulation 17 assessment should demonstrate whether a safety level equivalent to that of a prescriptive design is achieved by the proposed trial alternative designs.

Regulation 17 was developed to undertake innovative design solutions, typically high atriums and long shopping promenades on cruise vessels, without compromising with fire safety. The regulation is in that sense employed to make safety more attractive, but it can also be used to make fire safety more cost-efficient, i.e. to accomplish the same level of fire safety at a lower cost or to increase fire safety at the same cost. In the present case, all steel divisions have been redesigned in FRP composite. Above all, the material is combustible and the fire integrity will be fundamentally affected, which implies significant effects on fire safety. Making claim to Regulation 17, an evaluation of the alternative fire safety design should be based on Circular 1002, which has been identified as a “plausible worst-case type” type of risk assessment. However, in order to establish whether the fire safety of a design with FRP composite can be regarded at least as safe as prescriptive requirements, it has been judged that the risk assessment needs to be more elaborated than what is outlined in Circular 1002 [7]. It is namely not evident how fire risks in such a novel design should be assessed to adequately display effects on fire safety. For one thing, all fire safety requirements are made up around steel designs, leaving many implicit requirements unwritten. To further complicate the comparison of safety levels, prescriptive requirements have unclear connections with the purpose statements of their regulations and also with the fire safety objectives and functional requirements of the fire safety chapter, which are supposed to define “fire safety” [7]. A Regulation 17 assessment involving FRP composite, as any Regulations 17 assessment, should hence not only comply with what is stipulated in Circular 1002, but must also be of sufficient sophistication to describe the introduced novelty in terms of fire safety.

As part of the LASS-C project, a more elaborated method for the first step of the Regulation 17 assessment was developed, which comprises all the requirements of MSC/Circ.1002 but brings the analysis to a higher level [7]. The main differences introduced by the new approach (marked green in Figure A1) are the way verification needs are identified as well as the way these differences in fire safety are collected and rated. Furthermore, since the sophistication of the following quantitative analysis needs to be more elaborated in the present application case, the way fire scenarios are specified is also different. The revised approach is further described subsequently.

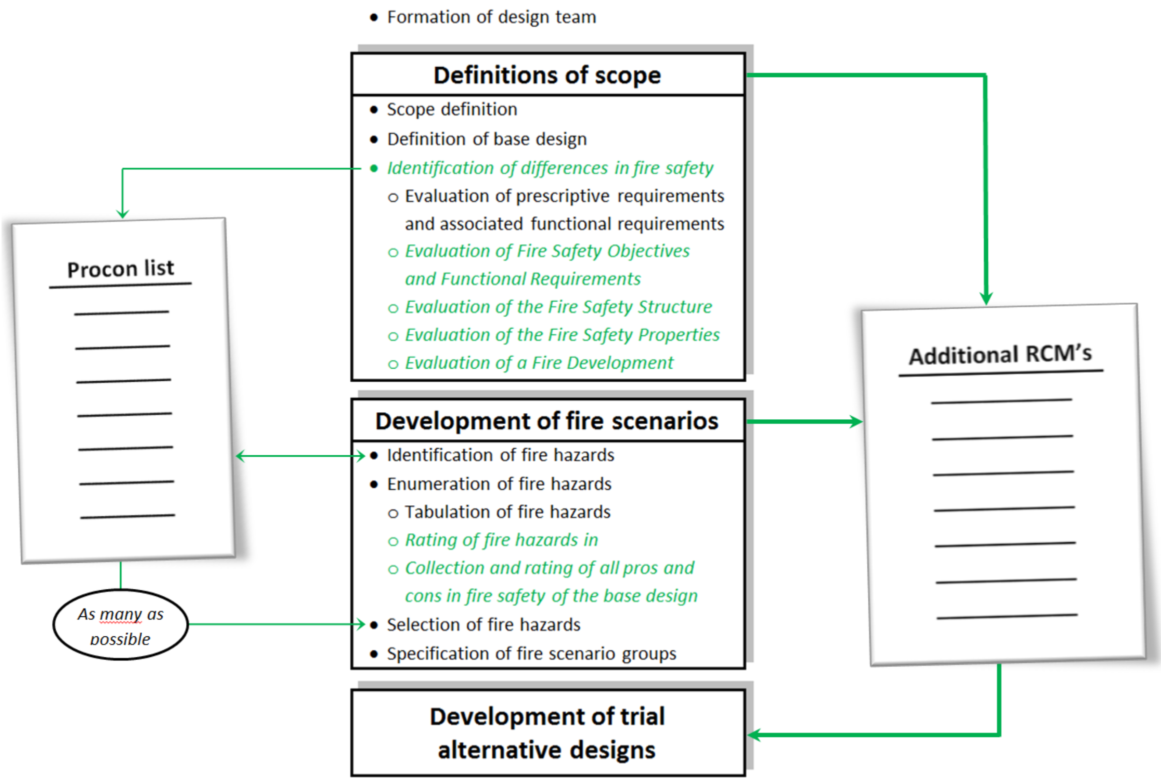


Figure A1. Procedure of the preliminary analysis in qualitative terms, where green represents introduced processes to capture the novelty of FRP composite structures.

Definitions of scope

As described above, the preliminary analysis in qualitative terms can be divided in the three main parts: definitions of scope, development of fire scenarios and development of trial alternative designs. The definitions of scope part consists of three main bullets. Initially, the scope of the current case of alternative fire safety design is simply presented and the regulatory prescribed reference design is defined. Thereafter follow a definition the base design, i.e. the foundational alternative design against which the coming evaluations will be made and to which additional safety measures may be added. In the present case, the scope of the Regulation 17 assessment was the Eco-Island-Ferry with hull and structural elements designed in FRP composite. This ship works as the base design and the corresponding ship built in steel works as the prescriptive design. Most interiors, fire protection systems and equipment were assumed equal in the two designs, and in agreement with SOLAS requirements. In some places differences the passive fire safety measures were designed differently in the base design, as described above.

The third bullet is key for the following assessment since it is meant to identify the areas of impaired fire safety which need to be regained in an alternative way. However, Circular 1002 only describes to identify deviated prescriptive fire safety requirements and associated functional requirements to identify differences in fires safety. As described above, for a FRP composite design this is not sufficient since all fire safety requirements are made up around steel designs, leaving many implicit requirements unwritten. Furthermore, the fire safety objectives and functional requirements of the fire safety chapter are not fully covered by the regulations purpose statements and these are not fully covered by prescriptive requirements, and vice versa (hence identification of implicit effects on fire safety may be necessary in any Regulation 17 assessment) [7]. Based on the above weaknesses in regulations, it was suggested that the identification of effects on fire safety includes the following additional components when evaluating FRP composite designs (at least until FRP composite in shipbuilding gains more field history and for large scopes of FRP composite designs and deviations):

- evaluation of how fulfilment of fire safety objectives and functional requirements are affected;
- evaluation of how the fire safety structure is affected;
- evaluation of how the fire safety properties are affected; and
- evaluation of how a fire development is affected.

The revised approach thus undertakes the investigation of potential effects on fire safety from a broader perspective.

Development of fire scenarios

In the next part (the development of fire scenarios) there are changes in the suggested approach stemming from weaknesses in the descriptions in Circular 1002, from the above changes and from the required sophistication of the forthcoming quantitative analysis. Firstly a hazard identification is performed where the design team meats in a systematic brainstorming session to thoroughly investigate fire safety in each space of the novel design. At this stage it is important to recognize how the previously identified differences in fire safety will affect the different kinds of fire hazards in the individual spaces. A new logistical process was therefore added to the new approach, where all pros and cons from a fire safety perspective are collected in a “Procon list”. This document works as input to the hazard identification to recognize how the differences in fire safety result in actual fire hazards or improvements and how these work along with other fire hazards at different stages of a fire scenario. Further differences in fire safety which are identified during the development of fire scenarios are also added to the Procon list. In the present application case, fire hazards were identified in a workshops held at Kockums in Malmö with participants from the design team.

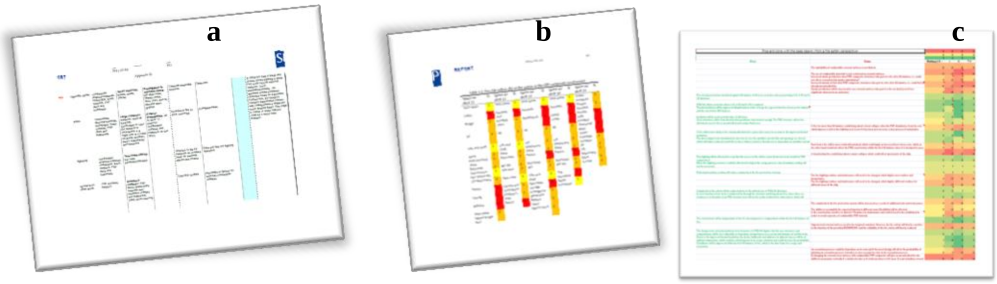


Figure A2. (a) Tabulation of the fire hazards from the hazard identification. (b) Fire hazard ratings of the spaces in the FRP composite construction. (c) A different but more useful enumeration of fire hazards where pros and cons with the base design were rated from a fire safety perspective.

In the hazard identification, fire hazards are naturally organized in different categories, as illustrated in Figure A2. This tabulation normally automatically fulfils the stipulation in Circular 1002 to enumerate fire hazards in three different incident categories. The guidelines are although quite vague in this area. What Circular 1002 could be aiming at when stipulating an enumeration into incident classes, and what is more useful, is to rather identify and categorize the plausibly worst fire developments in the spaces, based on the identified fire hazards (illustrated in Figure A2). It can be said to constitute some form of fire hazard rating of the concerned spaces, since only plausibly worst consequences are considered and probability thereby is included to a very limited extent. Despite this, and although it is founded on value judgement, this new fire hazard rating provides an indication of the fire risks as perceived by the design team. The fire hazard rating was performed for the involved spaces on the Eco-Island-Ferry (see Table 3.3) and proved useful when selecting fire hazards to form design fires and event trees, which define the fire scenarios. Before the selection, another process was although added, where the collected differences in fire safety in the Procon list were reviewed and rated (see Figures A1 and A2). The first priority when selecting fire hazards should be to include as many of those differences in fire safety between the prescriptive design and the base design as possible. Particularly the highly rated differences in fire safety need to be considered in fire scenarios whilst less significant differences alternatively could be managed qualitatively. Thereafter, hazards that significantly will affect the fire development should be taken into account in the fire scenarios. Finally it should be a goal to include as many of the identified hazards as possible and, hence, not only the hazards resulting in the most severe consequences. In the selection process in the present application case, spaces with similar fire hazards are grouped together to cover all the spaces of the alternative design.

The groups of spaces could be said to be represented by a fictitious representative space. In the following fire scenario specification, relevant failure modes affecting a fire development in the representative space are specified along with a plausibly worst-case uncontrolled design fires in that space. Instead of representing all spaces and possible fire scenarios by a few design fire scenarios, the full range of possible fire scenarios can now be quantified for the groups of spaces with similar conditions governing fire development (e.g. potential fire growth, implemented safety measures etc.).

Trial alternative designs

The base design usually needs additional risk control measures (RCM) in order to achieve sufficient safety. A combination of risk control measures makes up a risk control option (RCO) and applied to the base design the RCOs make up trial alternative designs, as illustrated in Figure A3. In order to develop suitable trial alternative designs, it is important that the suggested RCMs originate from the identified differences in fire safety and their effects in a fire scenario. It is also during these previous parts that RCMs are generally identified. In the revised approach it is therefore simply suggested that RCMs are collected throughout the assessment and combined to suitable RCOs at the end of the preliminary analysis in qualitative terms. However, new RCMs can be found further on, certain combinations can be missed and their effects on safety are still not evident. Therefore it is not constructive to eliminate risk control measures or combinations of such. Even if particularly suitable RCOs could be suggested, it is therefore advised in the revised approach that trial alternative designs are not firmly defined at this stage.

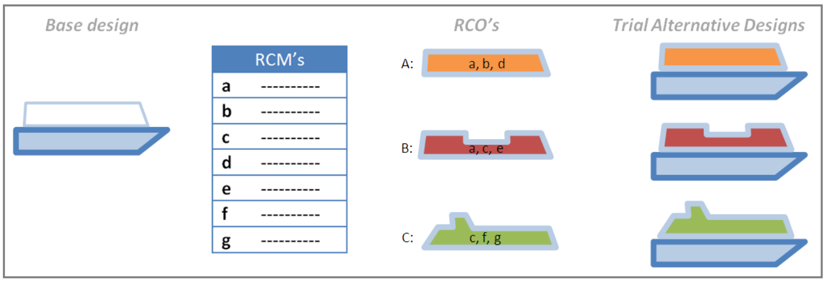
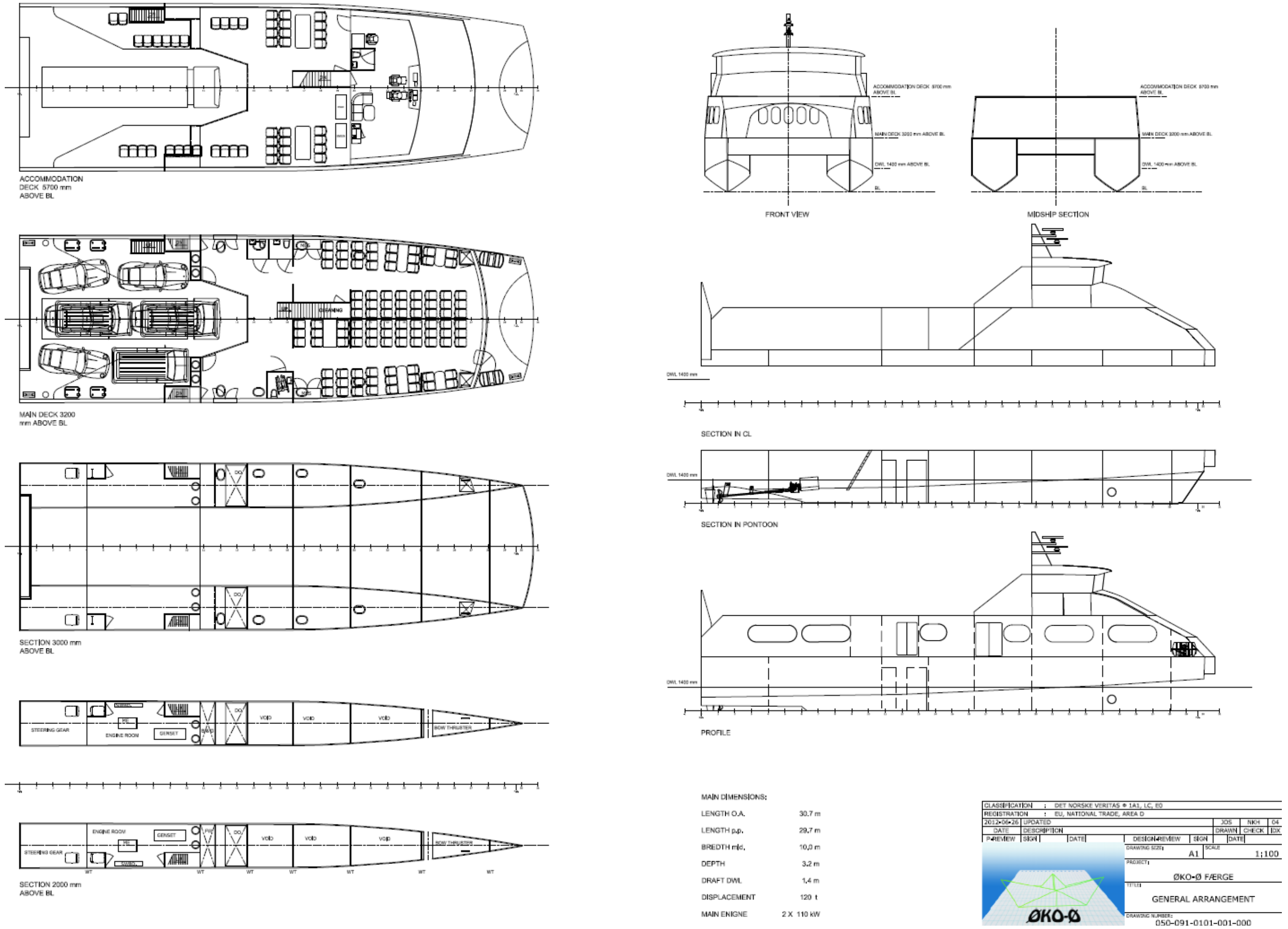


Figure A3. Illustration of the base design in relation to trial alternative designs.

General arrangement



FRP composite panels and fire performance

Steel is a robust ship building material with a high limit for destruction, both when it comes to temperature and loading. Steel divisions generally deteriorate at 400-500^{o}C but permanent deformation as well as fire can spread in great areas when structures are heated to temperatures below those levels. FRP composite matches the rigid and strong qualities of steel and also works as a good thermal barrier [10]. Other benefits with FRP composite are the minimization of maintenance, lack of corrosion, prolonged lifetime, reduced efforts for repairs and, above all, the reduction in weight. However, the material is inevitably combustible and will increase the amount of fuel and the production of toxic smoke if embraced by fire.

Below follow more detailed descriptions of an FRP composite constructions and the keys to its qualities. Thereafter, properties revealed from fire tests are described and weaknesses of tests are discussed.

The structure of a FRP composite panel

An FRP composite panel essentially consists of a lightweight core separating two stiff and strong FRP laminates, which is illustrated in Figure C1. The core material generally consists of PVC (polyvinyl chloride) foam or balsa wood and the face sheets are generally made by carbon or glass fibre reinforced polymer. When these laminates are bonded on the core the composition altogether makes up a lightweight construction material with very strong and rigid qualities [2].

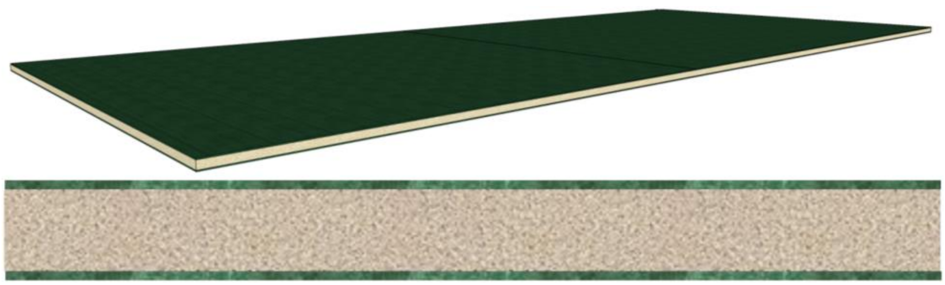


Figure C1. Illustration of an FRP composite panel (top) and a close-up on the lightweight core and the rigid and strong fibre reinforced laminates (bottom).

The key to the prominent properties of the FRP composite is anchored in the separation of the strong laminates. It makes them effective in carrying all in-plane loads and gives ability to withstand high working strains. The separation also provides bending stiffness when exposed to local transverse loading. The core, separating the face sheets, works as a prolate stiffener in the whole structure. It carries local transverse loads as sheer stresses, comparable with how webs of stiffeners behave in stiffened steel panels. The way the material is designed makes it altogether function as a stretched out "I-beam" (see Figure C2) and leads to an advantageous distribution of stresses [58, 59].

Figure C2. Illustration of how the lightweight core works as a prolate stiffener in order to provide the FRP composite panel with a distribution of loads similar to an "I-beam".

The performance of FRP composites exposed to fire varies with the composition of core and laminates, mainly depending on the following three conditions:

- thickness of face sheets – a thinner laminate gives a worse performing composite;
- density of core material – a lighter material gives a negative effect on the performance;
- type of plastic – a polymer with lower softening temperature gives less fire resistance.

A typical composite set-up would be a 50 mm PVC foam core (80 kg/m^3) surrounded by two 1.5 mm glass fibre reinforced polymer laminates (approximately 2,100 kg/m^3). The total weight of such FRP-composite would be ~10.5 kg/m^2. This composite could replace a 7 mm steel plate that weighs 55 kg/m^2. Even if the composite requires additional fire insulation or other safety measures the weight-loss is substantial when using FRP composite instead of steel. The strong and rigid characteristics, in conjunction with the weight-effectiveness, makes FRP composite a cost-effective alternative for maritime load-bearing structures.

The FRP composite panel has a low modulus of elasticity, compared to steel. However, due to the “I-beam” type of construction, the panel becomes very stiff. The stiffness, being an extensive property, depends on the amount of material while, on the other hand, the elastic modulus is an intensive property of the constituent material. It allows the FRP composite structure to deform elastically under high working strains and omits reaction forces at interfaces when the hull girder deforms. The ability to deform without stresses in the hull and superstructure is an advantage that eliminates fatigue cracking in deckhouses and reduces maintenance efforts in an FRP composite structure [60].

Insulating qualities

The hull and superstructure of merchant ships are typically made in steel, even if aluminium is also used to some extent. Constructions in steel or aluminium conduct heat very well and will cause a different fire development in comparison with a fire development in a concrete or wood construction. In a metal construction, heat can be conducted far through a ship construction and secondary fires can occur in the most unexpected places if a fire is long-lasting. A shared experience is that there is great probability for fire spread to adjacent spaces if a fire is not controlled within 20-30 minutes, due to the effects from radiation and conduction of heat in traditional ship constructions [61].

Lightweight constructions already have a market in maritime applications, not only when it comes to leisure boats, but also in high speed crafts (HSC). For this purpose, new regulations and standardized tests have been implemented applying to aluminium and composite structures in high speed crafts, the International Code of Safety for High-Speed Crafts [13], also called the HSC Code. The tests for load-bearing structures are equivalent to the standardized tests for steel constructions except for an additional load-bearing requirement. This requirement implies that lightweight decks and bulkheads need to withstand the standard fire test while subject to transverse and in-plane loading, respectively.

For a division made in FRP composite to pass the HSC Code requirements regarding integrity, strength and heat transfer, a certain amount of insulation needs to be attached to the panel. According to requirements, insulation is generally to be applied on the side of the division with the greatest risk of fire. An “A” class steel division is for example generally allowed with insulation only on one side of the bulkhead. However, in structural fire zones in aluminium constructions, where divisions are to be made in steel or equivalent material, the requirements compel to attach insulation on both sides of the bulkhead. Since the strength in aluminium deteriorates at relatively low temperatures it has been required for aluminium divisions to be insulated on both sides in order to be considered as equivalent to steel in structural fire zones [62]. An FRP composite is a good thermal barrier and has demonstrated ability to contain fire on its own [10, 17, 63, 64]. The arrangement with insulation on one or both sides of the structure may still be useful also for FRP composite constructions. Such composition of FRP composite and insulation makes up a Fire Resisting Division (FRD), which has been subject to tests at SP Technical Research Institute of Sweden (see Figure C3).

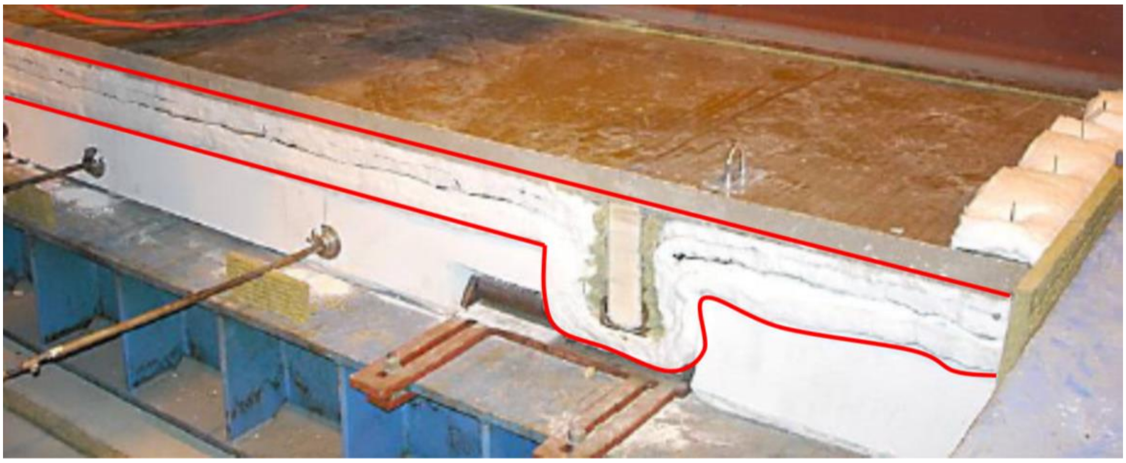


Figure C3. The insulation marked in the picture provides heat integrity to the FRP composite, a composition that makes up a fire resisting division (FRD). An FRD60 deck construction is here tested on top of a large furnace in accordance with MSC.45(65) [14] in the IMO Fire Test Procedures Code [15].

An FRD deck or bulkhead structure must sustain the specified fire load in a large scale furnace for 30 or 60 minutes in order to be certified as an “FRD-30” or “FRD60” division, respectively. This kind of division is not to be confused with the currently used light-weight panels, which have no requirements on structural integrity in SOLAS.

Protecting the composite construction from getting involved in the fire for 60 minutes with thermal insulation implies that the temperature on the exposed side of the FRP composite will be kept low enough for the construction to keep its integrity (typically <140˚C when using a PVC foam). It means that the temperature on the unexposed side of the division will be low (35-40˚C when using a PVC-foam) for the full 60 minute period. Thereby the probability for fire spread to the other side is lowered in comparison with steel divisions.

Below follows a summary of some important properties revealed from tests, which are important for the subsequent analyses of the fire safety in the base design.

Properties revealed from fire tests

Throughout the numerous and detailed tests carried out at SP Technical Research Institute of Sweden on FRP composites, the weak link for structural stability of the construction has appeared to be the core material and its bonding to the face sheets. As long as the core is intact and well adhered to both laminates the structural strength of the material is not affected by heat. Therefore the temperature between the core and the face sheet on the side exposed to fire becomes a critical feature. For a low performing FRP composite, with a relatively thin glass fibre reinforced polyester laminate and a PVC foam core, the joint between the first laminate and the core may begin to soften at about 100˚C if it is a weak FRP composite. When those weak constructions have been tested reached a joint temperature of about 130-140˚C the structural performance could be considered deteriorated as the construction becomes deformable. However, if just a part of the material would be exposed to heat, only that limited area would be subject to deformation since FRP composite, unlike steel, does not conduct heat very well.

Before the temperature of the interface between the exposed laminate and the core becomes critical, the strength of the structure will not be affected. However, when the temperature exceeds that level, the load-bearing capacity of the structure will deteriorate quite fast. It is therefore not necessary to test FRD60 with case specific loading, since its performance in fire tests will not depend on the magnitude of the loading. As explained above, the FRD60 has therefore been tested with a nominal load, analogous to what is prescribed by the IMO for HSC. Its performance in fire will rather depend on the fire development, i.e. the heat production (temperature) and the time of exposure. When exposing a specimen to a fire specified by the standard temperature-time curve the strength of an FRP composite panel will for that reason mainly depend on the time of exposure [2].

In the 60 minute fire test it is critical that the temperature of the FRP laminate-core interface of the fire exposed side stays below the critical temperature in order for the structural performance to be satisfying throughout the test. The temperature on the unexposed side of a FRD60 division will, down to its high insulation capacity, therefore be virtually at room temperature even after 60 minutes of fire. Tests confirmed a temperature on the unexposed side of the division of about 45˚C, which can compare to the average 140˚C or peak 180˚C allowed according to the strictest division requirement in SOLAS. Penetrations and other arrangements, such as windows, doors, ducts, cables and other penetrations, for insulated FRP composite panels have also been tested and certified in accordance with MSC.45(65) [14], as shown in Figure C4 [2].

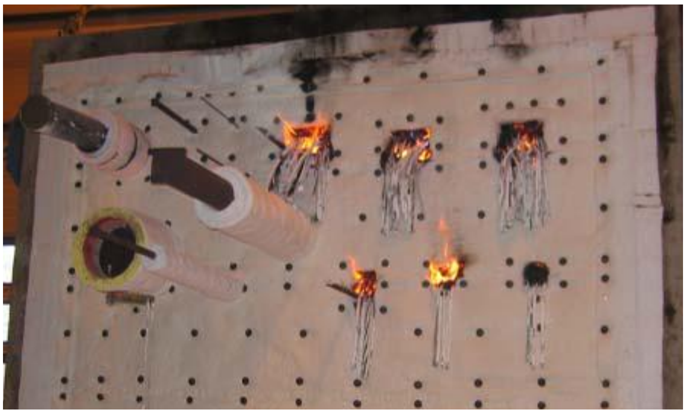


Figure C4. Exposed side of a FRD bulkhead specimen after successful penetration test.

An FRP composite module was tested in full-scale at SP Technical Research in December 2007 [17]. The tests showed that a construction made up by FRD divisions will withstand a fully developed fire for more than 60 minutes without critical damage. A range of tests also investigated different mitigating measures and different fire scenarios.

Uncertainties when using tests to verify constructions

Full-scale testing is the method that typically will give the most accurate results of how a design will perform, even if natural variations always will be present. Since it would be very costly to perform all possible scenarios in full scale tests, some chosen scenarios are often tested from which the safety of the rest of the design is evaluated through knowledge of fire dynamics and an engineering approach. This is basically what the prescriptive requirements of SOLAS are founded upon; tests of steel or equivalent materials make out if the construction is valid as a certain division. Numerous performance tests have been carried out on FRP composite to discern whether the novel concept would be valid for different classes of divisions. Apart from the fact that the material is not equivalent to steel in the sense of being combustible, the tests proved for the materials' advantages.

A comparison through tests can although be considered as a quite obtuse way of evaluating the performance of two such diverse materials. When comparing designs through tests there is always a lowest level for passing the test, an acceptance criterion. Obviously the assurance of identical set-ups and measurements is of greatest significance when tests are carried out by different people and stations in several countries throughout the world. However, even without those uncertainties, a test says nothing concerning the performance not represented in the test, e.g. the function if the load, temperature or time in the test increases by 10, 20 or 50 per cent. In general, the prescriptive fire tests of the Fire Test Procedures Code only give pass or no pass. Therefore no information is given on **how** the construction performed during the test or how long it could have performed with satisfaction.

Testing is a good tool for construction comparisons when the main characteristics of the tested materials are similar and a lowest acceptable level of performance is well defined. However, it would be very hard to construct a test that would engage the many different characteristics of steel and FRP composite in a way that all fire risks are represented. Today's fire tests are constructed to measure some key properties reflecting different disadvantages with steel designs and, ideally, representing the performance of steel when exposed to fire. Some characteristics are left out in the tests because of the implicit benefits with the traditional steel solutions. Implicit advantages with steel structures that are not represented in tests are neither possible to evaluate through the tests. Such a property is its ability to withstand high temperatures before deterioration. It is because of the implicit advantages with steel, not visible in tests, that there is an additional requirement for some divisions to be made in non-combustible material. When aluminium was introduced to merchant shipbuilding another advantage of steel needed to be highlighted, its high-performing load-bearing qualities. Therefore aluminium structures need to pass a load-bearing requirement in order to pass structural tests, see [13]. Even if insulated FRP composite passes the structural tests, there is reason to believe that the tests do not fully reflect the risks and benefits with the construction in case of fire. **Hence, implicit properties beyond the tests need to be identified and evaluated.** The fact that FRP composite is combustible is one of the differences that need to be evaluated with a more elaborated approach.

Identified risk control measures

The following risk control measures have been identified by the design team as potential measures to reduce the risks of the base design, particularly those caused by deviation from prescriptive requirements.

Redundant fire extinguishment system

In order to increase the probability of a functional extinguishment system, a fully redundant fire extinguishment system can be installed. A correctly designed extinguishment system has proven efficiency against enclosure fires and the extinguishment system itself does not cause any human hazards.

With this risk control measure a redundant water spray system or a water mist system complying with IMO-requirements is installed. The extinguishing systems would be installed with one in each hull. There are although alternatives as to if the whole system should be redundant and in what spaces. The alternatives for system redundancy are to either only have redundant supply units for the extinguishing system or to have full redundancy. Supply unit in this case refers to redundant pumps with full capacity, power supply (including power supply independent of main switchboard) and pressure vessels with the capacity to cover a minimum area of 280 m^2 for 1 minute according to the FSS code [51]. One common piping and nozzle system would be fed from the redundant supply units, placed in each pontoon. Full redundancy would include the redundant supply unit plus fully redundant piping and nozzle system, resulting in two completely redundant extinguishment systems in the concerned spaces. Note that the redundant power supply for sprinkler pumps not only provides 100% redundancy for all emergency electrical systems and functions related to habitable conditions but to all systems on board. Furthermore, the engine room was also considered with a gas extinguishing system for redundancy. Depending on the spaces to be protected, this RCM was divided accordingly:

RCM a1: Redundant supply unit for extinguishing system in stairways, accommodation space (including the void space above the ceiling in the accommodation space if extinguishing system is installed there, see RCM b), wheelhouse and toilets.

RCM a2: Fully redundant extinguishing system in stairways, accommodation space (including the void space above the ceiling in the accommodation space if extinguishing system is installed there, see RCM b), wheelhouse and toilets.

RCM a3: Fully redundant extinguishing systems in engine room. The SB extinguishment system will protect the PS engine room and vice versa.

RCM a4: Redundant supply unit for extinguishing system on ro-ro deck.

RCM a5: Fully redundant extinguishing system on ro-ro deck.

RCM a6: Additional gas extinguishing systems in engine rooms.

Water mist in void space above ceiling in accommodation

Since deck 3 does not fulfil sufficient fire resistance in the base design, the purpose for this RCM is to cool the hot gases in the void space above the ceiling in the accommodation space, in case of an accommodation space fire. Furthermore, if a fire would start in the void space this extinguishment system will control or extinguish such a fire.

This RCM is denominated RCM b.

Drencher on external composite surfaces

The ships drencher system used for protection under the overhangs on ro-ro deck is expanded to cover external composite surfaces. The purpose would be to avoid flame spread and structural damages. This RCM is divided into three RCMs and denominated accordingly:

RCM c1: Drencher system covering the outside of the bulkhead separating the accommodation space from the ro-ro deck.

RCM c2: Drencher system covering the whole ro-ro deck.

RCM c3: Drencher system covering the sides and front of the ship from deck 3 and down. To get reasonable dimensions of the drencher system, the external surfaces would be divided into sections.

Extinguishing system on ro-ro deck with pop-up nozzles

One of the most common origins of a fire on a ro-ro vessel is the ro-ro deck, where ignition sources may be hard control and hydro-carbon fuels are present. Swift extinguishment of a potential fire may be managed with an extinguishing system with pop-up nozzles coming up from the deck.

This RCM is denominated RCM d.

Fog nail for use as a fire fighting tool

The fognail (or fogspear) is a piercing nozzle which allows fire fighters to reach fires into confined spaces. From a technical point, the fognails are very simple. It is a kind of piercing metal nozzle with a specially hardened face. In one end there is a shutoff valve connected to a regular fire hose and from the nail tip a fine water mist is created. It offers the possibility to drive the nail with a hammer through divisions or doors to fight enclosure fires from the outside. The small size of the access hole also minimizes additional oxygen supply to the fire and reduces any risk of flashover or backdraft. The aim with the tool was to reduce the risk to fire fighters and to ensure a speedy and effective use. This fire fighting tool could advantageously be used to reach into spaces which are otherwise not easily accessed in case of fire, such as the many void spaces. In the base design these void spaces have unprotected composite surfaces, implying fuel will always be available. However, the available amount of oxygen is quite restricted since there are no openings to the spaces, except for service hatches and minor ventilation openings for pressure equalization. The most relevant positions for this fire fighting tool would be on deck 2.

This RCM is denominated RCM e.

Cutting extinguisher for use as a fire fighting tool

The cutting extinguisher is a fire extinguishing tool which combines abrasive waterjet cutting with water spray extinguishing through a hand-held nozzle. The fire-fighter can approach the fire from outside the fire compartment and then use the cutting action to drill a small hole through a door or wall. Switching to a water spray then allows the fire to be fought, as with a conventional fog nozzle. The main advantages of this system are in increased safety for the fire-fighter, as they may remain outside the most hazardous area. The small size of the access hole also minimizes the additional oxygen supply to the fire and reduces any risk of flashover or backdraft. This fire fighting tool could be relevant on the ship, particularly to reach spaces in order to reach into spaces which are otherwise not easily accessed for fire fighting, mainly found on deck 1 and deck 1.5.

This RCM is denominated RCM f.

Smoke detectors in void spaces

With this RCM the fire detection system is expanded to cover the void spaces. If a fire starts in a void space there is typically a significant amount of available fuel provided by the unprotected combustible FRP composite materials. However, oxygen supply is quite limited.

This RCM is denominated RCM g.

Encapsulated electrical equipment

In order to further reduce the probability of ignition in certain spaces, only encapsulated (IP 44 or better) electrical equipment is used. This RCM is divided into three parts, covering different spaces:

RCM h1: Encapsulated electrical equipment in void spaces on deck 1.

RCM h2: Encapsulated electrical equipment in void spaces on deck 1.5.

RCM h3: Encapsulated electrical equipment in auxiliary machinery spaces.

Surfaces of low flame-spread characteristics

With this RCM surfaces in certain spaces will be made to achieve low flame-spread characteristics according to the FTP Code [15]. This will reduce both the probability of ignition as well as the probability and speed of fire growth. Note that this is a safety measure which is in accordance with prescriptive requirement and thus decreases the posed deviations. This RCM is relevant in a few different places and the RCM was therefore divided accordingly:

RCM i1: Surfaces of low flame-spread characteristics in auxiliary machinery spaces.

RCM i2: Surfaces of low flame-spread characteristics in void spaces on deck 1.

RCM i3: Surfaces of low flame-spread characteristics in voids on deck 1.5.

RCM i4: Low flame-spread characteristics on FRP composite surface facing ro-ro deck on bulkhead between ro-ro deck and accommodation space.

RCM i5: Low flame-spread characteristics on all FRP composite surfaces facing ro-ro deck.

RCM i6: Low flame-spread characteristics on all FRP composite surfaces facing open deck space on deck 3.

RCM i7: Low flame-spread characteristics on all FRP composite surfaces above deck 2.

Fire Resisting Material covering FRP composite surfaces

With this RCM surfaces are covered with a panel or liner complying with Fire Restricting Material requirements in the HSC Code. This will affect the fire and smoke development in the initial stages of a fire. In later stages when the fire has reached a certain size, the covered combustible materials may still contribute to the fire. If improved surface materials are deemed necessary it might not be needed in all spaces in the ship. Hence this RCM is divided into seven parts covering different spaces:

RCM j1: FRM in accommodation space.

RCM j2: FRM in toilets.

RCM j3: FRM in stairways.

RCM j4: FRM in auxiliary machinery spaces.

RCM j5: FRM in wheelhouse.

RCM j6: FRM in void spaces.

RCM j7: FRM in cleaning closet.

Improved floor construction

This RCM concerns two areas where non-combustible surfaces could be relevant. In the base design the deck surfaces in the accommodation space and wheelhouse are covered with a 20 mm thick plywood. With this RCM the plywood is replaced with 20 mm thick Rockwool (high density) plates, reducing the amount of combustible material in the accommodation space, covered by a carbon FRP laminate.

This is denominated RCM k.

Non-combustible surfaces on ro-ro deck

This RCM implies making different surfaces on ro-ro deck in non-combustible material. The RCM has therefore been divided in the deck, overhang as well as the bulkhead towards the accommodation space. Making the ro-ro deck surface non-combustible could imply covering the FRP composite with a 5 mm aluminium sheet. Such a surface would not be easily ignited by a small initial fire, e.g. due to a fuel spill. Overhang structures above ro-ro deck are vulnerable and exposed in case of fire. In the base design they are made in FRP composite but this part of the RCM consists in making them in non-combustible material instead (e.g. aluminium or galvanized steel grating). In order to make the outer surface of the bulkhead between ro-ro deck and the accommodation area non-combustible a thin aluminium sheet could be fitted on the surfaces.

RCM l1: Covering the ro-ro deck by a non-combustible surface.

RCM l2: Covering boundary bulkhead towards the accommodation space with a non-combustible surface.

RCM l3: Non-combustible overhangs above ro-ro deck.

Improved FRP composite qualities

This RCM implies adjustments of the FRP composite composition in order to gain better fire resistance in certain exposed places where extra fire resistance is needed to protect from collapse. Primarily substitution of the core material is considered at this stage. The RCM has been divided depending on the concerned spaces and is denominated accordingly.

RCM m1: FRP composite with balsa core in the overhangs above the ro-ro deck.

RCM m2: FRP composite with balsa core in deck 3.

Improved structural fire resistance

The purpose of this RCM is to gain fire integrity as well as structural resistance for the FRP composite divisions on the ship. Particularly those divisions where A-60 requirements apply are relevant for this RCM but also some divisions where A class requirements apply without requirements on thermal insulation. To gain the desired fire protection, thermal insulation is provided sufficiently for the structure to be classified as a FRD-30 or FRD60 . Relevant doors in the concerned space will also be changed to achieve equal protection. The RCM has been divided depending on the concerned spaces accordingly:

RCM n1: Thermal insulation under deck 3 towards the accommodation space and WCs.

RCM n2: Thermal insulation on the accommodation space side of the boundary bulkhead between the accommodation space and the open deck space on deck 3 (in the staircase).

RCM n3: Thermal insulation on the accommodation space side of the boundary bulkhead between accommodation space and ro-ro deck.

RCM n4: Thermal insulation on the ro-ro deck side of the boundary bulkhead between ro-ro deck and accommodation space. Must be considered along with RCM l2 to provide weather protection, also resulting in a non-combustible surface towards ro-ro deck.

RCM n5: Thermal insulation on the accommodation space side of the boundary bulkhead between accommodation space and fore deck.

RCM n6: Thermal insulation on the wheelhouse side of the boundary bulkhead between wheelhouse and open deck space.

RCM n7: Thermal insulation under the overhang above the ro-ro deck. Must be considered along a weather resistant protection.

RCM n8: Thermal insulation on the accommodation space side of the boundary bulkhead between accommodation space and cleaning cabinet.

RCM n9: Thermal insulation on the cleaning cabinet side of the boundary bulkhead between cleaning cabinet and accommodation space.

RCM n10: Thermal insulation on the fuel tank side of the boundary deck between fuel tank and accommodation space.

RCM n11: Thermal insulation encapsulating fuel tanks (made in steel or equivalent material).

RCM n12: Structural redundancy in the boundary bulkhead between accommodation space and ro-ro deck, achieved e.g. by use of a triple laminate sandwich structure, internal stiffeners (to ensure that the inner laminate and the stiffeners have sufficient strength to prevent collapse until the inner laminate reaches critical temperatures) in combination with thermal insulation on the inside or use of internal bulkheads or bulkheads and stiffeners in combination to ensure that the inner laminate supported by the bulkheads and stiffeners have sufficient strength to prevent collapse until the inner laminate reaches critical temperatures (it is assumed that any of these alternatives is used and that the outer laminate and the core are not necessary to prevent collapse).

Additional structural divisions

This RCM is meant to structurally subdivide different spaces in order to prevent fire development and fire spread. In the accommodation space this RCM suggests a FRD60 division is provided as a longitudinal bulkhead, demonstrated by the red line in Figure D1. Doors with automatic (magnetic) closing devices in the front and aft end of the space would be suitable. An alternative subdivision could be provided as a transversal bulkhead, also illustrated in Figure D1. The subdivision would give the passengers an alternative assembly station in case of a fire in the accommodation space and it will also create two alternative embarkation stations if these are moved suitably. The subdivisions could also be made as B-15 divisions.

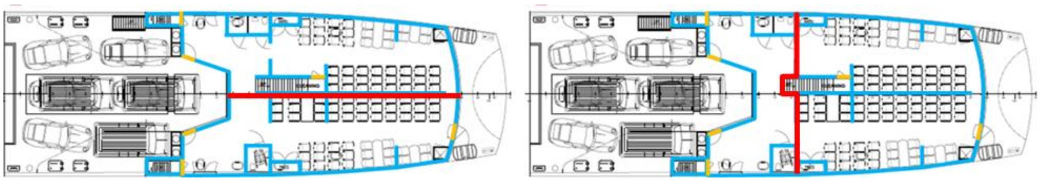


Figure D1. Alternative subdivisions of the accommodation space.

The WCs are prescriptively required to be subdivided by B-0 divisions. This RCM also considers such divisions of the WCs. Reg. 9.2.2.3.3 gives possibility to wholly or partly provide the required integrity and insulation of a division by continuous B class ceiling. This RCM therefore also included to make the ceilings in the accommodation space in at least B-0, which provides structural integrity for 30 minutes (the FRP composite provides sufficient thermal insulation). This RCM also entails division of the largest void spaces so that fire cannot prevail. This RCM has hence been divided according to the concerned spaces, denominated accordingly:

RCM o1: FRD60 division dividing the accommodation space longitudinally.

RCM o2: FRD60 division dividing the accommodation space transversely.

RCM o3: B-15 division dividing the accommodation space longitudinally.

RCM o4: B-15 division dividing the accommodation space transversely.

RCM o5: B class ceilings in the accommodation space.

Door-closing devices

To make sure fire does not spread to or from WCs this RCM suggests to provide door closing devices on WCs.

This is denominated RCM p.

Fire resistant windows

This RCM addresses the risk of fire spread between decks and involves the accommodation space as well as the wheelhouse. The former poses a threat of fire spread to the open deck space and the wheelhouse whilst the wheelhouse itself also could be exposed by a fire on fore deck. The RCM has been divided depending on the concerned spaces and is denominated accordingly.

RCM q1: A-0 windows on the sides of the wheelhouse.

RCM q2: A-0 windows in the wheelhouse.

RCM q3: A-0 windows in the front part of the accommodation space (frame #16 and forward) under the wheelhouse.

RCM q4: A-0 windows in the whole accommodation space.

Alarm on openings to confined spaces

This RCM aims to control whether doors and hatches are open, since oxygen supply may be critical to confined spaces with much combustibles (consisting of unprotected FRP composite surfaces). The door alarm would sound in the wheelhouse and only applies to doors which are normally closed and are not opened due to repair/maintenance. The RCM has been divided depending on the concerned spaces and is denominated accordingly.

RCM r1: Door alarm for WCs. Only considered in combination with RCM p.

RCM r2: Hatch alarm for voids.

RCM r3: Hatch alarm for auxiliary machinery spaces.

RCM r4: Door alarm for engine rooms.

Smoking hazard minimization

This RCM means that smoking will not be allowed on the ship and could also entail a number of measures to make sure that this requirement is followed. The RCM has been divided and denominated accordingly:

RCM t1: Clear no smoking signs provided on ro-ro deck, in the accommodation space, on the open deck space, fore deck and in the wheelhouse.

RCM t2: Rounds for crew in accommodation space and open deck space during voyage and notification on ro-ro deck during embarkation, to make sure no one is smoking.

RCM t3: Information TV screens showing that smoking is not allowed, flammable liquids are not allowed to carry in the accommodation space and about the evacuation procedure.

RCM t4: Spoken information through speakers given before each voyage about smoking restrictions, handling of flammable liquids and evacuation routines.

RCM t5: Only use of trash cans designed so that fire cannot survive.

New routines

This RCM implies new routines for different purposes to improved fire safety. The RCM has been divided in several new routines, which are denominated and further described accordingly:

RCM u1: Maximum 25 passengers on board when oil tank truck is transported.

RCM u2: No passengers on board during bunkering.

RCM u3: Redundant manual extinguishing equipment ready during bunkering.

RCM u4: Manual extinguishing equipment brought down to the auxiliary machinery spaces in case of repair (portable extinguisher or hydrant from above).

Evaluation of prescriptive requirements and associated functional requirements

In the following paragraphs it is discussed whether the general change from steel to FRP composite on the Eco-Island ferry is affected by the fire safety regulations of SOLAS. As illustrated in Figure 3.2, each fire safety regulation consists of a purpose statement and prescriptive requirements. As part of the revised approach, not only fulfilment of prescriptive is investigated but the achievement of purpose statements is also evaluated individually. The purpose statements have been reproduced for each regulation, followed by comments on how achievement of different parts of the regulations are affected. The most important effects are summarized in *3.3. Discussion of affected SOLAS chapter II-2 regulations and their functional requirements*.

Regulation 4 - Probability of ignition

Purpose statement:

The purpose of this regulation is to prevent the ignition of combustible materials or flammable liquids. For this purpose, the following functional requirements shall be met:

.1 means shall be provided to control leaks of flammable liquids;

.2 means shall be provided to limit accumulation of flammable vapours;

.3 the ignitability of combustible materials shall be restricted;

.4 ignition sources shall be restricted;

.5 ignition sources shall be separated from combustible materials and flammable liquids; and

.6 the atmosphere in cargo tanks shall be maintained out of the explosive range.

Comments: Using combustible materials in structures is not in conflict with the objective of this regulation. It although states that the regulation aims at preventing the ignition of combustible materials. Looking at the prescriptive requirements they prevent the occurrence of fire by putting restrictions on ignition sources and some combustibles. Mainly fuels and the handling of highly flammable substances are concerned, but also a few miscellaneous items in enclosures. Except a few ignition sources, the only actual combustible material concerned is primary deck coverings. If applied within accommodation, service or control spaces or on cabin balconies, they shall not readily ignite (Reg. 4.4.4). This requirement may seem a bit illogical since a primary deck covering is the first layer fitted on a deck, used to smooth out unevenness, and covered by a floor construction. It is rather the surface of the floor construction which may be exposed to a potential ignition source. Furthermore, the requirement implies the primary deck coverings should be of low flame-spread characteristics, which is a requirement more fitted in Regulation 5. However, except from this requirement there are no other prescriptive requirements found on how the ignitability of combustible materials shall be restricted, as stated amongst the functional requirements in the purpose statement (Reg. 4.1.3). Nevertheless, even if the regulation mainly concerns fuels and the handling of highly flammable substances it may be argued that leaving external combustible surfaces unprotected is not in line with that functional requirement. External surfaces on ships are typically made up of painted steel and the ignitability will therefore likely be worsened. It should although be recognized that FRP composite surfaces are generally not easily ignited. They could very well be included in a fire but a fire is not likely to initiate on a FRP composite surface. Even if the exterior FRP composite surfaces will have less restricted ignitability than painted steel surfaces the functional requirement is therefore considered met and the deficiency is considered to concern fire growth rather than ignitability.

Regulation 5 - Fire growth potential

Purpose statement:

The purpose of this regulation is to limit the fire growth potential in every space of the ship. For this purpose, the following functional requirements shall be met:

.1 means of control for the air supply to the space shall be provided;

.2 means of control for flammable liquids in the space shall be provided; and

.3 the use of combustible materials shall be restricted.

Comments: This regulation oversees materials in spaces with the intention to limit the fire growth potential. In the prescriptive requirements, use of non-combustible and combustible materials is primarily managed in paragraph 3. Except interiors and furnishings the requirements concern linings, grounds, draught stops, ceilings, faces, mouldings, decorations, veneers, insulation materials, partial bulkheads etc. These are also the materials that will govern the growth face of a fire, together with e.g. luggage, furniture and fittings. In general, all surfaces and linings in accommodation and service spaces must fulfil requirements of a maximum calorific value of 45 MJ/m^2, a maximum volume of combustible material and have low flame-spread characteristics according to the FTP code. This is why the accommodation space, stairways and wheelhouse are designed with such surface material. If the FRP composite surfaces would have been left uncovered here it could have been argued that the surface laminate in fact represents the surface of the wall construction, to which the requirements apply. That is also in line with the purpose of this regulation. For other spaces these requirements do not apply, which is the reason why tanks, voids and auxiliary machinery spaces were left without such a protective surface in the base design. However, these uncovered divisions are normally made of non-combustible material. Similarly, constructions with surfaces of low flame-spread characteristics are normally not constructed with a combustible FRP composite just underneath. It has probably not been relevant to stipulate requirements for the bulkhead plate behind a wall construction or insulation since it has been assumed to be made in non-combustible material. Since these fire hazards could affect fire growth and the first stages of a fire (which is covered by this regulation) they must be addressed appropriately. The revised base design includes some relevant additional safety measures. Smoke detectors are placed in the void spaces and redundant supply units for the extinguishing system working in all spaces where the FRP composite simply has a surface of low flame-spread characteristics. New routines apply to the auxiliary machinery spaces which together with void spaces only include encapsulated electrical equipment. Nevertheless, particularly the auxiliary machinery spaces have been identified to may need further attention. The presented RCOs are meant to address these hazards further.

In the engine room, where most fires occur [23], the FRP composite will be protected from fire for 60 minutes by usage of insulation, forming a so called fire resistant division in its boundaries to adjacent spaces. This means that the FRP composite will not add to the fire growth potential of the space within the first hour of fully developed fire. Since the purpose of the regulation is to limit fire **in** spaces, and the FRD60 construction in no way will increase the fire load in the spaces until the fire is allowed to spread to adjacent spaces after 60 minutes, compliance could be connoted in this regard for this space. Since most fires occur in the engine room the revised base design includes redundant supply units for the extinguishing system.

Even if all prescriptive requirements of regulation 5 considering enclosures could be argued complied with, the design in FRP composite will still have implications for the fire growth potential. Looking at the functional requirements, neither of the first two is affected by use of FRP composite in ship constructions. The third regulation functional requirement (Reg. 5.1.3) could although be claimed challenged as it states that the use of combustible materials shall be restricted. The definition of a non-combustible material is given in SOLAS II-2/3.33 and describes it as a material that neither burns nor gives off flammable vapours when heated to 750°C. Vinyl ester, which is used as resin on the Eco-Island-Ferry, will give rise to pyrolysis gases when heated above 500°C and it could therefore be argued that the amount of combustible material is increased when changing from steel to FRP composite. However, the focus of the regulation is *in spaces*, as stated in the regulation objective. This basically implies everything visible in a space and which could take part in the first stages of a fire; not the material in structures behind a wall construction. However, if open deck is considered a space, the unprotected combustible external surfaces could give reason to assert deviation from the regulation functional requirement. The most hazardous of the exterior surface has therefore been protected in the revised base design; the ro-ro deck has been covered by a non-combustible surface.

Furthermore, when scrutinizing Regulations 5 and 6 it is important to realize that "smoke production" and "smoke generation potential and toxicity" imply different things. They have to do with the quantity and the quality of the smoke. The former is mainly covered in Regulation 5 (fire growth potential) whilst the latter mainly has to do with the individual material characteristics, covered by Regulation 6. One could say that Regulation 5 manages so that an unrestricted amount of kilos of combustible materials do not catch on fire and Regulation 6 manages the potential of each kilo that can be involved in a fire. Hence, a consequence of affecting Regulation 5 (fire growth potential) is increased smoke production. Intrinsically this consequence of affecting the fire growth potential is not as relevant of a problem in external areas where smoke management is not critical.

Concluding, surfaces that have to be taken into concern are primarily the external FRP composite surfaces (due to the risk of fire spread) and surfaces in spaces such as voids and the auxiliary machinery spaces. However, none of these areas will be high risk zones as they are not commonly occupied by persons nor contain a high potential of ignition sources. Combining redundant extinguishing system with combustible material just underneath the surfaces of low-flame spread characteristics must be further evaluated.

Regulation 6 - Smoke generation potential and toxicity

Purpose statement:

The purpose of this regulation is to reduce the hazard to life from smoke and toxic products generated during a fire in spaces where persons normally work or live. For this purpose, the quantity of smoke and toxic products released from combustible materials, including surface finishes, during fire shall be limited.

Comments: Similar to Regulation 5, the scope of Regulation 6 is also enclosures and the first stages of a fire, which is primarily when people could be exposed to toxic smoke. Thereafter, radiation and heat will pose greater threats in a fire compartment, even if the conditions have been inhabitable for long. All materials involved in a fire will contribute to the production of toxic smoke but during the first stages of a fire it is mainly the exposed surface that will contribute to the generation and toxicity of smoke. This regulation therefore generally controls exposed surface finishes (once again with the exception of primary deck coverings which are also required not to give rise to smoke or toxic or explosive hazards at elevated temperatures).

In order to reduce the hazard to life, only approved linings, floors, surface materials etc. are used in the base design. However, in the spaces where the FRP composite is left unprotected, Regulation 6.2.1 may be claimed challenged. Even if this regulation only applies to surface finishes it may be argued that a non-combustible material is implied underneath. The generation and toxicity of smoke may therefore not be limited to the same extent as in a prescriptive design in these spaces. Reflecting in what spaces such deviation would be relevant, fires on open deck and involving exterior surfaces in FRP composite could affect the smoke generation and toxicity. This is although not considered a problem (compared to the actual fire spread) since smoke management is not necessary. Furthermore, the aim of the regulation is spaces where people work or live, which excludes void spaces. The only spaces left without such a surface are the steering gear and the bow thruster spaces, if those are considered as spaces where people work.

In the engine room thermal insulation will be used in internal divisions to protect the combustible FRP composite surfaces from becoming involved in a fire. For the time that the construction is thermally protected, the FRP composite will not add to the generation or toxicity of the produced smoke.

Yet, even if all the prescriptive requirements would be complied with and the aim of the regulation is the first stages of a fire in spaces where people normally work or live, the production of smoke and toxic products may not be limited to the extent as in a prescriptive design in case of a long lasting fire. In the event of a fire lasting long enough to involve the FRP composite divisions, increased generation and toxicity of smoke could be argued to occur, in comparison with a steel ship. This will depend on the selection of plastic materials, where for instance PVC is known to release highly toxic HCl during combustion. However, comparing the amount of produced HCl from a PVC cored FRP composite deck when involved in a fire with the fire products from standard issue interior and luggage in a cabin, based on large scale cabin fire tests carried out by SP [17], the FRP composite deck was shown to produce HCl in the region of 14% of what was produced by the cabin with approved materials. If the fire growth is equal, the smoke generation and toxicity from a fire may hence not be significantly affected.

Regulation 7 - Detection and alarm

Purpose statement:

The purpose of this regulation is to detect a fire in the space of origin and to provide for alarm for safe escape and fire-fighting activity. For this purpose, the following functional requirements shall be met:

.1 fixed fire detection and fire alarm system installations shall be suitable for the nature of the space, fire growth potential and potential generation of smoke and gases;

.2 manually operated call points shall be placed effectively to ensure a readily accessible means of notification; and

.3 fire patrols shall provide an effective means of detecting and locating fires and alerting the navigation bridge and fire teams.

Comments: This regulation is not further discussed as it is fully complied with.

Regulation 8 - Control of smoke spread

Purpose statement:

The purpose of this regulation is to control the spread of smoke in order to minimize the hazard from smoke. For this purpose, means for controlling smoke in atriums, control stations, machinery spaces and concealed spaces shall be provided.

Comments: This regulation is not further discussed as it is fully complied with.

Regulation 9 - Containment of fire

Purpose statement:

The purpose of this regulation is to contain the fire in the space of origin. For this purpose the following requirements shall be met:

.1 the ship shall be divided by thermal and structural boundaries;

.2 thermal insulation boundaries shall have due regard to the fire risk of the space and adjacent spaces; and

.3 the fire integrity of the division shall be maintained at openings and penetrations.

Comments: This regulation prescribes main vertical and horizontal zones and, where necessary, internal bulkheads to be made up by A class divisions. Requirements on fire integrity of internal decks and bulkheads between different categories of spaces of the ship are given in table 9.1 and 9.2 in SOLAS II-2/9. A class division means that steel or equivalent material should be used (except insulation). Reg. 3.43 defines steel or equivalent material as a non-combustible material which, by itself or down to insulation provided, has structural and integrity properties equivalent to those of steel at the end of the standard fire test. Note that there are requirements regarding non-combustibility as well as regarding structural and integrity properties but that the latter are time limited and should be achieved until the end of the one-hour standard fire test. An aluminium alloy with appropriate insulation is used to exemplify an equivalent material. Generally doors, pipes, windows etc. are also required to be made in metal when penetrating A-class division as a result of the above definition.

FRP composite ignites when exposed to fire and must be combined with thermal insulation in order to gain sufficient fire integrity corresponding to A class standard. Tests carried out by SP have demonstrated that the temperature rise at the unexposed side of a FRD60 will be as low as about 45°C after 60 minutes of fire exposure (temperature rise and integrity test in accordance with the standard test for bulkheads and decks, MSC.45(65) [15]). This low conduction of heat will prevent heat from being transferred long distances through the ship structure [7]. However, the low conductivity of an FRD60 division can also give rise to a faster fire development within the enclosed space. If sufficient oxygen is available when the insulation (after 60 minutes) or any protective surface layer is deteriorated, the FRP composite will contribute to the fire and could accelerate the fire development. To fulfil the A class requirement some of the FRP composite divisions and penetrations have been fitted with 60 minutes of protective thermal insulation. Some FRP composite divisions in the base design are although not insulated even though such requirements apply (see *2.2.4.2. Passive fire protection*) according to tables 9.1 and 9.2 in SOLAS II-2/9. For example most boundary bulkheads facing the ro-ro deck need to be insulated to A-60 class standard according to Reg. 9.6.6.1, which is not fulfilled by the base design (the same requirement is found in Reg. 20, where it is further commented). The ro-ro deck has although been covered by a non-combustible surface plate. The fore deck needs to be protected from a fire in the accommodation space by A-60 and therefore FRD60 is used here. It although does not protect the accommodation space from a fire on the fore deck (which an A-60 division would). FRD60 is also found between open deck and the accommodation space and the wheel house, even though only A-0 requirements apply here.

In case of an engine room fire, the base design achieves equal structural properties to A-60 and the added thermal insulation in divisions and penetrations makes it exceed the requirements on integrity by all means. Especially where only A-0 divisions are required and there is no obligation to insulate divisions or to use fire rated penetrations. Thanks to improved thermal insulation, the engine room in the base design will contain a fire in its origin better than the reference design. However, it is a deviation that the divisions surrounding the engine room are only protective one way, i.e. the division doesn't function equally if a fire starts in the surrounding compartments. Furthermore, even if structural and integrity properties in divisions are achieved by thermal insulation, using combustible FRP composite in A divisions and penetrations pose deviations since the material is combustible.

In addition, Reg. 9.7 further describes that ventilation ducts have to be of non-combustible material. As the ducts in the base design are made of FRP composite, this prescriptive requirement is also deviated. There is also a requirement to protect the spaces with fuel tanks with A-60 divisions which was not achieved. The actual tanks occupy approximately one third of the spaces. The spaces with tanks could have been fitted with insulation on the inside. However, that would not better protect the tanks from involvement in a fire in the accommodation space, which is the reason to the A-60 requirement.

Regulation 10 - Fire fighting

Purpose statement:

The purpose of this regulation is to suppress and swiftly extinguish fire in the space of origin. For this purpose the following requirements shall be met:

.1 fixed fire-extinguishing systems shall be installed, having due regard to the fire growth potential of the spaces; and

.2 fire-extinguishing appliances shall be readily available.

Comments: This regulation presents requirements on the active extinguishing systems and other fire extinguishing equipment. The fire extinguishing systems and equipment on a ship with constructions in FRP composite will not be affected directly. However, the first functional requirement states that the fixed fire extinguishing systems shall have due regard to the growth potential of the space. If the fire growth potential differs this needs to be taken into account in the design of the fire extinguishing systems. In the void spaces, where the ignition sources and the oxygen supply are very limited, safety has simply been enhanced by installing smoke detectors. Furthermore, only encapsulated electrical equipment will be used, which is also the case in auxiliary machinery spaces. New routines also apply to the auxiliary machinery spaces but these may need further attention to provide sufficient safety. In all spaces where the FRP composite simply has a surface of low flame-spread characteristics, the extinguishing system redundancy has been improved by additional supply units.

Additional routines and tools for fire fighting are included in the base design. Hence, fire extinguishing systems and appliances should be readily available regardless of the construction material of the ship. In order to manage potential fire spread, hazardous external surfaces could also be protected by drenchers covering the exterior bulkheads from deck 3 and down. Thereby fire spread to other decks via the exteriors (due to e.g. an open or broken window) is prevented.

Regarding prescriptive requirements, Reg. 10.2.1.4.1 states that piping penetrating machinery spaces should be enclosed by a steel casing or insulated to A-60 class standard. All piping penetrating machinery spaces are of such or FRD60 standard. FRP piping could be relevant also in the rest of the ship. Reg. 10.2.1.1 requires not to use piping material which is readily rendered ineffective by heat unless adequately protected. Hence it seems acceptable to have piping in FRP if fitting sufficient insulation.

Even though this regulation only covers fire extinguishing systems and appliances, it may be necessary to consider effects on the fire fighting routines. There are several factors that speak for an improved fire-fighting effectiveness on board a ship with FRP composite constructions when comparing to a prescriptive steel ship. First and foremost, removing the need to perform defensive boundary cooling will free fire-fighting resources that can be rerouted to either assist in actively combating the fire or adopting a defensive or offensive strategy involving cooling of hot gases from an adjacent compartment. Boundary cooling is a strategy that requires resources without actually fighting the fire but mainly hinders fire spread. A much more efficient way to fight an enclosure fire is to quickly get water in to the fire origin, which may although not be possible due to the heat or risk of fire spread if a door is opened. Combining the relieved fire-fighting resources on a ship with FRP composite use of a fog nail will allow dampening the fire from outside of the fire origin. Furthermore, it is even more important to quickly extinguish a fire in a FRP composite construction since several fire tests have shown that a fire that has been quite severe for some time and has taken root in the FRP composite will be more difficult to fully extinguish than a prescriptive design. This implies more resources may be needed for keeping watch over fire scorched areas to ensure flames do not reignite. However, this will likely not significantly interfere with the critical stages of taking control of the fire. Another aspect of how fire fighting routines could be affected is that the improved thermal resistance of FRP composite structures could imply difficulties in finding the seat of the fire from adjacent compartments with a commonly used thermal imaging camera. All in all the ability to focus more resources on actively fighting the fire, combined with the introduction of tools to cool hot fire gases from an adjacent compartment are expected to improve the efficiency and effectiveness of fire-fighting efforts in ships with FRP composite constructions. In any case, effects on fire-fighting routines need to be taken into consideration when making ship constructions in FRP composite.

Regulation 11 - Structural integrity

Purpose statement:

The purpose of this regulation is to maintain structural integrity of the ship, preventing partial or whole collapse of the ship structures due to strength deterioration by heat. For this purpose, the materials used in the ships' shall ensure that the structural integrity is not degraded due to fire.

Comments:

This regulation intends to ensure that structural integrity is maintained in case of fire. After the purpose statement of the regulation follows a foundational requirement for this regulation (SOLAS II-2/11.2):

> "The hull, superstructures, structural bulkheads, decks and deckhouses shall be constructed of steel or other equivalent material. For the purpose of applying the definition of steel or other equivalent material as given in regulation 3.43, the 'applicable fire exposure' shall be according to the integrity and insulation standards given in tables 9.1 to 9.4. For example, where divisions such as decks or sides and ends of deckhouses are permitted to have 'B-0' fire integrity, the 'applicable fire exposure' shall be half an hour."

Structures shall thus be constructed in steel or other equivalent material, i.e. any non-combustible material which, by itself or due to insulation provided, has structural and integrity properties equivalent to steel at the end of the standard fire test (MSC.45(65)). This prescriptive requirement cannot be complied with, as FRP composite per definition is not a non-combustible material. The structural and integrity properties equivalent to steel may although be achieved at the end of the applicable exposure to the standard fire test if the FRP composite is sufficiently insulated. However, unlike the requirements on structural and integrity properties, the requirement for non-combustibility is not time-limited.

All materials lose their structural strength when exposed to a large fire. Generally steel loses its structural strength at about 400-600°C and suffers from deformation problems. Still, steel ships have proved to be able to survive fire for several days without progressive structural collapse occurring. The reason to steel losing structural integrity is due to heat transfer, which gives potential for fire spread to adjacent compartments. For FRP composite it is different. It loses structural integrity due to strength deterioration when bonding is lost between the core and the exposed laminate. There are hence different reasons to use thermal insulation for FRP composite, aluminium and steel divisions.

The structural integrity in case of fire should not be worse in a construction with FRD60 divisions compared to one with A-60 divisions during the first 60 minutes. They all pass the 60 minute standard test for A-60 bulkheads and decks according to MSC.45(65) [15]. However, in some cases in the base design FRD60 is used instead of A-0, which has no restrictions regarding the temperature rise at the unexposed side, only to achieve fire integrity for 60 minutes. Using FRD60 here will hence improve safety. There are also cases where unprotected FRP composite is used instead of FRD60, which evidently is a decline in passive fire protection. This hazard has been addressed partly by redundancy in the sprinkler system. Good structural behaviour of unprotected FRP composite in fires has also been documented in several tests by SP Technical Research Institute of Sweden and e.g. [10, 11]. Yet, the fact that FRP composite constructions are combustible may not be overlooked, both for unprotected and protected divisions. A prolonged fire could involve and deteriorate a FRP composite structure when the thermal insulation is no longer enough. A worst-case scenario fire could bring about a local collapse when the FRP laminates detach from the core. Such a scenario was although documented in a full scale cabin fire test carried out at SP Technical Research Institute of Sweden. Even if local delamination occurred in the composite due to high temperatures, collapse did not occur [17].

Regulation 12 - Notification of crew and passengers

Purpose statement:

The purpose of this regulation is to notify crew and passengers of a fire for safe evacuation. For this purpose, a general emergency alarm system and a public address system shall be provided.

Comments: This regulation is not further discussed as it is fully complied with.

Regulation 13 - Means of escape

Purpose statement:

The purpose of this regulation is to provide means of escape so that persons on board can safely and swiftly escape to the lifeboat and liferaft embarkation deck. For this purpose, the following functional requirements shall be met:

.1 safe escape routes shall be provided;

.2 escape routes shall be maintained in a safe condition, clear of obstacles; and

.3 additional aids for escape shall be provided as necessary to ensure accessibility, clear marking, and adequate design for emergency situations.

Comments: This regulation aims to provide means for persons to safely and swiftly escape a fire, assemble and proceed to their evacuation station (embarkation deck). In order to achieve safe escape routes Regulation 13 requires fire integrity and insulation in several places, referring to values in SOLAS II-2/9 (tables 9.1 to 9.4). It may be argued that steel is therefore implicitly required. However, it is only referred to fire integrity and insulation values and not to the class of the divisions. Hence, the requirement on non-combustible construction material does not apply and a sufficiently insulated FRP composite division could be claimed to achieve the requirements of this regulation.

Looking at the prescriptive requirements in more detail, Regulation 13.3.1.3 requires all stairways in accommodation spaces, service spaces and control stations to be of steel frame construction or other equivalent material sanctioned by the Administration. The same applies to stairways and ladders in machinery spaces (Reg.13.4.1). Such constructions are not within the scope of the FRP composite design of the Eco-Island ferry and the regulations are thus fulfilled. The steering gear room only has one escape route, which is although acceptable since the maximum distance to the door, in this case a hatch, is less than 5 meters (see Regulation 13.4.2.3). Safe escape from the engine room is provided via a ladder in a protected enclosure in combination with a regular stairway (an alternative measure according to SOLAS but required by the national regulations of Sweden [65]), both found behind A-60 doors. Furthermore, from SOLAS III it is apparent that two alternative evacuation stations must be provided. This was not fulfilled when the base design originally consisted of only one large evacuation station, i.e. the accommodation space. In the revised base design an additional FRD60 division is used to divide the accommodation space longitudinally in order to achieve evacuation station redundancy (unless there is a fire in the other evacuation station, which leaves only one choice). Furthermore, the life rafts on foredeck must be protected from a fire in the accommodation space, which is achieved by the FRD60 division against the foredeck.

Regarding deviations, the requirements in Regulation 13.5.1 imply that the escape routes from ro-ro deck must be thermally protected from fire on the decks below; in this case by A-0 divisions against the void spaces and by A-60 divisions against the steering gear and the engine room. The separations against steering gear does not fulfil these requirements, which although the void spaces and engine rooms do (not considering any requirement on non-combustibility).

In addition, from the discussion on critical temperature for softening of the FRP laminate-core interface, it is clear that the temperature on the unexposed side of an FRD60 construction will, down to the high insulation capacity, be virtually at room temperature even after 60 minutes of fire. The heat from a fire will therefore to a larger extent stay in the fire enclosure and not easily be transmitted to adjacent spaces. Down to the improved thermal insulation, the decks, bulkheads and ambience in adjacent spaces will be of ambient temperature, which could be advantageous in an escape situation and could increase the probability of a successful escape. More crew could also help with the evacuation since there is no need for boundary cooling and the time available for escape and evacuation could thereby be increased.

Regulation 14 - Operational readiness and maintenance

Purpose statement:

The purpose of this regulation is to maintain and monitor the effectiveness of the fire safety measures the ship is provided with. For this purpose the following functional requirements shall be met:

.1 fire protection systems and fire-fighting systems and appliances shall be maintained ready for use; and

.2 fire protection systems and fire-fighting systems and appliances shall be properly tested and inspected.

Comments: The functional requirements are not affected by changing the structural material from steel to FRP composite. Inspection should also include detection of holes or openings in the FRD60 divisions that could affect fire resistance.

Regulation 15 - Instructions, on-board training and drills

Purpose statement:

The purpose of this regulation is to mitigate the consequences of fire by means of proper instructions for training and drills of persons on board in correct procedures under emergency conditions. For this purpose, the crew shall have the necessary knowledge and skills to handle fire emergency cases, including passenger care.

Comments: This regulation is not further discussed as it is fully complied with.

Regulation 16 - Operations

Purpose statement:

The purpose of this regulation is to provide information and instructions for proper ship and cargo handling operations in relation to fire safety. For this purpose, the following functional requirements shall be met:

.1 fire safety operational booklets shall be provided on board; and

.2 flammable vapour releases from cargo tank venting shall be controlled.

Comments: This regulation is not further discussed as it is fully complied with.

Regulation 18 - Helicopter facilities

Purpose statement:

The purpose of this regulation is to provide additional measures in order to address the fire safety objectives of this chapter for ships fitted with special facilities for helicopters. For this purpose, the following functional requirements shall be met:

.1 helideck structure shall be adequate to protect the ship from the fire hazards associated with helicopter operations;

.2 fire-fighting appliances shall be provided to adequately protect the ship from the fire hazards associated with helicopter operations;

.3 refuelling and hangar facilities and operations shall provide the necessary measures to protect the ship from the fire hazards associated with helicopter operations; and

.4 operation manuals and training shall be provided.

Comments: This regulation is not commented as it is not relevant for the reference object.

Regulation 19 - Carriage of dangerous goods

Purpose statement:

The purpose of this regulation is to provide additional safety measures in order to address the fire safety objectives of this chapter for ships carrying dangerous goods. For this purpose, the following functional requirements shall be met:

.1 fire protection systems shall be provided to protect the ship from the added fire hazards associated with carriage of dangerous goods;

.2 dangerous goods shall be adequately separated from ignition sources; and

.3 appropriate personnel protective equipment shall be provided for the hazards associated with the carriage of dangerous goods.

Comments: Our reference ship is designed to carry both ordinary passenger cars as well as trucks, e.g. garbage trucks and trucks loaded with oil for domestic heating. Garbage trucks will most likely not fall into any category for dangerous goods but heating oil could fall into class 3, flammable liquids, according to the International Maritime Dangerous Goods Code list [66]. Regulation 19 therefore needs to be kept in mind in the Regulation 17 assessment. However, none of the requirements are affected by the change from a steel to FRP composite in the ship structures.

Regulation 20 - Protection of vehicle, special category and ro-ro spaces

Purpose statement:

The purpose of this regulation is to provide additional safety measures in order to address the fire safety objectives of this chapter for ships fitted with vehicle, special category and ro-ro spaces. For this purpose, the following functional requirements shall be met:

.1 fire protection systems shall be provided to adequately protect the ship from the fire hazards associated with vehicle, special category and ro-ro spaces;

.2 ignition sources shall be separated from vehicle, special category and ro-ro spaces; and

.3 vehicle, special category and ro-ro spaces shall be adequately ventilated.

Comments: This regulation describes requirements for ventilation, alarm and detection systems, fire extinguishing equipment and structural requirements for spaces with vehicles. In Regulation 20.5 it is stated that in passenger ships carrying more than 36 passengers, the boundary bulkheads and decks of a vehicle space must achieve A-60. The structural fire protection can although be reduced to A-0 where the adjacent spaces are of category 5, 9 or 10, i.e. against steering gear and void spaces. Except from not fulfilling A class standard the base design does not achieve A-60 towards the engine room, the accommodation space and the overhang (the open deck space above parts of the ro-ro deck). In order to address the risk of fire spread to surrounding spaces the deck has although been covered by a non-combustible plate in the base design.

The fixed detection and alarm systems on ro-ro deck will be according to prescriptive requirements. The ship will furthermore be designed with an approved fixed water-spraying system and an appropriate drainage system due to risks associated with dangerous goods on the ro-ro deck. As on a steel ship, the vehicle deck will be equipped with fire extinguishers, water-fog applicators and portable foam applicator according to prescriptive requirements.

Regulation 21 - Casualty threshold, safe return to port and safe areas

Purpose statement:

The purpose of this regulation is to establish design criteria for a ship´s safe return to port under its own propulsion after casualty that does not exceed the casualty threshold stipulated in paragraph 3 and also provides functional requirements and performance standards for safe areas.

Comments: Passenger ships constructed on or after 1 July 2010 having a length of 120 m or above or having three or more main vertical zones shall comply with this regulation. As our reference ship is less than 120 meters this regulation can be overlooked.

Regulation 22 - Design criteria for systems to remain operational after a fire casualty

Purpose statement:

The purpose of this regulation is to provide design criteria for systems required to remain operational for supporting the orderly evacuation and abandonment of a ship, if the casualty threshold, as defined in regulation 21.3 is exceeded.

Comments: Passenger ships constructed on or after 1 July 2010 having a length of 120 m or above or having three or more main vertical zones shall comply with this regulation. As our reference ship is less than 120 meters this regulation can be overlooked.

Regulation 23 - Safety centre on passenger ships

Purpose statement:

The purpose of this regulation is to provide a space to assist with the management of emergency situations.

Comments: Passenger ships constructed on or after 1 July 2010 shall have a safety centre on board complying with the requirements of this regulation. The Eco-Island-Ferry will contain a safety centre wherefrom all fire safety systems are available, such as ventilation systems, alarm systems, fire detection and alarm system, fire and emergency pumps etc. However, this is not affected by the new construction material.

Additional regulation and fire safety evaluations

The individual regulations were analysed above. The fire safety objectives and functional requirements are although not fully embodied in the regulations. Therefore, in order to attain the full extent of the fire safety chapter, the change from steel to FRP composite was judged to need further evaluation [7, 8]. Based on the weaknesses in regulations and the novelty and scope of the ship design, effects on fire safety were identified through the following additional components:

- evaluation of how fulfilment of fire safety objectives and functional requirements are affected;
- evaluation of how the fire safety structure is affected;
- evaluation of how the fire safety properties are affected; and
- evaluation of how a fire development is affected.

The above evaluations may not be necessary as FRP composite in shipbuilding gains more field history and for smaller scopes of FRP composite designs and deviations. Descriptions of the evaluations and their results are presented below.

Fire safety objectives and functional requirements

The fire safety objectives and functional requirements in SOLAS II-2/2 highlight the purpose of the whole fire safety chapter in SOLAS. They are thereby the framework for the following regulations, each with its own purpose statement. From Circular 1002 [6] it can be interpreted that only these purpose statements should be used as functional requirements for an alternative design and arrangements. However, since this is unclear and due to the high degree of innovation in the base design, also the fire safety objectives and functional requirements were evaluated.

Many of the fire safety objectives are clearly represented in functional requirements and prescriptive requirements but others are not as evident. The effects on fire safety will therefore be evaluated through a consideration of how the base design challenges the fire safety objectives and functional requirements, respectively. It also needs to be clear if the design changes will affect a few or several of these, since this will influence the needs for verification.

Fire safety objectives

Using FRP composite instead of steel in deck and bulkhead structures will inevitably affect some of the fire safety objectives. Comments concerning each fire safety objective are summarized in Table E1and discussed below.

Table E1. A summary of the fire safety objectives in SOLAS II-2/2.1 and comments on how they are challenged by the base design

The fire safety objectives in SOLAS II-2/2	***Comment on compliance***
.1 prevent the occurrence of fire and explosion;	Generally complied with in the same way as in a prescriptive design.
.2 reduce the risk to life caused by fire;	This objective will be affected, the question is how, which is to be analyzed and verified by the quantitative analysis.
.3 reduce the risk of damage caused by fire to the ship, its cargo and the environment;	On a passenger ship the risk to life is the most significant, even if other values may be of interest to evaluate further.
.4 contain, control and suppress fire and explosion in the compartment of origin; and	Generally the active systems are as required. Many divisions although miss sufficient thermal insulation and are made up by combustible material, which will affect the possibilities to contain and control a fire.
.5 provide adequate and readily accessible means of escape for passengers and crew.	The base design will imply improved conditions for escape within the first 60 minutes.

The use of spaces and its related activities and interiors will be governed by prescriptive requirements. As a result, there will generally not be any differences in the ship designs affecting the first objective. However, it depends on how occurrence of fire is defined, i.e. if it is merely defined as a source of fire or as a fire becoming uncontrolled. The former will not be worse on the Eco-Island-Ferry but the latter may be affected since more fuels are exist and are left unprotected.

The greatest needs for verification tend to appear in the second and third fire safety objectives (see Table E1). These objectives insist on reducing the risk to life, property and environment. Whilst acceptance criteria for risk to property are typically set by shipping companies, criteria for the environment should be set by authorities. A prescribed reduction in risk of damage to the environment is although not clearly presented in the fire safety regulations of SOLAS. Even though the risks to environment and property will definitely be affected by the novel design to some extent, this is outside the scope of this report and is evaluated in a separate life-cycle assessment. The value of hundreds of lives will although always be greater than the cost of a ship or the environmental effects from a ship catastrophe. The greatest risk caused by fire on a passenger ship is therefore the risk of life, which needs to be further evaluated. The second objective does not only mean that passengers and crew should be protected, e.g. by preventing the construction from collapsing during escape. The objective also implies that the construction should be protected from collapse for a certain period after flashover in order to allow for safe fire fighting. There are few requirements on safety for fire fighters (e.g. Reg. 5.2.2.5 and Reg. 8.3.4) but the change from steel to insulated FRP composite will certainly imply some changes which are not represented in prescriptive requirements. This matter therefore needs to be further analysed.

The fourth fire safety objective insists on containing, controlling and suppressing a fire in the space of origin. This objective will generally not be achieved as well by the base design as by a prescriptive design since many divisions lack required thermal insulation and are made up by combustible materials. The base design could, however, also contain improvements which could be beneficial to verify, e.g. from the well-insulated engine room.

The fifth fire safety objective covers escape, which generally is defined as the transportation from a fire to the assembly station, i.e. not to confuse with the evacuation which also includes embarking and launching life safety appliances, or transferring passengers to shore or another ship. Surfaces in some spaces are not of low flame-spread characteristics and some have combustible material (FRP composite) just beneath such protective layer. The escape situation may thereby e.g. be affected by a faster fire growth. It may also be affected by the lack of a second assembly station.

The above effects on the fire safety objectives from implementing FRP composite particularly implies that the safety of human life needs to be verified. Risks to life caused by fire can be evaluated through a risk assessment which will also include some of the other affected fire safety objectives implicitly meant to reduce the risk to life. However, also the effects on property and environment should be assessed, even if left out of the scope of the present study.

Functional requirements

In order to achieve the fire safety objectives set out in Table E1, the functional requirements in Table E2 have been embodied in the regulations of SOLAS II-2. The change from steel to FRP composite will be viewed through the functional requirements in order to identify relevant differences and needs for verification. Comments concerning each functional requirement are summarized in Table E2 and discussed below.

Table E2. A summary of the functional requirements in SOLAS II-2/2.2 and comments on how they are affected by the base design

The functional requirements in SOLAS II-2/2	***Comment on compliance***
.1 division of the ship into main vertical and horizontal zones by thermal and structural boundaries;	The ship is too small to subdivide in such zones but differences in behaviour between FRP composite and steel divisions still need to be established.
.2 separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries;	The effects from separating spaces in the base design by FRP composite divisions need to be established since the divisions are combustible.
.3 restricted use of combustible materials;	Combustible materials will be added but not without restriction and as a general rule not unprotected in spaces occupied by people.
.4 detection of any fire in the zone of origin;	The base design will not affect fulfilment of this requirement.
.5 containment and extinction of any fire in the space of origin;	If using insulation the FRP composite could contain a fire better and thereby promote self-extinguishment. In most cases fire integrity and resistance have although been decreased.
.6 protection of means of escape and access for fire fighting;	The protection of escape routes and access for fire fighting will be affected to some extent.
.7 ready availability of fire-extinguishing appliances; and	The base design will not affect fulfilment of this requirement.
.8 minimization of possibility of ignition of flammable cargo vapour.	The base design will not affect fulfilment of this requirement.

The review of SOLAS II-2/2.2 enlightened some areas that will be affected by a change from steel to FRP composite in the ship structures. The first and the second functional requirements concern the division of a ship and the separation of spaces. Differences in behaviour between boundaries in steel and FRP composite will affect these regulations and are therefore necessary to identify. Regarding the first functional requirement the ship is too small to fall under to corresponding prescriptive requirement in Reg. 9, but there may still be a need for fire zones on the ship, e.g. to provide for safe evacuation. Differences in behaviour between FRP composite and steel divisions need to be established in order to discern the effects on this requirement. When it comes to the second functional requirement, the FRP composite divisions in the base design work as excellent thermal and structural boundaries. However, in case of fire the base design does not achieve this requirement as well as a prescriptive design since the material is combustible and may deteriorate. The effects from separating spaces by FRP composite divisions therefore need to be established.

The third functional requirement makes the usage of combustible materials topical. It invokes an evaluation of the effects from using combustible materials beyond what is permitted in and implied by prescriptive requirements. As a general rule there should not be any unprotected combustible materials added in spaces occupied by people. However, the effects from having external combustible FRP composite surfaces, potentially with some safety measure, need to be verified. The same goes for the effects from having insulated FRP composite in the ship structures.

Functional requirements five and six will be affected in similar ways as the first and second. Depending on the properties of the FRP composite material there will be effects when it comes to containment and extinction of the fire as well as the protection from and access to the fire. If using insulation on the FRP composite panels the improved thermal insulation capacity implies the containment of fire may be affected in a positive way. Except from the ability to contain a fire better and thereby promote self-extinguishment, the base design will not better extinct a fire. In most cases the fire integrity of divisions has although been worsened by decreasing the thermal insulation and fire resistance. The protection of escape routes and access for fire fighting will be affected to some extent. Mainly from making the structures in FRP composite but also since redundant assembly stations are not available. These and the above effects on functional requirements indicate some important needs for verification that ought to be targeted when evaluating the ship design.

Fire safety structure

The analysis in this section utilizes a methodology presented by [67], endorsing an investigation of the goals of different fire safety functions, with consideration to the structure of fire protection as a whole. The goal is to identify the effects on fire safety and the scope of changes in fire protection when implementing a novel design or arrangements. The investigation is a process which begins with a division of the SOLAS II-2 regulations into different fire protection categories. Thereafter follows some relevant theory and an estimation of how a change from steel to FRP composite will affect the fire protection strategy. An interpretation of the changes in the fire protection strategy based on the theory follows subsequently. The result from the investigation is, however, not only the interpretation of the analysis but the whole process giving perspective to the changes.

Different types of fire protection

Depending on the deviations from prescriptive requirements, different parts of the fire protection strategy will be affected. Prescriptive requirements impose a certain design or properties and lead to physical fire protection in the shape of detectors, alarms and sprinkler systems etc. They can also imply restrictions in size, number of people and usage allowed in a compartment. The question is what kind of fire risks a certain requirement was meant to minimize and how? What were the intentions with implementing one or a number of risk control measures [67]?

A synoptic classification of different forms of fire protection was carried out by [68] and implies the following three categories:

- source, i.e. preventing fire;
- exposure, i.e. limiting the development and spread of fire and smoke;
- effect, i.e. preventing and limiting the damage on endpoints.

With this perspective, risk control measures are meant to prevent or limit the occurrence of fire, the spread of fire and smoke or the damage on endpoints (load bearing structures, people on the ship, cargo, environment, neighbouring ships etc.). Each risk control measure can reach one or more of these functions or will give an effect only in conjunction with other measures. A sprinkler system is an example of a system that provides fire protection in more than one way. Except extinguishing the fire and limiting its abilities to spread it can decrease the temperature in the smoke layer, which reduces the thermal effect on load bearing structures [67]. The three categories of fire protection almost represent how SOLAS II-2 is divided into Part B – Prevention of fire and explosion, Part C – Suppression of fire and Part D – Escape. There are, however, some differences. In order to get a better overview of the fire protection strategy in SOLAS II-2 the three categories of fire protection worked as basis for a slightly different division of the regulations:

Source
Regulation 4 - Probability of ignition
Regulation 16 – Operations

Exposure
Regulation 5 - Fire growth potential
Regulation 6 - Smoke generation potential and toxicity
Regulation 7 - Detection and alarm
Regulation 8 - Control of smoke spread
Regulation 9 - Containment of fire
Regulation 10 - Fire fighting
Regulation 14 - Operational readiness and maintenance

Effect
Regulation 11 - Structural integrity
Regulation 12 - Notification of crew and passengers
Regulation 13 - Means of escape
Regulation 15 - Instructions, on-board training and drills

The division is omits Regulation 17 and Part G: Special requirements. From the above division one can tell a certain focus on managing the fire development. This is probably due to the fact that every fire starts small and if it is (1) detected at an early stage, (2) not given the fuel to develop or (3) contained in the space of origin, then there is a great probability it will stay small. To get early control over a fire and limit its potential to grow are two crucial factors to limit the possible consequences of a fire. It is also mainly during this time that people can be present since the risk of inhaling toxic products or getting lost in the smoke while escaping could be hazardous. That is probably the reasons to the focus in SOLAS chapter II-2 on the first stages of a fire.

Multi-purpose complexities

The level of fire safety composed in the prescriptive requirements is based on a network of protection chains made up of numerous risk control measures. A protection chain consists in a number of functions provided by risk control measures (RCM) targeting the source, exposure and effect for a certain endpoint in order to reduce or prevent its risks (see Figure E1).

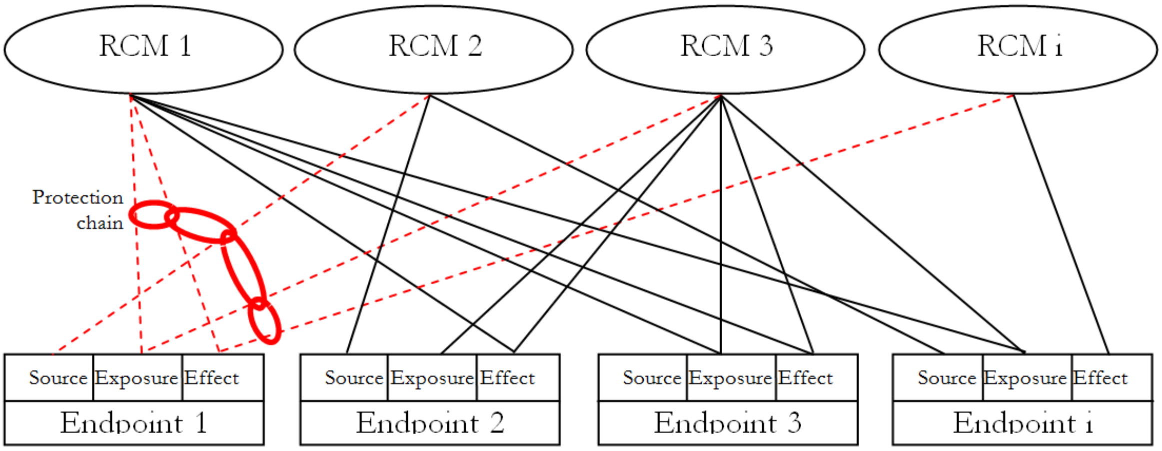


Figure E1. A simplified illustration of how risk control measures (RCM) make up protection chains for a certain endpoint.

The ellipse shaped objects in Figure E1 represent risk control measures (e.g. sprinkler system, fire detector or structural division) and the boxes below symbolize endpoints and different categories of how they can be affected by a fire. RCM 3 could for example be structural divisions, preventing fire spread between compartments. Endpoints 2 and 3 could then represent fire fighting crew and property, respectively, since structural divisions limit the exposure and effect on fire fighting crew and the ship itself. All the RCMs connecting with the protection categories of a certain endpoint make up a protection chain. RCMs can have many targets and the connections with endpoints make up a network of protection chains, representing the fire protection strategy. The strategy can be hard to grasp since many of the risk control measures are integrated, i.e. target more than one endpoint. RCM 2, for example, prevents a certain fire source that implies risks to Endpoint 1, Endpoint 2 and Endpoint i (see Figure E1). If it was to be exchanged with RCM i it would mean that effects would be mitigated for Endpoint 1 and Endpoint i, but not for Endpoint 2. It is therefore important to identify all intended endpoints, and the aspired protection strategy, when a change is on the table.

It is seldom possible to obtain the intended safety level by implementing risk control measures only targeting one of the three fire protection categories. If it was possible to eliminate all fire sources this would definitely be the best way to minimize fire risks. Fire safety on ships is therefore also to a large extent about how to avoid accidents [69]. However, since it is not possible to fully prevent fire, the exposure category needs to be addressed, e.g. by implementing a sprinkler system as an RCM. A sprinkler system will although not put out a fire with 100 % reliability and it is therefore necessary to also target the possible effects from a fire, e.g. by providing means of escape. In the same way as it is unfavourable to focus only on one fire protection category, it is not beneficial to reduce the number of connections targeting a certain fire protection category. It could be tempting to increase the capacity of one risk control measure, e.g. an RCM targeting the effect from fire, in order to eliminate another RCM. That would, however, reduce the redundancy of the system and it is also often more expensive to reach the same level of safety with one measure than with several [67]. Implementing risk control measures targeting several endpoints or fire protection strategies will help increase redundancy and will decrease the sensitivity of a system. Building protection chains with integrated risk control measures will also imply a more efficient use of resources. However, the complexity grows with the increasing number of connections, which makes it hard for a designer to discern the intrinsic safety level of a system. It is although necessary to comprehend the network of protection chains when implementing novel technology in order to advocate the most suitable risk control measures [67].

Matrix describing universal effects

When modifying fire safety arrangements it is important to be aware of how the protection chains in prescriptive requirements will be affected. A matrix was therefore created, based on a division of the regulations in SOLAS II-2 depending on the fire protection category (see Table E3). The matrix will help to identify the protection chains affected by a modification; in the present study a change from steel to FRP composite. It can also be of assistance when taking in the overall effects on fire safety if adapting supplementary arrangements. The matrix is one of the tools employed to assess the effects on fire safety from implementing FRP composite in maritime structures.

Table E3. Matrix describing the overall effects to the fire protection strategy when implementing novel fire safety arrangements, adapted from [67]. The markings symbolize possibly affected functions in the fire protection strategy when exchanging steel (Fe) with FRP composite (FRP)

	Regulation in SOLAS II-2		Change						
			Fe → FRP	Reduction			Supplement		
				R1	R2	R3	S1	S2	S3
Source	4	Probability of ignition	0						
	16	Operations	0						
Exposure	5	Fire growth potential	X						
	6	Smoke generation potential and toxicity	x						
	7	Detection and alarm	0						
	8	Control of smoke spread	0						
	9	Containment of fire	X						
	10	Fire fighting	x						
	14	Operational readiness and maintenance	x						
Effect	11	Structural integrity	X						
	12	Notification of crew and passengers	0						
	13	Means of escape	X						
	15	Instructions, on-board training and drills	0						

A description of how the matrix should be used and interpreted could be useful before the markings are explained. The matrix is meant to help identify and evaluate how different fire safety strategies will be affected when exchanging risk control measures. The functions of the risk control measure intended for removal are marked in the table with minus signs. The same thing is done for the risk control measures planned to be implemented, but the functions are marked with plus signs. By handling each function separately (horizontally) it can be discerned if additional risk control measures need to be supplemented in order to accomplish the same protection. If, for example, the number of minus and plus signs are unbalanced it indicates the protection is more or less centralized (relies on fewer risk control measures). It will affect redundancy and imply an increased need for verification. The same goes for the minus and plus signs in the vertical direction. A balance of minus and plus signs will, however, not imply the same level of safety has been achieved. If the markings are spread vertically it indicates a fire protection function has been replaced by protection of a different category. It means some of the protection chains have been modified which also increases the requirements on verification. If, however, a change implies reduction and supplement only within one fire protection category there could be a possibility that the needs for verification are minor. An evaluation of safety functions is although always necessary [67].

Marking changes in the matrix

In this study the change from steel to FRP composite is to be evaluated in terms of fire safety. It is a quite large exchange of risk control measures but the matrix can reveal some interesting information from even a general use of the matrix. For the purpose of evaluating a design with FRP composite in relation to a steel design, an additional column was added to the matrix. Markings in this column show how functions (regulations) in the fire protection strategy may be affected by a change from steel (Fe) to FRP composite (FRP). Below follow explanations to the markings in the added column.

Section *2.3 Fire safety regulations affecting the base design* made a number of fire safety functions topical. Some of them were Regulations 9, 11 and 13 which are marked with a capital “X” in the matrix, implying the functions will definitely be affected. Regulation 9, placed under “exposure” in the fire protection strategy, is one of the functions which will both positively and negatively affected. The increased thermal insulating capacity in places where FRD60 is used implies less heat will be conducted through divisions than through a steel division. This would delay propagation of fire and better isolate the fire in the space of origin, which is what the regulation is about. Many divisions will although have reduced fire integrity. Regulation 11 and Regulation 13 represent functions placed under “effect” in the fire protection strategy. Local collapse will be more likely to occur in the base design but the insulating capacity could improve conditions in adjacent spaces. Furthermore, there is no secondary assembly station. There will be certain differences in the fire protection strategy but the total effects need to be further establish.

Regulation 5 is also marked with a capital “X” in Table E3. The regulation is placed under “exposure” in the fire protection strategy and, considering the unprotected external surfaces, this function will clearly be affected. The external surfaces will probably be subject to supplementary mitigation efforts, which could be marked in the matrix when established. An outdoor fire would, however, make smoke production less significant (Regulation 6). Leaving out external surfaces there the combustible FRP composite just beneath the surface of low flame-spread characteristics in many places imply a negative change. The smoke production could therefore also be affected, hence the lower-case “x” (representing functions with possibly minor effects due to a change to FRP composite) by Regulation 6. There are although no reasons to believe that smoke spread would behave differently. This and other functions in the fire protection strategy without any relevant effects are marked therefore with “0”.

Regulation 10 and Regulation 14, under ‘exposure’ in the fire protection strategy, have also been denoted with lower-case “x” in the matrix. The reason for this is the need for special training for fire fighting and maintenance in the novel structure. When carrying out work on board, personnel need to know how to renovate with sufficient fire protection afterwards. Strict routines for maintenance and control need to be established in order to avoid exposure of naked FRP composite panels. This issue, on the other hand, needs to be brought up in management systems also for steel. When it comes to fire fighting there will be no need for boundary cooling when fire occurs in compartments with FRP composite boundaries and particularly for FRD60 divisions. This effect could relieve some of the crew to assist with the evacuation instead. Another difference when fighting fires in composite compartments is that it can be carried out without actually entering the fire enclosure. The gear for such operations is considered standard equipment for fire fighting in composite structures. It is obviously more effective for fires in small spaces whilst regular routines are more practicable in larger spaces. Moreover, fire fighters need to further consider the risk of local collapse.

Using the matrix to analyse a change to FRP composite

The markings in the matrix are now to be interpreted. Since the indications are only made to recognize changes, there is obviously nothing to be made out of the horizontal balance of signs. Whether the effects on the marked functions in the fire protection strategy are positive or negative needs to be further analysed which, however, also is a result. When the effects on functions have been made clear, supplementary risk control measures can be implemented to mitigate risks to the relevant functions. Looking at the markings from a vertical point of view there are no indications on effects on ignition sources. The markings are, however, widely spread in the “exposure” and “effect” categories of the fire protection strategy. It indicates many different parts of the strategy will be affected by a change to FRP composite, which increases the needs for verification. Seven out of eleven functions will possibly be affected by the change, meaning many of the protection chains will be modified. This is also a reason for a thorough verification in order to establish all effects on fire safety. When the effects have been recognized and estimated, the matrix can help find suitable supplementary actions.

Using the matrix helps identify and evaluate how different fire safety strategies are affected but it is also important to evaluate the intrinsic effects on fire safety. Can for example an increase in capacity for a risk control measure targeting the effects to an endpoint replace a measure targeting the exposure, or are there other perspectives to consider. This will be evaluated by investigating fire safety properties and how different functions interrelate.

Fire safety properties

When evaluating changes in safety systems it is typically done by comparing the affected functions, e.g. how changes will have an effect on conditions for evacuation. Safety systems can, however, also be described by different properties revealing their overall performance [70]. For example, the distance in escape routes, quality of linings and insulation for load-bearing structures cannot be reduced and complemented only by installing a sprinkler system intended to extinguish a possible fire. The achieved safety will not be the same, e.g. since it is not enough only comparing systems when they are working. Active systems generally have lower reliability than passive systems, which needs to be accounted for when comparing safety [67]. Even if the reliability of a sprinkler system is fairly high and the expected outcome from a system is acceptable, it does not imply the distribution of outcomes is acceptable. The consequences in case a system does not reach the expected function may be catastrophic and might not be accepted by society, which will imply great effects on the market and development of technology.

This section will evaluate how the implicit fire safety in a prescriptive design will be affected by a change to FRP composite in order to establish the needs for verification. It will be done by investigating characteristic properties of a system for fire safety, suggested by [67], and how these will be affected. The effects when changing from steel (Fe) to FRP composite are marked in Table E4 and explained subsequently.

Table E4. Matrix used to get an overview of the effects from a change posed by an alternative design and arrangements. The upper and lower case “x” markings denote significant and minor changes and the plus and minus signs describe if the effect can be discerned positive or negative

Fire safety properties	Change				
	Will the property be affected?				Implications for safety?
	Fe → FRP	S1	S2	S3	Fe → FRP
Human intervention	x				0
Complexity in fire protection strategy	X				-
Fire protection complexity	x				0
Flexibility	x				0
Sensitivity	x				x
Reliability	X				-
Vulnerability	X				-

The markings in the matrix above have the same meanings as in Table E3, except minus and plus signs have also been used to describe if an effect can be discerned positive or negative. The “S” followed by a number represents a possible supplementary measure, the effect of which can be evaluated through the matrix. Below follow further discussions on how each of the fire safety properties are be affected by a change from steel to FRP composite and what the effects imply regarding the needs for verification.

Human intervention

This property does not merely describe human intervention as an organisational measure, i.e. human actions as safeguards. It should rather be seen as an illustration of the human role in technical systems and how systems depend on humans in order to be functional. The impact of human intervention on the safety level is significant but hard to model because of the inherent uncertainties. As mentioned earlier, active systems generally contribute with more uncertainties than passive systems, but human intervention is even less reliable. Human errors are common and often the triggering actions setting off incidents. Therefore it is meaningful to establish if the novel systems for fire safety will be more depending on human intervention than a prescriptive design. A higher degree of influence from human intervention will invoke a more sophisticated verification [67].

A change from steel to FRP composite will imply new routines in order to assure the quality of FRP divisions. There need to be stringent standards for repair, maintenance and control to verify that penetrations are carried out correctly and divisions are refitted with sufficient insulation. This issue will be important in a design with FRP composite in order to prevent fire spread, but it is relevant also on steel ships. Other areas where human intervention plays a great role are in systems for fire safety, where human actions are critical for the consequences of a fire. Manually activated sprinkler systems or general alarms are common key issues as well as decisions for fire-fighting and search and rescue made by crew, based on their perception of the severity of the fire. These decisions will rather depend on the training, experience and personal qualities of the decision-maker than the structural materials. It appears many of the conditions, such as training, experience and routines for work and control, which are the basis for human intervention, could be slightly affected. However, even though this property will be affected by the change, it does not mean the safety of the design will be lower. Human intervention will affect the novel design similar to how it will affect the fire safety of a prescriptive design. New routines and training might even be a stimulating change to the crew. The limited experience of ships with FRP composite might although have a negative influence on human intervention. As a general conclusion, the changes in human intervention are not considered to have any significant effects on fire safety.

Complexity in the fire protection strategy

If it was possible it would be safe and uncomplicated if every single hazard was targeted with its own specific protection. There are, however, great benefits with coordinating risk control measures to target several parts of the fire protection strategy and more than one endpoint, as explained above. Building interdependent protection chains will, however, not only result in a complex network, which can be hard to comprehend, it will also provide conditions for common cause failures (CCFs). When several risk control measures are replaced by one measure, or by many dependant measures, it will cause some protection barriers to fail. An example can be a failure in detection of a fire which will cause late responses in escape, fire fighting and sprinkler activation (if activated manually or as a result of detection). The relationships between systems can also cover dependencies, which can bring about hazardous and incontrollable “snow ball” (exponential) effects when several systems fail at the same time. Increased complexities in the fire protection strategy can get huge consequences if the designer is not aware of the relationships between protection chains. A fire protection strategy with high complexity therefore implies higher demands on verification [67].

A relevant example of how common cause failures can be mitigated is by dividing a construction into fire zones. This is accomplished in SOLAS by prescribing structural main vertical and horizontal zones (see e.g. Regulations 2 and 9). The division into structural fire zones will limit the consequences in case e.g. the sprinkler system fails to work as intended or if the fire fighting crew needs to fall back. A reduction in complexity may e.g. be the result when heat can no longer be conducted far through the structure and bring about fires where there are weaknesses in integrity. This is particularly the case for the engine room. However, even if the engine room is well isolated from the rest of the ship there are no other fire zone divisors in the base design, which could be relevant to target. The combustible surfaces represent another target for risk control measures. Additional mitigating efforts on the necessary to make up for identified deficiencies will inevitably also add to the already complex fire protection strategy. The total effect on complexity in the fire protection system is estimated negative but needs to be further verified.

Fire protection complexity

The function of a technical system for fire protection many times depends on the performance of several components or subsystems. For example, in order to get smoke ventilation to function the smoke needs to be detected, detectors need to be functioning, control systems need to work as intended, the ventilation openings must open and the supply of air needs to function. The same thing applies to sprinkler systems where detectors, sprinkler heads, pipes, control systems, pumps and, not the least, drainage need to be functioning in order to assure the expected function. Building technical systems depending on the function of many components will increase the complexity and inevitably the probability of failure since more sources and combinations for error exist. It is also common for technical systems for fire protection to be integrated with everyday functions, e.g. ventilation and control of doors. The cooperation with other systems will further enlarge the network of systems. It will increase the complexities and also the needs for verification [67].

The least complex fire protection is that of passive structures. They are generally quite independent from other influences even if those occur, e.g. doors, windows and penetrations. The overall change to FRP composite is on this level and will not imply any great increases in complexity. However, they require additional passive or active measures which will somewhat increase the complexity of the whole fire protection system. Care should be taken to design those systems as simple as possible. Other than that, there are no apparent increases in complexity in the fire protection system that will affect safety. The above changes should be taken into account and the effects verified even if changes in complexity are not considered to have any great negative effects on safety if the systems are designed in a smart way.

Flexibility

The possibility for a system to accomplish the expected function in different ways is called flexibility. Systems for fire safety can often achieve objectives by targeting different parts of the fire protection strategy (see Figure E1). If prevention of fire sources fails there will be measures to prevent and limit exposure of fire, and if that fails there are measures to prevent and limit the effects from fire. Combining different independent risk control measures targeting different parts of the fire protection strategy will give the system several possibilities to e.g. control fire. It will make the system flexible, which also characterizes a measure of redundancy. If a change in the fire protection strategy will make a system less flexible it can somewhat be compensated by increasing the reliability, i.e. the probability for a system to obtain the expected function. A lower flexibility will although also increase the needs for verification [67].

Making structures of a ship in FRP composite will imply differences in the approach for fire fighting crew. There is no need for boundary cooling and with new gear the new material allows for fire fighting without entering the fire enclosure, which could be an additional measure for fire protection. Furthermore, if the probability for collapse is greater in the base design it can hinder fire fighting crew from accomplishing their task, which will reduce flexibility. The overall effect on flexibility posed by the base design is although considered minor and will not have any significant effect on safety.

Sensitivity

The sensitivity of a system describes the importance of conditions and assumptions for a system to function as intended. In a system for fire safety there might be conditions and assumptions necessary to make the design for fire protection sufficient. Will achievement depend on the number of people in the compartment, weather conditions, occurrence of fire sources, the activities in the space, if a fire was set off by arson, if a penetration is not properly insulated, on the furnishings or on a certain risk control measure such as the sprinkler system? Factors such as the activity in the compartment, how things are carried out or necessary restrictions will often increase the sensitivity of a system. Restrictions to activities and human behaviour are often hard to control and seldom given enough resources. An increase in sensitivity needs to be taken into account when verifying system safety [67].

When evaluating fire safety in the base design there are some functions of great importance for the design to perform satisfactory. The sprinkler system is one of the most important systems on board and will determine the consequences of a fire. This will, however, be the same in both designs with steel and with FRP composite. In spaces where FRD60 is used a fire will although most likely be better contained in the space of origin. It makes such a design more less dependent on circumstances, such as the performance of fire fighting and sprinkler system. Furthermore, a fire on external surfaces will also be sensitive to the function of its protection, which will imply a difference between the designs. The effects on sensitivity by a change to FRP composite need to be further analysed in order to establish how the safety will be affected.

Reliability

The reliability of a system can be defined as the probability of achieving the intended function of a system. The reliability of a system is generally connected with the probability of errors in the system but can also have to do with its ability to manage working strains. For example, the reliability of a sprinkler system will not only depend on the probability of technical failure but also on how likely it is that the specific fire is manageable. Low reliability naturally implies greater needs for verification and especially requires an evaluation of the consequences if the system fails [67].

The increased probability of a fire on exterior surfaces will inevitably imply a decreased reliability, regardless of the mitigating efforts. Drencher systems generally have high reliability and fire fighting crew can also assist to make the fire protection strategy more flexible and reliable. However, since the surfaces go from being non-combustible to combustible the reliability will be lessened as long as the surfaces are not made non-combustible again. This decrease in reliability can have minor effects on safety but the possible consequences of an uncontrolled external fire need to be analysed in order to verify the safety of the ship with FRP composite. The weakened thermal insulation for interior divisions will also decrease reliability when it comes to containing the fire in the compartment of origin. The reliability will definitely be affected by a change to FRP composite and as for the base design it the effects on safety are judged to be negative. These effects need to be further analysed in the risk assessment.

Vulnerability

Vulnerability is an undesired property which describes the ability of a system to survive internal and external strains. Internal vulnerability refers to the same characteristics as reliability whilst external vulnerability is determined by the probability that a system will function as designed when exposed to external stresses, such as arson, power outs, explosion, weather conditions etc. Some of the qualities characterizing low vulnerability are stability, perseverance and an ability to resist interference [67].

Common sources of vulnerability are activities and circumstances, which e.g. can lead to keeping doors open in some way and for some time. In case of fire it will provide additional oxygen to the fire and obliterate the limitation of smoke and fire spread. The general rule in prescriptive requirements is to provide two escape routes from all spaces in order to increase the reliability of successful escape. In the same way as doors are often kept open, they are also vulnerable to blockage, which will reduce the possibility to escape fire. These vulnerabilities can be reduced by a better understanding of the different functions in the system for fire protection, i.e. through education, training and experience. The above vulnerabilities are although the same in both the base design and prescriptive design. Except what is mentioned above concerning reliability there may be differences in vulnerability when it comes to maintenance and sabotage. Provided thermal insulation or active systems for fire protection may namely also become sources of vulnerability. Another point mentioned above is the external surfaces and how e.g. a drencher system will be a vulnerable component when it comes to extinguishing an external fire. Having only one assembly station is also a major source of vulnerability.

The fact that the novel design in this case implies a change from steel to FRP composite in the whole structure could both make the ship more and less vulnerable, depending on the implemented risk control measures. Some of the properties represented in the sections above are closely related to the vulnerability of a system, which makes it hard to delimit the changes in this property. From the discussions, the general conclusion is although drawn that the vulnerability of the fire protection will be affected and that the overall effects on safety could be negative. This, however, needs to be further investigated throughout the assessment.

Fire development

In the previous analyses, characteristics of the base design have been investigated in order to ascertain the impact of the novel FRP composite structure on fire safety. In this section the above revealed differences are discussed with regards to fire dynamics and based on diverse tests carried out at SP Technical Research Institute of Sweden [2, 17]. This suggests how differences between the structures may affect the fire development from a general point of view. The analysis aims to identify differences for inclusion in the proceeding analysis of fire safety. The first sections consider the internal spaces in different stages of a fire whilst exterior surfaces are discussed separately in the following.

Ignition and the first stages of an enclosure fire

Differences in routines for e.g. maintenance and repair will imply dissimilarities when it comes to fire sources. It is, however, justified to assume neither the probability of ignition nor the first development of enclosure fires will be considerably affected by the new design of load-bearing structures. Ignition sources will for the most part be alike even if they are hard to restrict on passenger ships, especially when including arson as a possible source of fire. The first stages of a fire do not depend on the load-bearing structures but are rather dependable on conditions such as ignition sources, the availability of flammable materials, surface materials of divisions, ventilation openings, fire control installations, etc. for the most part are identical in the two designs. In some spaces there will although be naked FRP composite without a protective surface or insulation. In this case the surfaces may contribute to the fire development at an early stage. Even if ignition is very unlikely there need to be risk control measures implemented to care for detection and extinguishment in those spaces. A fire should at this stage be detected and sprinkler system and other active measures will be set off and general alarms will be activated and evacuation initiated. It implies most fires will be controlled and extinguished in this early stage of fire development. That is before the combustible FRP composite, in the cases it is protected by a surface of low flame-spread characteristics, will take part in the fire. If a fire for some reason is given the possibility to develop, dissimilarities will eventually appear as the fire proceeds.

In spaces protected with FRD60, the conditions are not likely to be worse than in a prescriptive design within the first 60 minutes. The outbreak and the first stage of a fire will be formed by settings within the space, such as possible ignition sources, fire load, ventilation openings, fire suppressing installations, etc. These circumstances will not be affected by the material in divisions and will be assumed identical to the conditions in a prescriptive design. Most likely a fire will be extinguished at an early stage but in case e.g. the sprinkler system fails it might progress into a fully developed fire. If the fire restricting installations fail, the differences with an alternative design can cause a somewhat higher temperature in the fire enclosure because of the increased thermal insulation in the composite construction. On the other hand, for the same reason, conduction of heat and propagation of fire to adjacent spaces would be delayed which improves fire safety. For spaces enclosed by FRD60 the question is rather what will happen after 60 minutes of fire.

Structural divisions within the first 60 minutes

Spaces with unprotected surfaces contain very few ignition sources and limited furnishings and other combustibles (except the fuel tanks). The spaces are also generally closed and of rather small volume. This limits the oxygen available to stimulate fire development if a fire would appear, however unlikely. With a possibility to detect and extinguish fires in those spaces it may be possible to leave the surfaces naked.

Several spaces have surfaces of low flame-spread characteristics but no thermal insulation to protect the FRP composite divisions (which replace A class divisions with 60 minutes fire resistance). Tests have been carried out within the LASS project [2] with FRP composite bulkheads to find out how long they sustain fire exposure without thermal insulation. They showed that 10 minutes of fire resistance (of a fully developed fire) is expectable from a FRP composite panel of rather low quality. For the structure to be safe without protective passive measures there must be redundant active measures to control the fire within that time. Spaces with insufficiently protected surfaces, such as the accommodation space, therefore need more attention to gain sufficient safety [17].

In compartments protected by insulation (FRD60) less heat will be conducted through the construction to adjacent compartments. It will diminish the risk for fire spread due to heat transfer through the enclosure boundary and delay propagation of fire to adjacent spaces. Down to the improved thermal insulation, the decks, bulkheads and ambience in adjacent spaces will be of ambient temperature, which could be advantageous in an escape situation and could increase the probability of a successful escape. More crew could help with the evacuation since there is no need for boundary cooling and the time available for escape and evacuation could be increased down to the improved thermal insulation. Evacuation should be designed to be completed within these first 60 minutes of improved conditions.

A non-extinguished fire will be confined within a space with FRD60 boundaries for the first 60 minutes and it will be better contained than a prescriptive steel design. The structure will not be deformed even if a fire is uncontrolled and reaches flash-over, and heat will not be conducted to other places of the ship as in a steel design. A backside to the improved insulation could be an increased temperature in the fire compartment, which also would imply a somewhat increased heat release rate. However, the possible increase in temperature due to the decreased transmission of heat through boundaries will reasonably be minute. Furthermore, if a fire is not isolated in one space, e.g. if a door is left open, air from adjacent spaces will mix in which will make the effect even less significant. If a fire is isolated in one space it will lead to lack of oxygen and diminish the fire before any such effects would occur. The heat release rate is rather depending on the contents in the space which, however, would not affect theFRD60 division as it is tested against 60 minutes of fully developed fire. An increase in temperature in the space of origin will probably be insignificant but there could still be reasons to confirm this. If the hypothesis is proved, the increased insulation will only lead to improved conditions for fire safety within the first 60 minutes.

The sensitivity to defects in fire protection should also be evaluated to ensure robustness of the novel design. Since the properties of an FRP composite structure are heavily based on the improved insulation capacity it needs to be established how sensitive the performance is to damage. Routines for maintenance and control need to be established in order to avoid exposure of combustible FRP composite. The consequences if the structure would be damaged, e.g. from maintenance, penetrations or sabotage still need to be investigated.

Structural divisions after propagation or deterioration

If active and passive risk control measures fail and the fire falls out of control, then the FRP composite will take part in the developing fire. This would in fact worsen the already hazardous conditions. Not only by adding more fuel to the fire and letting it continue but also by increasing the smoke production. This stage would only be reached after 60 minutes of uncontrolled fire if divisions are made up in FRD60, which gives plenty of time to evacuate. In other spaces this stage could be reached significantly earlier if e.g. sprinkler system, manual extinguishment fail and the protective surface is deteriorated by fire. This scenario must be counteracted by additional risk control measures. Any magnitude of consequences will although not be acceptable if e.g. a sprinkler system fails. However, evacuations are not seldom protracted [23] and such a safety measure may therefore need to be combined with e.g. a safe place or redundancy.

Hence, open questions are still how much more likely a fire is to be uncontrolled in the base design and what the consequences will be? In the exceptional case of a time-consuming fire, collapse will be more likely to occur in the FRP composite construction, due to the properties of the FRP composite. Although, if only a part of the FRP composite is exposed to extraordinary heat or flames, the deterioration and collapse would be local. Furthermore, the load-bearing capacity of FRP composite is not very dependable on the loading but rather on the fire development and the time of exposure. The reference steel construction also suffers from deformation problems and strength deterioration when heated enough. In this case it is mainly dependable on the heat transfer properties of steel. Fire fighting will therefore be very difficult at this stage, both in the base design and a prescriptive design [17].

Exterior surfaces

In the exterior of the ship, a direct change from steel to FRP would not imply increased risks when it comes to ignition sources. Unprotected external surfaces would although definitely be a source of fire risk. Exchanging the external steel surfaces with combustible FRP composite will give an uncontrolled fire the ability to propagate vertically if a window breaks or if a door is left open. Except including external surfaces in the fire it could imply fire spread between decks and potential fire zones. This issue has been given much attention and full scale tests have been carried out on the matter in order to find suitable mitigating measures [17]. To produce FRP face sheets with low flame-spread characteristics and to install a drencher system for all external surfaces are the leading alternatives at the moment. If a drencher will be used to extinguish an external fire, the achievement will be sensitive to the function of the system which makes the drencher a vulnerable measure. New routines could also be an option, including fire fighting crew to preventing and limiting fire propagation on external surfaces. The change from “non-combustible” to “combustible but protected” implies a possibility for smoke production and fire spread in case the chosen risk control measure malfunctions and will therefore reduce reliability. The fact that external surfaces on ships are typically made of painted steel makes it hard to distinguish from prescriptive requirements what level of fire safety should be required. However, the unprotected external surfaces of the base design need to be managed and the effects evaluated in the assessment [17].

As a general conclusion, the ignition and the first stage of a fire development could be regarded equal on the novel design, comparing with the prescriptive design from a fire safety perspective. Depending on the proceeding scenario, differences between the designs might come in to play which will affect the fire safety negatively in the base design. The conditions in the spaces separated by FRD60 divisions would better contain a fire but in all other spaces there are deficiencies that could stimulate the fire development, if not right away at least in case of an uncontrolled fire.

Data from fire hazard identification

Below follow the tabulated fire hazards for the concerned spaces divided in decks.

Deck 3

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Wheelhouse	Electrical failure in equipment or cables	Newspapers, magazines, books, tissues, etc.	Control panel and plastics in electrical equipment	WC	1-3	Medium sized space volume. All doors to the wheelhouse are generally closed (have automatic closing devices), none of which are possible to open for passengers. Windows are seldom open (not for ventilation).	Oxygen supply	A0-windows
	Fire spread surrounding areas	Clothes	Furniture and consoles	Accommodation space		Division surfaces, furniture and seats (all surfaces have LFS characteristics and upholstered chairs are certified Res. A.652(16))	Reaction to fire properties	Sprinkler redundancy
	Human error	Textiles: Surface of	FRP composite	Open deck space		Quality of FRP composite divisions,	Structural fire resistance	Trash cans in which a fire cannot survive

(smoking, lighter, match)	seats	underneath protective surface layer			no thermal insulation provided		
Pyrotechnical equipment (emergency flares etc.)	Plastics in electrical equipment	Temporary baggage, backpack etc.	Exterior surfaces		Smoke detectors available	Detection	Provide clearly visible "no smoking" signs
	Trash/dust	Cables			Water mist system installed	Automatic extinguishment	Improved fire resistance by FRP composite material selection
		Upholstered furniture (certified)			Portable fire extinguishers available	Manual extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
		Trash can					FRM (fire restricting material) on surfaces
		Papers, binders, books					

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
WC	Smoking	Clothes	Trash bag	Accommodation space	0-1	Very limited space volume, door to the wheelhouse generally closed	Oxygen supply to fire	Self-closing doors
	Electrical failure in equipment or cables	Toilet paper, tissues, newspapers, magazines, books, etc.	FRP composite underneath protective surface layer	Open deck		Surface materials (LFS)	Reaction to fire properties	Trash cans in which a fire cannot survive
	Waste that ignites trash in waste basket	Waste bag	Toilet furnishing (sink etc.)	Wheelhouse		FRP composite without thermal insulation	Fire resistance	Improved fire resistance by FRP composite material selection
	Fire spread from surrounding areas	Plastic material in the furnishings	Textiles			Smoke detector available	Detection	FRM (fire restricting material) on surfaces
	Arson	Lighter fluid				Water mist extinguishment system (not required)	Automatic extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
		Trash/dust				Portable extinguishers found in wheelhouse	Manual extinguishment	Internal divisions in B-0 around toilets (according to

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
								regulations)
						Quality of FRP composite divisions, no thermal insulation provided	Structural fire resistance	Provide clearly visible "no smoking" signs
								Sprinkler redundancy
								Door alarm, if not closed
Open deck space	Human error (smoking etc.)	Plastics/rubber on deck	Composite structural materials	Wheelhouse	0-100	Impossible to limit, large open area with unlimited access to oxygen	Oxygen supply	Surface with low flame spread characteristics (possibly non-combustible lining glued to surface)
	Arson	Deck equipment	Deck equipment	Ro-ro deck		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	Surfaces of low flame-spread characteristics on all FRP composite surfaces
	Electrical failure	Garbage bags	Life rafts	WC		Quality of FRP composite divisions, no insulation provided in base design	Fire resistance	Extinguishing system/drencher

	Fire spread from other areas	Flammable liquid	Plastic seats and tables	Accommodation space		No extinguishing system provided	Automatic extinguishment	Clear no smoking signs and strict rules for crew
	Overheating or mechanical failure in HVAC/Em.gen.	Diesel from Em.gen.	Luggage	Stairways to engine rooms		Portable extinguishers and fire hoses available	Manual extinguishment	EX classified equipment
	Electrical failure in HVAC/Em.gen.			Engine room ventilation			Risk of fire spread to exteriors for vulnerable overhang	Rounds by crew to make sure no one is smoking on deck
						No detection system	Detection	Smoke detectors
						Manual fire extinguishers	Extinguishment	

Deck 2

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Ro-ro deck	Human error (smoking etc.)	Hydrocarbon fuel	Dangerous goods	Surrounding exteriors	0-30 (30 in case of 5 people in 6 cars, normal case 10-15, possible with bus?)	Impossible to limit, large open area with unlimited access to oxygen	Oxygen supply	Oil/fuel spill check by personnel

Arson	Burning car	Vehicles	Open deck space on deck above		Trash cans, flammable oils	Amount of initial fuels	Forward boundary bulkhead towards accommodation space etc. covered by aluminium plating
Car fire due to any failure	Deck equipment	Lighter fluid or other flammable liquid or fuel.	Accommodation space		FRP composite surfaces	Amount of secondary fuels	Redundant extinguishing system for ro-ro deck
Electrical failure	Trash cans	Composite structural materials			Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	Surfaces of low flame-spread characteristics on all FRP composite surfaces
Bunkering	Plastics/rubber on deck	Deck equipment			Quality of FRP composite divisions, no insulation	Fire resistance	Maximum 25 passengers on board when oil tank is transported
Fire spread from other areas	Lighter fluids				Engines in vehicles, smoking	Ignition sources	Clear no smoking signs and staff controlling this
					Drencher under overhang according to requirements	Automatic extinguishment	Aluminium deck plating
					Portable extinguishers and fire hoses	Manual extinguishment	EX classified equipment
					Evacuation routes	Detection	Trash cans in which a fire cannot survive

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
						Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Evacuation	Locked doors and control of no one on ro-ro deck during voyage
							Risk of fire spread to exteriors and particularly under overhang	Adjusted deck with channel to collect potential oil spill (away from FRP composite).
Accommodation space	Electrical failure in equipment or cables	Textiles: Surface of seats and curtains	Textiles: Surface of seats and curtains	Void spaces	Maximum 200	Large space volume. All doors to the accommodation space are generally closed (have automatic closing devices) and only doors to toilets and to open deck (via stairs) are possible to open for passengers. Windows are not possible to open.	Oxygen supply	Division of the space into two fire zones (FRD60)

Fire spread from surrounding areas	Clothes	Flammable liquids spilled by passengers, such as alcohol, lighter fluid etc.	Ro-ro deck		Combustible products, such as walls, furniture, luggage, ceiling and other secondary fuels (all surfaces have LFS characteristics and upholstered chairs are certified)	Heat release rate	Improved fire resistance by FRP composite material selection
Arson	Plastics in electrical equipment	FRP composite underneath protective surface layer	Open deck space above		Quality of FRP composite divisions, no thermal insulation provided	Structural fire resistance	FRM (fire restricting material) on surfaces
Human error (smoking, lighter, match)	Trash/dust	Luggage, baggage	Wheelhouse		Surfaces, furniture and luggage (all surfaces have LFS characteristics and upholstered chairs are certified Res. A.652(16))	Reaction to fire properties	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
	Newspapers, magazines, books, tissues, etc.	Upholstered furniture (certified)	Toilets		Information (smoking signs could probably be more visible, information given in speakers?)	Restriction of ignition sources	Information TV screens showing that smoking is not allowed, flammable liquids are not allowed to carry in the accommodation space (?) and the evacuation procedure
		Trash can	Fore deck		Information	Evacuation	Trash cans in which a fire cannot survive

				Cleaning cabinet		Water mist extinguishment system	Automatic extinguishment	Crew look through the accommodation areas after each trip
				Staircases		Smoke detectors	Detectors	Information is given before each voyage about evacuation routines through speakers
				Engine room ventilation		Portable fire extinguishers available	Manual extinguishment	A0-windows
				Fuel tanks				Sprinkler redundancy
				Bow thruster spaces				Provide clearly visible "no smoking" signs
				Water tanks				Luggage area or area for "dangerous goods", such as lighter fluids
								Door alarms, if not closed

Compartment	**Ignition sources**	**Initial fuels**	**Secondary fuels**	**Extension potential**	**Range of occupants**	**Target locations**	**Critical factors**	**Possible RCMs**
WCs	Smoking	Clothes	Trash bag	Accommodation space	0-2 (normally 1 or possibly 2)	Door to the accommodation space, natural ventilation, limited space volume	Oxygen supply to fire	Self-closing doors
	Electrical failure in equipment or cables	Toilet paper, tissues, newspapers, magazines, books, etc.	FRP composite underneath protective surface	Open deck		Surface materials (LFS)	Reaction to fire properties	Trash cans in which a fire cannot survive

		layer					
Waste that ignites trash in waste basket	Waste bag	Toilet furnishing (sink etc.)	Void spaces		FRP composite without thermal insulation	Fire resistance	Improved fire resistance by FRP composite material selection
Fire spread from surrounding areas	Plastic material in the furnishings	Luggage			Smoke detector available	Detection	FRM (fire restricting material) on surfaces
Arson	Lighter fluid				Water mist extinguishment system (not required)	Automatic extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
	Trash/dust				Portable extinguishers found in accommodation space	Manual extinguishment	Internal divisions in B-0 around toilets (according to regulations)
					Quality of FRP composite divisions, no thermal insulation provided	Structural fire resistance	Provide clearly visible "no smoking" signs
							A0-windows
							Door alarm, if not closed

Sprinkler redundancy

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Ventilation casings	Electrical failure (almost no electrical equipment)	Dust, trash	Structural FRP composite material	Ro-ro deck	0	Very limited space volume. Door/hatch, normally closed except in case of inspection. Ventilation from the engine room (fire damper) and open vent to ro-ro deck.	Oxygen supply to fire	Ex classified equipment in the space
	Fire spread from surrounding areas	Grease	Cabling	Stairway		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	No cable penetrations or other unnecessary ignition sources
	Hot surfaces	Cabling		Engine room		Quality of FRP composite divisions	Structural fire resistance	Surface materials of good reaction to fire properties (LFS)
				Void spaces		Smoke detectors not available	Detection	FRM (fire restricting material) on surfaces
				Accommodation space		Means for manual extinguishment are provided on ro-ro deck e.g. portable extinguishers.	Manual extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
				Open deck space above		No automatic fire extinguishment system	Automatic extinguishment	Sprinkler system

							Possible fire growth rate and heat release	Fognail for manual fire extinguishment from outside
								Improved fire resistance by FRP composite material selection

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Fore deck	Human error (smoking etc.)	Plastics/rubber on deck	Composite structural materials	Surrounding exteriors	0-2 (only crew in case of mooring)	Impossible to limit, large open area with unlimited access to oxygen	Oxygen supply	Surfaces of low flame-spread characteristics on all FRP composite surfaces
	Arson	Deck equipment	Deck equipment	Wheelhouse		FRP composite surfaces	Amount of fuels	Extinguishing system/drencher for fore deck
	Electrical failure	Garbage bags	Life rafts	Accommodation space		Quality of FRP composite divisions, no insulation provided in base design	Fire resistance	Boundary bulkhead towards accommodation space with thermal insulation on the inside (FRD60).
	Fire spread from other areas	Flammable liquid		Void spaces		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	Clear no smoking signs and strict rules for crew
				Bow thruster spaces		No extinguishing system provided	Automatic extinguishment	EX classified equipment
						Portable extinguishers and fire hoses are not available	Manual extinguishment	

		No automatic fire extinguishment system	Automatic extinguishment	
		No detection system	Detection	
			Risk of fire spread to exteriors for vulnerable overhang	

Deck 1.5

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Voids	Electrical failure, e.g. overheating, shortcut	Dust, trash	Structural FRP composite material	Ro-ro deck	0 (1 in case of inspection)	Door/hatch, normally closed except in case of inspection. Otherwise only an approx. 50 mm diam. ventilation penetration is provided.	Oxygen supply to fire	Ex classified equipment in the space
	Fire spread from surrounding areas	Grease, oils	Cabling	Steering gear		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	No cable penetrations or other unnecessary ignition sources
		Cabling	Combustible piping and insulation	Engine room		Quality of FRP composite divisions	Structural fire resistance	Surface materials of good reaction to fire properties (LFS)
			Plastics in electronics	Adjacent void spaces on deck 1		Smoke detectors are not available	Detection	FRM (fire restricting material) on surfaces
				Accommodation space		No means for manual extinguishment are provided, e.g. portable extinguishers.	Manual extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
						No automatic fire extinguishment system (e.g. sprinkler system)	Automatic extinguishment	Sprinkler system

							Possible fire growth rate and heat release	Fognail for manual fire extinguishment from outside Manual extinguishment system/routine Improved fire resistance by FRP composite material selection Hatch alarm, in case not closed Smoke detectors

Deck 1

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Steering gear space	Arson (only crew since hatch is locked, possible to open from below)	Grease/hydraulic oil	Grease/hydraulic oil	Engine room (insulation in engine room)	0 (1-2 persons in connection with service)	Door/hatch, if not closed a ventilation opening (diam. approx. 100 mm) is provided to cargo deck	Oxygen supply to fire	Hatch alarm, in case not closed
	Human error (unmanned during operation)	Oil mist	Structural FRP composite material	Void space on deck 1.5		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties of surface materials	Improved fire resistance by FRP composite material selection

Electrical equipment (very limited amount, mainly lights)	Paper/trash (very limited)	Signal cable (very limited amount)	Ro-ro deck		Smoke detectors	Structural fire resistance	LFS (low flame spread) surfaces
Static electricity	Rags (very limited)	Tubing			No automatic fire extinguishment system (e.g. sprinkler system)	Manual extinguishment	FRM (fire restricting material) on surfaces
Fire spread from surrounding areas					No means for manual extinguishment are provided, e.g. portable extinguishers, however hydrant is provided on car deck.	Automatic extinguishment	B-class panels internally on divisions
					Quality of FRP composite divisions	Detection	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
						Fire growth rate	Sprinkler system
							Camera for hatch and fire detection
							Fognail for manual fire extinguishment from outside
							EX-classified equipment in compartment

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Engine rooms	Hot surfaces (normally insulated)	Grease/hydraulic oil	Grease/hydraulic oil pool and spray	Steering gear (FRD60)	0-1 (periodically unmanned engine room, typically 1 person <1 h/day)	Door closers A-60/FRD60 doors	Oxygen supply to fire	Sprinkler system redundancy
Comment: Design fire: hydrocarbon fire igniting unprotected deck side	Electrical equipment causing statistic electricity or overheating (generator, lighting, main switchboard, enclosed battery system, heat fan, engine room fan, bearings, etc.)	Fuel (diesel)	Fuel (diesel pool and spray)	Void space on deck 1.5 (FRD60)		Ventilation system routine in case of fire, fire dampers	Reaction to fire properties of surface materials	Extinguishment system with inert gas
	Fire spread from surrounding areas	Cabling	Cabling, hoses	Cargo deck (FRD60)		Non-insulated surfaces below insulation (only LFS). FRD60 down to 300 mm below summer waterline.	Manual extinguishment	Fognail for manual fire extinguishment from outside

	Arson (two locked doors separating from passengers)	Plastic covers/electronics	Plastic covers/electronics, switchboard, fuse box etc.	Water tanks (FRD60)		Quality of insulation, FRD60	Automatic extinguishment	Stricter requirements for insulation of hot surfaces.
		Fuel/oil spray	Clothes	Staircase (FRD60)		Smoke and heat detectors	Detection	Alarm for doors in case they are not closed
		Paper/trash (very limited)				Water mist extinguishment system	Fire growth rate	FRD XX (fire resisting division, where XX is >60)
		Rags (very limited)				Portable fire extinguishers	Evacuation	FRM surface lining
						Hydrants on cargo deck		Camera for hatch and fire detection
						Insulation of hot surfaces.		EX-classified equipment in compartment
						Water mist extinguishing system		Improved fire resistance by FRP composite material selection
Compartment	**Ignition sources**	**Initial fuels**	**Secondary fuels**	**Extension potential**	**Range of occupants**	**Target locations**	**Critical factors**	**Possible RCMs**
Water tanks	N/A							

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Fuel tanks	Static electricity in connection to filling of fuel.	Fuel (gases) in fuel tank	Fuel tank FRP composite material	Surrounding void spaces	0	Quality of FRP composite divisions	Fire integrity of tank/divisions	Not have any passengers on board during bunkering
Comment: Anders Lönnermark refers to SP project (2004:14) "Tank fire review" where ignition of diesel occurred when transferring diesel from one tank to another.	Fire spread from surrounding areas			Cargo deck		Integrity (insufficient supply of oxygen)	Oxygen supply to fire	Manual extinguishment ready during filling of tank
							Heating of tank/fuel, which could lead to leakage	Grounding of tanks
Compartment	**Ignition sources**	**Initial fuels**	**Secondary fuels**	**Extension potential**	**Range of occupants**	**Target locations**	**Critical factors**	**Possible RCMs**
Void spaces	Electrical failure, e.g. overheating, shortcut	Cabling	Structural FRP composite material	Fuel tank	0 (1 in case of inspection)	Door/hatch, normally closed except in case of inspection. Otherwise only an approx. 50 mm diam. ventilation penetration is provided.	Oxygen supply to fire	Hatch alarm, in case not closed

Fire spread from surrounding areas	Combustible piping and insulation	Cabling	Adjacent void spaces		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	LFS (low flame spread) surfaces
		Combustible piping and insulation	Stairway		Quality of FRP composite divisions	Structural fire resistance	Improved fire resistance by FRP composite material selection
		Plastics in electronics	Water tanks		Smoke detectors are not available	Detection	FRM (fire restricting material) on surfaces
			Bow thruster space		No means for manual extinguishment are provided, e.g. portable extinguishers.	Manual extinguishment	Fognail for manual fire extinguishment from outside
			Accommodation space		No automatic fire extinguishment system (e.g. sprinkler system)	Automatic extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
						Possible fire growth rate and heat release	Manual extinguishment system
							Smoke detectors
							Ex classified equipment in the space
							Sprinkler system

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Bow thruster spaces	Human failure in reparation work	Paper/trash (very limited)	Grease/hydraulic oil	Adjacent void spaces	0 (1-2 persons in connection with service)	Door/hatch, normally closed except in case of inspection. Otherwise only an approx. 50 mm diam. ventilation penetration is provided.	Oxygen supply to fire	Hatch alarm, in case not closed
	Hot surfaces (normally insulated)	Grease/hydraulic oil	Structural FRP composite material	Accommodation space		Surface material, unprotected in base design provides fuel to potential fire without restrictions.	Reaction to fire properties	Improved fire resistance by FRP composite material selection
	Electrical failure or overheating (generator, lightning)	Cabling	Cables (limited amount)			Quality of FRP composite divisions	Structural fire resistance	LFS (low flame spread) surfaces
	Fire spread from surrounding areas	Plastic covers/electronics	Tubing (limited amount)			No means for manual extinguishment are provided, e.g. portable extinguishers.	Manual extinguishment	In case of reparation, manual extinguishment equipment is brought down to the space (portable extinguisher or hydrant from above)
	Mechanical failure or overheating	Rags (very limited)				Smoke detectors	Detection	FRM (fire restricting material) on surfaces

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
	Arson (not easily accessible)					No automatic fire extinguishment system (e.g. sprinkler system)	Automatic extinguishment	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
							Possible fire growth rate and heat release	Sprinkler system
								Manual extinguishment system
								Fognail for manual fire extinguishment from outside
Stairways	Electrical failure in equipment or cables	Cables	Ceiling and bulkheads (LFS)	Engine room	0 (sporadically 1 or possibly 2)	Doors to engine room and accommodation space are normally closed. Then only sparse natural ventilation from accommodation space.	Oxygen supply to fire	Door closer and locks to engine room and accommodation space.
	Fire spread from surrounding areas	Dust/trash	Furnishing (not allowed)	Accommodation space		The walls, floors and other surfaces in the staircase fulfil low flame-spread characteristics	Reaction to fire properties	Improved fire resistance by FRP composite material selection
	Arson	Wall decorations	Garbage bags (not allowed)	Void space		Quality of FRP composite divisions	Structural fire resistance	Fire damper also between stairway and accommodation space

Human error (smoking?)	Garbage bags	Ro-ro deck		No portable extinguishers available	Manual extinguishment	FRM (fire restricting material) on surfaces
		Engine room ventilation		Smoke detectors	Detection	FRD XX (fire resisting division, where XX is 15, 30, 60, 90…) in combination with LFS or FRM surface lining
				Water mist extinguishing system	Automatic extinguishment	Portable extinguisher
						Sprinkler redundancy
						Fognail for manual fire extinguishment from outside
						Door alarm, if not closed

Whole ship

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Vertical exterior fire spread	Fire spread from internal spaces	Fire in internal space	External FRP surfaces	Ships external surface, upwards downwind		Windows	Flame spread characteristics of FRP composite surfaces	Low flame-spread characteristics on FRP composite surfaces
						Drencher system (if added RCM)	Possibility to manoeuver the ship to assure fire is spread in the most preferred direction (wind)	Redundant drencher system
						Bridge/manoeuvre station	Window integrity and resistance to fire	Sprinkler system on ro-ro deck
						FRP composite surfaces	Drencher efficiency (if added)	Fire rated windows
							Drencher reliability (if added)	Drencher covering the bulkheads from deck 3 and down

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Increased smoke production	Any fire continuing until insulation failure	Any internal fire	FRP bulkheads and decks	Smoke spread down wind		Embarkation deck stations	Passenger safety on embarkation stations	Low flame-spread characteristics on FRP composite surfaces
			External FRP surfaces			FRD60 construction	Passenger safety while abandoning ship	Redundant drencher system
						Bridge/manoeuvre station	Toxicity	Sprinkler system on ro-ro deck
							Possibility to manoeuvre the ship to assure that embarkation deck is kept up wind from fire	Use of LEO or composite material with surface laminate with improved fire properties

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Increased amount of combustible materials	Any fire continuing until insulation failure	Any internal fire	FRP bulkheads and decks	Adjacent fire zone		Embarkation deck stations	Passenger safety on embarkation stations	Improved thermal insulation
			External FRP surfaces			FRD60 construction	Passenger safety while abandoning ship	Redundant sprinkler system
						Bridge/manoeuvre station	Maintained insulation on FRP surfaces adjacent to the fire	Swift manual extinguishment

							Possibility to manoeuvre the ship to assure fire is spread in the most preferred direction	
							Insulations ability to stick to deforming FRP decks and bulkheads	

Compartment	Ignition sources	Initial fuels	Secondary fuels	Extension potential	Range of occupants	Target locations	Critical factors	Possible RCMs
Loss of structural integrity	Any fire continuing until insulation failure	Any internal fire	FRP bulkheads and decks	Entire ship		Embarkation deck stations	Passenger safety on embarkation stations	Structural redundancy
			External FRP surfaces	Adjacent void spaces		FRD60 construction	Passenger safety while abandoning ship/on embarkation deck	LFS (low flame spread) surfaces
			Combustible piping and insulation	Stairway		Quality of FRP composite divisions	No major structural collapses before passengers has abandoned the ship	Drencher system on outboard sides of the ship

Procon list

Since all effects on the safety level of a prescriptive design cannot be determined from deviated prescriptive requirements a number of additional evaluations were carried out. All pros and cons from a fire safety perspective were summarized in a Procon list, where they were also rated by fire experts according to the Delphi method to provide guidance for the selection of fire hazards. Note that this was carried out in the preliminary analysis and hence founded on the initial base design.

Pros and cons with the base design from a fire safety perspective	Rating	Comments
The ignitability of combustible external surfaces is not as limited as steel.	-1	No fire scenarios are expected to start from a small ignition source igniting the FRP composite since its ignitability is nevertheless quite limited. This could be verified through small scale test, such as the Cone Calorimeter or Small Flame. Hence, risks associated with this particular hazard should be possible to manage independently.
The use of combustible materials is not restricted on external surfaces, which implies fire spread is more likely.	-4	Exchanging the external steel surfaces with combustible FRP composite will give an uncontrolled fire (which may have started in a space adjacent to exteriors or in other materials than the FRP composite on open deck) the ability to propagate which, except including outboard FRP composite surfaces in the fire, could imply fire spread between decks. These hazards are crucial to quantify in the fire scenarios.
Smoke production will be increased in case external surfaces take part in a fire (even if smoke production is not critical on open deck).	-1	A fire which has started in a space adjacent to exteriors or in other materials than the FRP composite on open deck could spread to include external FRP composite surfaces, which would increase the smoke production. This fire hazard should be looked into further.
Unprotected external surfaces need to be targeted somehow. However, the fire safety will then be sensitive to the function of the provided RCM/RCMs and the reliability of the fire safety will then be reduced regardless of the added measures	-2	This deficiency is accounted for in the fire scenarios of fire scenarios.
The engine room bottoms are only protected with a surface of low flame spread characteristics more than 300 mm below the water line where a non-combustible surface is customary.	-2	This fire hazard must be cared for and should be included in the fire scenarios.
Voids, auxiliary machinery spaces and tanks do not have non-combustible surfaces, as customary in prescriptive designs. It will affect	-1	The potential of this hazard must be further investigated in the fire scenarios.

fire growth and smoke production in case of fire. Oxygen supply is although likely limited.		
FRP composite divisions simply faced with surfaces of low flame spread characteristics may provide fuel to a fire since the underlying divisions are combustible. It will affect fire growth and smoke production in case of an extended fire.	-2	FRP composite with surfaces of low flame-spread characteristics will only hinder the combustible FRP composite from involvement in the fire in the early phase and this hazard may need to be managed better, which should be investigated in the fire scenarios.
Since the thermal insulation provided in the engine rooms only works "one way" the engine rooms are not sufficiently protected from a fire occurring in adjacent spaces. In sufficiently insulated FRP composite surfaces towards the engine room are found on ro-ro deck and in stairways where A-60 and A-30 standards apply, respectively.	-1	The fire hazards in the stairways are very restricted and the layout of the staircases makes it unlikely that a fire could deteriorate the bulkhead towards the engine room. From ro-ro deck there is an additional steel deck on the ship, which could account to the deck division. Nevertheless, the potential of these hazards should be taken into account in the fire scenarios.
No evacuation station redundancy is provided	-3	An evacuation process could be hazardous, in particular if an evacuation station is not provided. The base design will hence affect the probability of successful evacuation but also the the probability of initiating an evacuation process. There is therefore a need to account for risks associated with the evacuation process in the fire scenarios.
Structural integrity according to A-class standard is not fulfilled by divisions in the base design since FRP composite is combustible. A continuing fire could bring about a local collapse when the FRP delaminates from the core which imposes a risk to fire-fighting crew (even if it has been proven to be a slow process). Fire fighting will however be very difficult at this stage, both in a design with FRP composite and a prescriptive design. This applies to principally all divisions on the ship (except e.g. toilets).	-3	An uncontrolled fire could imply a greater risk for fire-fighting crew. However, with new fire-fighting strategies and equipment combined with adequate training it has been assessed [18] that the fire-fighting efforts can be performed in a manner that is at least as safe in the trial alternative designs as in a prescriptive design.
The toilets are enclosed by combustible FRP composite with surfaces of low flame spread characteristics instead of by B-0 divisions (30 minutes of structural fire protection).	-1	This fire hazard should be looked into and could be necessary to be incorporated in the fire scenarios.
The ro-ro deck is not thermally protected against fire in the accommodation space, in the steering gear and on the overhang for 60 minutes as required but simply	-2	The reason for the A-60 requirement towards the ro-ro deck is associated with the fire hazards on ro-ro deck. Nevertheless, the potential effects from a fire in the surrounding spaces must be

by FRP composite.		looked into. In particular a fire in the accommodation space could lead to deterioration of the separating division.
The accommodation space is not thermally and structurally protected against fire on ro-ro deck, as required (A-60), but simply by FRP composite.	-4	The effects from this hazard in combination potential with risk control measures must be investigated further through fire scenarios.
The steering gear is not thermally and structurally protected against fire on ro-ro deck, as required (A-60), but simply by FRP composite.	-3	A fire on ro-ro deck could spread downwards to the steering gear. However, a steel deck is provided and the effects of this should be further evaluated in the fire scenarios.
The overhang is not thermally and structurally protected against fire on ro-ro deck, as required (A-60), but simply by FRP composite.	-1	This could be hazardous both for people on the overhang and for people exposed to risks associated with collapse of the overhang. These risks should be looked in to in the fire scenarios.
The cleaning cabinet is not sufficiently protected against fire spread from the accommodation space (A-60 required), but simply by FRP composite with surfaces of low flame spread characteristics.	-1	A fire in the accommodation space could spread to and include the cleaning cabinet and its contents. The fire should by then already be quite severe and the effects of this event may be irrelevant. However, this should be accounted for in the fire scenarios.
The accommodation space is not sufficiently protected against fire spread from the cleaning cabinet (A-60 required), but simply by FRP composite with surfaces of low flame spread characteristics.	-2	A fire in the cleaning cabinet is not likely to continue if the door is closed. This should be looked into and could possibly be managed independently.
The life rafts on fore deck are not separated from the accommodation space by A-60 divisions but simply by FRP composite.	-2	This could be managed by FRD60 insulation or by drencher but should be investigated in the fire scenarios.
A fire will be more likely to be contained/isolated in the engine room on account to the improved thermal insulation in comparison to an A-60 construction. Hence, steering gear spaces, water tanks, voids and the stairways are thermally protected from an engine room fire for 60 minutes even though A-0, A-0, A-0 and A-30 is required.	2	An enclosed engine room fire is more likely to be contained, which should be included in the fire scenarios.
The above (improved containment) is also true in case the sprinkler system fails and openings are closed which will induce reduced sensitivity to these failures (safety is thereby not as dependant on sprinkler system and fire fighting)	1	This is accounted for in the assessment of fire scenarios.
A long-lasting fire could bring about a major collapse which could affect great parts of the ship	-2	A fire which is uncontrolled anywhere in the ship could lead to structures collapsing. People should by then be on the

		embarkation deck and be able to move if so that they are not affected by the fire. This risk should be considered in the fire scenarios.
Ventilation ducts have to be of non-combustible material but the ducts in the base design are made of FRP composite.	-1	This hazard is ignored, i.e. non-combustible ducts are assumed.
The fuel tank spaces are left without any passive fire protection in the base design even though A-60 is required towards the accommodation space above and A-0 toward the surrounding void spaces	-1	The tanks are made as independent volume inside the space and should not be able to be affected by a fire in adjacent spaces. This risk could be managed independently but should otherwise be included in the fire scenarios.
Relieving boundary cooling will reduce complexity in the fire protection strategy	1	This hazard should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting. This could be managed independently.
The fire fighting routines and maintenance will need to be changed, which implies new routines and inexperience	0	This hazard should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting. This could be managed independently.
Increased amount of fuel when FRP composite structures take part in a fire, i.e. could fuel an already uncontrolled fire.	-2	An uncontrolled fire will be given more fuel which could develop and particularly prolong the fire.
In steel structures heat can be conducted far through the structure and bring about fires where there are weaknesses in integrity. In an FRP composite construction heat will not be easily conducted to other places which will reduce the complexity in the fire protection strategy.	1	This could be taken into account when considering FRD60 divisions replacing A-0 divisions, which although does not exist in this design case and was therefore ignored.
Down to the improved thermal insulation where FRD60 is used, the adjacent decks, bulkheads and ambience in adjacent spaces will be of ambient temperature, which could be advantageous in an escape situation and could increase the probability of a successful escape.	2	This is primarily relevant if there is a fire in a compartment where an A-0 deck above a compartment is replaced by a FRD60 deck. The floor on the deck above will then not become untenable. However, normal evacuation routes must already perform A-60 and this is only relevant between the engine room and the ro-ro deck and was therefore ignored.
Is the construction sensitive to defects? Routines for maintenance and control need to be established in order to avoid exposure of combustible FRP material.	-2	It has been shown that the FRD60 construction is not particularly sensitive to defects [71]. Routines for maintenance and control nevertheless must be established in order to avoid unnecessary exposure of FRP composite. With those established this effect is estimated insignificant.

Fire-fighting in large FRP composite passenger ships

No need for boundary cooling, new fire-fighting tools and some further changes in the fire-fighting routines imply that the probability of successful fire-fighting may be affected. Furthermore, the risks for fire-fighters could also be affected due to the risk of collapse after. These issues were investigated for a different design case though a dissertation supervised by SP Technical Research Institute of Sweden. A student concluding his fire safety engineering degree at Lund University carried out the study and below follows a summary of the report [18]. Implications for the Eco-Island ferry are given in *4.1.3. Fire-fighting*.

Scope and method of study

The purpose of the study was to evaluate fire-fighting on a panamax cruise vessel, called the Eco-Island ferry, where the five uppermost decks had been designed in FRD60 instead of in steel. This was done from two perspectives:

- Investigate the FRP composite design's implications for fire-fighters' personal risk.
- Investigate the FRP composite design's implications for the fire-fighting organization's effectiveness and efficiency.

An objective was also to give recommendations on how to adopt current fire-fighting routines so that they are suitable for an FRP composite environment.

The study was based on literature studies, interviews and analytical risk assessments.

Current state of the art

Articles, reports and regulations were studied and interviews were held with a former fire Safety Officer, First Fire-fighter and Fire Chief on large Panamax cruise ships as well as with fire safety regulators (Flag) and professors at fire-fighting academies for rescue services on land and in the navy. This was done in order to find the state of the art for fire-fighting routines on traditional prescriptive cruise ships, on current navy ships in FRP composite and on land. The study also gave ideas for how fire-fighting can be improved in order to assure safety for both crew and the ship.

Differences in fire scenarios for fire-fighters

Reports from tests on FRP composite and ship accident reports (some involving FRP composite structures) were studied and gave information on the behaviour of FRP composite in fire situations, such as the structural collapse process. Fire scenarios that can be regarded detrimental, unobtrusive or beneficial (to fire-fighters' personal risks) were also inventoried, with consideration of novel fire-fighting strategies and materiel taken into account.

In respect to fire behaviour, the base design was found to change the following parameters:

- increased thermal inertia;
- possibility of structural collapse;
- combustibility of structural material;
- production of pyrolysis gases by structural material, adding to the fire load; and
- production of toxic gases from combusted structural material.

Analysing the parameters from a fire dynamics point of view, the following differences were found to be implied by the base design when compared to the prescriptive design:

- Probable similar fire development up until the point in time that the inner ceiling fails. The inner ceiling separates the enclosure from the load-bearing structure via a void space.
- Fires in larger inboard spaces, such as restaurants or theatres, will also likely behave in a similar fashion up until the point in time that the inner ceiling fails.
- If, or when, the inner ceiling fails, the temperatures in the hot smoke layer and ceiling jet may get higher with the novel design due to the increased thermal inertia (e.g. when FRD60 replaces A-0). Although inner ceilings are designed fail after some 10-20 minutes of exposure to severe fire, it was able to withstand a fully developed fire that lead to an almost completely burnt out cabin in the fire incident on the Star Princess. This speaks for smaller differences where B-class divisions are installed.
- In case either no inner ceiling is installed, which may be the case in e.g. machinery spaces, fire development may be faster. The improved thermal barrier in the base design may result in higher temperatures and the difference may be significant, especially if the divisions are of A-0 class in the prescriptive design which has great conductive capabilities.
- Outboard fire spread is possible with the novel design. It is at this point unclear what preventive protection will be installed, but external drencher system or surface layer that have low flame-spread characteristics are solutions that are being considered.
- Fire spread over load-bearing boundaries may occur following a collapse in the base design, rather than by conduction as in the prescriptive steel design.
- Fire spread through installation passages seems possible both in the base and the prescriptive design. Especially when the ship has seen some years of service and may have undergone upgrades, maintenance, repairs etc.
- The great thermal resistance of the FRD60 construction will make it much more difficult or even impossible to locate the fire seat by detecting hotspots in the adjacent space.

This knowledge was concretized in what fire scenarios a fire-fighter could be exposed to, taking into consideration structural failure, added smoke production and toxicity, added fuel, current and improved fire-fighting strategies, techniques and equipment, fire-fighting operations' effectiveness and efficiency, the complexity and robustness of fire-fighting performance as well as the fire-fighters' personal risks.

Recommended fire-fighting and implications for effectiveness and efficiency

A number of changes in the fire-fighting strategies and use of equipment were recommended based on the above studies. The main differences to consider when fighting a fire in an FRP composite superstructure are the following:

- The possibility of structural collapses must be regarded as a great threat to both the safety of the crew, as well as to the effectiveness of the fire-fighting efforts. In case a fire is difficult to combat by traditional means with BA-teams, it is important to quickly apply hot gas cooling. This will not only lower temperatures and dampen the fire, enabling the BA-teams greater chances of success in subsequent attempts, but will also protect the load bearing structure from high thermal loads, increasing its chance of not collapsing.
- Traditional boundary cooling is ineffective and should be replaced with cooling of hot smoke from an adjacent compartment, with Cutting Extinguisher or Fog Nail. The strategy is effective both for improving fire-fighters' working conditions by suppressing the fire prior to entering, as well as holding a boundary line since it will greatly reduce the structure's exposure to heat.
- Fire-fighting commanders must be aware of the fact that the structure is susceptible to collapses and that individual parts of the structure is likely to withstand roughly one

hour of exposure to fire. Commanders must, in order to prevent collapses from occurring, always try to stay one step ahead of the fire and plan for what's next.
- After a severe fire in an FRP composite area has been successfully suppressed, it may tend to reignite locally for some time afterwards. Thus, the area needs to be monitored until temperatures in the structure have fallen to a safe level. Furthermore, the adjacent compartments will also need to be monitored to ensure no creeping fires are propagating slowly through the construction.
- That a deck or bulkhead is of ambient temperature on the unexposed side is no indication as to whether or not there is a severe fire in the adjacent compartment. This is due to the FRP composite's high thermal inertia.
- Non-insulated FRP composite materials that have been subjected to severe fire may produce harmful particles that require extra caution when working in, or decontaminating, a fire-exposed area.
- Large inboard areas such as cinemas or restaurants that at the same time expose a larger part of the load bearing structure to fire, may be a priority to combat. The weakening of an FRP composite structure is localized to the actual site of exposure to fire, due to its poor conductive properties. The size of a collapse occurring in such an area may thus be larger than in a small area, such as a cabin. The risk of a collapse taking place is also likely higher due to the larger part of the load bearing structure that is affected.

With the introduction of the above new fire-fighting strategies and equipment, in combination with adequate training, it was assessed that fire-fighting efforts can be undertaken in a more effective and efficient way in the novel design.

Furthermore, with regards to how the ship may be constructed to ease the adaptation of the new fire-fighting techniques and equipment it was suggested to make the following additions:

- Mark areas that are suitable for deploying a Cutting Extinguisher. This could be done discreetly and would decrease the risk of fire-fighters accidently cutting apart vital installations such as sprinkler piping etc. It would also increase the chance of effective results.
- Pre-install discreet holes where Fog Nails can be inserted. This would increase the chance of effective results and also greatly ease deployment as pre-drilling of holes is not needed.
- Pre-install connections through the main vertical and horizontal zones for extending the Cutting Extinguisher hose throughout the ship, without compromising the fire zone boundaries.

Relative comparison of fire-fighters risks

When the scenarios had been identified, a ratio of how common they are was assessed based on the ice-berg model, illustrated in Figure I1, which allows for a relative risk comparison of how much the (more frequent) beneficial scenarios must increase fire-fighters' safety in order for them to make up for the (less frequent) detrimental scenarios. Performing a fully quantitative risk analysis for this type of question is not very suitable and would be associated with great uncertainties. The method used in the report did not attempt to deliver an exact figure of relative risk e.g. $P(A)=0.8 \cdot P(B)$. However, the objective was to answer a question such as *whether* $P(A) \leq P(B)$*?* With the ice-berg model one can say that if for instance the beneficial scenarios outnumber the detrimental ones by 5:1, it implies that the safety increase in each beneficial scenario must equal at least 20% of the increase in fire-fighters' risk caused by one detrimental scenario in order for safety to stay the same.

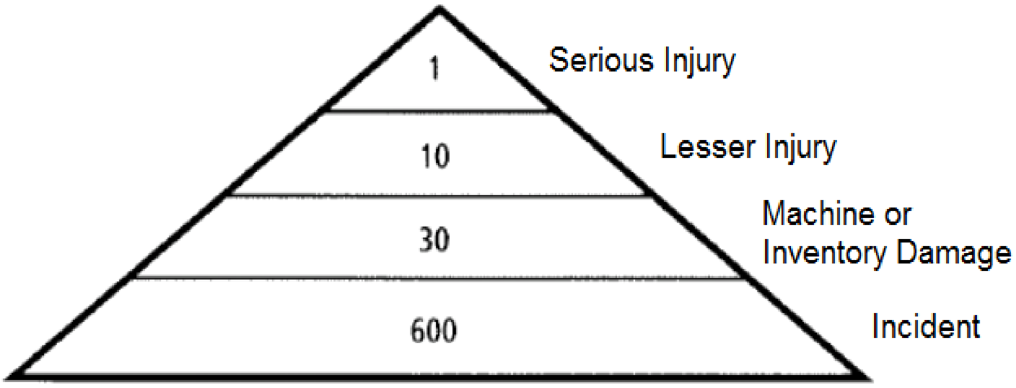


Figure I1. Ice-berg model example.

Looking once again at the different scenarios that affect fire-fighters' personal risk; catastrophic (detrimental) and serious (beneficial) while keeping in mind the introduction of hot smoke cooling strategy which is believed to increase fire-fighting effectiveness and help protect the structure from collapses by lowering temperatures, it seems that the ratio could be estimated to somewhere in the region of 1:5 - 1:10. This would be the ratio between the serious scenarios and ones where collapses occur that may lead to a full or near total loss of the ship, which take place in an area built in FRP composite.

What implications does this have for the relative risk (RR) comparison? Given that the serious scenarios are five to ten times more likely than the catastrophic one; to be able to state that the novel design is at least as safe as the prescriptive design in terms of fire-fighters' risk, the combined safety increase in all the serious scenarios must match or surpass the safety decrease of the one catastrophic scenario. In other terms, each serious scenario must induce a reduction of fire-fighters' absolute personal risk that corresponds to at least 10% - 20% of the personal risk increase caused by a catastrophic scenario.

So, is the fire-fighters' personal risk reduced by the smoke cooling strategies in combination with increased manpower enough to outweigh the increased risk implied by the danger of structural collapses? It is difficult to say for sure with this ratio interval of 1:5 - 1:10; it may be so.

However, upon installing Cutting Extinguishers (CE) on board, the author of this report recommends that it is done in such a manner that it covers the whole ship. Considering the reach of a unit, it should not be a too large undertaking. The reason for this recommendation is the following. Giving fire-fighters the option of cooling of hot smoke strategies not only in the uppermost FRP composite decks but also the rest of the ship, of course gives them the same benefits when it comes to reduced personal risk when fighting fires in the steel built areas. It has slightly other implications when it comes to effectiveness as complementary boundary cooling still may be necessary, if the CEs are not effective, but effectiveness is believed to increase also in the steel built areas.

Assuming the areas built in FRP composite make out roughly 1/3 of all spaces, implies that the number of serious fire scenarios (that of course can occur at any deck, not just on composite decks) that benefit from the access to CEs, are now tripled. At the same time, the added risk of collapses that may occur in the FRP composite design is not really a concern in these areas. This in turn means that the previously mentioned ratio interval of 1:5 - 1:10 is now 1:15 - 1:30. Expressed in other terms, a serious scenario must induce a reduction of fire-fighters' absolute personal risk that corresponds to at least 3% - 7% of the personal risk increase caused by a catastrophic scenario.

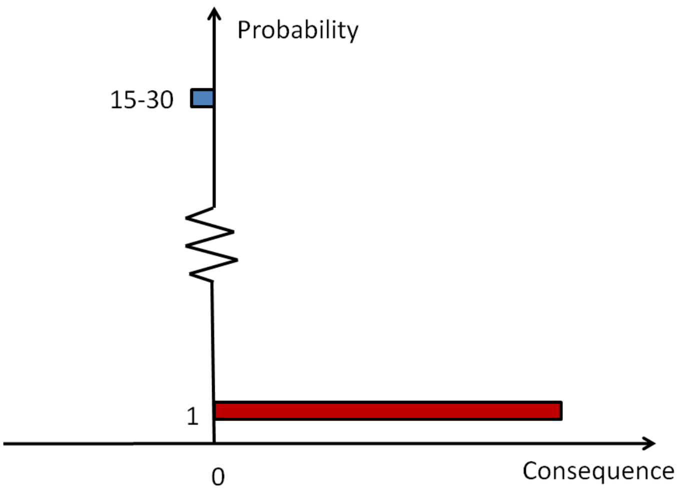


Figure I2. Illustration of how different scenarios may affect the RR; if the beneficial scenarios each reduce fire-fighters' absolute personal risk by an amount that corresponds to at least 1/30 - 1/15 of the personal risk increase caused by one detrimental scenario, the consequence is zero or negative, which indicates that the RR is at the most 1.

The different scenarios' consequences for the RR comparison are again illustrated in Figure I2. The figure illustrates how a number of beneficial scenarios with a modest decrease in consequence (thus lowering fire-fighters' personal risk), may balance the increase caused by a detrimental catastrophic scenario. If it is so, that the beneficial scenarios balances or outweighs the detrimental one, the summarized consequence to fire-fighters' personal risk remains at, or below zero. This indicates that in a comparison of relative risk prior to, and after the introduction of the novel design, the RR is at the most 1.

With this interval of scenarios and keeping in mind the crew's often somewhat modest experience with aggressive BA-team operations in difficult environments, it appears probable to the author of this report that the benefits from new fire-fighting strategies and tools would negate or outweigh the increased personal risk to fire-fighting crew caused by structural collapses. Proper training should of course not be forgotten.

Concluding, with the introduction of the new fire-fighting strategies and equipment presented above and in combination with adequate training, it is assessed that fire-fighting efforts can be performed in a manner that is at least as safe in the novel design as in a prescriptive design.

Validation of yields

In order to determine when untenable conditions are reached in a fire scenario it is important to have reliable information regarding the production of toxic products. In order to validate the smoke yields used in fire simulations, two-zone fire simulations were performed in BRANZFIRE [53] to recreate the conditions in different fire scenarios in the full scale cabin fire tests carried out at SP Fire Technology [17]. In this experiment a standard cabin was built with B-class divisions and realistic interiors, e.g. luggage, beds and furniture.

Heat release rate

To determine realistic smoke yields based on the results from the experiments, a heat release rate curve was established to fit the experimental result. The fire development was represented by two phases of fire growth, described as “t-squared fires” [20], where the heat release is expressed as:

$$\dot{Q} = \alpha * t^2.$$

The two phases were attributed the following values:

- incipient phase: 4 minutes, α = 0,000868, resulting in a 50 kW fire after 240 seconds;
- growth phase: α = 0,047 (generally denominated “fast”).

A compartment with similar dimensions and ventilation openings as in the experiments was modelled in BRANZFIRE and resulted in the heat release curves in Figure J1.

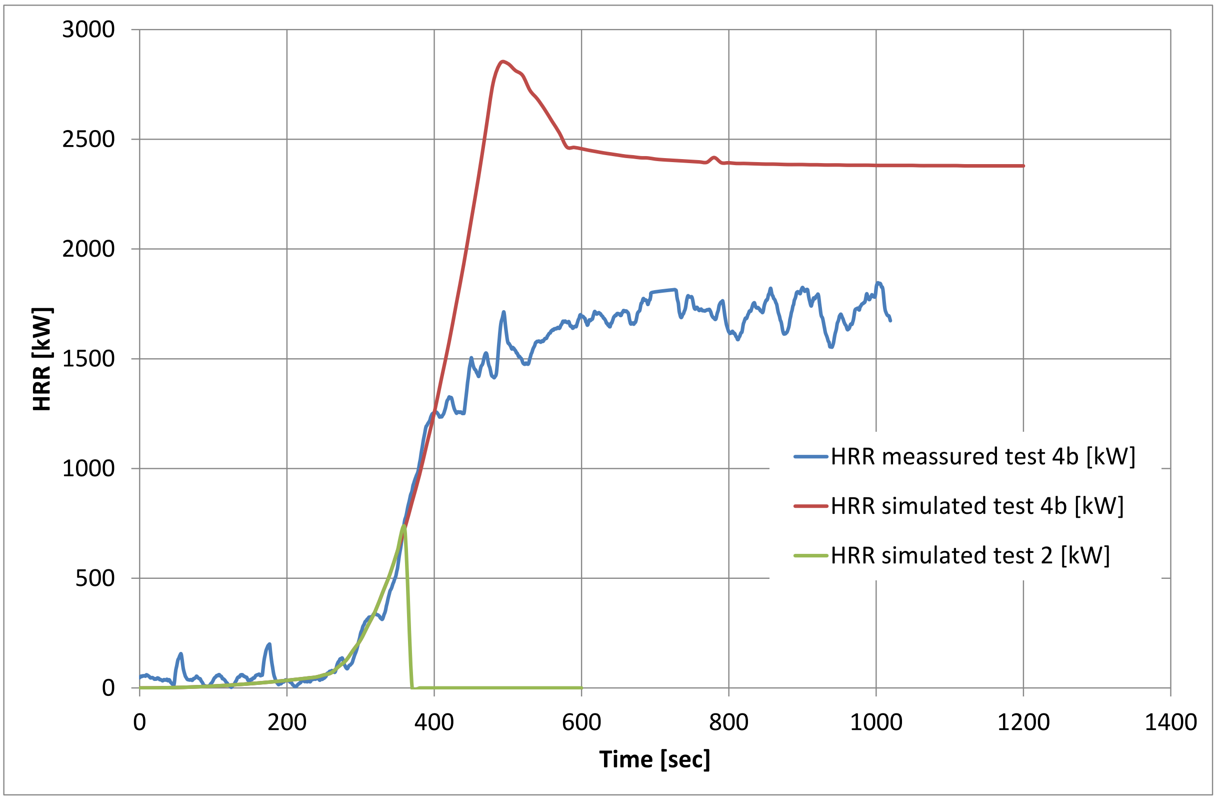


Figure J1. Measured and simulated heat release rates.

Smoke yield calibration

To validate the soot-, CO- and CO^2-yields, a well-ventilated fire (test 4b) and an under-ventilated fire (test 2) were simulated with the HRR-curves determined above. After an iterative calibration process the following results were found representable for the smoke yields in a cabin fire, as presented in Table J2.

Table J2. Validated smoke yields along with commonly referred values for reference

Smoke yields [g/g]	***Validated against full scale cabin fire [17]***	***Plastics* (SFPE handbook [41])***	***Wood (SFPE handbook [41])***	***Wood (BRANZFIRE database [53])***
Soot yield	0,01	0,08 – 0,16	0,015	0,015
CO_2 yield	2,5	0,5 – 2,3	1,33	1,19
CO yield pre-flashover	0,15	0,04 – 0,06	0,005	0,05
CO yield post-flashover	0,35			0,5
Energy yield [kJ/g]	12,4			12,4

*** (nylon, PVC, Polystyrene, Polyurethane)**

The smoke yields gave results corresponding with the values attained in the trials, at least until reaching untenable conditions, as shown in Figure J2, Figure J3, Figure J4 and Figure J5.

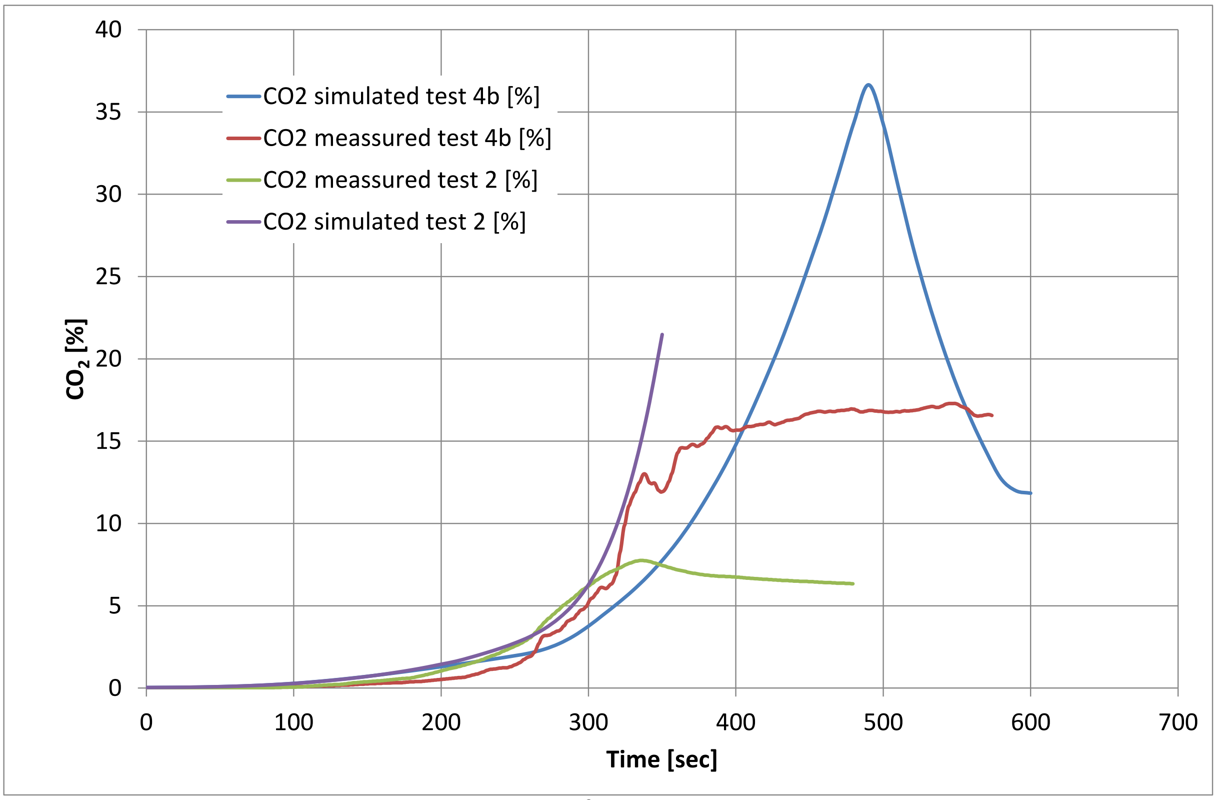


Figure J2. Measured and simulated CO^2 rates (tenability limit is 5 %).

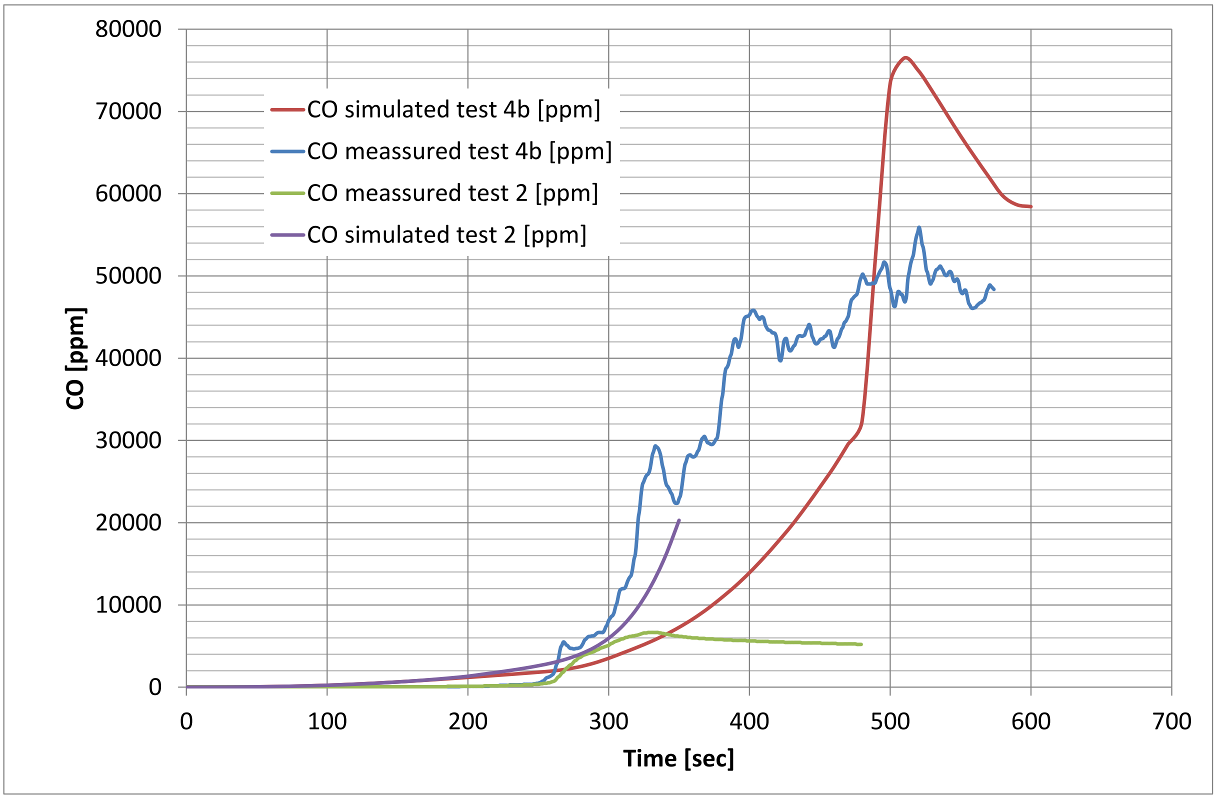


Figure J3. Measured and simulated CO rates (tenability limit is 2000 ppm).

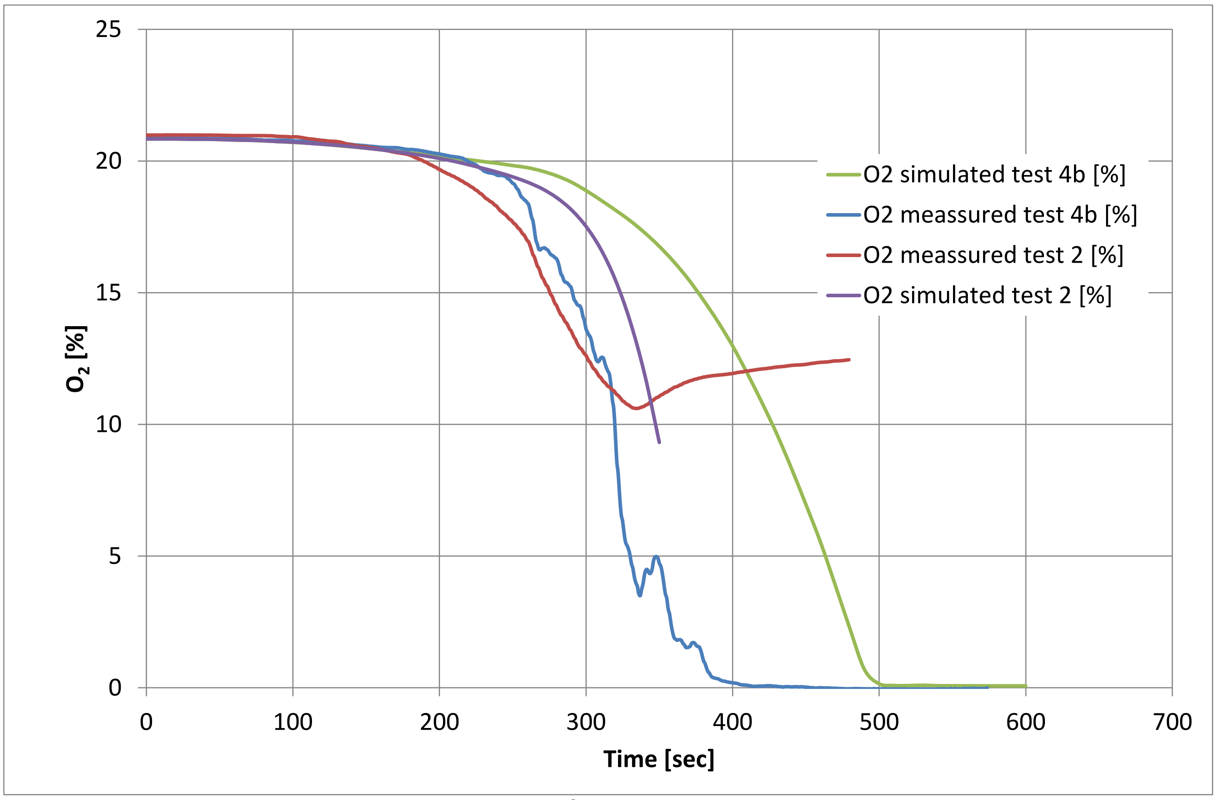


Figure J4. Measured and simulated O^2 rates (tenability limit is 15 %).

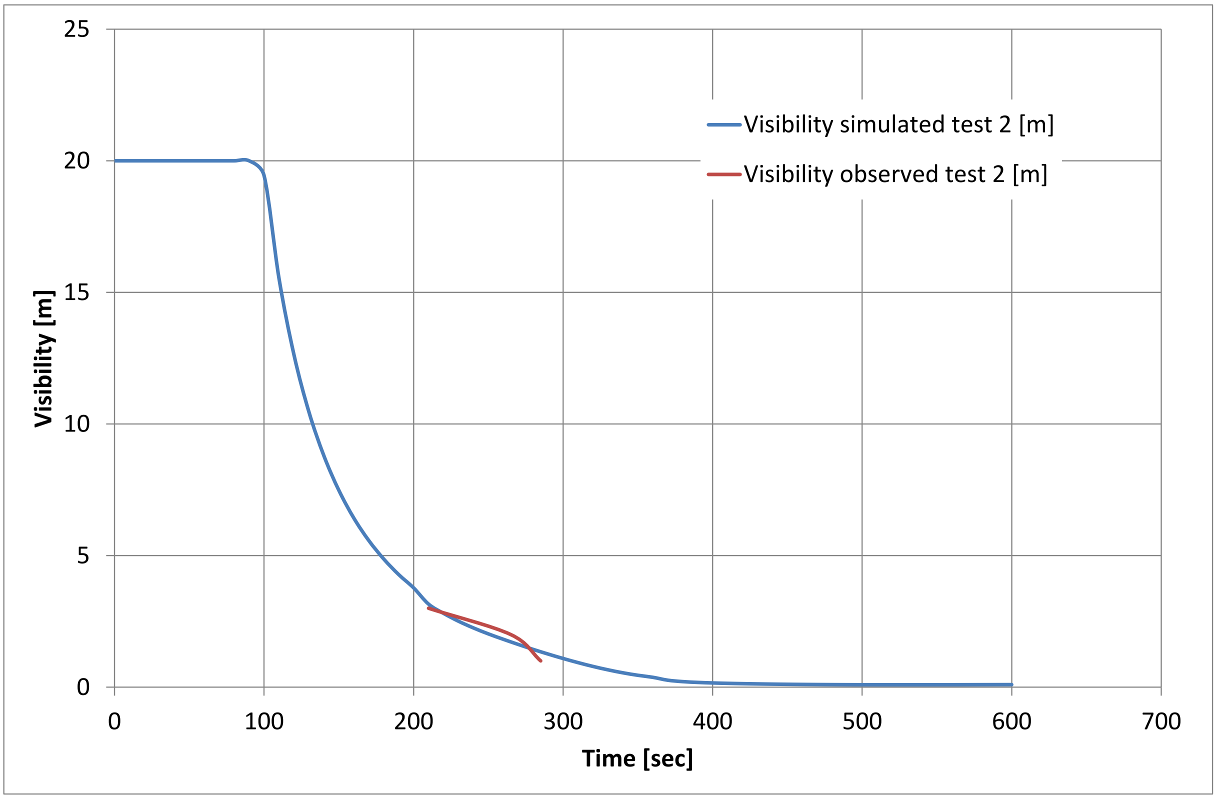


Figure J5. Observed and simulated visibility (tenability limit is 3 m in a cabin).

Detection

In BRANZFIRE there is a function which makes it possible to model the time to activation of a fire detectors. With the HRR-curves and yields determined above the detection times presented in Table J3 were simulated when placing the fire detector in the same location as in the experiments. Actual detection times from the tests are also presented in Table J3 for comparison.

Table J3. Observed and simulated detection times based on experiments and validated smoke yields

Test setup	***Detection time in experiment [min:sec]***	***Detection time in simulation [min:sec]***
Test 2 (door closed)	1:15	1:32
Test 4b (door open)	1:32	1:32

FDS input files

In determining the available time until critical conditions are reached in the accommodation space in case of fire, simulations were performed using the software Fire Dynamics Simulator [FDS]. They also helped to determine other conditions affecting the fire development, e.g. the expected time until glass breakage.

Two fundamentally different models were set up, one simulating the conditions in case the accommodation space is subdivided longitudinally and all separating doors close properly and one on case there is an opening between the port and starboard sides of the accommodation space. The input files for these simulations are presented in the subsequent paragraphs.

Closed doors between the accommodation space

```
&HEAD CHID='EKO_ship', TITLE='EKO Ship Johan Anderson'  /
&MESH IJK=168,50,23, XB=0.0,16.8,0.0,5.0,0.0,2.4 / 10 cm grid
&TIME T_END=500 /
&DUMP NFRAMES=500/ Measurements 500 times
&MISC RADIATION=.TRUE./
CO_PRODUCTION=.TRUE.
----------------------------------------------------------------

Geometry
&VENT MB='XMAX' ,SURF_ID='OPEN' / to the outside in x - direction
&VENT MB='ZMAX' ,SURF_ID='OPEN' / to the outside in z -direction
&VENT MB='XMIN' ,SURF_ID='OPEN'/
&VENT MB='YMIN' ,SURF_ID='OPEN'/
&VENT MB='YMAX' ,SURF_ID='OPEN'/
&VENT MB='ZMIN' ,SURF_ID='WALL'/floor
&OBST XB=16.7,16.8,0.00,5.00,0.00,2.30,SURF_ID='WALL'/left front wall
&OBST XB=0.10,16.7,4.90,5.00,0.00,2.30,SURF_ID='WALL'/left wall
&OBST XB=0.10,16.7,0.00,0.10,0.00,2.30,SURF_ID='WALL'/right wall
&OBST XB=0.00,0.10,0.00,5.00,0.00,2.30,SURF_ID='WALL'/back wall
&OBST XB=0.00,16.8,0.00,5.00,2.30,2.40,SURF_ID='WALL'/ceiling

&OBST XB=0.10,2.60,0.10,1.80,0.00,2.30,SURF_ID='WALL'/ lower left obstr
&OBST XB=15.7,16.7,4.90,3.90,0.00,2.30,SURF_ID='WALL'/ upper right obstr
&OBST XB=2.60,4.80,4.90,3.90,0.00,2.30,SURF_ID='WALL'/ upper right obstr
&OBST XB=6.40,8.70,0.10,1.10,0.00,2.30,SURF_ID='WALL'/ lower left obstr

&OBST XB=13.3,13.4,4.90,3.90,0.00,2.30,SURF_ID='WALL'/ upper right wall
&OBST XB=5.50,5.60,4.90,3.00,0.00,2.30,SURF_ID='WALL'/ upper left wall
&OBST XB=5.50,5.60,1.10,2.00,0.00,2.40,SURF_ID='WALL'/ lower left wall
&OBST XB=8.70,8.80,0.10,1.60,0.00,2.40,SURF_ID='WALL'/ lower left wall
----------------------------------------------------------------

Materials
&MATL ID='FRP'
 FYI='FRANZ E'
 DENSITY=1870.
 CONDUCTIVITY_RAMP = 'k_FRP'
 SPECIFIC_HEAT_RAMP = 'c_FRP'
 EMISSIVITY = 0.8 /
```

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&RAMP ID='k_FRP', T= 80.0,  F=0.050 /
&RAMP ID='k_FRP', T= 150.0, F=0.051 /
&RAMP ID='k_FRP', T= 1200,  F=0.052 /

&RAMP ID='c_FRP', T= 20,   F=0.75 /
&RAMP ID='c_FRP', T= 80,   F=0.96  /
&RAMP ID='c_FRP', T= 180,  F=1.11  /
&RAMP ID='c_FRP', T= 1200, F=1.30  /

Materials
&MATL ID='comb'
 FYI='WIKI'
 DENSITY=500.
 CONDUCTIVITY = 0.03
 SPECIFIC_HEAT = 0.5
 EMISSIVITY = 0.8 /

&SURF ID='WALL'
 COLOR='GRAY'
 MATL_ID='FRP'
 THICKNESS=0.1
 BACKING='EXPOSED'/

Combustible material on the floor
&SURF ID='combustibles',
        HRRPUA=910,
        RAMP_Q='fire',
        MATL_ID='comb',
        TMP_FRONT=200.,
        THICKNESS=0.1,
        COLOR='RED' /
&RAMP ID='fire', T= 0.,      F=0.025 /
&RAMP ID='fire', T= 60.,     F=0.025 /
&RAMP ID='fire', T= 120.,    F=0.110 /
&RAMP ID='fire', T= 180.,    F=0.365 /
&RAMP ID='fire', T= 240.,    F=0.785 /
&RAMP ID='fire', T= 264.,    F=1.000 /
&RAMP ID='fire', T= 864.,    F=1.000 /
&RAMP ID='fire', T= 1000.,   F=0.000 /

&OBST
XB=2.5,3.5,2.0,3.0,0.00,0.30,SURF_IDS='combustibles','combustibles','combustibles'/

&DEVC ID='HD_1', PROP_ID='Acme Heat', XYZ=3.00,2.50,2.20 /
&DEVC ID='HD_2', PROP_ID='Acme Heat', XYZ=6.10,2.50,2.20 /
&DEVC ID='HD_3', PROP_ID='Acme Heat', XYZ=6.10,2.50,2.20 /
&DEVC ID='HD_4', PROP_ID='Acme Heat', XYZ=15.0,2.50,2.20 /

&PROP ID='Acme Heat', QUANTITY='LINK TEMPERATURE', RTI=20.,
ACTIVATION_TEMPERATURE = 57.0 /

&DEVC ID='SD_1', PROP_ID='Acme Smoke Detector', XYZ=3.00,2.50,2.20 /
&DEVC ID='SD_2', PROP_ID='Acme Smoke Detector', XYZ=6.10,2.50,2.20 /
&DEVC ID='SD_3', PROP_ID='Acme Smoke Detector', XYZ=6.10,2.50,2.20 /
&DEVC ID='SD_4', PROP_ID='Acme Smoke Detector', XYZ=15.0,2.50,2.20 /
```

&PROP ID='Acme Smoke Detector', QUANTITY='CHAMBER OBSCURATION', LENGTH=1.8, ACTIVATION_OBSCURATION=3.28 /

Output
&SLCF PBY=6.1, QUANTITY='TEMPERATURE' /Temperature
&SLCF PBY=6.1, QUANTITY='VELOCITY',VECTOR=.TRUE. /Flow
&SLCF PBY=6.1, QUANTITY='VISIBILITY' /Visibility
&BNDF QUANTITY= BURNING_RATE/
&BNDF QUANTITY='WALL_TEMPERATURE'/

Heat Flux gauge
&OBST XB=6.0,6.1,2.5,2.6,0.95,1.05,SURF_ID='WALL'/ heat flux meter
&DEVC XYZ=6.0, 2.5, 1.0, QUANTITY='GAUGE HEAT FLUX', ID='SB1',IOR=-1/

Temperatures in the middle of the room
&DEVC XYZ=6.1,2.5,1.60,QUANTITY='TEMPERATURE',ID='TC1'/
&DEVC XYZ=6.1,2.5,1.85,QUANTITY='TEMPERATURE',ID='TC2'/
&DEVC XYZ=6.1,2.5,2.00,QUANTITY='TEMPERATURE',ID='TC3'/
&DEVC XYZ=6.1,2.5,2.25,QUANTITY='TEMPERATURE',ID='TC4'/

Temperatures in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='TEMPERATURE',ID='TC5'/
&DEVC XYZ=10.5,2.5,1.85,QUANTITY='TEMPERATURE',ID='TC6'/
&DEVC XYZ=10.5,2.5,2.00,QUANTITY='TEMPERATURE',ID='TC7'/
&DEVC XYZ=10.5,2.5,2.25,QUANTITY='TEMPERATURE',ID='TC8'/

Temperatures in the middle of the room
&DEVC XYZ=15.0,2.5,1.60,QUANTITY='TEMPERATURE',ID='TC9'/
&DEVC XYZ=15.0,2.5,1.85,QUANTITY='TEMPERATURE',ID='TC10'/
&DEVC XYZ=15.0,2.5,2.00,QUANTITY='TEMPERATURE',ID='TC11'/
&DEVC XYZ=15.0,2.5,2.25,QUANTITY='TEMPERATURE',ID='TC12'/

Oxygen in the middle of the room
&DEVC XYZ=6.1,2.5,1.60,QUANTITY='oxygen',ID='O21'/
&DEVC XYZ=6.1,2.5,1.85,QUANTITY='oxygen',ID='O22'/
&DEVC XYZ=6.1,2.5,2.00,QUANTITY='oxygen',ID='O23'/
&DEVC XYZ=6.1,2.5,2.25,QUANTITY='oxygen',ID='O24'/

Oxygen in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='oxygen',ID='O25'/
&DEVC XYZ=10.5,2.5,1.85,QUANTITY='oxygen',ID='O26'/
&DEVC XYZ=10.5,2.5,2.00,QUANTITY='oxygen',ID='O27'/
&DEVC XYZ=10.5,2.5,2.25,QUANTITY='oxygen',ID='O28'/

Oxygen in the middle of the room
&DEVC XYZ=15.0,2.5,1.60,QUANTITY='oxygen',ID='O29'/
&DEVC XYZ=15.0,2.5,1.85,QUANTITY='oxygen',ID='O210'/
&DEVC XYZ=15.0,2.5,2.00,QUANTITY='oxygen',ID='O211'/
&DEVC XYZ=15.0,2.5,2.25,QUANTITY='oxygen',ID='O212'/

CO2 in the middle of the room
&DEVC XYZ=6.1,2.5,1.60,QUANTITY='carbon dioxide',ID='CO21'/
&DEVC XYZ=6.1,2.5,1.85,QUANTITY='carbon dioxide',ID='CO22'/
&DEVC XYZ=6.1,2.5,2.00,QUANTITY='carbon dioxide',ID='CO23'/

&DEVC XYZ=6.1,2.5,2.25,QUANTITY='carbon dioxide',ID='CO24'/

CO2 in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='carbon dioxide',ID='CO25'/
&DEVC XYZ=10.5,2.5,1.85,QUANTITY='carbon dioxide',ID='CO26'/
&DEVC XYZ=10.5,2.5,2.00,QUANTITY='carbon dioxide',ID='CO27'/
&DEVC XYZ=10.5,2.5,2.25,QUANTITY='carbon dioxide',ID='CO28'/

CO2 in the middle of the room
&DEVC XYZ=15.0,2.5,1.60,QUANTITY='carbon dioxide',ID='CO29'/
&DEVC XYZ=15.0,2.5,1.85,QUANTITY='carbon dioxide',ID='CO210'/
&DEVC XYZ=15.0,2.5,2.00,QUANTITY='carbon dioxide',ID='CO211'/
&DEVC XYZ=15.0,2.5,2.25,QUANTITY='carbon dioxide',ID='CO212'/

Layer height in the middle of the room
&DEVC XB=6.1,6.1,2.5,2.5,0.0,2.3,QUANTITY='LAYER HEIGHT',ID='L1'/
&DEVC XB=10.5,10.5,2.5,2.5,0.0,2.3,QUANTITY='LAYER HEIGHT',ID='L2'/
&DEVC XB=15,15,2.5,2.5,0.0,2.3,QUANTITY='LAYER HEIGHT',ID='L3'/

Visibility in the middle of the room
&DEVC XYZ=6.1,2.5,1.60,QUANTITY='VISIBILITY',ID='V1'/
&DEVC XYZ=6.1,2.5,1.85,QUANTITY='VISIBILITY',ID='V2'/
&DEVC XYZ=6.1,2.5,2.00,QUANTITY='VISIBILITY',ID='V3'/
&DEVC XYZ=6.1,2.5,2.25,QUANTITY='VISIBILITY',ID='V4'/

Visibility in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='VISIBILITY',ID='V5'/
&DEVC XYZ=10.5,2.5,1.85,QUANTITY='VISIBILITY',ID='V6'/
&DEVC XYZ=10.5,2.5,2.00,QUANTITY='VISIBILITY',ID='V7'/
&DEVC XYZ=10.5,2.5,2.25,QUANTITY='VISIBILITY',ID='V8'/

Visibility in the middle of the room
&DEVC XYZ=15.0,2.5,1.60,QUANTITY='VISIBILITY',ID='V9'/
&DEVC XYZ=15.0,2.5,1.85,QUANTITY='VISIBILITY',ID='V10'/
&DEVC XYZ=15.0,2.5,2.00,QUANTITY='VISIBILITY',ID='V11'/
&DEVC XYZ=15.0,2.5,2.25,QUANTITY='VISIBILITY',ID='V12'/

&TAIL /

Open doors between the accommodation space

&HEAD CHID='EKO_ship', TITLE='EKO Ship Johan Anderson' /
&MESH IJK=168,100,24, XB=0.0,16.8,-5.0,5.0,0.0,2.4 / 10 cm grid
&TIME T_END=500 /
&DUMP NFRAMES=500/ Measurements 500 times
&MISC RADIATION=.TRUE./
CO_PRODUCTION=.TRUE.

Geometry
&VENT MB='XMAX' ,SURF_ID='OPEN' / to the outside in x - direction
&VENT MB='ZMAX' ,SURF_ID='OPEN' / to the outside in z -direction
&VENT MB='XMIN' ,SURF_ID='OPEN'/
&VENT MB='YMIN' ,SURF_ID='OPEN'/
&VENT MB='YMAX' ,SURF_ID='OPEN'/
&VENT MB='ZMIN' ,SURF_ID='WALL'/floor

```
&OBST XB=16.7,16.8,0.00,5.00,0.00,2.30,SURF_ID='WALL'/left front wall
&OBST XB=0.10,16.7,4.90,5.00,0.00,2.30,SURF_ID='WALL'/left wall
&OBST XB=0.10,16.7,0.00,0.10,0.00,2.30,SURF_ID='WALL'/right wall
&OBST XB=0.00,0.10,0.00,5.00,0.00,2.30,SURF_ID='WALL'/back wall
&OBST XB=0.00,16.8,0.00,5.00,2.30,2.40,SURF_ID='WALL'/ceiling

&OBST XB=0.10,2.60,0.10,1.80,0.00,2.30,SURF_ID='WALL'/ lower left obstr
&OBST XB=15.7,16.7,4.90,3.90,0.00,2.30,SURF_ID='WALL'/ upper right obstr
&OBST XB=2.60,4.80,4.90,3.90,0.00,2.30,SURF_ID='WALL'/ upper right obstr
&OBST XB=4.40,8.70,0.10,1.10,0.00,2.30,SURF_ID='WALL'/ lower left obstr

&OBST XB=13.3,13.4,4.90,3.90,0.00,2.30,SURF_ID='WALL'/ upper right wall
&OBST XB=5.50,5.60,4.90,3.00,0.00,2.30,SURF_ID='WALL'/ upper left wall
&OBST XB=5.50,5.60,1.10,2.00,0.00,2.40,SURF_ID='WALL'/ lower left wall
&OBST XB=8.70,8.80,0.10,1.60,0.00,2.40,SURF_ID='WALL'/ lower left wall

&OBST XB=16.7,16.8,-5.00,0.00,0.00,2.30,SURF_ID='WALL'/left front wall
&OBST XB=0.10,16.7,-5.00,-4.90,0.00,2.30,SURF_ID='WALL'/left wall
&OBST XB=0.00,0.10,-5.00,0.00,0.00,2.30,SURF_ID='WALL'/back wall
&OBST XB=0.00,16.8,-5.00,0.00,2.30,2.40,SURF_ID='WALL'/ceiling

&OBST XB=0.10,2.60,-1.70,-0.10,0.00,2.30,SURF_ID='WALL'/ lower left obstr
&OBST XB=15.7,16.7,-4.90,-3.80,0.00,2.30,SURF_ID='WALL'/ upper right obstr
&OBST XB=2.60,4.80,-4.90,-3.80,0.00,2.30,SURF_ID='WALL'/ upper right obstr
&OBST XB=4.40,8.70,-1.10,-0.10,0.00,2.30,SURF_ID='WALL'/ lower left obstr

&OBST XB=13.3,13.4,-4.90,-3.90,0.00,2.30,SURF_ID='WALL'/ upper right wall
&OBST XB=5.50,5.60,-4.90,-3.00,0.00,2.30,SURF_ID='WALL'/ upper left wall
&OBST XB=5.50,5.60,-2.00,-1.10,0.00,2.40,SURF_ID='WALL'/ lower left wall
&OBST XB=8.70,8.80,-1.60,-0.10,0.00,2.40,SURF_ID='WALL'/ lower left wall

&HOLE XB=15.6,16.5,-0.10,0.20,0.00,2.30,/door 1
&HOLE XB=3.00,4.80,-0.10,0.20,0.00,2.30,/door 2
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Materials
&MATL ID='FRP'
 FYI='FRANZ E'
 DENSITY=1870.
 CONDUCTIVITY_RAMP= 'k_FRP'
 SPECIFIC_HEAT_RAMP= 'c_FRP'
 EMISSIVITY=0.8 /
&RAMP ID='k_FRP', T= 80.0,  F=0.050 /
&RAMP ID='k_FRP', T= 150.0, F=0.051 /
&RAMP ID='k_FRP', T= 1200,  F=0.052 /

&RAMP ID='c_FRP', T= 20,   F=0.75 /
&RAMP ID='c_FRP', T= 80,   F=0.96  /
&RAMP ID='c_FRP', T= 180,  F=1.11  /
&RAMP ID='c_FRP', T= 1200, F=1.30  /

Materials
&MATL ID='comb'
 FYI='WIKI'
 DENSITY=500.
 CONDUCTIVITY = 0.03
```

```
 SPECIFIC_HEAT = 0.5
 EMISSIVITY = 0.8 /

&SURF ID='WALL'
 COLOR='GRAY'
 MATL_ID='FRP'
 THICKNESS=0.1
 BACKING='EXPOSED'/

Combustible material on the floor
&SURF ID='combustibles',
        HRRPUA=910,
        RAMP_Q='fire',
        MATL_ID='comb',
        TMP_FRONT=200.,
        THICKNESS=0.1,
        COLOR='RED' /
&RAMP ID='fire', T= 0.,      F=0.025 /
&RAMP ID='fire', T= 60.,     F=0.025 /
&RAMP ID='fire', T= 120.,    F=0.110 /
&RAMP ID='fire', T= 180.,    F=0.365 /
&RAMP ID='fire', T= 240.,    F=0.785 /
&RAMP ID='fire', T= 264.,    F=1.000 /
&RAMP ID='fire', T= 864.,    F=1.000 /
&RAMP ID='fire', T= 1000.,   F=0.000 /

&OBST
XB=2.5,3.5,2.0,3.0,0.00,0.30,SURF_IDS='combustibles','combustibles','combustibles'/

&DEVC ID='HD_1', PROP_ID='Acme Heat', XYZ=3.00,2.50,2.20 /
&DEVC ID='HD_2', PROP_ID='Acme Heat', XYZ=6.10,2.50,2.20 /
&DEVC ID='HD_3', PROP_ID='Acme Heat', XYZ=10.5,2.50,2.20 /
&DEVC ID='HD_4', PROP_ID='Acme Heat', XYZ=15.0,2.50,2.20 /

&DEVC ID='HD_1', PROP_ID='Acme Heat', XYZ=3.00,-2.50,2.20 /
&DEVC ID='HD_2', PROP_ID='Acme Heat', XYZ=6.10,-2.50,2.20 /
&DEVC ID='HD_3', PROP_ID='Acme Heat', XYZ=10.5,-2.50,2.20 /
&DEVC ID='HD_4', PROP_ID='Acme Heat', XYZ=15.0,-2.50,2.20 /

&PROP ID='Acme Heat', QUANTITY='LINK TEMPERATURE', RTI=20.,
ACTIVATION_TEMPERATURE = 57.0 /

&DEVC ID='SD_1', PROP_ID='Acme Smoke Detector', XYZ=3.00,2.50,2.20 /
&DEVC ID='SD_2', PROP_ID='Acme Smoke Detector', XYZ=6.10,2.50,2.20 /
&DEVC ID='SD_3', PROP_ID='Acme Smoke Detector', XYZ=10.5,2.50,2.20 /
&DEVC ID='SD_4', PROP_ID='Acme Smoke Detector', XYZ=15.0,2.50,2.20 /

&DEVC ID='SD_1', PROP_ID='Acme Smoke Detector', XYZ=3.00,-2.50,2.20 /
&DEVC ID='SD_2', PROP_ID='Acme Smoke Detector', XYZ=6.10,-2.50,2.20 /
&DEVC ID='SD_3', PROP_ID='Acme Smoke Detector', XYZ=10.5,-2.50,2.20 /
&DEVC ID='SD_4', PROP_ID='Acme Smoke Detector', XYZ=15.0,-2.50,2.20 /

&PROP ID='Acme Smoke Detector', QUANTITY='CHAMBER OBSCURATION',
LENGTH=1.8, ACTIVATION_OBSCURATION=3.28 /
```

```
Outputs
&SLCF PBY=2.5, QUANTITY='TEMPERATURE' /Temperature
&SLCF PBY=-2.5, QUANTITY='TEMPERATURE' /Temperature
&SLCF PBY=2.5, QUANTITY='VISIBILITY' /Visibility
&SLCF PBY=-2.5, QUANTITY='VISIBILITY' /Visibility
&BNDF QUANTITY= BURNING_RATE/
&BNDF QUANTITY='WALL_TEMPERATURE'/

FIRE ROOM DATA
Heat Flux gauge
&OBST XB=6.0,6.1,2.5,2.6,0.95,1.05,SURF_ID='WALL'/ heat flux meter
&DEVC XYZ=6.0, 2.5, 1.0, QUANTITY='GAUGE HEAT FLUX', ID='SB1',IOR=-1/

Temperatures in the middle of the room
&DEVC XYZ=6.1,2.5,1.60,QUANTITY='TEMPERATURE',ID='TC1'/
&DEVC XYZ=6.1,2.5,1.85,QUANTITY='TEMPERATURE',ID='TC2'/
&DEVC XYZ=6.1,2.5,2.00,QUANTITY='TEMPERATURE',ID='TC3'/
&DEVC XYZ=6.1,2.5,2.25,QUANTITY='TEMPERATURE',ID='TC4'/

Temperatures in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='TEMPERATURE',ID='TC5'/
&DEVC XYZ=10.5,2.5,1.85,QUANTITY='TEMPERATURE',ID='TC6'/
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Temperatures in the middle of the room
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&DEVC XYZ=6.1,2.5,2.25,QUANTITY='oxygen',ID='O24'/

Oxygen in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='oxygen',ID='O25'/
&DEVC XYZ=10.5,2.5,1.85,QUANTITY='oxygen',ID='O26'/
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&DEVC XYZ=10.5,2.5,2.25,QUANTITY='oxygen',ID='O28'/

Oxygen in the middle of the room
&DEVC XYZ=15.0,2.5,1.60,QUANTITY='oxygen',ID='O29'/
&DEVC XYZ=15.0,2.5,1.85,QUANTITY='oxygen',ID='O210'/
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&DEVC XYZ=15.0,2.5,2.25,QUANTITY='oxygen',ID='O212'/

CO2 in the middle of the room
&DEVC XYZ=6.1,2.5,1.60,QUANTITY='carbon dioxide',ID='CO21'/
&DEVC XYZ=6.1,2.5,1.85,QUANTITY='carbon dioxide',ID='CO22'/
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&DEVC XYZ=6.1,2.5,2.25,QUANTITY='carbon dioxide',ID='CO24'/
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CO2 in the middle of the room
&DEVC XYZ=10.5,2.5,1.60,QUANTITY='carbon dioxide',ID='CO25'/
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&DEVC XYZ=10.5,2.5,2.25,QUANTITY='carbon dioxide',ID='CO28'/

CO2 in the middle of the room
&DEVC XYZ=15.0,2.5,1.60,QUANTITY='carbon dioxide',ID='CO29'/
&DEVC XYZ=15.0,2.5,1.85,QUANTITY='carbon dioxide',ID='CO210'/
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Visibility in the middle of the room
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Visibility in the middle of the room
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Visibility in the middle of the room
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NON FIRE ROOM DATA
Temperatures in the middle of the room
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Temperatures in the middle of the room
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&DEVC XYZ=10.5,-2.5,1.85,QUANTITY='TEMPERATURE',ID='TC6'/
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Temperatures in the middle of the room
&DEVC XYZ=15.0,-2.5,1.60,QUANTITY='TEMPERATURE',ID='TC9'/
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&DEVC XYZ=15.0,-2.5,2.25,QUANTITY='TEMPERATURE',ID='TC12'/

Oxygen in the middle of the room
```

&DEVC XYZ=6.1,-2.5,1.60,QUANTITY='oxygen',ID='O21'/
&DEVC XYZ=6.1,-2.5,1.85,QUANTITY='oxygen',ID='O22'/
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&DEVC XYZ=6.1,-2.5,2.25,QUANTITY='oxygen',ID='O24'/

Oxygen in the middle of the room
&DEVC XYZ=10.5,-2.5,1.60,QUANTITY='oxygen',ID='O25'/
&DEVC XYZ=10.5,-2.5,1.85,QUANTITY='oxygen',ID='O26'/
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&DEVC XYZ=10.5,-2.5,2.25,QUANTITY='oxygen',ID='O28'/

Oxygen in the middle of the room
&DEVC XYZ=15.0,-2.5,1.60,QUANTITY='oxygen',ID='O29'/
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&DEVC XYZ=15.0,-2.5,2.00,QUANTITY='oxygen',ID='O211'/
&DEVC XYZ=15.0,-2.5,2.25,QUANTITY='oxygen',ID='O212'/

CO2 in the middle of the room
&DEVC XYZ=6.1,-2.5,1.60,QUANTITY='carbon dioxide',ID='CO21'/
&DEVC XYZ=6.1,-2.5,1.85,QUANTITY='carbon dioxide',ID='CO22'/
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&DEVC XYZ=6.1,-2.5,2.25,QUANTITY='carbon dioxide',ID='CO24'/

CO2 in the middle of the room
&DEVC XYZ=10.5,-2.5,1.60,QUANTITY='carbon dioxide',ID='CO25'/
&DEVC XYZ=10.5,-2.5,1.85,QUANTITY='carbon dioxide',ID='CO26'/
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&DEVC XYZ=10.5,-2.5,2.25,QUANTITY='carbon dioxide',ID='CO28'/

CO2 in the middle of the room
&DEVC XYZ=15.0,-2.5,1.60,QUANTITY='carbon dioxide',ID='CO29'/
&DEVC XYZ=15.0,-2.5,1.85,QUANTITY='carbon dioxide',ID='CO210'/
&DEVC XYZ=15.0,-2.5,2.00,QUANTITY='carbon dioxide',ID='CO211'/
&DEVC XYZ=15.0,-2.5,2.25,QUANTITY='carbon dioxide',ID='CO212'/

Layer height in the middle of the room
&DEVC XB=6.1,6.1,-2.5,-2.5,0.0,2.3,QUANTITY='LAYER HEIGHT',ID='L1'/
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&DEVC XB=15,15,-2.5,-2.5,0.0,2.3,QUANTITY='LAYER HEIGHT',ID='L3'/

Visibility in the middle of the room
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&DEVC XYZ=6.1,-2.5,1.85,QUANTITY='VISIBILITY',ID='V2'/
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&DEVC XYZ=6.1,-2.5,2.25,QUANTITY='VISIBILITY',ID='V4'/

Visibility in the middle of the room
&DEVC XYZ=10.5,-2.5,1.60,QUANTITY='VISIBILITY',ID='V5'/
&DEVC XYZ=10.5,-2.5,1.85,QUANTITY='VISIBILITY',ID='V6'/
&DEVC XYZ=10.5,-2.5,2.00,QUANTITY='VISIBILITY',ID='V7'/
&DEVC XYZ=10.5,-2.5,2.25,QUANTITY='VISIBILITY',ID='V8'/

Visibility in the middle of the room
&DEVC XYZ=15.0,-2.5,1.60,QUANTITY='VISIBILITY',ID='V9'/
&DEVC XYZ=15.0,-2.5,1.85,QUANTITY='VISIBILITY',ID='V10'/

```
&DEVC XYZ=15.0,-2.5,2.00,QUANTITY='VISIBILITY',ID='V11'/
&DEVC XYZ=15.0,-2.5,2.25,QUANTITY='VISIBILITY',ID='V12'/

&TAIL /
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Results of FDS simulations

In determining the available time until critical conditions are reached in the accommodation space in case of fire, simulations were performed using the software Fire Dynamics Simulator [35]. They also helped to determine other conditions affecting the fire development, e.g. the probability of window breakage.

Two fundamentally different models were set up, one simulating the conditions in case the accommodation space is subdivided longitudinally (and all separating doors close properly) and one representing the case where there are openings between the port and starboard sides in the aft and the forward parts of the accommodation space. The results from these simulations are presented below in Figures L1-L18.

Conditions in the accommodation space in case doors are closed

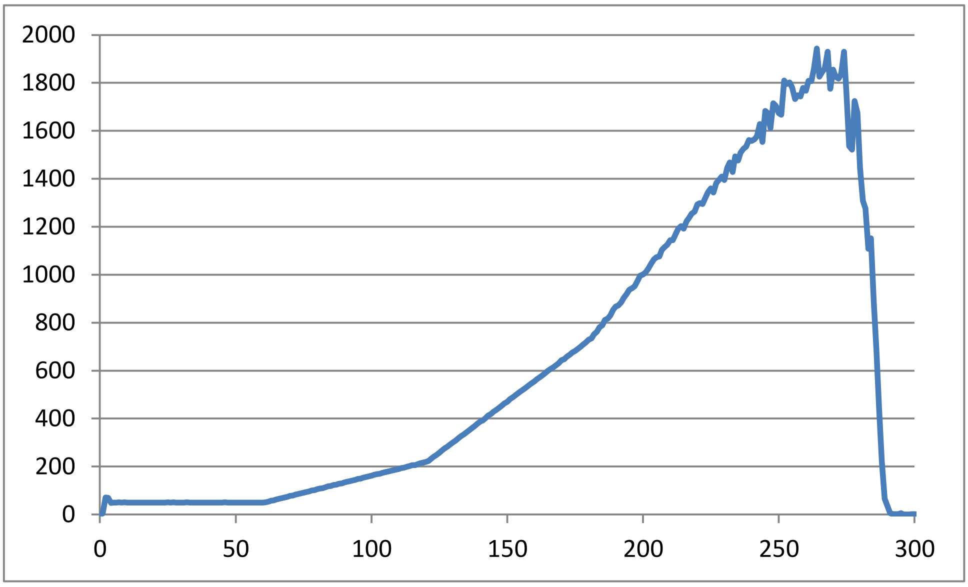


Figure L1. Heat release rate [kW/m^2] versus time[s] in the fire scenario (the fire self-extinguishes after approximately 270 s).

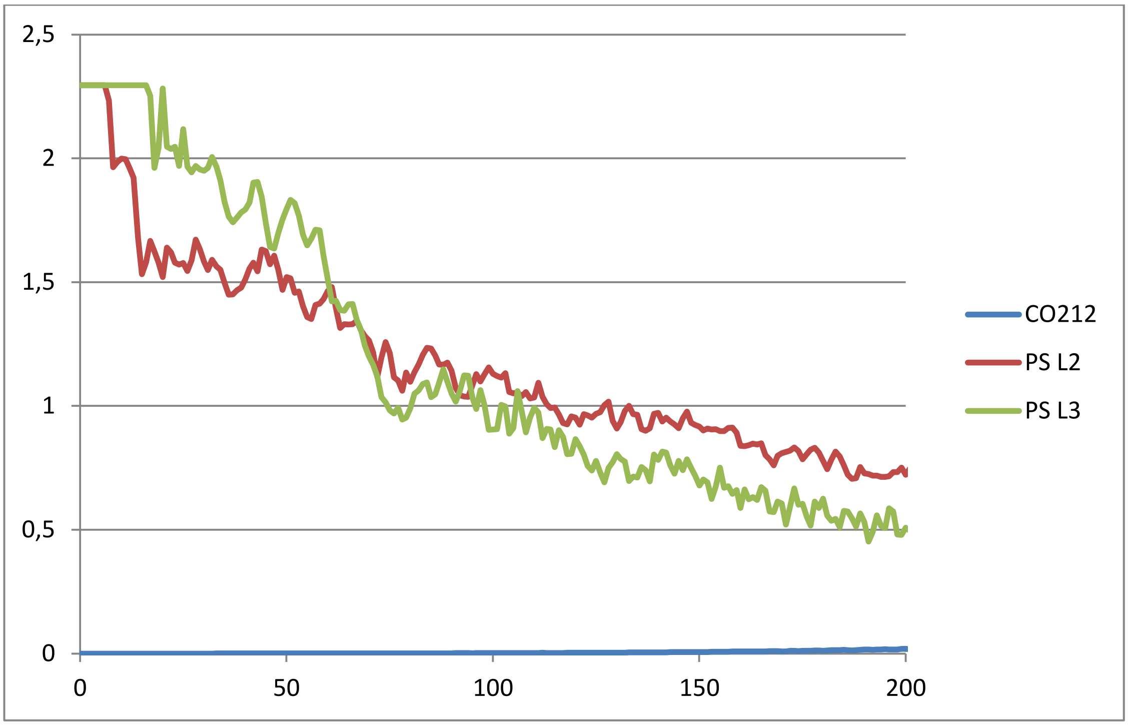


Figure L2. Layer height [m above the floor] versus time [s] measured at different locations on port side of the accommodation space.

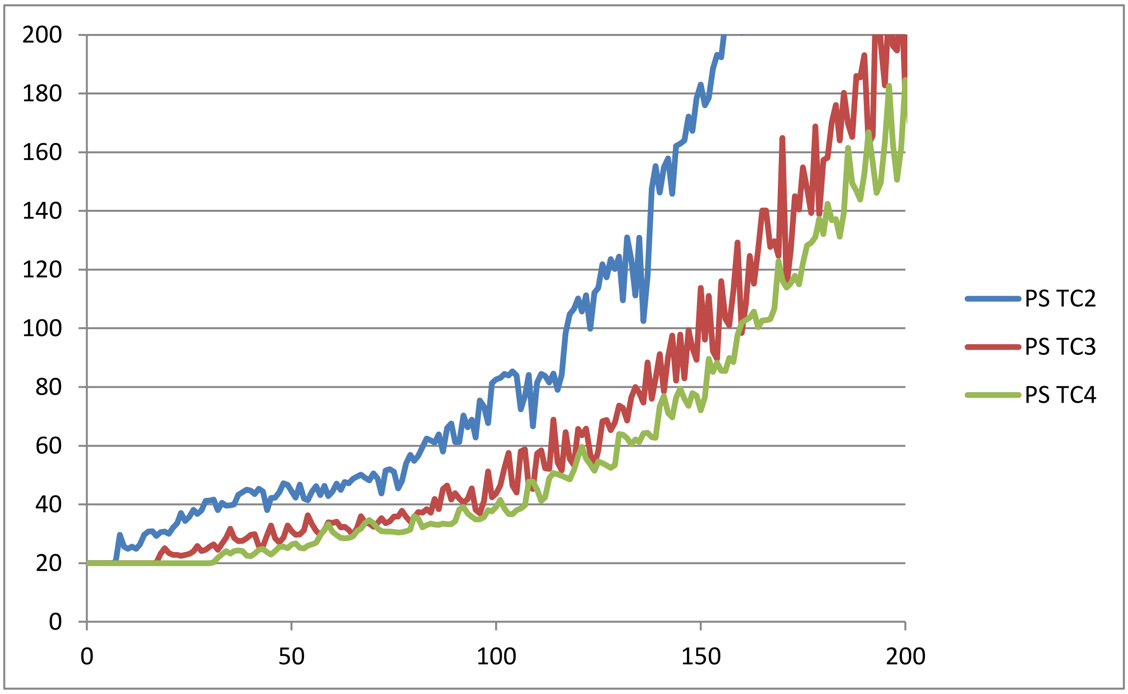


Figure L3. Gas temperature [°C] versus time [s] at 2.0 meters from the floor at different locations of the accommodation space (60°C is reached after about 80 s and 120 s at locations 2 and 3 and 80°C is reached after about 100 s and 140 s in these locations).

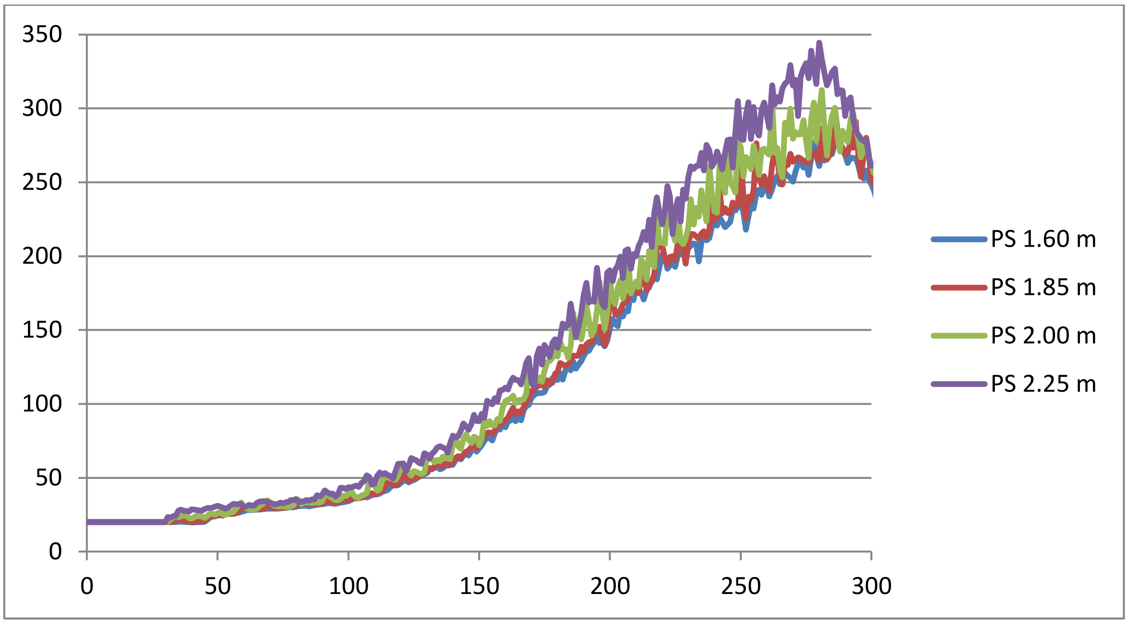


Figure L4. Gas temperature [°C] versus time [s] at different heights at location 4 (60°C is reached after about 130 s and 80°C is reached after about 150 s at a height 2.0 m).

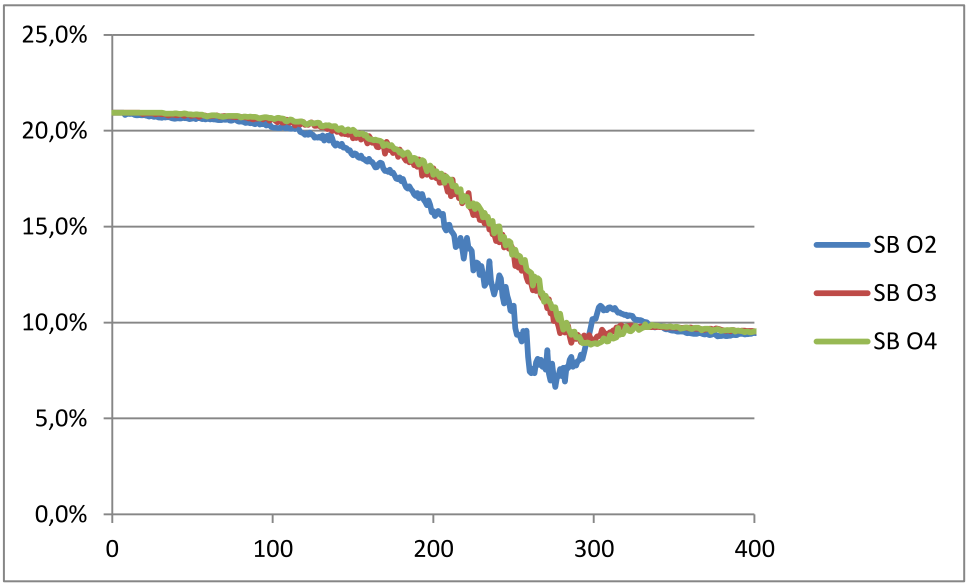


Figure L5. Oxygen concentration [mol%] versus time [s] at 2.0 meters from the floor at different locations of the accommodation space (untenable conditions are reached after about 235 s at location 4).

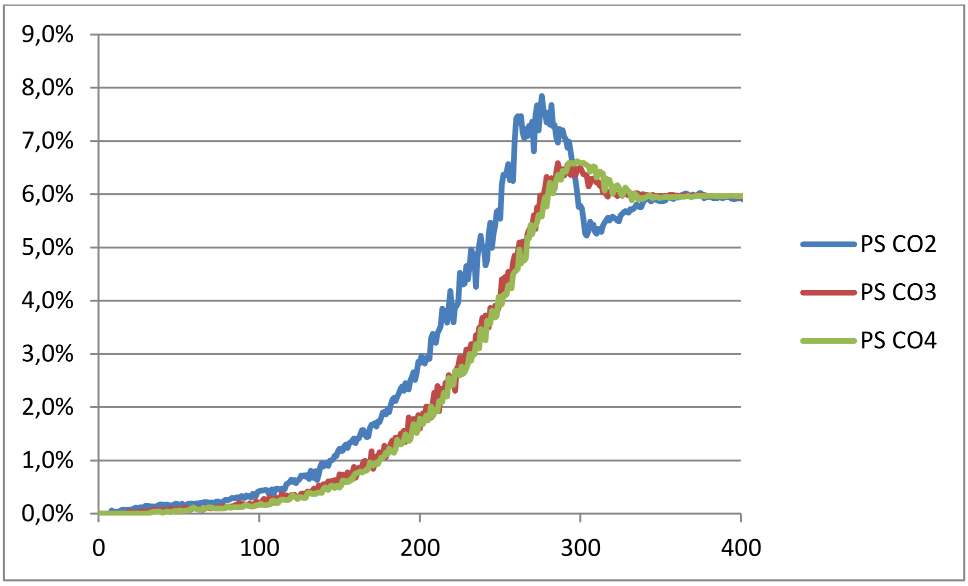


Figure L6. Carbon dioxide concentration [mol%] versus time [s] at 2.0 m from the floor at different locations (untenable conditions are reached after about 265 s at location 4).

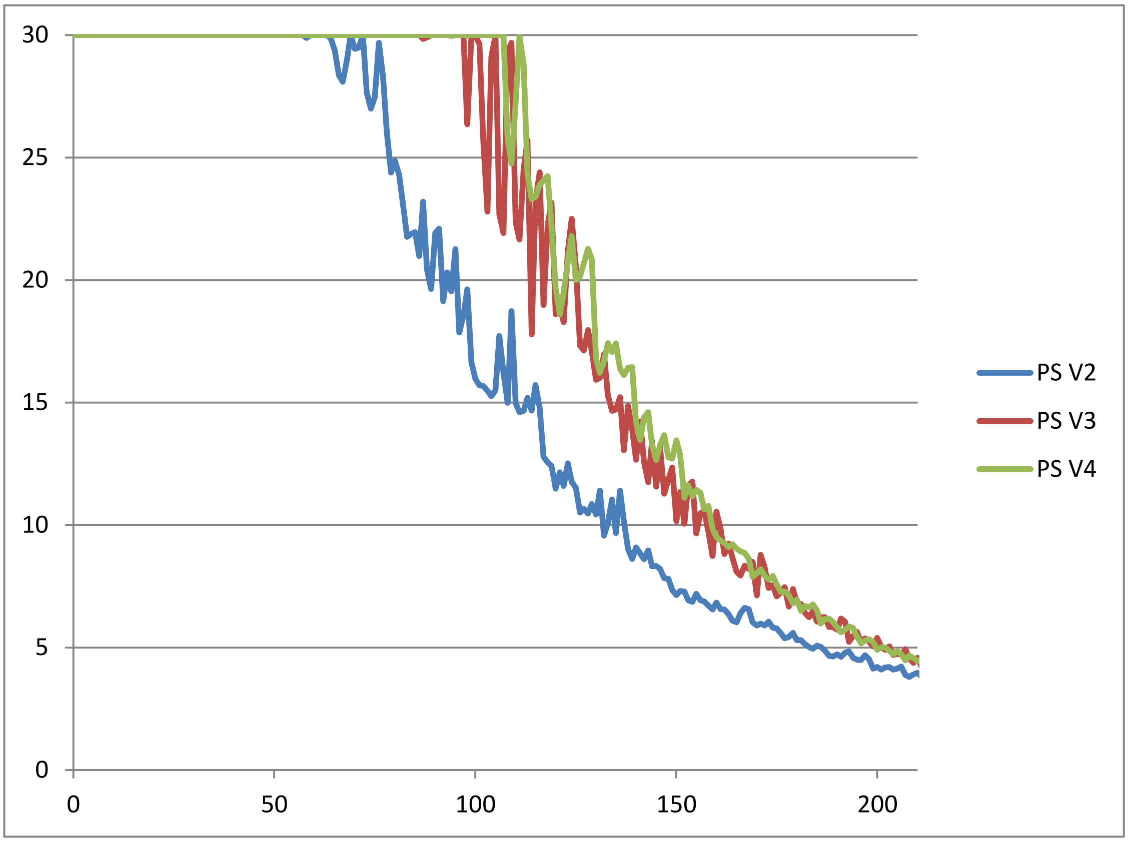


Figure L7. Visibility [m] versus time [s] at 2.0 m from the floor at different locations (untenable conditions are reached after about 160 s at location 4).

Conditions in the accommodation space in case doors are open

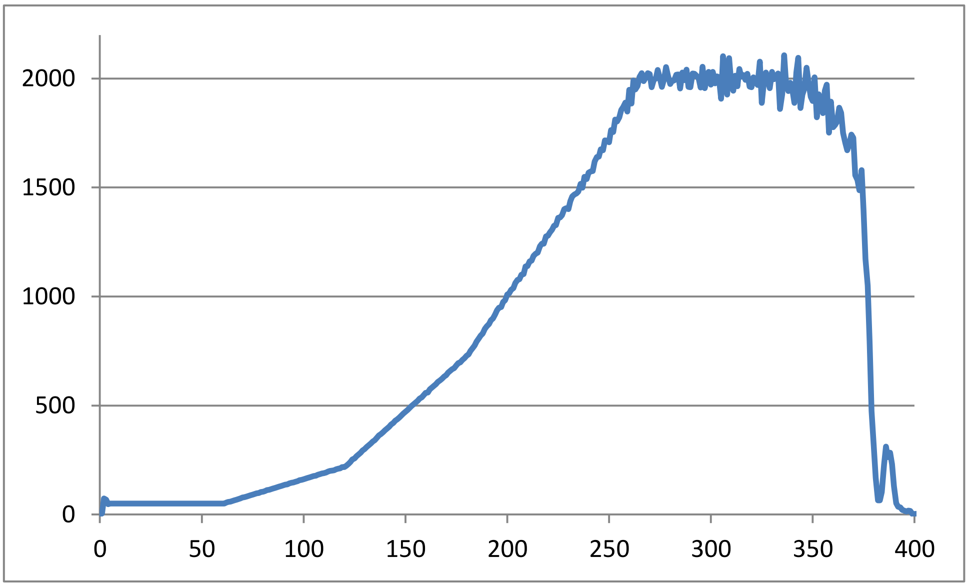


Figure L8. Heat release rate [kW/m^2] versus time[s] in the fire scenario (the fire self-extinguishes after approximately 360 s).

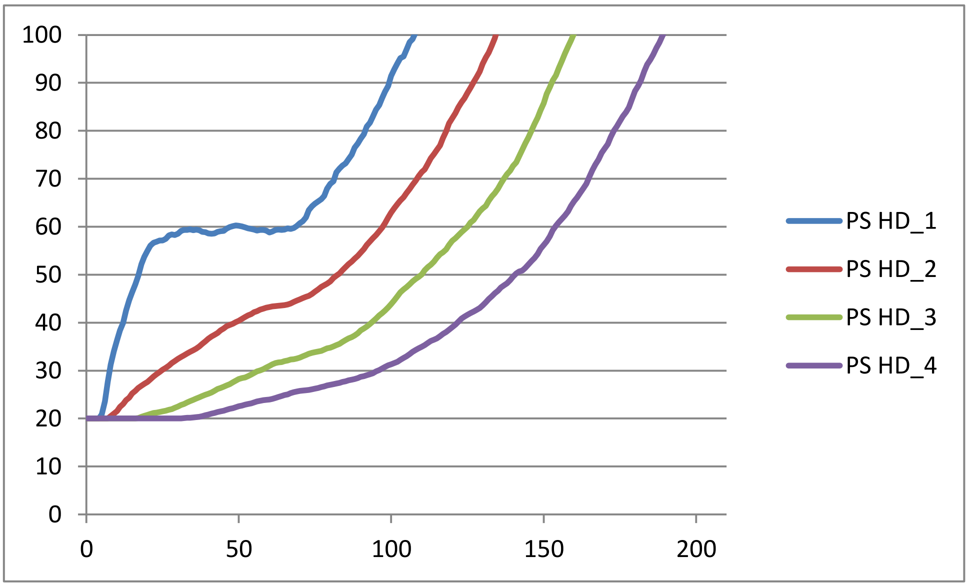


Figure L9. Detected temperature by heat detectors (sprinkler bulbs) [°C] versus time [s] in the ceiling (activation occurs at 57°C, i.e. after approximately 93 s in location 2 and after approximately 120 s in location 3).

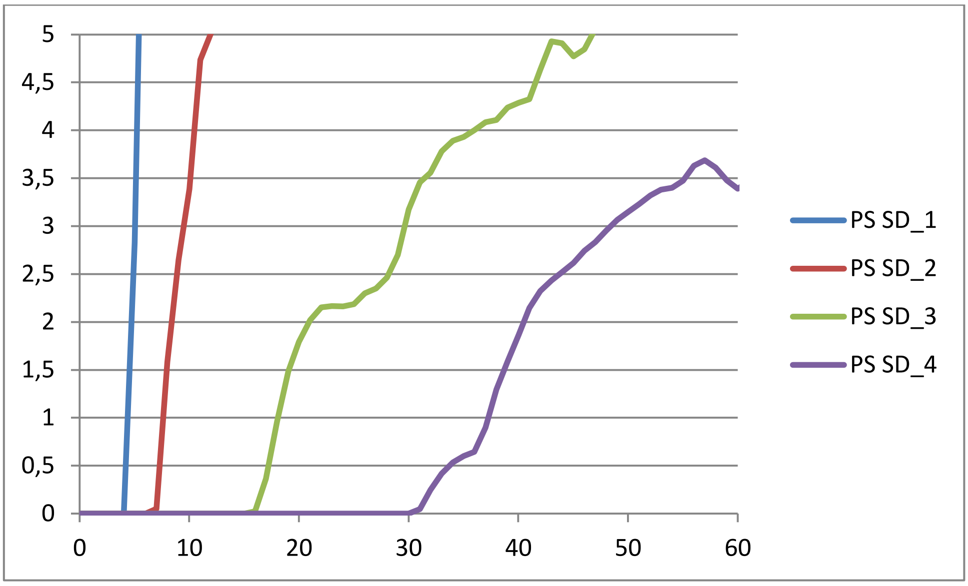


Figure L10. Smoke density [%/m] versus time [s] detected by smoke detectors at different locations in the ceiling (activation occurs after approximately 6, 10, 31 and 52 s at each location respectively].

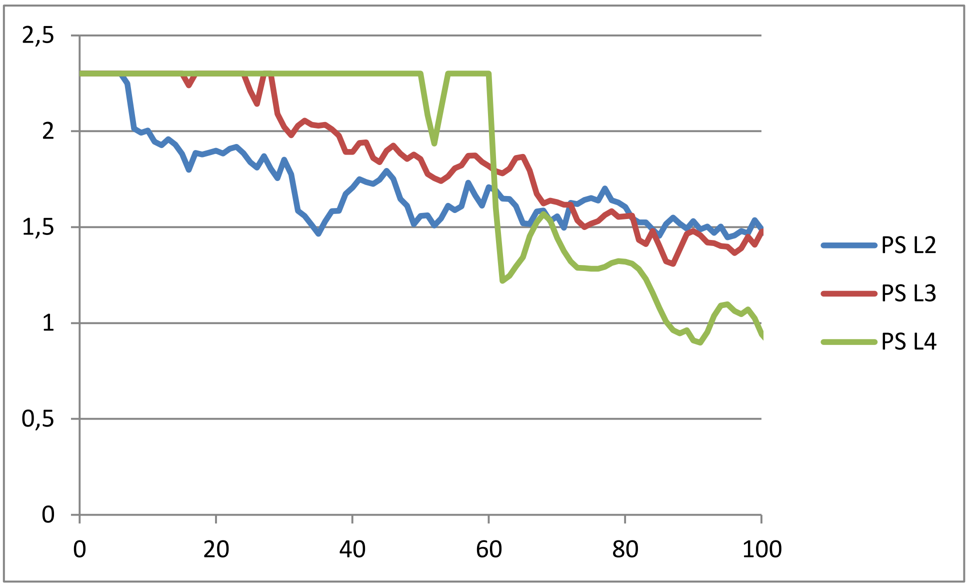


Figure L11. Layer height [m above the floor] versus time [s] measured at different locations on port side of the accommodation space.

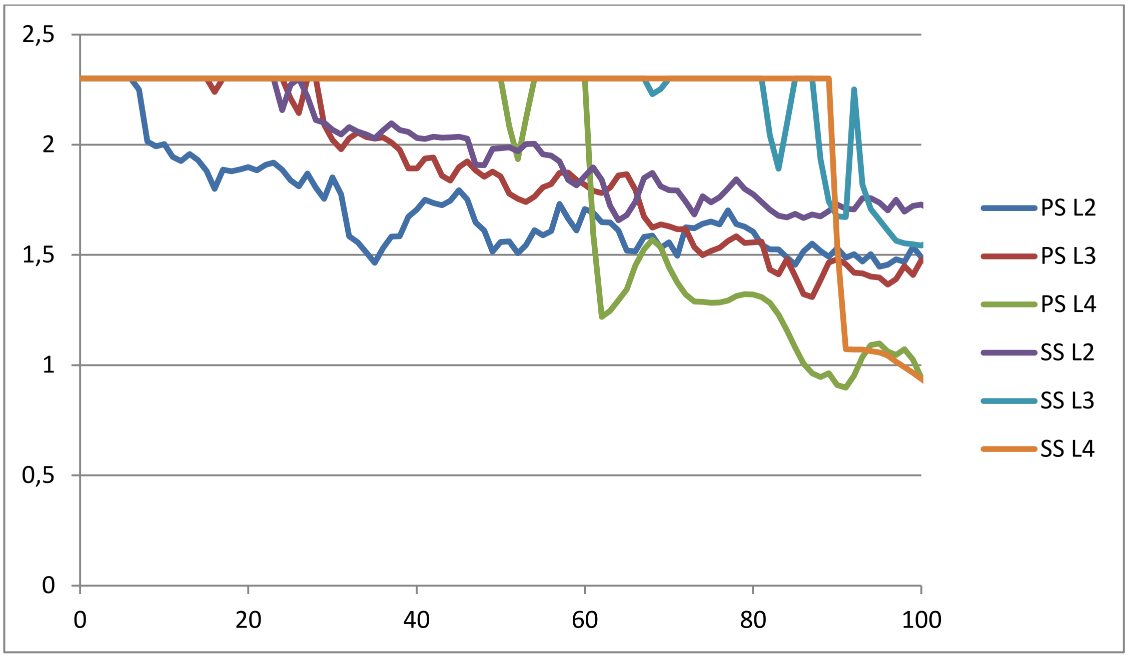


Figure L12. Layer height of the smoke layer [m above the floor] versus time [s] measured at different locations on port and starboard side of the accommodation space.

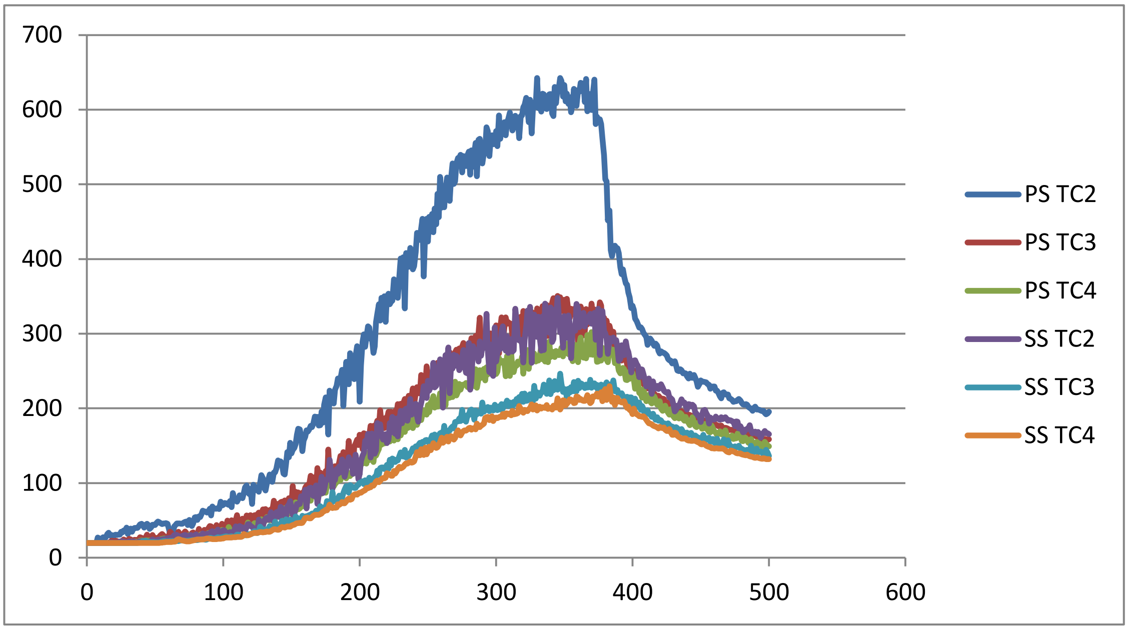


Figure L13. Gas temperature [°C] versus time [s] at 2.0 meters from the floor at different locations of the accommodation space.

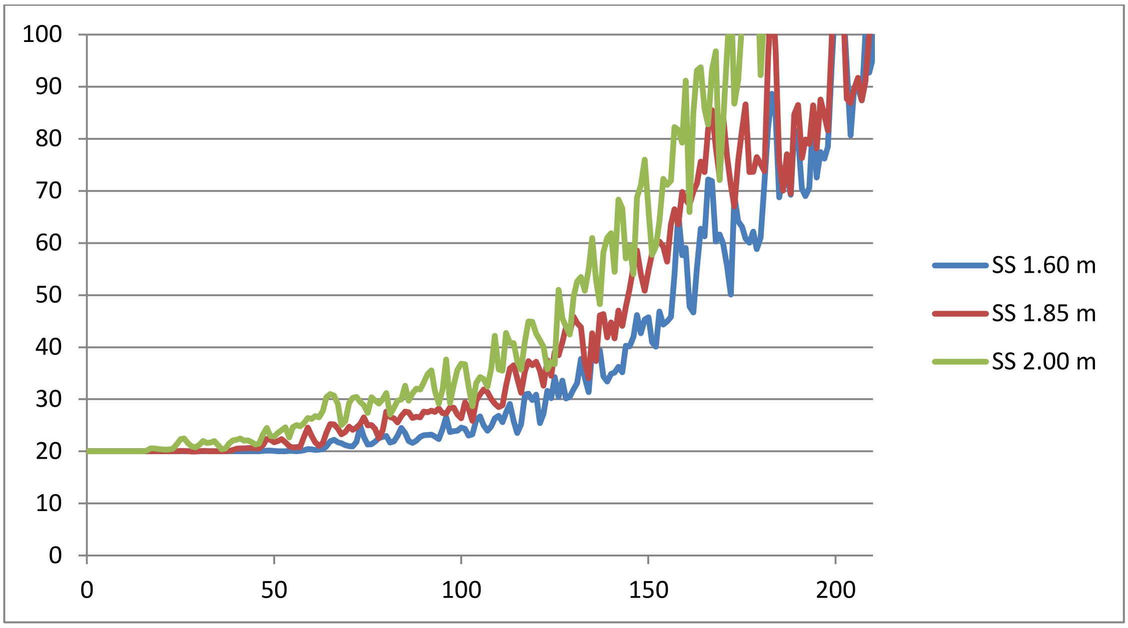


Figure L14. Gas temperature [°C] versus time [s] at location 2 (60°C is reached after about 140, 154 and 168 s at the different heights, respectively, and 80°C is reached after about 160, 177 and 190 s).

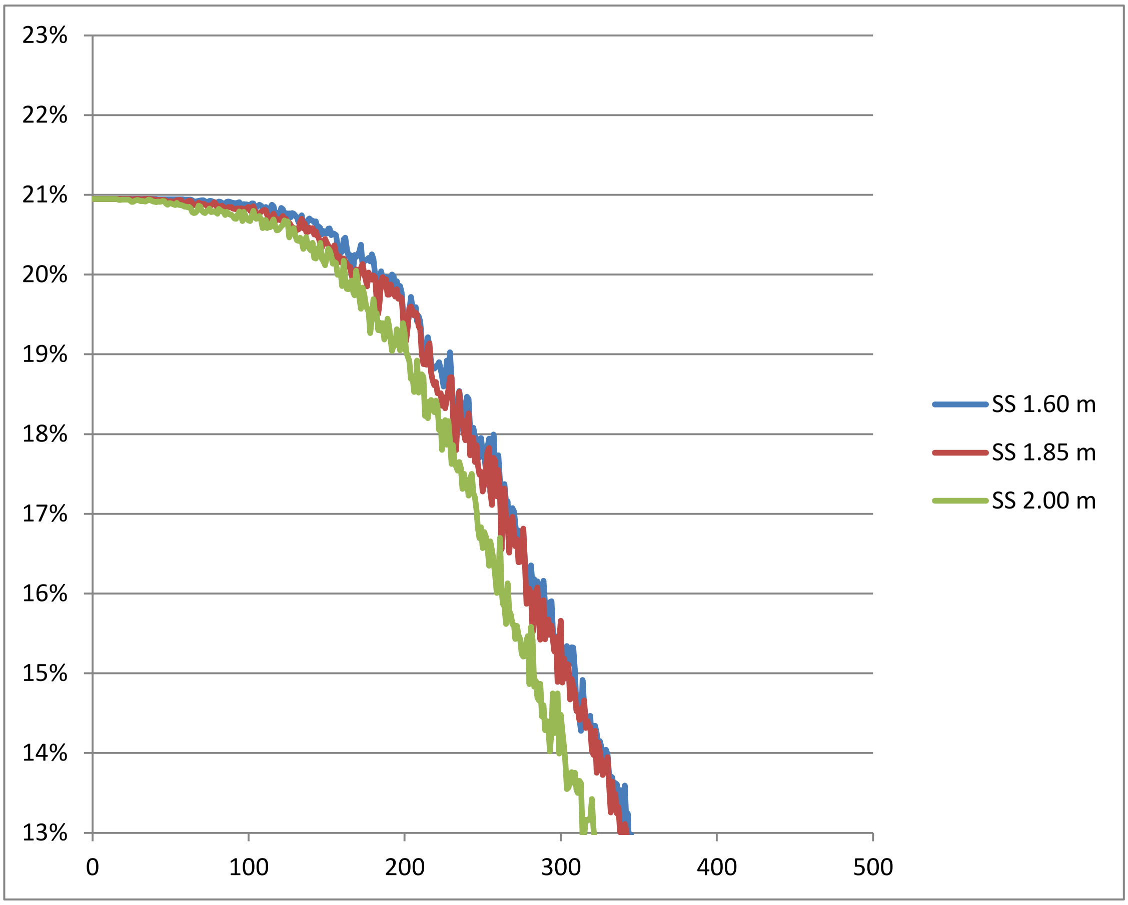


Figure L15. Oxygen concentration [mol%] versus time [s] at location 2 (untenable conditions at 2.0 m are not reached until after approximately 280 s.

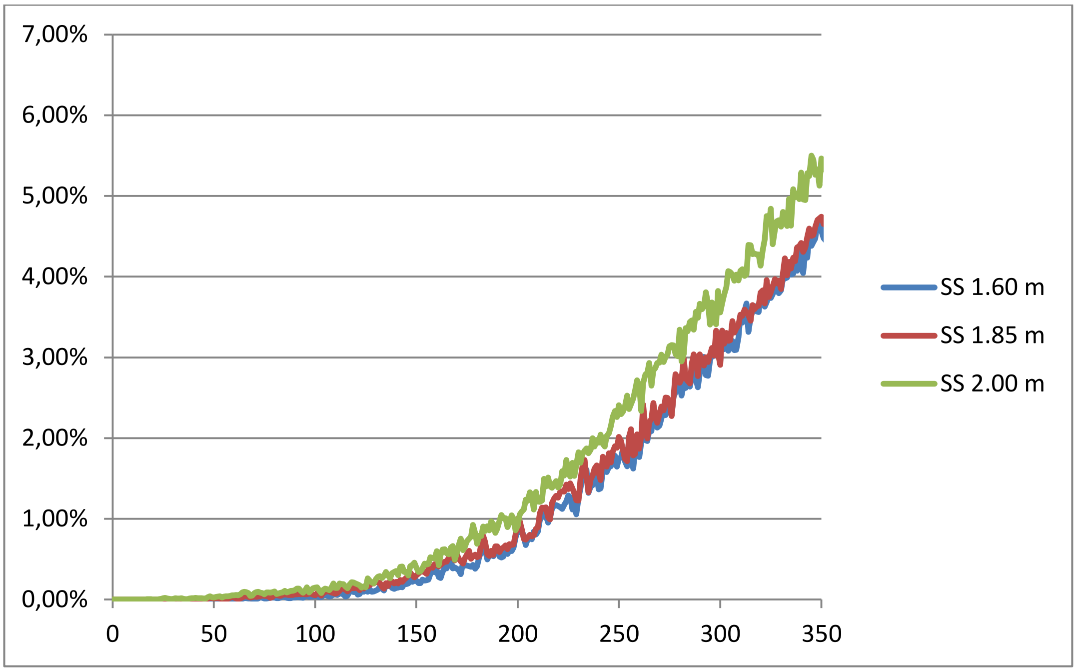


Figure L16. Carbon dioxide concentration [mol%] versus time [s] at location 2 (untenable conditions at 2.0 m are not reached until after approximately 335 s.

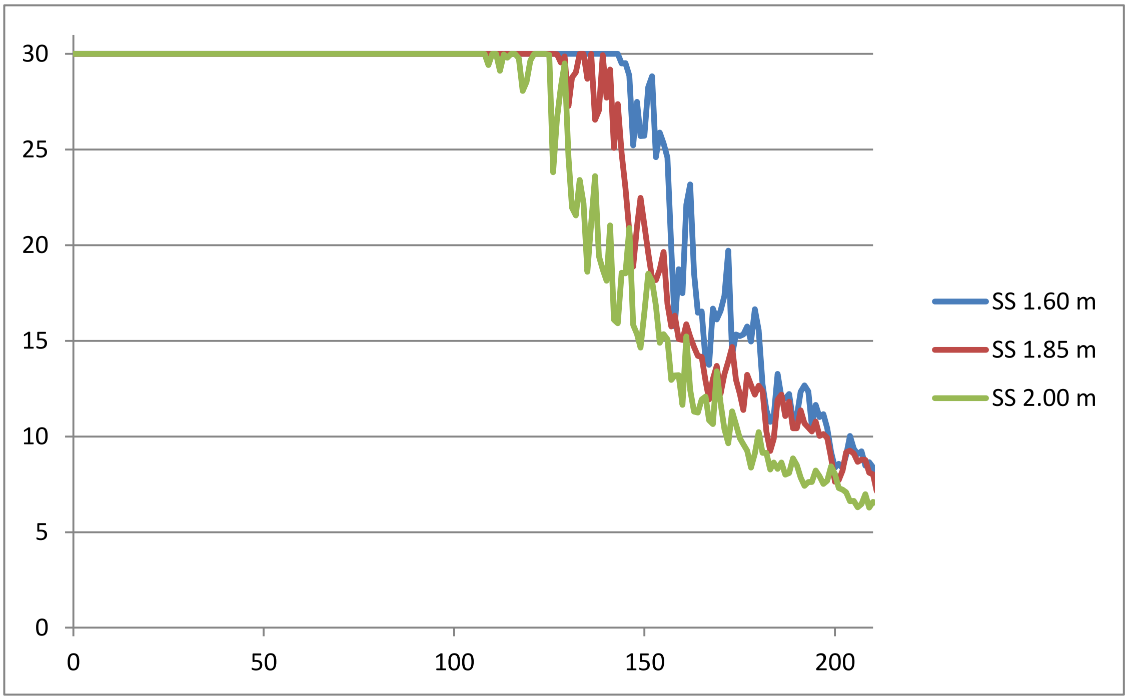


Figure L17. Visibility [m] versus time [s] at different heights at location 2 on starboard side of the accommodation space (untenable conditions reached after approximately 175 s at 2.0 m and after approximately 195 s at 1.85 m and 1.60 m).

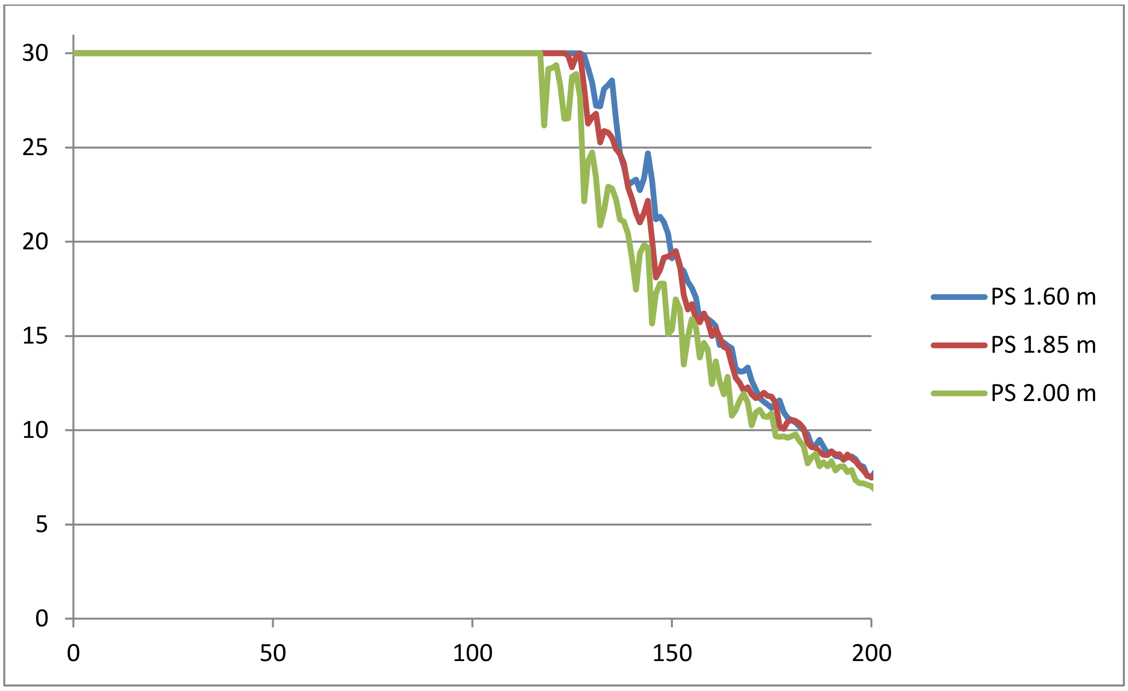


Figure L18. Visibility [m] versus time [s] at different heights at location 4 on port side of the accommodation space (untenable conditions reached after approximately 175 s at 2.0 m and after approximately 180 s at 1.85 m and 1.60 m).

Result files from Simulex simulations

In fire evacuation theory [e.g. 41], the evacuation time is said to consist of:

$$evacuation\ time = recognition\ time + response\ time + movement\ time$$

In determining the time required for safely evacuating the passengers in in case of an accommodation space fire scenario, simulations were performed using the software Simulex [42]. It was determined above that the function of the detection and alarm system (and connected door-closing devices) affects the recognition time. The different conditions in the base design and prescriptive design will also affect the response time in case the smoke and alarm system is functional. These conditions also affect the movement times and thereby the evacuation times in these scenarios. Hence, three different evacuation simulations were performed. The result files from these simulations are documented subsequently.

Evacuation result in case smoke and alarm system functions in the prescriptive design

Number of Floors = 2
Number of Staircases = 1
Number of Exits = 2
Number of Links = 2
Number of People = 101

Deck 2 (DXF file: 050-091-0101-...dxf) (Size: 30.732,10.050 metres)
Number of People Initially in This Floor = 101
Link 1 : (15.40,5.50 m), 0.00 degrees, 0.90 m wide, connected to Stairway
Sb exit : (11.10,3.45 m), -66.04 degrees, 0.80 m wide

Deck 3 (DXF file: 050-091-0101-...dxf) (Size: 30.733,10.050 metres)
Number of People Initially in This Floor = 0
Link 2 : (18.88,5.47 m), -148.57 degrees, 0.90 m wide, connected to Stairway
Open exit : (19.19,6.54 m), -90.00 degrees, 0.80 m wide

Stairway (Size: 0.900,3.500 metres)
Number of People Initially in This Stair = 0
Link 1 : (0.47,0.00 m), 270.00 degrees, 0.90 m wide, connected to Deck 2
Link 2 : (0.45,3.50 m), 90.00 degrees, 0.90 m wide, connected to Deck 3

All people reached the exit in 3:41.9.

Number of people through all exits over 5-second periods
Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0

60	0
65	0
70	0
75	0
80	0
85	1
90	1
95	1
100	1
105	3
110	3
115	1
120	3
125	4
130	5
135	5
140	3
145	3
150	6
155	3
160	4
165	3
170	4
175	4
180	5
185	6
190	5
195	4
200	4
205	6
210	4
215	4
220	3
225	2

Number of people through Sb exit over 5-second periods
Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	1
90	1

95	1
100	1
105	3
110	3
115	1
120	3
125	4
130	5
135	5
140	3
145	3
150	6
155	3
160	4
165	3
170	4
175	4
180	5
185	6
190	5
195	4
200	4
205	6
210	4
215	4
220	3
225	2

Number of people through Open exit over 5-second periods
Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0

130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0
210	0
215	0
220	0
225	0

Number of people through Link 1 over 5-second periods

Time(s), N (People)	
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0

165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0
210	0
215	0
220	0
225	0

Number of people through Link 2 over 5-second periods

Time(s), N (People)	
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0

200	0
205	0
210	0
215	0
220	0
225	0

Evacuation result in case smoke and alarm system functions in the base design

Number of Floors = 2
Number of Staircases = 1
Number of Exits = 2
Number of Links = 2
Number of People = 101

Deck 2 (DXF file: 050-091-0101-...dxf) (Size: 30.732,10.050 metres)
Number of People Initially in This Floor = 101
Link 1 : (15.40,5.50 m), 0.00 degrees, 0.90 m wide, connected to Stairway
Sb exit : (11.10,3.45 m), -66.04 degrees, 0.80 m wide

Deck 3 (DXF file: 050-091-0101-...dxf) (Size: 30.733,10.050 metres)
Number of People Initially in This Floor = 0
Link 2 : (18.88,5.47 m), -148.57 degrees, 0.90 m wide, connected to Stairway
Open exit : (19.19,6.54 m), -90.00 degrees, 0.80 m wide

Stairway (Size: 0.900,3.500 metres)
Number of People Initially in This Stair = 0
Link 1 : (0.47,0.00 m), 270.00 degrees, 0.90 m wide, connected to Deck 2
Link 2 : (0.45,3.50 m), 90.00 degrees, 0.90 m wide, connected to Deck 3

All people reached the exit in 3:24.4.

Number of people through all exits over 5-second periods
Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	2
75	1
80	2
85	2
90	2
95	5
100	4
105	3
110	4

115	4
120	6
125	5
130	3
135	4
140	4
145	4
150	4
155	4
160	4
165	4
170	3
175	4
180	5
185	4
190	4
195	3
200	4
205	3

Number of people through Sb exit over 5-second periods

Time(s),	N (People)
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	2
75	1
80	2
85	2
90	2
95	5
100	4
105	3
110	4
115	4
120	6
125	5
130	3
135	4
140	4
145	4
150	4
155	4
160	4
165	4

170	3
175	4
180	5
185	4
190	4
195	3
200	4
205	3

Number of people through Open exit over 5-second periods

Time(s),	N (People)
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0

Number of people through Link 1 over 5-second periods

Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0

Number of people through Link 2 over 5-second periods

Time(s),	N (People)
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0

60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0

Evacuation result in case smoke and alarm system fails
Number of Floors = 2
Number of Staircases = 1
Number of Exits = 2
Number of Links = 2
Number of People = 101

Deck 2 (DXF file: 050-091-0101-...dxf) (Size: 30.732,10.050 metres)
Number of People Initially in This Floor = 101
Link 1 : (15.40,5.50 m), 0.00 degrees, 0.90 m wide, connected to Stairway
Sb exit : (11.10,3.45 m), -66.04 degrees, 0.80 m wide

Deck 3 (DXF file: 050-091-0101-...dxf) (Size: 30.733,10.050 metres)
Number of People Initially in This Floor = 0
Link 2 : (18.88,5.47 m), -148.57 degrees, 0.90 m wide, connected to Stairway
Open exit : (19.19,6.54 m), -90.00 degrees, 0.80 m wide

Stairway (Size: 0.900,3.500 metres)
Number of People Initially in This Stair = 0
Link 1 : (0.47,0.00 m), 270.00 degrees, 0.90 m wide, connected to Deck 2
Link 2 : (0.45,3.50 m), 90.00 degrees, 0.90 m wide, connected to Deck 3

All people reached the exit in 3:49.7.

Number of people through all exits over 5-second periods

Time(s), N (People)	
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	1
85	0
90	0
95	0
100	1
105	2
110	2
115	4
120	3
125	2
130	6
135	4
140	4
145	4
150	6
155	3
160	3
165	3
170	5
175	3
180	5
185	5
190	4
195	5
200	4
205	3
210	5
215	5
220	3
225	4
230	2

Number of people through Sb exit over 5-second periods

Time(s), N (People)	
5	0
10	0
15	0
20	0

25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	1
85	0
90	0
95	0
100	1
105	2
110	2
115	4
120	3
125	2
130	6
135	4
140	4
145	4
150	6
155	3
160	3
165	3
170	5
175	3
180	5
185	5
190	4
195	5
200	4
205	3
210	5
215	5
220	3
225	4
230	2

Number of people through Open exit over 5-second periods

Time(s),	N (People)
5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0

55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0
210	0
215	0
220	0
225	0
230	0

Number of people through Link 1 over 5-second periods
Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0

85	0
90	0
95	0
100	0
105	0
110	0
115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0
210	0
215	0
220	0
225	0
230	0

Number of people through Link 2 over 5-second periods
Time(s), N (People)

5	0
10	0
15	0
20	0
25	0
30	0
35	0
40	0
45	0
50	0
55	0
60	0
65	0
70	0
75	0
80	0
85	0
90	0
95	0
100	0
105	0
110	0

115	0
120	0
125	0
130	0
135	0
140	0
145	0
150	0
155	0
160	0
165	0
170	0
175	0
180	0
185	0
190	0
195	0
200	0
205	0
210	0
215	0
220	0
225	0
230	0

Graphical results from Simulex simulations

In fire evacuation theory [e.g. 41], the evacuation time is said to consist of:

$$evacuation\ time = recognition\ time + response\ time + movement\ time$$

In determining the time required for safely evacuating the passengers in in case of an accommodation space fire scenario, simulations were performed using the software Simulex [42]. It was determined above that the function of the detection and alarm system (and connected door-closing devices) affects the recognition time. The different conditions in the base design and prescriptive design will also affect the response time in case the smoke and alarm system is functional. These conditions also affect the movement times and thereby the evacuation times in these scenarios. Hence, three different evacuation simulations were performed. The result files from these simulations are documented subsequently in Figures N1-15.

Evacuation result in case smoke and alarm system functions in the prescriptive design

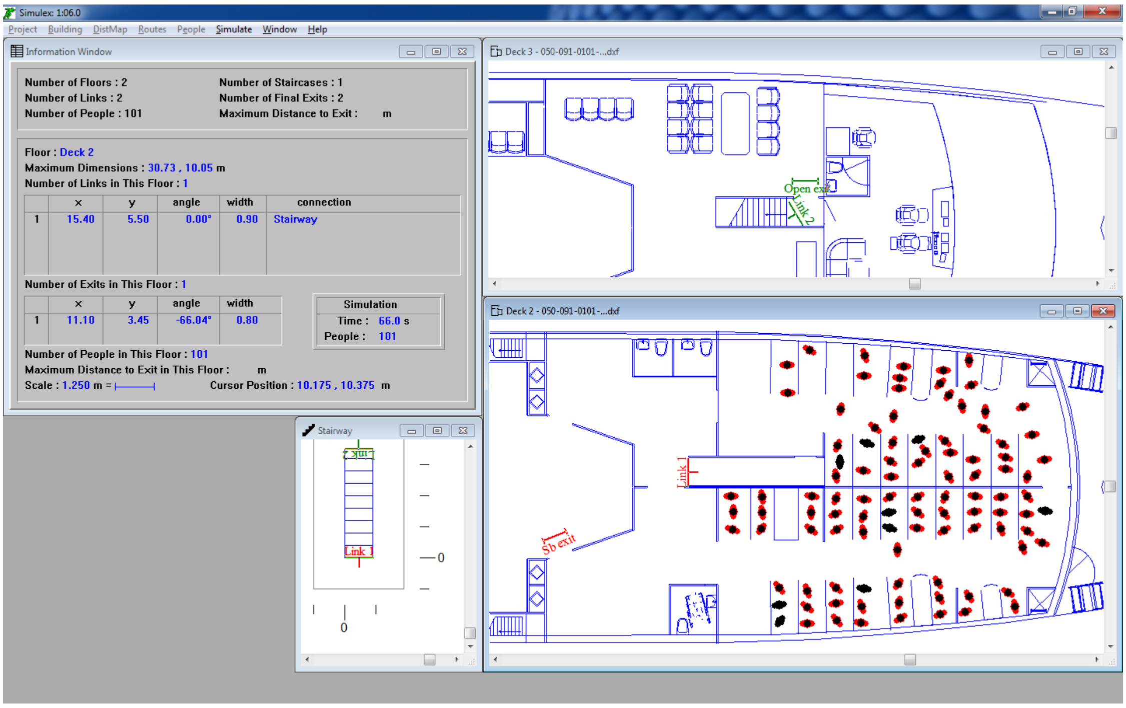


Figure N1. Evacuation situation after 66 s: 4 persons from the port side have reached the starboard side of the accommodation space as the people in this part of the space start to move.

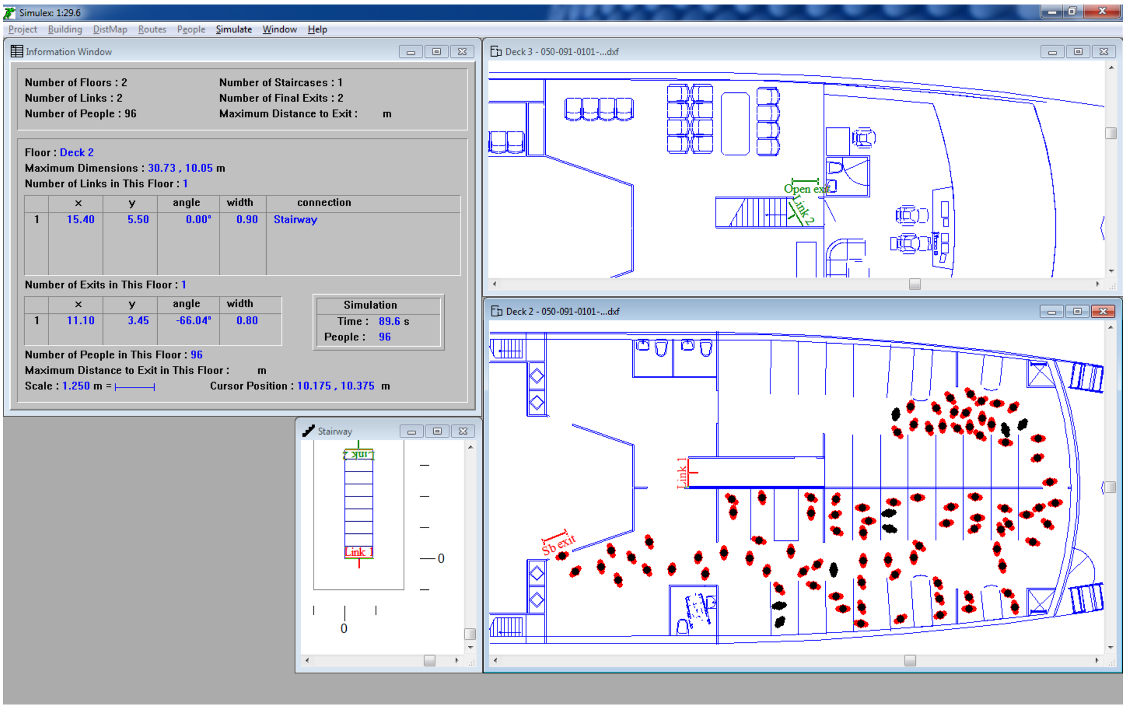


Figure N2. After about 75 s congestion problems appear on the port side of the accommodation space which last until evacuation from this side is finished.

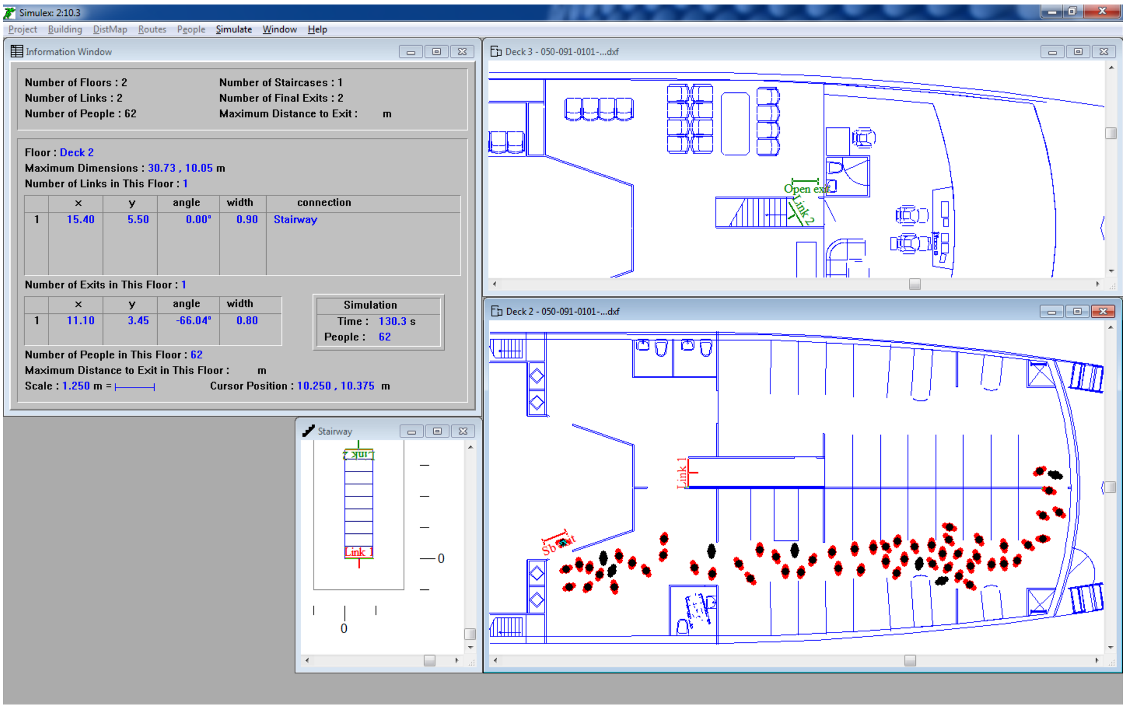


Figure N3. Evacuation situation after 130 s: there are 2 passengers left in the port side of the accommodation space as conditions soon become inhabitable due to 60°C at 2.00 m at location P4, which means that everyone passing this point will be exposed to inhabitable conditions (the passengers left in the port side of the space would likely not be exposed to untenable conditions as they have already passed the measuring point).

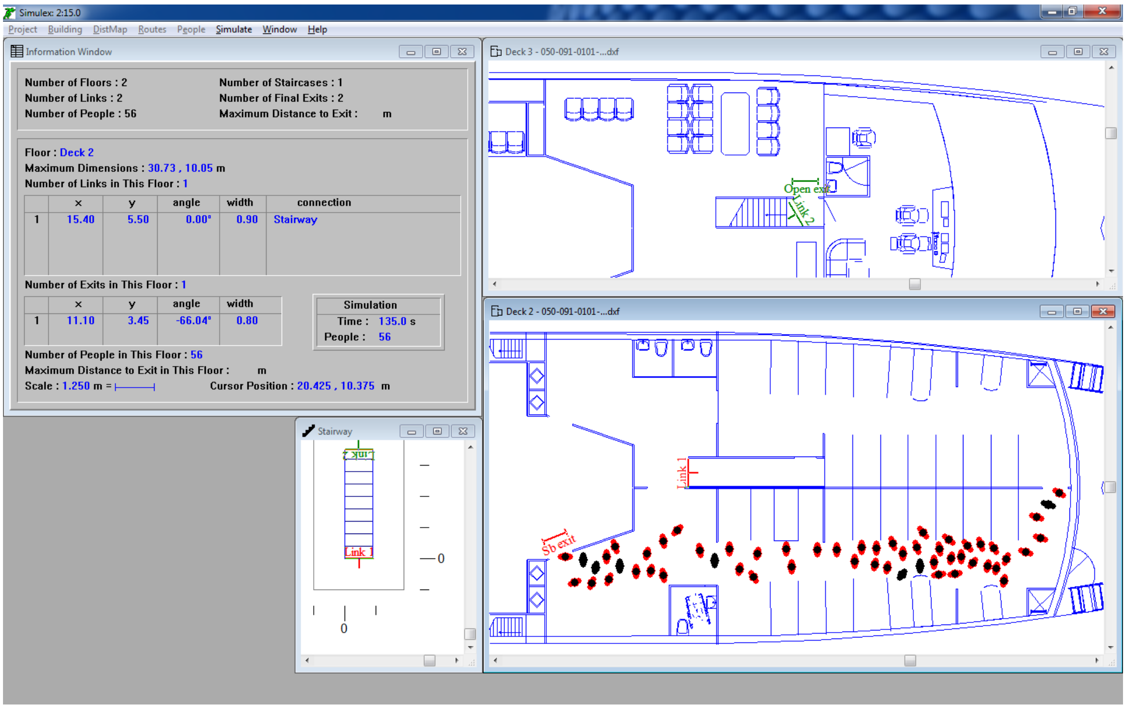


Figure N4. Evacuation situation after 135 s: no one is left in the port side of the accommodation space and the starboard side of the accommodation space becomes safe when the door is closed.

Evacuation result in case smoke and alarm system functions in the base design

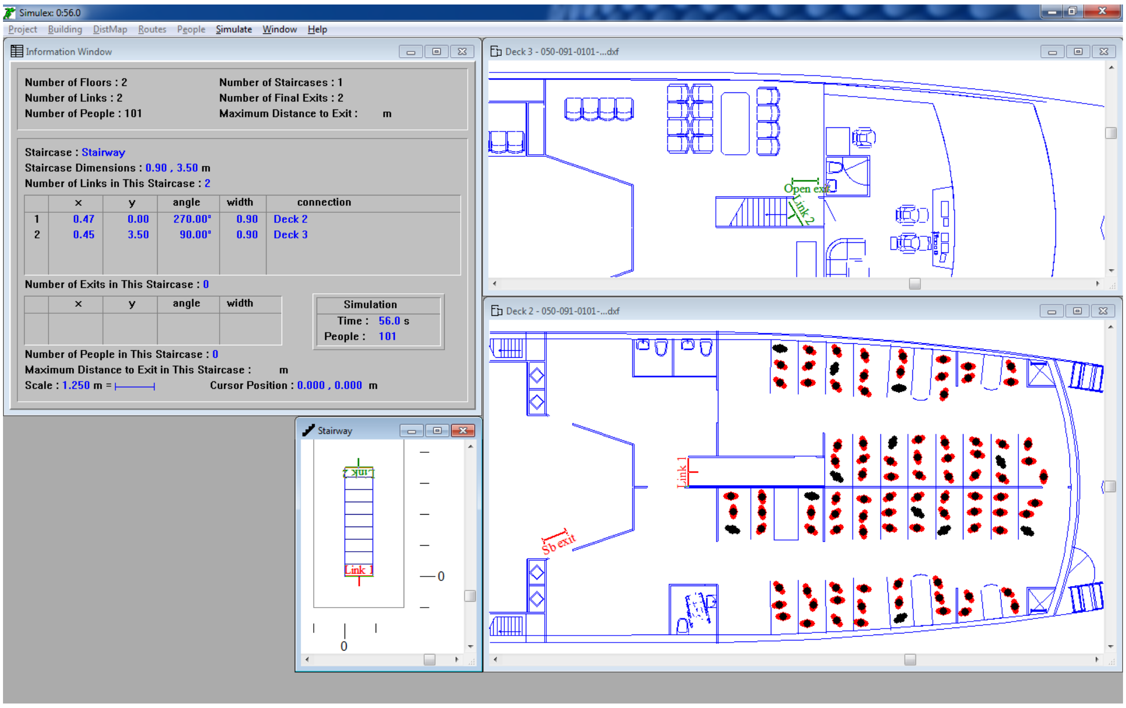


Figure N5. Evacuation situation after 56 s: persons on both the port side and the starboard side of the accommodation space have started to move, even if the people on the starboard side have a larger scatter in their response.

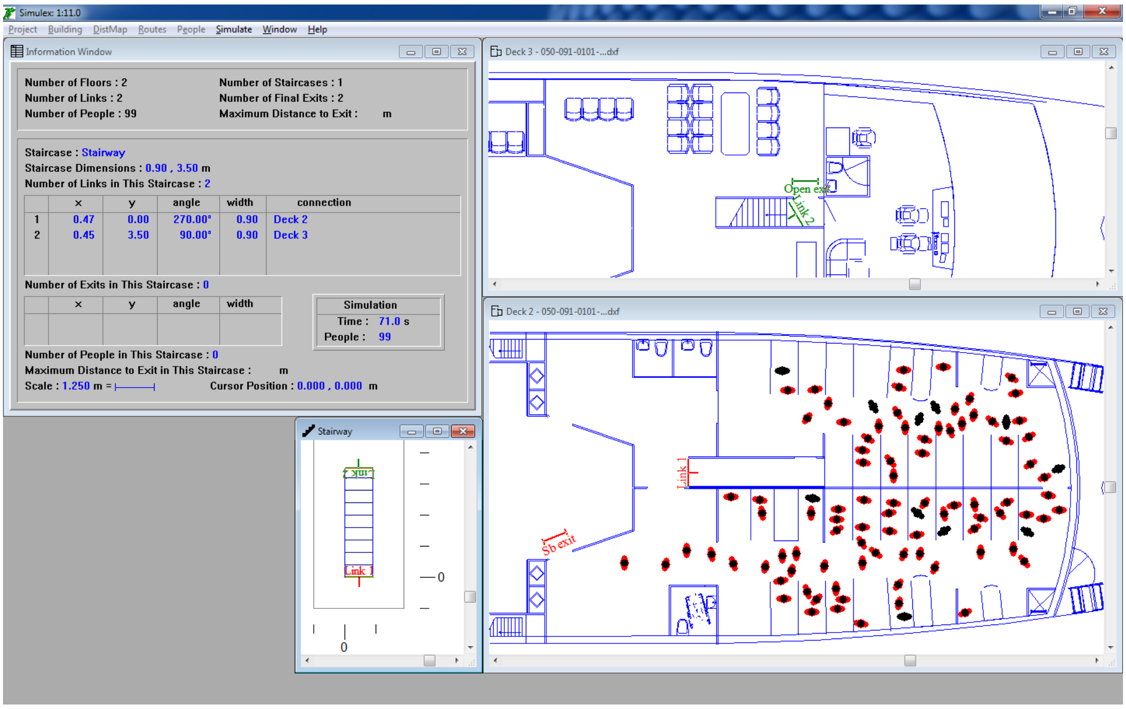


Figure N6. Evacuation situation after 71 s: all passengers in the port side have started their movement.

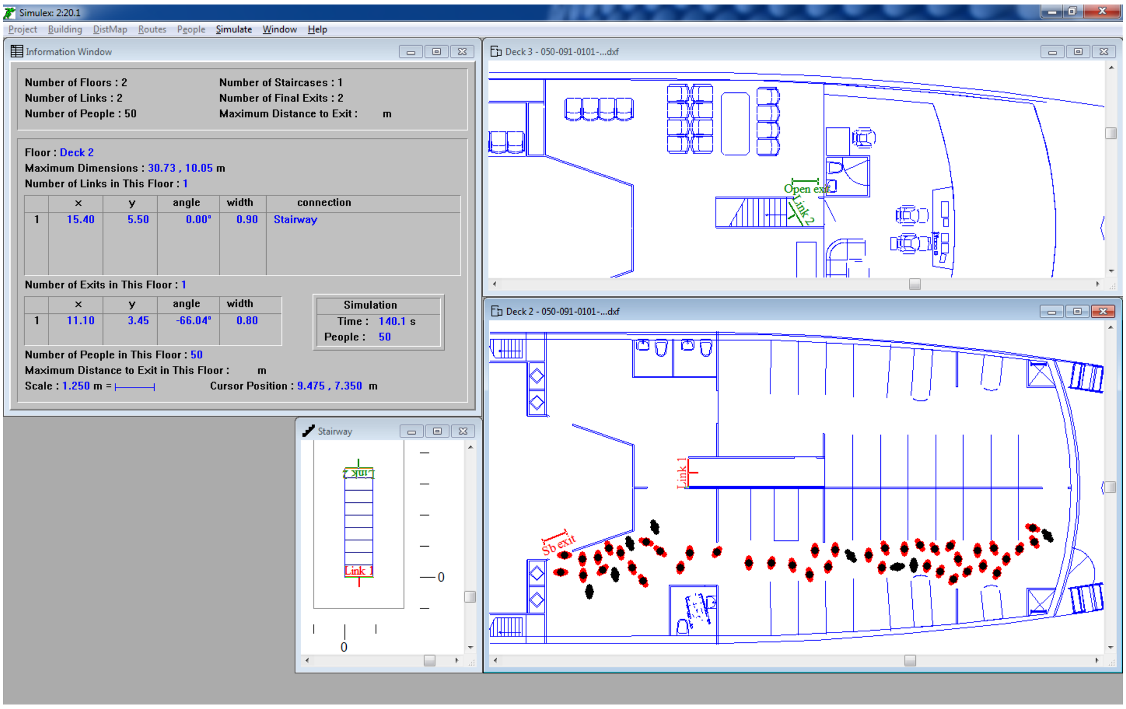


Figure N7. Evacuation situation after 140 s: no one is left in the port side of the accommodation space (where conditions soon after become inhabitable due to 60°C at 2.00 m in location P4) but the temperature at 2.0 m in location S2 has reached 80°C, which means that everyone passing this point will be exposed to inhabitable conditions (50 persons left in the accommodation space but all may not be exposed to untenable conditions as some have already passed the measuring point).

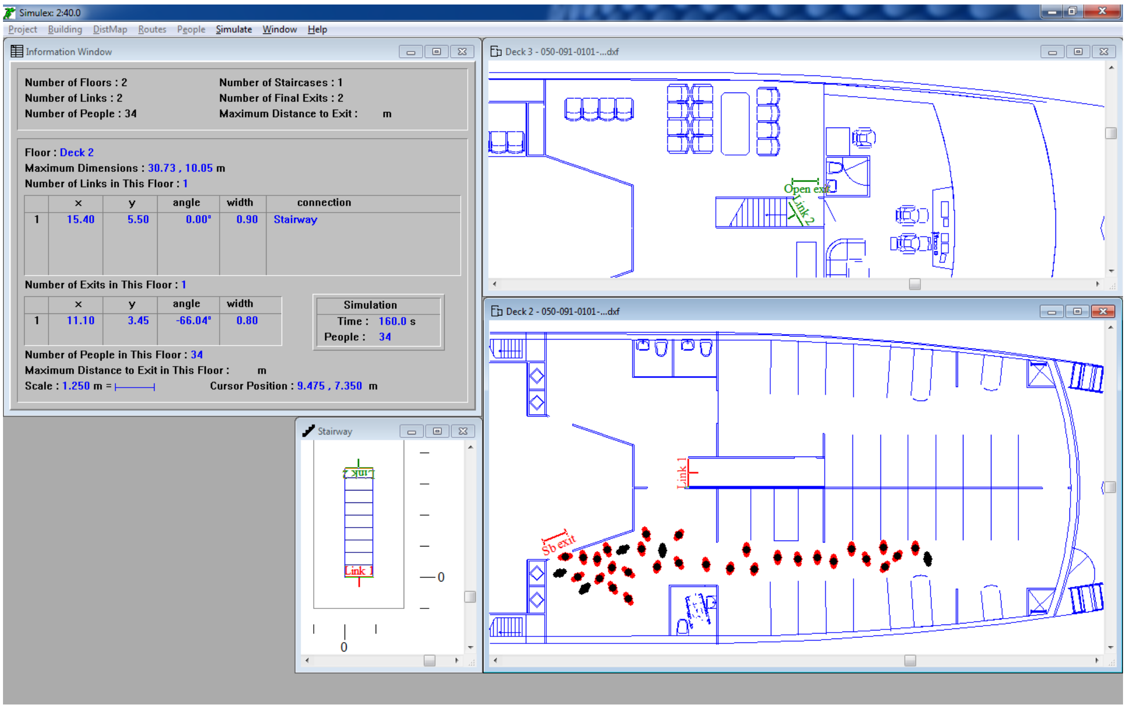


Figure N8. Evacuation situation after 160 s: the temperature at the second measuring point (S2) has reached 80°C, which means that everyone passing this point will be exposed to inhabitable conditions.

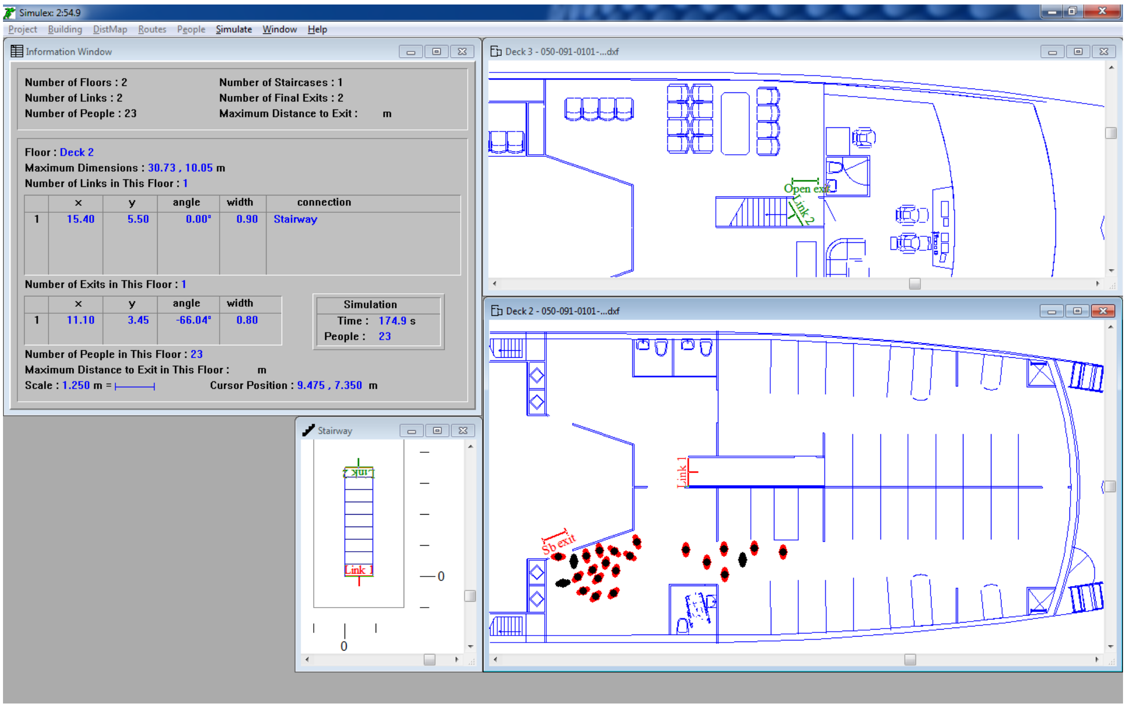


Figure N9. Evacuation situation after 175 s: at this time the visibility criterion is at 2.0 m at location S2.

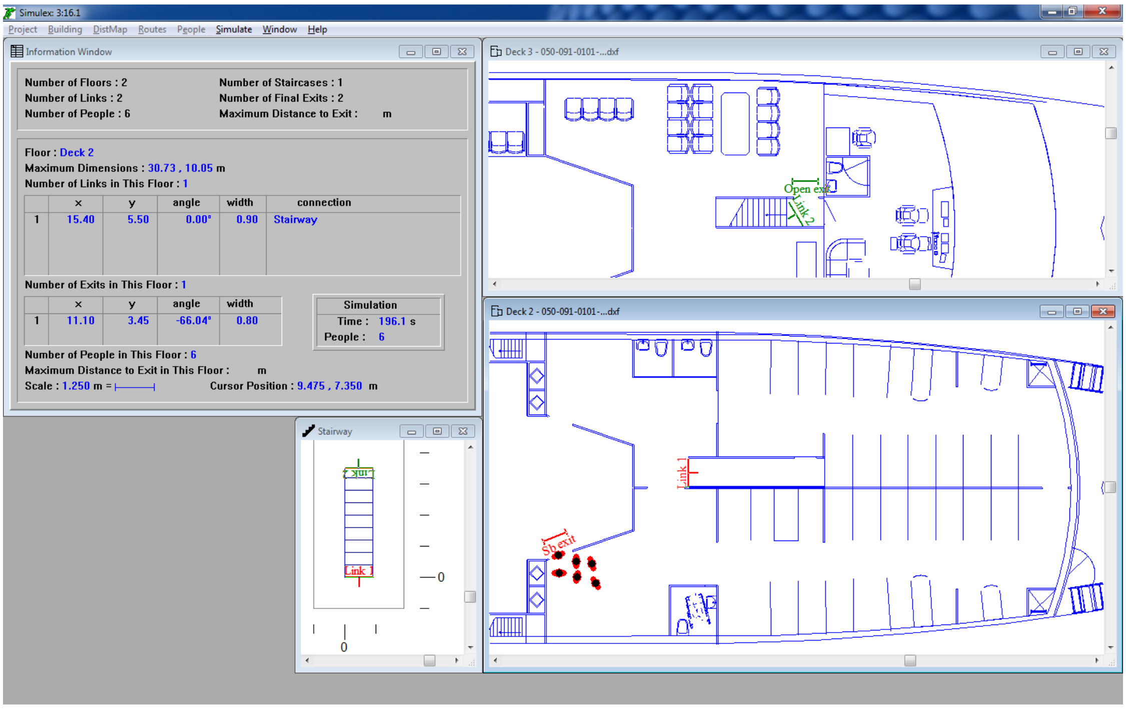


Figure N10. Evacuation situation after 196 s: the visibility is less than 10 m at all heights.

Evacuation result in case smoke and alarm system fails

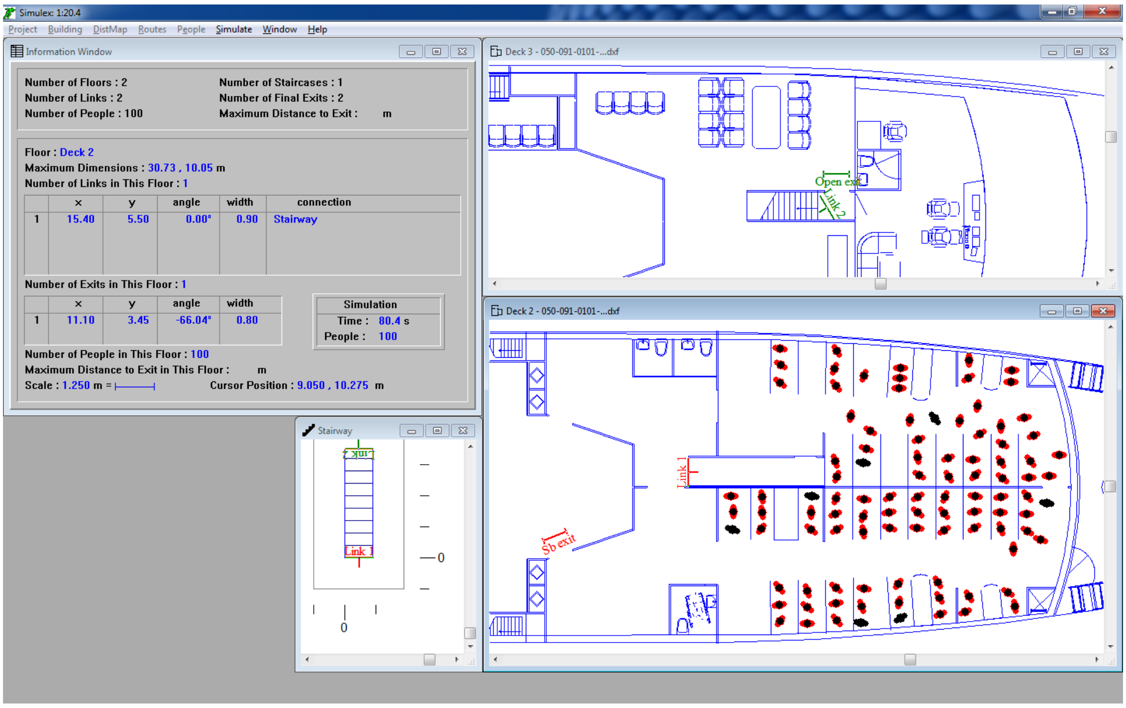


Figure N11. Evacuation situation after 80 s: 4 persons have reached the starboard side of the accommodation space (one has already reached the starboard exit).

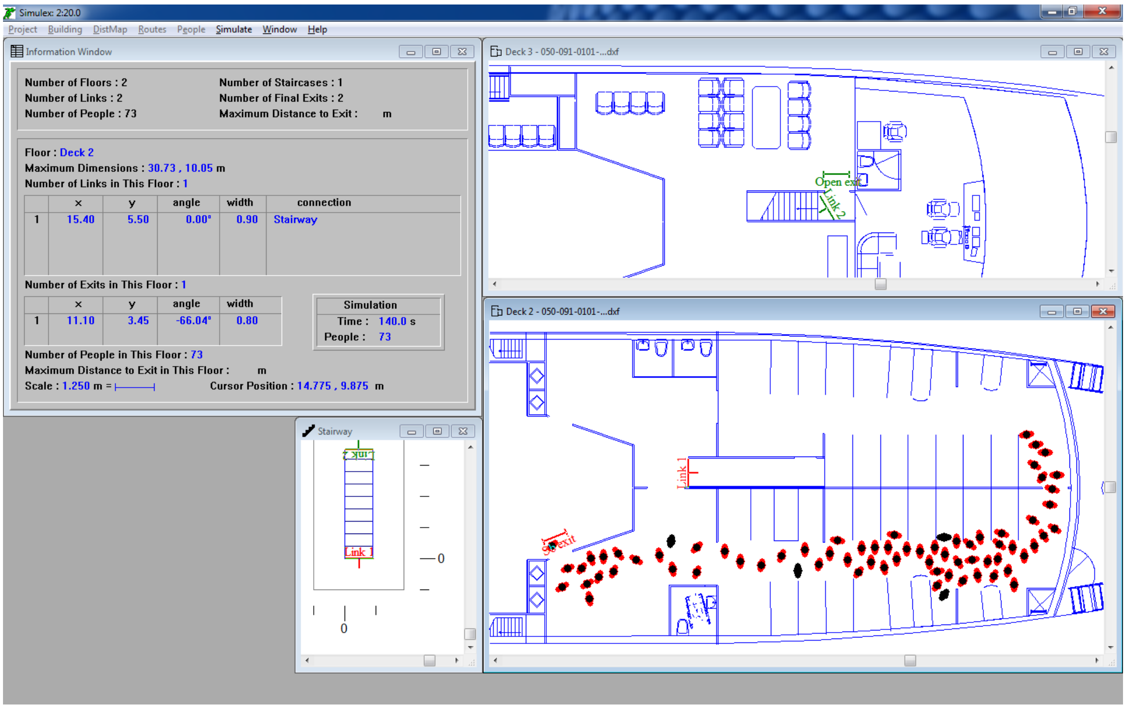


Figure N12. Evacuation situation after 140 s: no one is left in the port side of the accommodation space (where conditions soon after become inhabitable due to 60°C at 2.00 m in location P4) but the temperature at 2.0 m in location S2 has reached 80°C, which means that everyone passing this point will be exposed to inhabitable conditions (72 persons left in the accommodation space but all may not be exposed to untenable conditions as some have already passed the measuring point).

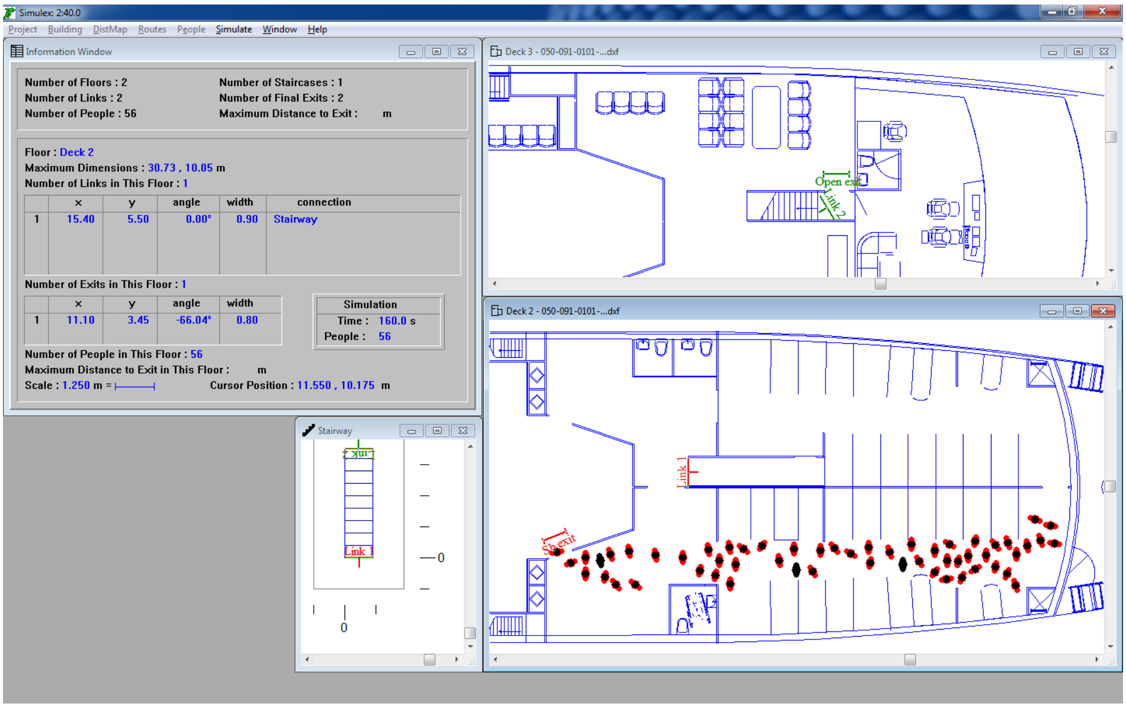


Figure N13. Evacuation situation after 160 s: the temperature at the second measuring point (S2) has reached 80°C, which means that everyone passing this point will be exposed to inhabitable conditions.

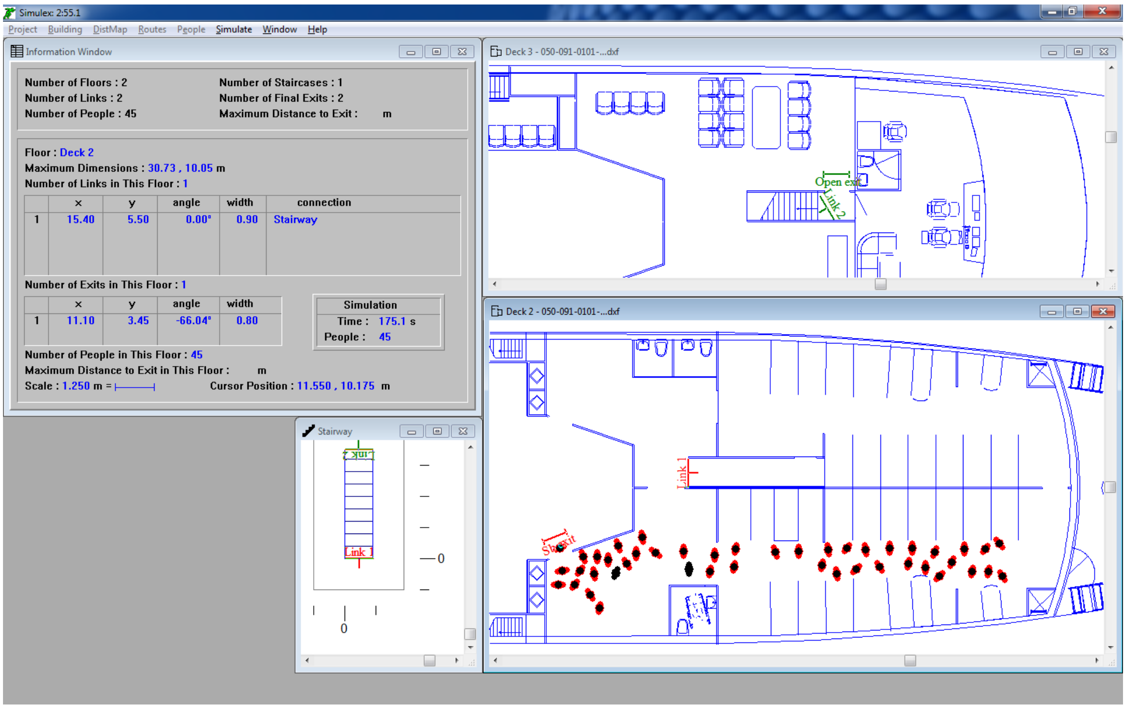


Figure N14. Evacuation situation after 175 s: the visibility criterion is reached at 2.0 m at location S2.

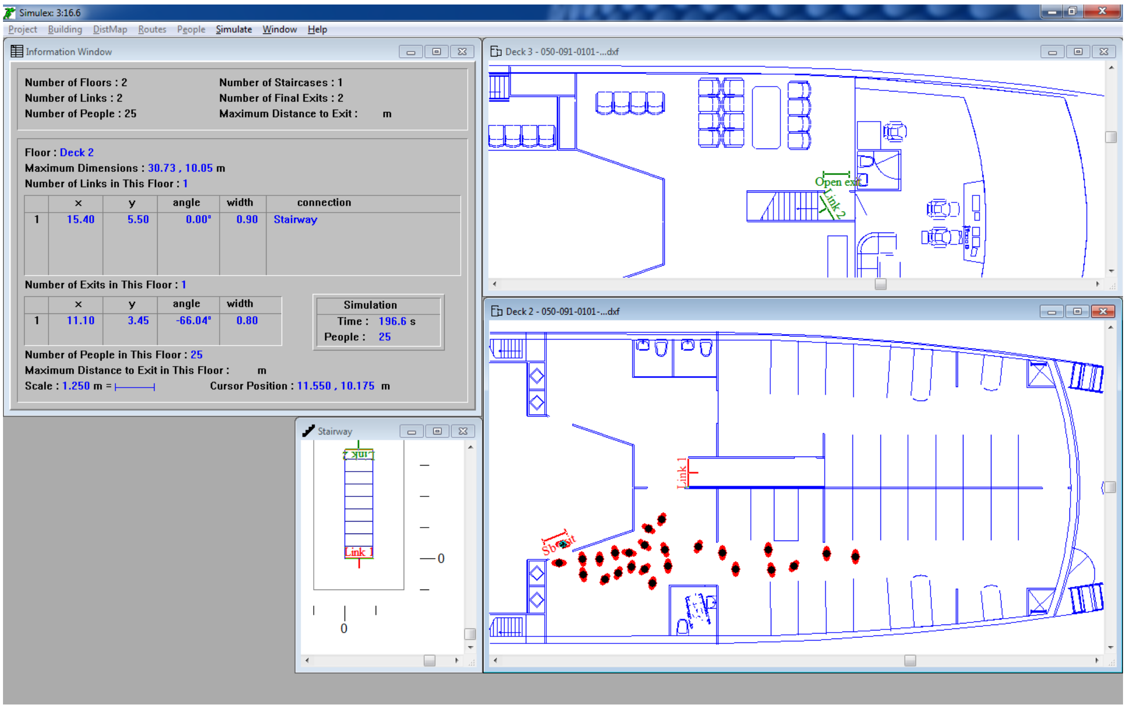


Figure N15. Evacuation situation after 196 s: the visibility is less than 10 m at all heights.

Event trees

The resulting event trees for the different representative spaces in the prescriptive design and the base design are presented subsequently. Note that some figures are split and that the upper row is repeated in these figures, for visibility.

Accommodation space event trees

The event trees for the accommodation space in the prescriptive design and the base design are presented in Figures O1 and O2 below.

Prescriptive design	Prob. of fire in space	Persons present	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	15,78%	33,33%	96%	44%									0,03628234	0,0	safe
Significant fire	Accommodation	7.5		56%	91%								0,04245033	0,0	safe
					9%	90%	10%						0,00037785	0,0	safe
							90%	70%		73%			0,00173775	0,0	safe
										27%	57%	95%	0,00034804	0,0	safe
												5%	0,00001832	1,0	Evacuation at shore
											43%	90%	0,00024874	0,0	safe
												10%	0,00002764	2,3	Evacuation at sea
								30%	60%	18%			0,00011018	0,0	safe
										82%	57%	95%	0,00027180	0,0	safe
												5%	0,00001431	1,0	Evacuation at shore
											43%	90%	0,00019425	0,0	safe
												10%	0,00002158	2,3	Evacuation at sea
									40%	18%			0,00007345	0,0	safe
										82%	44%	95%	0,00013987	0,0	safe
												5%	0,00000736	1,0	Evacuation at shore
											56%	64%	0,00011993	0,0	safe
												36%	0,00006746	2,3	Evacuation at sea
						10%	5%						0,00002099	0,0	safe
							95%	58%		73%			0,00016742	0,0	safe
										27%	57%	95%	0,00003353	0,0	safe
												5%	0,00000176	1,0	Evacuation at shore
											43%	90%	0,00002396	0,0	safe
												10%	0,00000266	2,3	Evacuation at sea
								43%	60%	18%			0,00001831	0,0	safe
										82%	57%	95%	0,00004516	0,0	safe
												5%	0,00000238	1,0	Evacuation at shore
											43%	90%	0,00003228	0,0	safe
												10%	0,00000359	2,3	Evacuation at sea
									40%	18%			0,00001220	1,0	Major fire
										82%	44%	95%	0,00002324	1,0	Major fire
												5%	0,00000122	2,0	Major fire, evacuation at shore
											56%	64%	0,00001993	1,0	Major fire
												36%	0,00001121	3,1	Major fire, evacuation at sea
			4%	31%									0,00107119	0,0	safe
				69%	91%								0,00216968	0,0	safe
			NO		9%	0%							0,00000000	0,0	safe
						100%	5%						0,00001073	0,0	safe
			YES				95%	58%		73%			0,00008557	0,0	safe
										27%	57%	95%	0,00001714	0,0	safe
												5%	0,00000090	1,0	Evacuation at shore
											43%	90%	0,00001225	0,0	safe
												10%	0,00000136	2,3	Evacuation at sea
								43%	60%	18%			0,00000936	0,0	safe
										82%	57%	95%	0,00002308	0,0	safe
												5%	0,00000121	1,0	Evacuation at shore
											43%	90%	0,00001650	0,0	safe
												10%	0,00000183	2,3	Evacuation at sea
									40%	18%			0,00000624	1,0	Major fire
										82%	44%	95%	0,00001188	1,0	Major fire
												5%	0,00000063	2,0	Major fire, evacuation at shore
											56%	64%	0,00001018	1,0	Major fire
												36%	0,00000573	3,1	Major fire, evacuation at sea
		34,67%	96%	64%									0,05541453	0,0	safe

Prescriptive design	Prob. of fire in space	Persons present	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
		34,67%	96%	64%									0,05541453	0,0	safe
		30		36%	91%								0,02805873	0,0	safe
					9%	90%	10%						0,00024975	0,0	safe
							90%	70%		73%			0,00114862	0,0	safe
										27%	57%	95%	0,00023005	0,0	safe
												5%	0,00001211	1,0	Evacuation at shore
											43%	90%	0,00016441	0,0	safe
												10%	0,00001827	7,4	Evacuation at sea
								30%	60%	18%			0,00007283	0,0	safe
										82%	57%	95%	0,00017965	0,0	safe
												5%	0,00000946	1,0	Evacuation at shore
											43%	90%	0,00012840	0,0	safe
												10%	0,00001427	7,4	Evacuation at sea
									40%	18%			0,00004855	0,0	safe
										82%	44%	95%	0,00009245	0,0	safe
												5%	0,00000487	1,0	Evacuation at shore
											56%	64%	0,00007927	0,0	safe
												36%	0,00004459	7,4	Evacuation at sea
						10%	5%						0,00001388	0,0	safe
							95%	58%		73%			0,00011066	0,0	safe
										27%	57%	95%	0,00002216	0,0	safe
												5%	0,00000117	1,0	Evacuation at shore
											43%	90%	0,00001584	0,0	safe
												10%	0,00000176	7,4	Evacuation at sea
								43%	60%	18%			0,00001210	0,0	safe
										82%	57%	95%	0,00002985	0,0	safe
												5%	0,00000157	1,0	Evacuation at shore
											43%	90%	0,00002133	0,0	safe
												10%	0,00000237	7,4	Evacuation at sea
									40%	18%			0,00000807	2,0	Major fire
										82%	44%	95%	0,00001536	2,0	Major fire
												5%	0,00000081	3,0	Major fire, evacuation at shore
											56%	64%	0,00001317	2,0	Major fire
												36%	0,00000741	9,0	Major fire, evacuation at sea
			4%	51%									0,00181481	0,0	safe
				50%	91%								0,00161877	0,0	safe
			NO		9%	0%							0,00000000	0,0	safe
						100%	5%						0,00000800	0,0	safe
			YES				95%	58%		73%			0,00006384	0,0	safe
										27%	57%	95%	0,00001279	0,0	safe
												5%	0,00000067	1,0	Evacuation at shore
											43%	90%	0,00000914	0,0	safe
												10%	0,00000102	7,4	Evacuation at sea
								43%	60%	18%			0,00000698	0,0	safe
										82%	57%	95%	0,00001722	0,0	safe
												5%	0,00000091	1,0	Evacuation at shore
											43%	90%	0,00001231	0,0	safe
												10%	0,00000137	7,4	Evacuation at sea
									40%	18%			0,00000465	2,0	Major external fire
										82%	44%	95%	0,00000886	2,0	Major external fire
												5%	0,00000047	3,0	Major external fire, evacuation at shore
											56%	64%	0,00000760	2,0	Major external fire
												36%	0,00000427	9,0	Major external fire, evacuation at sea
		32,00%	96%	70%									0,05592870	0,0	safe

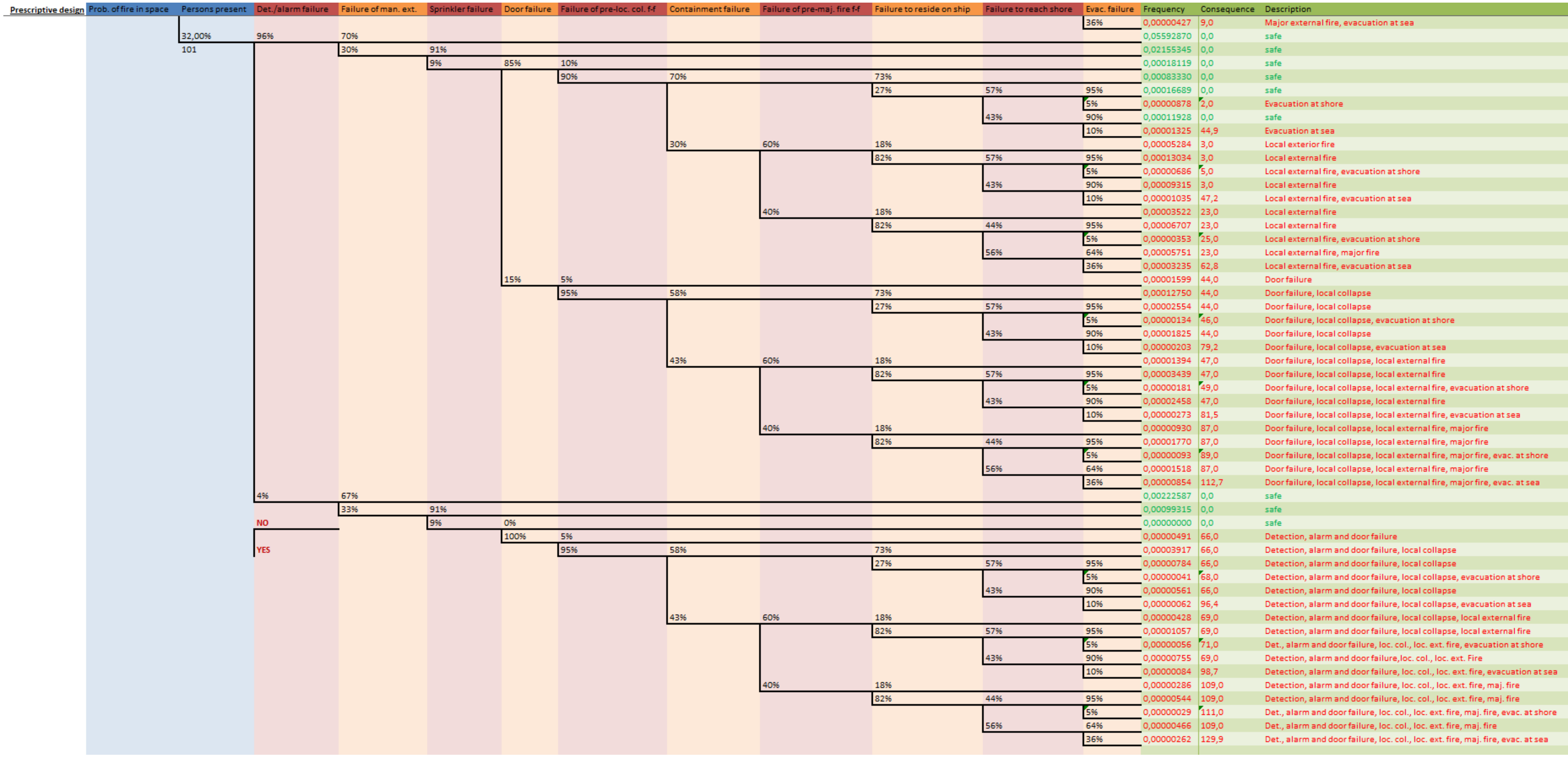


Figure O1. Event tree for the accommodation space in the prescriptive design.

Base design	Prob. of fire in space	Persons present	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,642087535	15,78%	33,33%	96%	44%									0,03628234	0,0	safe
Significant fire	Accommodation	7.5		56%	91%								0,04245033	0,0	safe
					9%	0%	15%						0,00000000	0,0	safe
							85%	43%		62%			0,00000000	1,0	Local collapse
										38%	30%	95%	0,00000000	1,0	Local collapse
												5%	0,00000000	2,0	Local collapse, evacuation at shore
											70%	80%	0,00000000	1,0	Local collapse
												20%	0,00000000	3,1	Local collapse, evacuation at sea
								57%	1%	3%			0,00000000	3,0	Local collapse, local external fire
										97%	30%	95%	0,00000000	3,0	Local collapse, local external fire
												5%	0,00000000	4,0	Local collapse, local external fire, evacuation at shore
											70%	80%	0,00000000	3,0	Local collapse, local external fire
												20%	0,00000000	4,7	Local collapse, local external fire, evacuation at sea
									99%	3%			0,00000000	4,0	Local collapse, local external fire, major fire
										97%	10%	95%	0,00000000	4,0	Local collapse, local external fire, major fire
												5%	0,00000000	5,0	Local collapse, local external fire, major fire, evacuation at shore
											90%	50%	0,00000000	4,0	Local collapse, local external fire, major fire
												50%	0,00000000	5,4	Local collapse, local external fire, major fire, evacuation at sea
						100%	8%						0,00033587	0,0	safe
							92%	20%		62%			0,00047320	1,0	Local collapse
										38%	30%	95%	0,00008266	1,0	Local collapse
												5%	0,00000435	2,0	Local collapse, evacuation at shore
											70%	80%	0,00016242	1,0	Local collapse
												20%	0,00004060	3,1	Local collapse, evacuation at sea
								80%	0%	3%			0,00000028	3,0	Local collapse, local external fire
										97%	30%	95%	0,00000257	3,0	Local collapse, local external fire
												5%	0,00000014	4,0	Local collapse, local external fire, evacuation at shore
											70%	80%	0,00000505	3,0	Local collapse, local external fire
												20%	0,00000126	4,7	Local collapse, local external fire, evacuation at sea
									100%	3%			0,00009270	5,0	Local collapse, local external fire, major fire
										97%	10%	95%	0,00028474	5,0	Local collapse, local external fire, major fire
												5%	0,00001499	6,0	Local collapse, local external fire, major fire, evacuation at shore
											90%	50%	0,00134878	5,0	Local collapse, local external fire, major fire
												50%	0,00134878	6,2	Local collapse, local external fire, major fire, evacuation at sea
			4%	31%									0,00107119	0,0	safe
				69%	91%								0,00216968	0,0	safe
			NO		9%	0%							0,00000000	0,0	safe
						100%	8%						0,00001717	0,0	safe
			YES				92%	20%		62%			0,00002419	1,0	Local collapse
										38%	30%	95%	0,00000422	1,0	Local collapse
												5%	0,00000022	2,0	Local collapse, evacuation at shore
											70%	80%	0,00000830	1,0	Local collapse
												20%	0,00000208	3,1	Local collapse, evacuation at sea
								80%	0%	3%			0,00000001	3,0	Local collapse, local external fire
										97%	30%	95%	0,00000013	3,0	Local collapse, local external fire
												5%	0,00000001	4,0	Local collapse, local external fire, evacuation at shore
											70%	80%	0,00000026	3,0	Local collapse, local external fire
												20%	0,00000006	4,7	Local collapse, local external fire, evacuation at sea
									100%	3%			0,00000474	5,0	Local collapse, local external fire, major fire
										97%	10%	95%	0,00001455	5,0	Local collapse, local external fire, major fire
												5%	0,00000077	6,0	Local collapse, local external fire, major fire, evacuation at shore
											90%	50%	0,00006894	5,0	Local collapse, local external fire, major fire
												50%	0,00006894	6,2	Local collapse, local external fire, major fire, evacuation at sea
		34,67%	96%	64%									0,05541453	0,0	safe

Base design	Prob. of fire in space	Persons present	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												50%	0,00006894	6,2	Local collapse, local external fire, major fire, evacuation at sea
		34,67%	96%	64%									0,05541453	0,0	safe
		30		36%	91%								0,02805873	0,0	safe
					9%	0%	15%						0,00000000	0,0	safe
							85%	43%		62%			0,00000000	1,0	Local collapse
										38%	30%	95%	0,00000000	1,0	Local collapse
												5%	0,00000000	2,0	Local collapse, evacuation at shore
											70%	80%	0,00000000	1,0	Local collapse
												20%	0,00000000	8,2	Local collapse, evacuation at sea
								57%	1%	3%			0,00000000	3,0	Local collapse, local external fire
										97%	30%	95%	0,00000000	3,0	Local collapse, local external fire
												5%	0,00000000	4,0	Local collapse, local external fire, evacuation at shore
											70%	80%	0,00000000	3,0	Local collapse, local external fire
												20%	0,00000000	9,7	Local collapse, local external fire, evacuation at sea
									99%	3%			0,00000000	5,0	Local collapse, local external fire, major fire
										97%	10%	95%	0,00000000	5,0	Local collapse, local external fire, major fire
												5%	0,00000000	6,0	Local collapse, local external fire, major fire, evacuation at shore
											90%	50%	0,00000000	5,0	Local collapse, local external fire, major fire
												50%	0,00000000	11,3	Local collapse, local external fire, major fire, evacuation at sea
						100%	8%						0,00022200	0,0	safe
							92%	20%		62%			0,00031278	1,0	Local collapse
										38%	30%	95%	0,00005464	1,0	Local collapse
												5%	0,00000288	2,0	Local collapse, evacuation at shore
											70%	80%	0,00010735	1,0	Local collapse
												20%	0,00002684	8,2	Local collapse, evacuation at sea
								80%	0%	3%			0,00000018	3,0	Local collapse, local external fire
										97%	30%	95%	0,00000170	3,0	Local collapse, local external fire
												5%	0,00000009	4,0	Local collapse, local external fire, evacuation at shore
											70%	80%	0,00000334	3,0	Local collapse, local external fire
												20%	0,00000083	9,7	Local collapse, local external fire, evacuation at sea
									100%	3%			0,00006127	7,0	Local collapse, local external fire, major fire
										97%	10%	95%	0,00018821	7,0	Local collapse, local external fire, major fire
												5%	0,00000991	8,0	Local collapse, local external fire, major fire, evacuation at shore
											90%	50%	0,00089151	7,0	Local collapse, local external fire, major fire
												50%	0,00089151	12,9	Local collapse, local external fire, major fire, evacuation at sea
			4%	51%									0,00181481	0,0	safe
				50%	91%								0,00161877	0,0	safe
			NO		9%	0%							0,00000000	0,0	safe
						100%	8%						0,00001281	0,0	safe
			YES				92%	20%		62%			0,00001804	1,0	Local collapse
										38%	30%	95%	0,00000315	1,0	Local collapse
												5%	0,00000017	2,0	Local collapse, evacuation at shore
											70%	80%	0,00000619	1,0	Local collapse
												20%	0,00000155	8,2	Local collapse, evacuation at sea
								80%	0%	3%			0,00000001	3,0	Local collapse, local external fire
										97%	30%	95%	0,00000010	3,0	Local collapse, local external fire
												5%	0,00000001	4,0	Local collapse, local external fire, evacuation at shore
											70%	80%	0,00000019	3,0	Local collapse, local external fire
												20%	0,00000005	9,7	Local collapse, local external fire, evacuation at sea
									100%	3%			0,00000353	7,0	Local collapse, local external fire, major fire
										97%	10%	95%	0,00001086	7,0	Local collapse, local external fire, major fire
												5%	0,00000057	8,0	Local collapse, local external fire, major fire, evacuation at shore
											90%	50%	0,00005143	7,0	Local collapse, local external fire, major fire
												50%	0,00005143	12,9	Local collapse, local external fire, major fire, evacuation at sea
		32,00%	96%	70%									0,05592870	0,0	safe
		101		30%	91%								0,02155345	0,0	safe

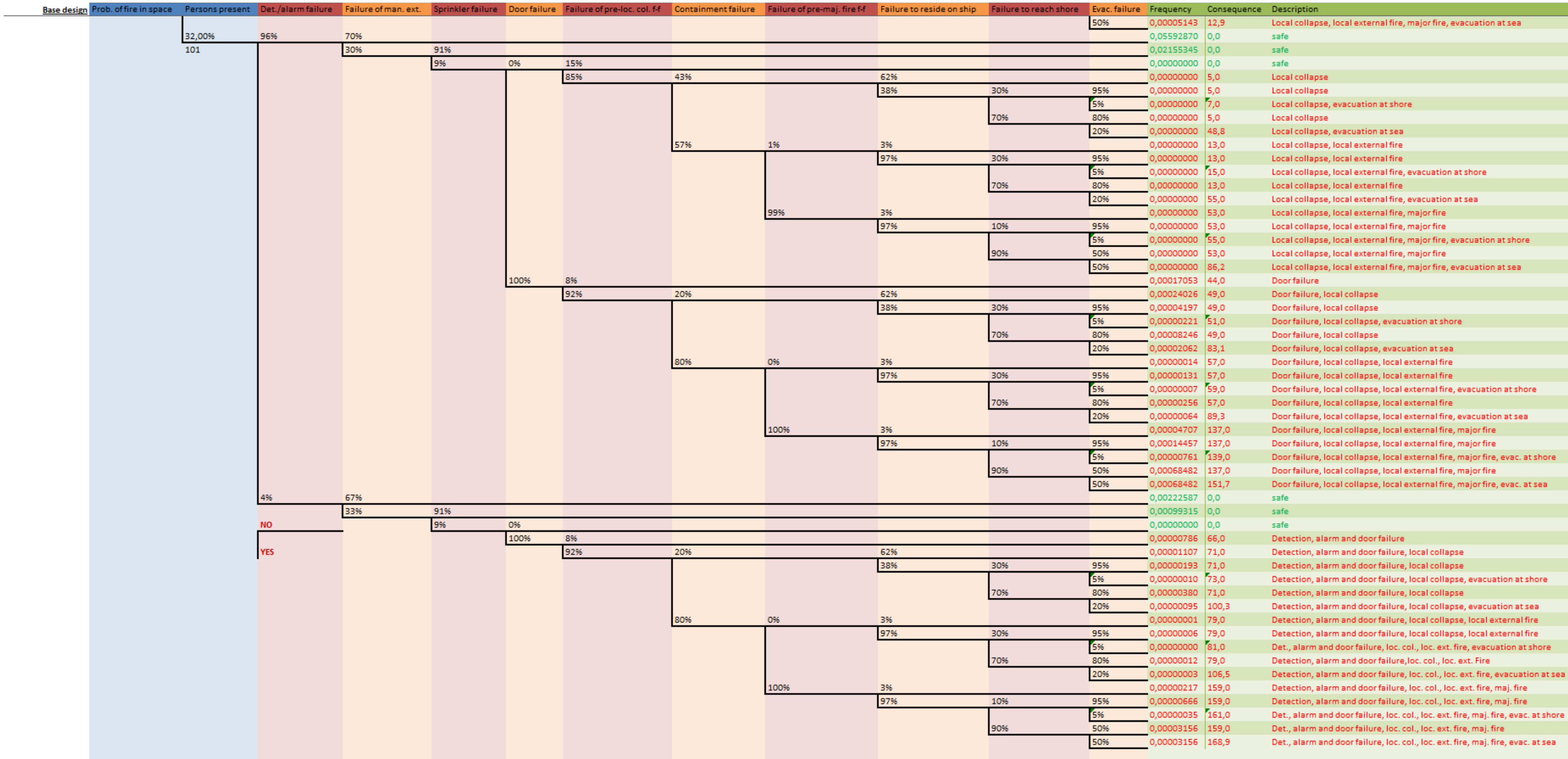


Figure O2. Event tree for the accommodation space in the base design.

Engine room event trees

The event trees for the engine rooms space in the prescriptive design and the base design are presented in Figures O3 and O4 below.

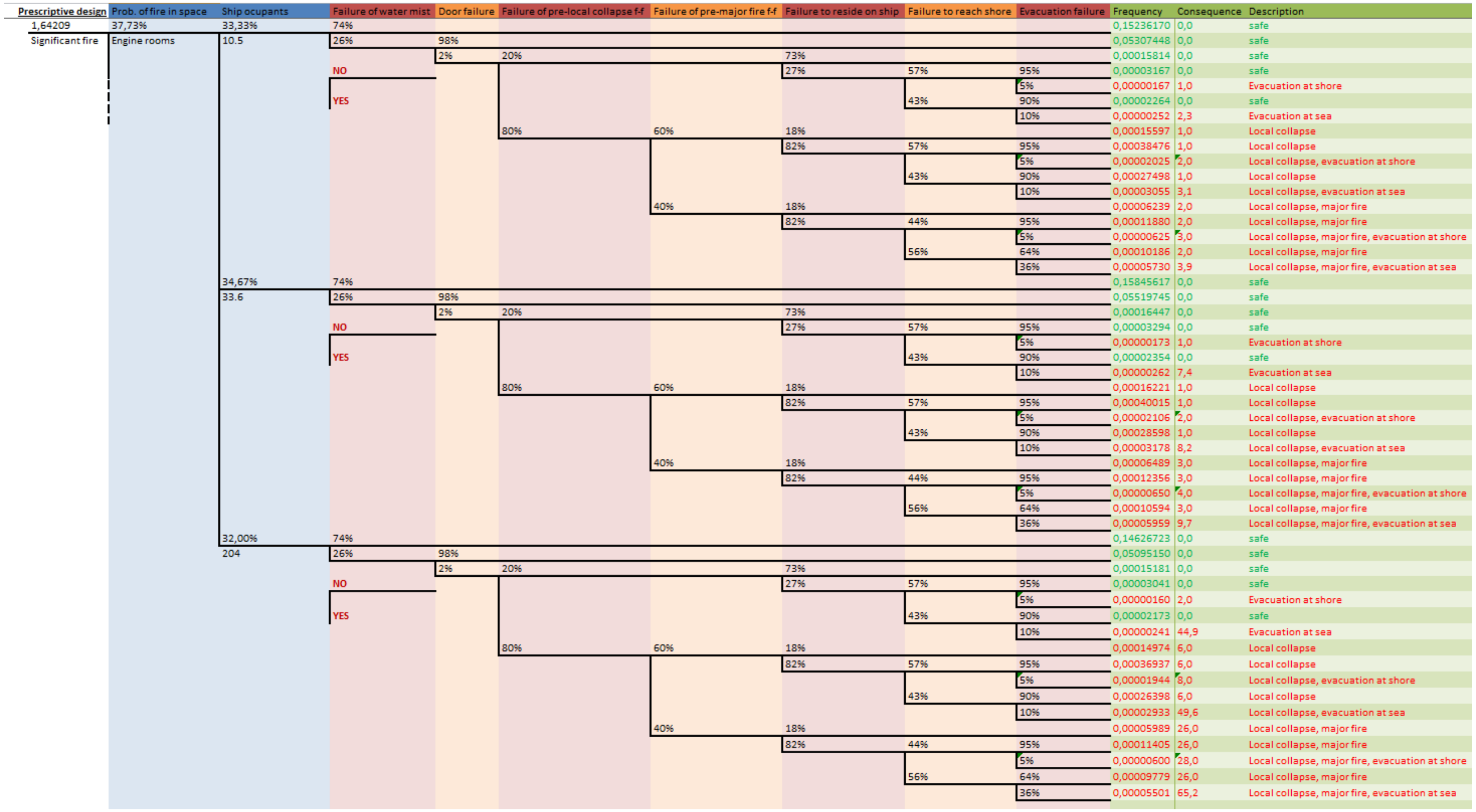


Figure O3. Event tree for the engine rooms in the prescriptive design.

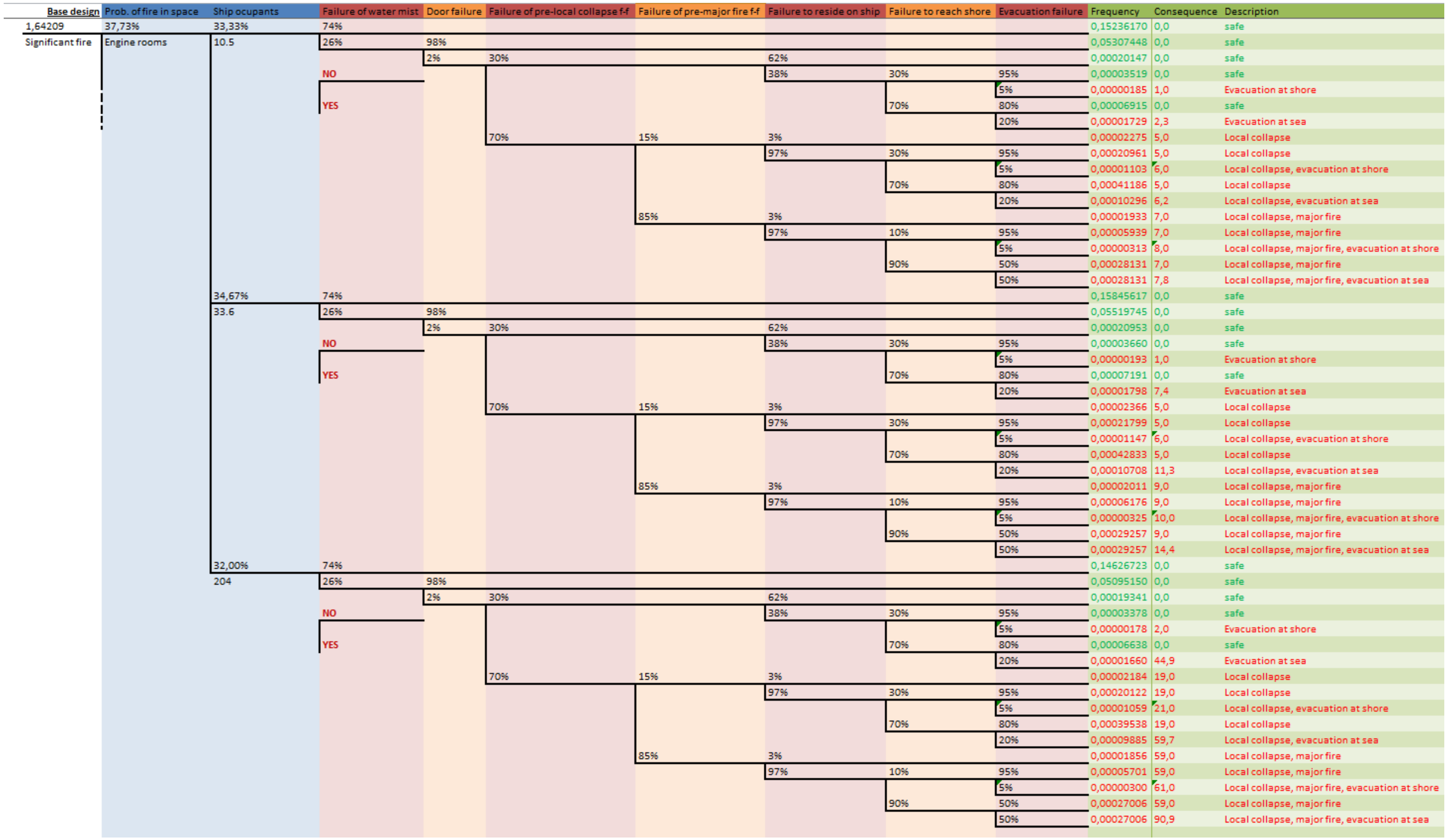


Figure O4. Event tree for the engine rooms in the base design.

Auxiliary machinery space event trees

The event trees for the auxiliary machinery spaces in the prescriptive design and the base design are presented in Figures O5 and O6 below.

Prescriptive design	Prob. of fire in space	Ship ocupants	Hatch failure	Detection and alarm failure	Failure of pre-local collapse f-f	Failure of pre-major fire f-f	Failure to reside on ship	Failure to reach shore	Evacuation failure	Frequency	Consequence	Description
1,64209	5,68%	33,33%	96%							0,02987116	0,0	safe
Significant fire	Aux. mach. spaces	10.5	4%	96%	70%					0,00083639	0,0	safe
					30%	60%	73%			0,00015700	1,0	Local collapse
							27%	57%	95%	0,00003144	1,0	Local collapse
									5%	0,00000165	2,0	Local collapse, evacuation at shore
								43%	90%	0,00002247	1,0	Local collapse
									10%	0,00000250	3,1	Local collapse, evacuation at sea
						40%	18%			0,00002581	2,0	Local collapse, major fire
							82%	44%	95%	0,00004915	2,0	Local collapse, major fire
									5%	0,00000259	3,0	Local collapse, major fire, evacuation at shore
								56%	64%	0,00004214	2,0	Local collapse, major fire
									36%	0,00002370	3,9	Local collapse, major fire, evacuation at sea
				4%	50%					0,00002489	0,0	safe
					50%	60%	73%			0,00001090	1,0	Local collapse
							27%	57%	95%	0,00000218	1,0	Local collapse
									5%	0,00000011	2,0	Local collapse, evacuation at shore
								43%	90%	0,00000156	1,0	Local collapse
									10%	0,00000017	3,1	Local collapse, evacuation at sea
						40%	18%			0,00000179	2,0	Local collapse, major fire
							82%	44%	95%	0,00000341	2,0	Local collapse, major fire
									5%	0,00000018	3,0	Local collapse, major fire, evacuation at shore
								56%	64%	0,00000293	2,0	Local collapse, major fire
									36%	0,00000165	3,9	Local collapse, major fire, evacuation at sea
		34,67%	96%							0,03106601	0,0	safe
		33.6	4%	96%	70%					0,00086985	0,0	safe
					30%	60%	73%			0,00016328	1,0	Local collapse
							27%	57%	95%	0,00003270	1,0	Local collapse
									5%	0,00000172	2,0	Local collapse, evacuation at shore
								43%	90%	0,00002337	1,0	Local collapse
									10%	0,00000260	8,2	Local collapse, evacuation at sea
						40%	18%			0,00002684	3,0	Local collapse, major fire
							82%	44%	95%	0,00005111	3,0	Local collapse, major fire
									5%	0,00000269	4,0	Local collapse, major fire, evacuation at shore
								56%	64%	0,00004382	3,0	Local collapse, major fire
									36%	0,00002465	9,7	Local collapse, major fire, evacuation at sea
				4%	50%					0,00002589	0,0	safe
					50%	60%	73%			0,00001134	1,0	Local collapse
							27%	57%	95%	0,00000227	1,0	Local collapse
									5%	0,00000012	2,0	Local collapse, evacuation at shore
								43%	90%	0,00000162	1,0	Local collapse
									10%	0,00000018	8,2	Local collapse, evacuation at sea
						40%	18%			0,00000186	3,0	Local collapse, major fire
							82%	44%	95%	0,00000355	3,0	Local collapse, major fire
									5%	0,00000019	4,0	Local collapse, major fire, evacuation at shore
								56%	64%	0,00000304	3,0	Local collapse, major fire
									36%	0,00000171	9,7	Local collapse, major fire, evacuation at sea
		32,00%	96%							0,02867632	0,0	safe
		204	4%	96%	70%					0,00080294	0,0	safe

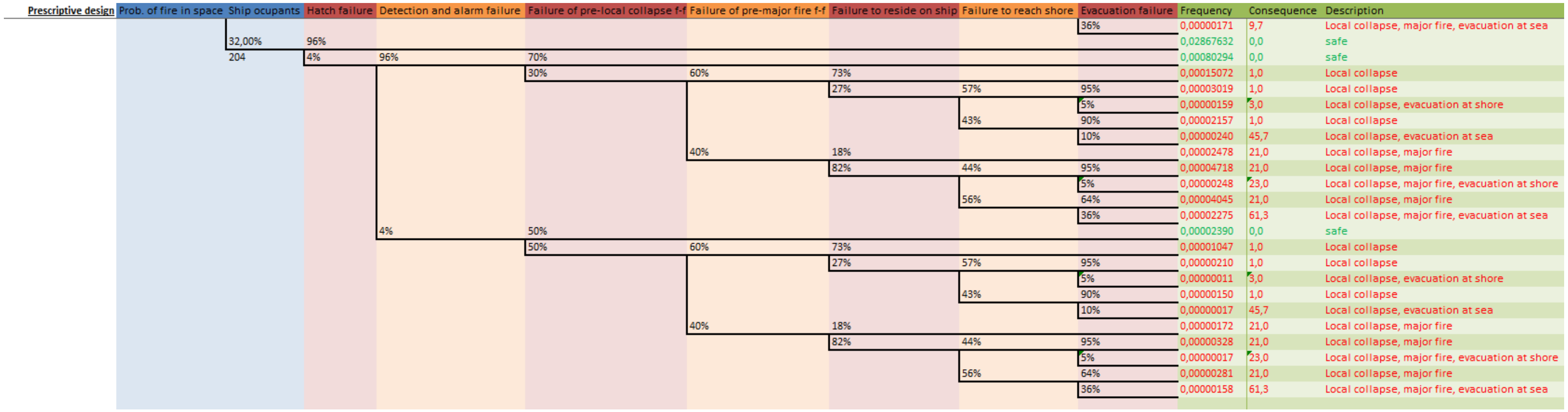


Figure O5. Event tree for the auxiliary machinery spaces in the prescriptive design.

Base design	Prob. of fire in space	Ship ocupants	Hatch failure	Detection and alarm failure	Failure of pre-local collapse f-f	Failure of pre-major fire f-f	Failure to reside on ship	Failure to reach shore	Evacuation failure	Frequency	Consequence	Description
1,64209	5,68%	33,33%	96%							0,02987116	0,0	safe
Significant fire	Aux. mach. spaces	10.5	4%	96%	70%					0,00083639	0,0	safe
					30%	15%	62%			0,00003334	4,0	Local collapse
							38%	30%	95%	0,00000582	4,0	Local collapse
									5%	0,00000031	5,0	Local collapse, evacuation at shore
								70%	80%	0,00001144	4,0	Local collapse
									20%	0,00000286	5,4	Local collapse, evacuation at sea
						85%	3%			0,00000914	7,0	Local collapse, major fire
							97%	10%	95%	0,00002808	7,0	Local collapse, major fire
									5%	0,00000148	8,0	Local collapse, major fire, evacuation at shore
								90%	50%	0,00013300	7,0	Local collapse, major fire
									50%	0,00013300	7,8	Local collapse, major fire, evacuation at sea
				4%	40%					0,00001991	0,0	safe
					60%	15%	62%			0,00000278	4,0	Local collapse
							38%	30%	95%	0,00000049	4,0	Local collapse
									5%	0,00000003	5,0	Local collapse, evacuation at shore
								70%	80%	0,00000095	4,0	Local collapse
									20%	0,00000024	5,4	Local collapse, evacuation at sea
						85%	3%			0,00000076	7,0	Local collapse, major fire
							97%	10%	95%	0,00000234	7,0	Local collapse, major fire
									5%	0,00000012	8,0	Local collapse, major fire, evacuation at shore
								90%	50%	0,00001108	7,0	Local collapse, major fire
									50%	0,00001108	7,8	Local collapse, major fire, evacuation at sea
		34,67%	96%							0,03106601	0,0	safe
		33.6	4%	96%	70%					0,00086985	0,0	safe
					30%	15%	62%			0,00003467	4,0	Local collapse
							38%	30%	95%	0,00000606	4,0	Local collapse
									5%	0,00000032	5,0	Local collapse, evacuation at shore
								70%	80%	0,00001190	4,0	Local collapse
									20%	0,00000297	10,5	Local collapse, evacuation at sea
						85%	3%			0,00000951	9,0	Local collapse, major fire
							97%	10%	95%	0,00002920	9,0	Local collapse, major fire
									5%	0,00000154	10,0	Local collapse, major fire, evacuation at shore
								90%	50%	0,00013832	9,0	Local collapse, major fire
									50%	0,00013832	14,4	Local collapse, major fire, evacuation at sea
				4%	40%					0,00002071	0,0	safe
					60%	15%	62%			0,00000289	4,0	Local collapse
							38%	30%	95%	0,00000050	4,0	Local collapse
									5%	0,00000003	5,0	Local collapse, evacuation at shore
								70%	80%	0,00000099	4,0	Local collapse
									20%	0,00000025	10,5	Local collapse, evacuation at sea
						85%	3%			0,00000079	9,0	Local collapse, major fire
							97%	10%	95%	0,00000243	9,0	Local collapse, major fire
									5%	0,00000013	10,0	Local collapse, major fire, evacuation at shore
								90%	50%	0,00001153	9,0	Local collapse, major fire
									50%	0,00001153	14,4	Local collapse, major fire, evacuation at sea
		32,00%	96%							0,02867632	0,0	safe
		204	4%	96%	70%					0,00080204	0,0	safe

Base design	Prob. of fire in space	Ship ocupants	Hatch failure	Detection and alarm failure	Failure of pre-local collapse f-f	Failure of pre-major fire f-f	Failure to reside on ship	Failure to reach shore	Evacuation failure	Frequency	Consequence	Description
									50%	0,00001153	14,4	Local collapse, major fire, evacuation at sea
		32,00%	96%							0,02867632	0,0	safe
		204	4%	96%	70%					0,00080294	0,0	safe
					30%	15%	62%			0,00003200	5,0	Local collapse
							38%	30%	95%	0,00000559	5,0	Local collapse
									5%	0,00000029	7,0	Local collapse, evacuation at shore
								70%	80%	0,00001098	5,0	Local collapse
									20%	0,00000275	48,8	Local collapse, evacuation at sea
						85%	3%			0,00000877	55,0	Local collapse, major fire
							97%	10%	95%	0,00002695	55,0	Local collapse, major fire
									5%	0,00000142	57,0	Local collapse, major fire, evacuation at shore
								90%	50%	0,00012768	55,0	Local collapse, major fire
									50%	0,00012768	87,8	Local collapse, major fire, evacuation at sea
				4%	40%					0,00001912	0,0	safe
					60%	15%	62%			0,00000267	5,0	Local collapse
							38%	30%	95%	0,00000047	5,0	Local collapse
									5%	0,00000002	7,0	Local collapse, evacuation at shore
								70%	80%	0,00000092	5,0	Local collapse
									20%	0,00000023	48,8	Local collapse, evacuation at sea
						85%	3%			0,00000073	55,0	Local collapse, major fire
							97%	10%	95%	0,00000225	55,0	Local collapse, major fire
									5%	0,00000012	57,0	Local collapse, major fire, evacuation at shore
								90%	50%	0,00001064	55,0	Local collapse, major fire
									50%	0,00001064	87,8	Local collapse, major fire, evacuation at sea

Figure O6. Event tree for the auxiliary machinery spaces in the base design.

Void space event trees

The event trees for the void spaces in the prescriptive design and the base design are presented in Figures O7 and O8 below.

Prescriptive design	Prob. of fire in space	Hatch failure	Frequency	Consequence	Description
1,64209	2,32%	100%	0,03816652	0,0	safe
Significant fire	Void spaces	0%	0,00000000	0,0	-

Figure O7. Event tree for the void spaces in the prescriptive design.

Base design	Prob. of fire in space	Hatch failure	Frequency	Consequence	Description
1,64209	2,32%	100%	0,03816652	0,0	safe
Significant fire	Void spaces	0%	0,00000000	0,0	-

Figure O8. Event tree for the void spaces in the base design.

Wheelhouse event trees

The event trees for the wheelhouse in the prescriptive design and the base design are presented in Figures O9 and O10 below.

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	6,51%	33,33%	99,6%	5%									0,00177564	0,0	safe
Significant fire	Wheelhouse	10.5		95%	91%								0,03070088	0,0	safe
					9%	99%	30%						0,00090180	0,0	safe
							70%	93%		73%			0,00142086	0,0	safe
										27%	57%	95%	0,00028457	0,0	safe
												5%	0,00001498	1,0	Evacuation at shore
											43%	90%	0,00020338	0,0	safe
												10%	0,00002260	2,3	Evacuation at sea
								8%	36%	18%			0,00001023	0,0	safe
										82%	57%	95%	0,00002523	0,0	safe
												5%	0,00000133	1,0	Evacuation at shore
											43%	90%	0,00001803	0,0	safe
												10%	0,00000200	2,3	Evacuation at sea
									64%	18%			0,00001818	1,0	Major fire
										82%	44%	95%	0,00003462	1,0	Major fire
												5%	0,00000182	2,0	Major fire, evacuation at shore
											56%	64%	0,00002968	1,0	Major fire
												36%	0,00001670	3,1	Major fire, evacuation at sea
						1%	50%						0,00001518	0,0	safe
							50%	78%		73%			0,00000859	0,0	safe
										27%	57%	95%	0,00000172	0,0	safe
												5%	0,00000009	1,0	Evacuation at shore
											43%	90%	0,00000123	0,0	safe
												10%	0,00000014	2,3	Evacuation at sea
								23%	18%	18%			0,00000011	0,0	safe
										82%	57%	95%	0,00000027	0,0	safe
												5%	0,00000001	1,0	Evacuation at shore
											43%	90%	0,00000020	0,0	safe
												10%	0,00000002	2,3	Evacuation at sea
									82%	18%			0,00000050	1,0	Major fire
										82%	44%	95%	0,00000096	1,0	Major fire
												5%	0,00000005	2,0	Major fire, evacuation at shore
											56%	64%	0,00000082	1,0	Major fire
												36%	0,00000046	3,1	Major fire, evacuation at sea
			0,4%		91%								0,00012979	0,0	safe
					9%	99%	30%						0,00000381	0,0	safe

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												36%	0,00000046	3,1	Major fire, evacuation at sea
			0,4%		91%								0,00012979	0,0	safe
					9%	99%	30%						0,00000381	0,0	safe
			NO				70%	93%		73%			0,00000601	0,0	safe
										27%	57%	95%	0,00000120	0,0	safe
			YES									5%	0,00000006	1,0	Evacuation at shore
											43%	90%	0,00000086	0,0	safe
												10%	0,00000010	2,3	Evacuation at sea
								8%	36%	18%			0,00000004	0,0	safe
										82%	57%	95%	0,00000011	0,0	safe
												5%	0,00000001	1,0	Evacuation at shore
											43%	90%	0,00000008	0,0	safe
												10%	0,00000001	2,3	Evacuation at sea
									64%	18%			0,00000008	1,0	Major fire
										82%	44%	95%	0,00000015	1,0	Major fire
												5%	0,00000001	2,0	Major fire, evacuation at shore
											56%	64%	0,00000013	1,0	Major fire
												36%	0,00000007	3,1	Major fire, evacuation at sea
						1%	50%						0,00000006	0,0	safe
							50%	78%		73%			0,00000004	0,0	safe
										27%	57%	95%	0,00000001	0,0	safe
												5%	0,00000000	1,0	Evacuation at shore
											43%	90%	0,00000001	0,0	safe
												10%	0,00000000	2,3	Evacuation at sea
								23%	18%	18%			0,00000000	0,0	safe
										82%	57%	95%	0,00000000	0,0	safe
												5%	0,00000000	1,0	Evacuation at shore
											43%	90%	0,00000000	0,0	safe
												10%	0,00000000	2,3	Evacuation at sea
									82%	18%			0,00000000	1,0	Major fire
										82%	44%	95%	0,00000000	1,0	Major fire
												5%	0,00000000	2,0	Major fire, evacuation at shore
											56%	64%	0,00000000	1,0	Major fire
												36%	0,00000000	3,1	Major fire, evacuation at sea
		34,67%	99,6%	5%									0,00184667	0,0	safe

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												36%	0,00000000	3,1	Major fire, evacuation at sea
		34,67%	99,6%	5%									0,00184667	0,0	safe
		33.6		95%	91%								0,03192892	0,0	safe
					9%	99%	30%						0,00093787	0,0	safe
							70%	93%		73%			0,00147769	0,0	safe
										27%	57%	95%	0,00029595	0,0	safe
												5%	0,00001558	1,0	Evacuation at shore
											43%	90%	0,00021151	0,0	safe
												10%	0,00002350	7,4	Evacuation at sea
								8%	36%	18%			0,00001064	0,0	safe
										82%	57%	95%	0,00002624	0,0	safe
												5%	0,00000138	1,0	Evacuation at shore
											43%	90%	0,00001875	0,0	safe
												10%	0,00000208	7,4	Evacuation at sea
									64%	18%			0,00001891	1,0	Major fire
										82%	44%	95%	0,00003600	1,0	Major fire
												5%	0,00000189	2,0	Major fire, evacuation at shore
											56%	64%	0,00003087	1,0	Major fire
												36%	0,00001736	8,2	Major fire, evacuation at sea
						1%	50%						0,00001579	0,0	safe
							50%	78%		73%			0,00000893	0,0	safe
										27%	57%	95%	0,00000179	0,0	safe
												5%	0,00000009	1,0	Evacuation at shore
											43%	90%	0,00000128	0,0	safe
												10%	0,00000014	7,4	Evacuation at sea
								23%	18%	18%			0,00000012	0,0	safe
										82%	57%	95%	0,00000028	0,0	safe
												5%	0,00000001	1,0	Evacuation at shore
											43%	90%	0,00000020	0,0	safe
												10%	0,00000002	7,4	Evacuation at sea
									82%	18%			0,00000052	1,0	Major fire
										82%	44%	95%	0,00000100	1,0	Major fire
												5%	0,00000005	2,0	Major fire, evacuation at shore
											56%	64%	0,00000086	1,0	Major fire
												36%	0,00000048	8,2	Major fire, evacuation at sea
			0,4%		91%								0,00013498	0,0	safe
					9%	99%	30%						0,00000386	0,0	safe

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												36%	0,00000048	8,2	Major fire, evacuation at sea
			0,4%		91%								0,00013498	0,0	safe
					9%	99%	30%						0,00000396	0,0	safe
			NO				70%	93%		73%			0,00000625	0,0	safe
										27%	57%	95%	0,00000125	0,0	safe
			YES									5%	0,00000007	1,0	Evacuation at shore
											43%	90%	0,00000089	0,0	safe
												10%	0,00000010	7,4	Evacuation at sea
								8%	36%	18%			0,00000004	0,0	safe
										82%	57%	95%	0,00000011	0,0	safe
												5%	0,00000001	1,0	Evacuation at shore
											43%	90%	0,00000008	0,0	safe
												10%	0,00000001	7,4	Evacuation at sea
									64%	18%			0,00000008	1,0	Major fire
										82%	44%	95%	0,00000015	1,0	Major fire
												5%	0,00000001	2,0	Major fire, evacuation at shore
											56%	64%	0,00000013	1,0	Major fire
												36%	0,00000007	8,2	Major fire, evacuation at sea
						1%	50%						0,00000007	0,0	safe
							50%	78%		73%			0,00000004	0,0	safe
										27%	57%	95%	0,00000001	0,0	safe
												5%	0,00000000	1,0	Evacuation at shore
											43%	90%	0,00000001	0,0	safe
												10%	0,00000000	7,4	Evacuation at sea
								23%	18%	18%			0,00000000	0,0	safe
										82%	57%	95%	0,00000000	0,0	safe
												5%	0,00000000	1,0	Evacuation at shore
											43%	90%	0,00000000	0,0	safe
												10%	0,00000000	7,4	Evacuation at sea
									82%	18%			0,00000000	1,0	Major fire
										82%	44%	95%	0,00000000	1,0	Major fire
												5%	0,00000000	2,0	Major fire, evacuation at shore
											56%	64%	0,00000000	1,0	Major fire
												36%	0,00000000	8,2	Major fire, evacuation at sea
		32,00%	99,6%	5%									0,00170462	0,0	safe

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												36%	0,00000000	8,2	Major fire, evacuation at sea
		32,00%	99,6%	5%									0,00170462	0,0	safe
		204		95%	91%								0,02947285	0,0	safe
					9%	90%	30%						0,00078702	0,0	safe
							70%	93%		73%			0,00124002	0,0	safe
										27%	57%	95%	0,00024835	0,0	safe
												5%	0,00001307	2,0	Evacuation at shore
											43%	90%	0,00017749	0,0	safe
												10%	0,00001972	44,9	Evacuation at sea
								8%	36%	18%			0,00000892	1,0	Local external fire
										82%	57%	95%	0,00002202	1,0	Local external fire
												5%	0,00000116	3,0	Local external fire, evacuation at shore
											43%	90%	0,00001573	1,0	Local external fire
												10%	0,00000175	45,7	Local external fire, evacuation at sea
									64%	18%			0,00001587	11,0	Local external fire, major fire
										82%	44%	95%	0,00003021	11,0	Local external fire, major fire
												5%	0,00000159	13,0	Local external fire, major fire, evacuation at shore
											56%	64%	0,00002591	11,0	Local external fire, major fire
												36%	0,00001457	53,5	Local external fire, major fire, evacuation at sea
						10%	50%						0,00014574	0,0	safe
							50%	78%		73%			0,00008246	0,0	safe
										27%	57%	95%	0,00001651	0,0	safe
												5%	0,00000087	2,0	Evacuation at shore
											43%	90%	0,00001180	0,0	safe
												10%	0,00000131	44,9	Evacuation at sea
								23%	18%	18%			0,00000106	1,0	Local external fire
										82%	57%	95%	0,00000262	1,0	Local external fire
												5%	0,00000014	3,0	Local external fire, evacuation at shore
											43%	90%	0,00000187	1,0	Local external fire
												10%	0,00000021	45,7	Local external fire, evacuation at sea
									82%	18%			0,00000484	11,0	Local external fire, major fire
										82%	44%	95%	0,00000922	11,0	Local external fire, major fire
												5%	0,00000049	13,0	Local external fire, major fire, evacuation at shore
											56%	64%	0,00000790	11,0	Local external fire, major fire
												36%	0,00000445	53,5	Local external fire, major fire, evacuation at sea
			0,4%		91%								0,00012459	0,0	safe
					9%	90%	30%						0,00000333	0,0	safe

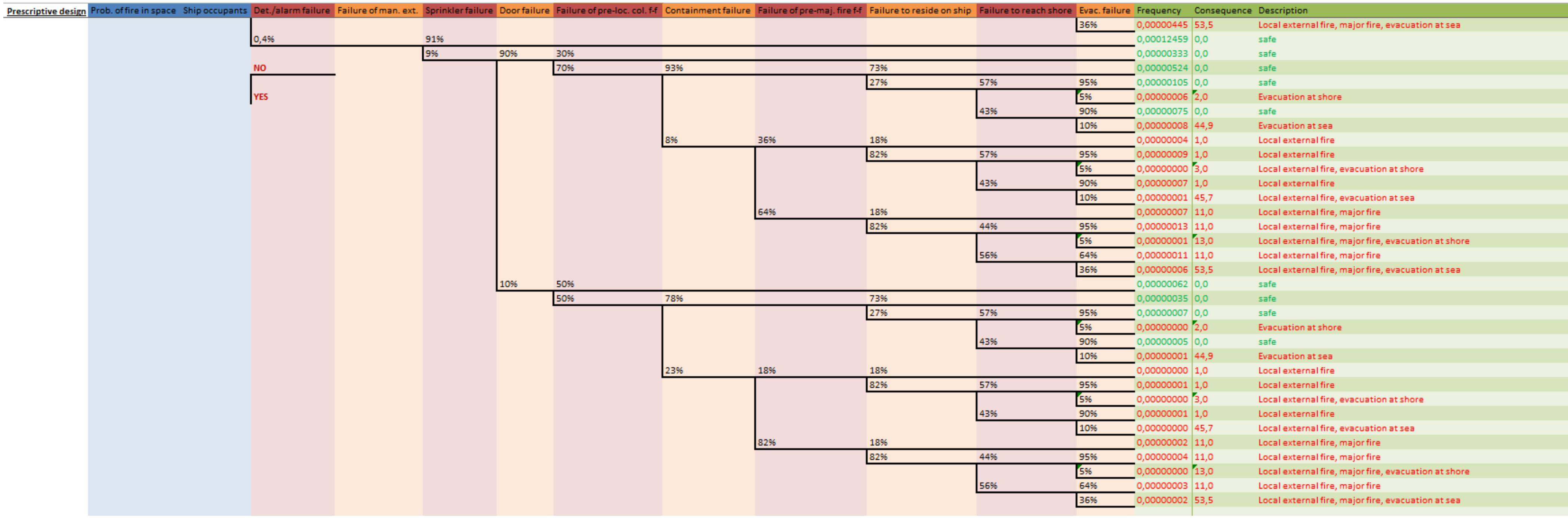


Figure O9. Event tree for the wheelhouse in the prescriptive design.

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	6,51%	33,33%	99,6%	5%									0,00177564	0,0	safe
Significant fire	Wheelhouse	10.5		95%	91%								0,03070088	0,0	safe
					9%	99%	15%						0,00045090	0,0	safe
							85%	88%		62%			0,00139406	0,0	safe
										38%	30%	95%	0,00024351	0,0	safe
												5%	0,00001282	1,0	Evacuation at shore
											70%	80%	0,00047848	0,0	safe
												20%	0,00011962	2,3	Evacuation at sea
								12%	5%	3%			0,00000041	1,0	Local external fire
										97%	30%	95%	0,00000381	1,0	Local external fire
												5%	0,00000020	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000749	1,0	Local external fire
												20%	0,00000187	3,1	Local external fire, evacuation at sea
									96%	3%			0,00000878	2,0	Local external fire, major fire
										97%	10%	95%	0,00002698	2,0	Local external fire, major fire
												5%	0,00000142	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00012781	2,0	Local external fire, major fire
												50%	0,00012781	3,9	Local external fire, major fire, evacuation at sea
						1%	40%						0,00001215	0,0	safe
							60%	64%		62%			0,00000723	0,0	safe
										38%	30%	95%	0,00000126	0,0	safe
												5%	0,00000007	1,0	Evacuation at shore
											70%	80%	0,00000248	0,0	safe
												20%	0,00000062	2,3	Evacuation at sea
								36%	2%	3%			0,00000000	1,0	Local external fire
										97%	30%	95%	0,00000003	1,0	Local external fire
												5%	0,00000000	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000005	1,0	Local external fire
												20%	0,00000001	3,1	Local external fire, evacuation at sea
									99%	3%			0,00000019	2,0	Local external fire, major fire
										97%	10%	95%	0,00000060	2,0	Local external fire, major fire
												5%	0,00000003	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00000282	2,0	Local external fire, major fire
												50%	0,00000282	3,9	Local external fire, major fire, evacuation at sea
			0,4%		91%								0,00012979	0,0	safe
					9%	99%	15%						0,00000191	0,0	safe

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												50%	0,00000282	3,9	Local external fire, major fire, evacuation at sea
			0,4%		91%								0,00012979	0,0	safe
					9%	99%	15%						0,00000191	0,0	safe
			NO				85%	88%		62%			0,00000589	0,0	safe
										38%	30%	95%	0,00000103	0,0	safe
			YES									5%	0,00000005	1,0	Evacuation at shore
											70%	80%	0,00000202	0,0	safe
												20%	0,00000051	2,3	Evacuation at sea
								12%	5%	3%			0,00000000	1,0	Local external fire
										97%	30%	95%	0,00000002	1,0	Local external fire
												5%	0,00000000	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000003	1,0	Local external fire
												20%	0,00000001	3,1	Local external fire, evacuation at sea
									96%	3%			0,00000004	2,0	Local external fire, major fire
										97%	10%	95%	0,00000011	2,0	Local external fire, major fire
												5%	0,00000001	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00000054	2,0	Local external fire, major fire
												50%	0,00000054	3,9	Local external fire, major fire, evacuation at sea
						1%	40%						0,00000005	0,0	safe
							60%	64%		62%			0,00000003	0,0	safe
										38%	30%	95%	0,00000001	0,0	safe
												5%	0,00000000	1,0	Evacuation at shore
											70%	80%	0,00000001	0,0	safe
												20%	0,00000000	2,3	Evacuation at sea
								36%	2%	3%			0,00000000	1,0	Local external fire
										97%	30%	95%	0,00000000	1,0	Local external fire
												5%	0,00000000	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000000	1,0	Local external fire
												20%	0,00000000	3,1	Local external fire, evacuation at sea
									99%	3%			0,00000000	2,0	Local external fire, major fire
										97%	10%	95%	0,00000000	2,0	Local external fire, major fire
												5%	0,00000000	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00000001	2,0	Local external fire, major fire
												50%	0,00000001	3,9	Local external fire, major fire, evacuation at sea
		34,67%	99,6%	5%									0,00184667	0,0	safe
		33.6		95%	91%								0.03192892	0.0	safe

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												50%	0,00000001	3,9	Local external fire, major fire, evacuation at sea
		34,67%	99,6%	5%									0,00184667	0,0	safe
		33.6		95%	91%								0,03192892	0,0	safe
					9%	99%	15%						0,00046893	0,0	safe
							85%	88%		62%			0,00144982	0,0	safe
										38%	30%	95%	0,00025325	0,0	safe
												5%	0,00001333	1,0	Evacuation at shore
											70%	80%	0,00049762	0,0	safe
												20%	0,00012440	7,4	Evacuation at sea
								12%	5%	3%			0,00000043	1,0	Local external fire
										97%	30%	95%	0,00000397	1,0	Local external fire
												5%	0,00000021	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000779	1,0	Local external fire
												20%	0,00000195	8,2	Local external fire, evacuation at sea
									96%	3%			0,00000914	2,0	Local external fire, major fire
										97%	10%	95%	0,00002806	2,0	Local external fire, major fire
												5%	0,00000148	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00013293	2,0	Local external fire, major fire
												50%	0,00013293	9,0	Local external fire, major fire, evacuation at sea
						1%	40%						0,00001263	0,0	safe
							60%	64%		62%			0,00000752	0,0	safe
										38%	30%	95%	0,00000131	0,0	safe
												5%	0,00000007	1,0	Evacuation at shore
											70%	80%	0,00000258	0,0	safe
												20%	0,00000065	7,4	Evacuation at sea
								36%	2%	3%			0,00000000	1,0	Local external fire
										97%	30%	95%	0,00000003	1,0	Local external fire
												5%	0,00000000	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000006	1,0	Local external fire
												20%	0,00000001	8,2	Local external fire, evacuation at sea
									99%	3%			0,00000020	2,0	Local external fire, major fire
										97%	10%	95%	0,00000062	2,0	Local external fire, major fire
												5%	0,00000003	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00000293	2,0	Local external fire, major fire
												50%	0,00000293	9,0	Local external fire, major fire, evacuation at sea
			0,4%		91%								0,00013498	0,0	safe

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
												50%	0,00000293	9,0	Local external fire, major fire, evacuation at sea
			0,4%		91%								0,00013498	0,0	safe
					9%	99%	15%						0,00000198	0,0	safe
			NO				85%	88%		62%			0,00000613	0,0	safe
										38%	30%	95%	0,00000107	0,0	safe
			YES									5%	0,00000006	1,0	Evacuation at shore
											70%	80%	0,00000210	0,0	safe
												20%	0,00000053	7,4	Evacuation at sea
								12%	5%	3%			0,00000000	1,0	Local external fire
										97%	30%	95%	0,00000002	1,0	Local external fire
												5%	0,00000000	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000003	1,0	Local external fire
												20%	0,00000001	8,2	Local external fire, evacuation at sea
									96%	3%			0,00000004	2,0	Local external fire, major fire
										97%	10%	95%	0,00000012	2,0	Local external fire, major fire
												5%	0,00000001	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00000056	2,0	Local external fire, major fire
												50%	0,00000056	9,0	Local external fire, major fire, evacuation at sea
						1%	40%						0,00000005	0,0	safe
							60%	64%		62%			0,00000003	0,0	safe
										38%	30%	95%	0,00000001	0,0	safe
												5%	0,00000000	1,0	Evacuation at shore
											70%	80%	0,00000001	0,0	safe
												20%	0,00000000	7,4	Evacuation at sea
								36%	2%	3%			0,00000000	1,0	Local external fire
										97%	30%	95%	0,00000000	1,0	Local external fire
												5%	0,00000000	2,0	Local external fire, evacuation at shore
											70%	80%	0,00000000	1,0	Local external fire
												20%	0,00000000	8,2	Local external fire, evacuation at sea
									99%	3%			0,00000000	2,0	Local external fire, major fire
										97%	10%	95%	0,00000000	2,0	Local external fire, major fire
												5%	0,00000000	3,0	Local external fire, major fire, evacuation at shore
											90%	50%	0,00000001	2,0	Local external fire, major fire
												50%	0,00000001	9,0	Local external fire, major fire, evacuation at sea
		32,00%	99,6%	5%									0,00170462	0,0	safe
		204		95%	91%								0,02947285	0,0	safe

Base design

Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Containment failure	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
											50%	0,00000001	9,0	Local external fire, major fire, evacuation at sea
	32,00%	99,6%	5%									0,00170462	0,0	safe
	204		95%	91%								0,02947285	0,0	safe
				9%	90%	15%						0,00039351	0,0	safe
						85%	88%		62%			0,00121663	2,0	Local collapse
									38%	30%	95%	0,00021252	2,0	Local collapse
											5%	0,00001119	4,0	Local collapse, evacuation at shore
										70%	80%	0,00041758	2,0	Local collapse
											20%	0,00010439	46,4	Local collapse, evacuation at sea
							12%	5%	3%			0,00000036	8,0	Local collapse, local external fire
									97%	30%	95%	0,00000333	8,0	Local collapsel local external fire
											5%	0,00000018	10,0	Local collapse, local external fire, evacuation at shore
										70%	80%	0,00000654	8,0	Local collapse, local external fire
											20%	0,00000164	51,1	Local collapse, local external fire, evacuation at sea
								96%	3%			0,00000767	18,0	Local collapse, local external fire, major fire
									97%	10%	95%	0,00002355	18,0	Local collapse, local external fire, major fire
											5%	0,00000124	20,0	Local collapse, local external fire, major fire, evacuation at shore
										90%	50%	0,00011155	18,0	Local collapse, local external fire, major fire
											50%	0,00011155	58,9	Local collapse, local external fire, major fire, evacuation at sea
					10,0%	40%						0,00011660	0,0	safe
						60%	64%		62%			0,00006940	2,0	Local collapse
									38%	30%	95%	0,00001212	2,0	Local collapse
											5%	0,00000064	4,0	Local collapse, evacuation at shore
										70%	80%	0,00002382	2,0	Local collapse
											20%	0,00000595	46,4	Local collapse, evacuation at sea
							36%	2%	3%			0,00000003	8,0	Local collapse, local external fire
									97%	30%	95%	0,00000026	8,0	Local collapsel local external fire
											5%	0,00000001	10,0	Local collapse, local external fire, evacuation at shore
										70%	80%	0,00000051	8,0	Local collapse, local external fire
											20%	0,00000013	51,1	Local collapse, local external fire, evacuation at sea
								99%	3%			0,00000186	18,0	Local collapse, local external fire, major fire
									97%	10%	95%	0,00000571	18,0	Local collapse, local external fire, major fire
											5%	0,00000030	20,0	Local collapse, local external fire, major fire, evacuation at shore
										90%	50%	0,00002707	18,0	Local collapse, local external fire, major fire
											50%	0,00002707	58,9	Local collapse, local external fire, major fire, evacuation at sea
		0,4%		91%								0,00012459	0,0	safe
				9%	90%	15%						0,00000166	0,0	safe

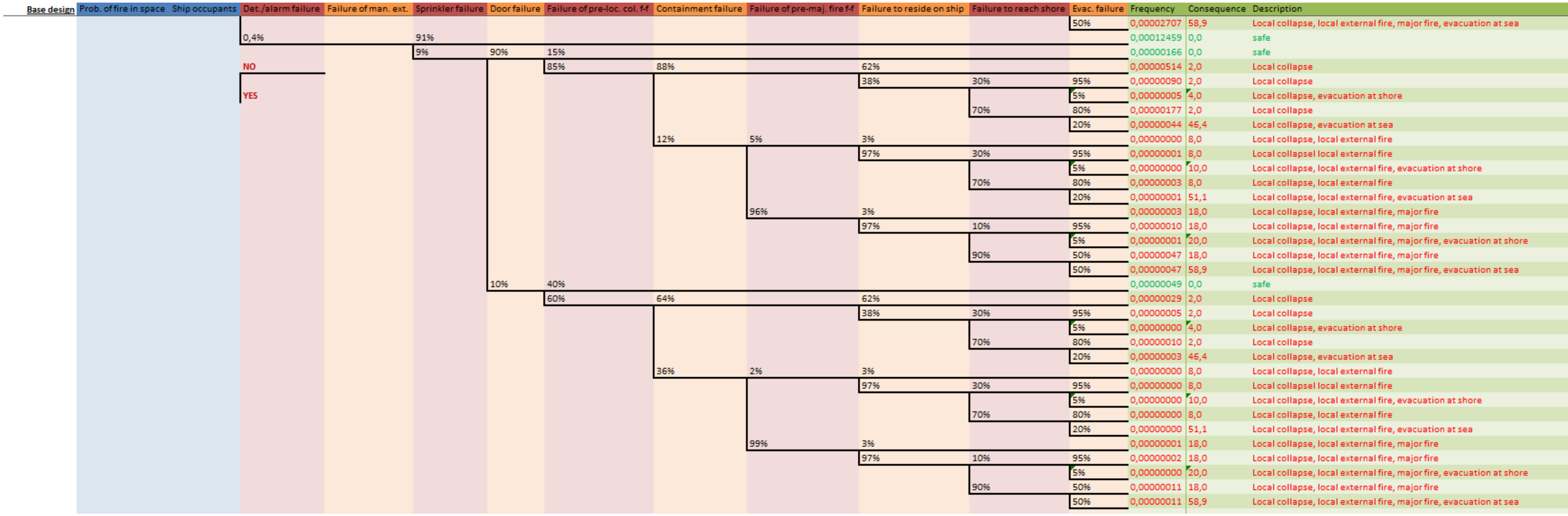


Figure O10. Event tree for the wheelhouse in the base design.

Ro-ro deck space event trees

The event trees for the ro-ro deck in the prescriptive design and the base design are presented in Figures O11 and O12 below.

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Drencher failure	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	21,41%	33,33%	96,0%	65%								0,07311607	0,0	safe
Significant fire	Ro-ro deck	10.5		35%	0%							0,00000000	0,0	safe
					100%	17%	65%					0,00435041	0,0	safe
							35%	30%	73%			0,00051301	1,0	Local fire
									27%	57%	95%	0,00010275	1,0	Local fire
											5%	0,00000541	2,0	Local fire, evacuation at shore
										43%	90%	0,00007343	1,0	Local fire
											10%	0,00000816	3,1	Local fire, evacuation at sea
								70%	18%			0,00029516	2,0	Local fire, major fire
									82%	44%	95%	0,00056205	2,0	Local fire, major fire
											5%	0,00002958	3,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00048191	2,0	Local fire, major fire
											36%	0,00027107	3,9	Major fire, evacuation at sea
						83%	35%					0,01143704	0,0	safe
							65%	30%	73%			0,00465161	1,0	Local fire
									27%	57%	95%	0,00093163	1,0	Local fire
											5%	0,00004903	2,0	Local fire, evacuation at shore
										43%	90%	0,00066582	1,0	Local fire
											10%	0,00007398	3,1	Local fire, evacuation at sea
								70%	18%			0,00267627	2,0	Local fire, major fire
									82%	44%	95%	0,00509621	2,0	Local fire, major fire
											5%	0,00026822	3,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00436957	2,0	Local fire, major fire
											36%	0,00245788	3,9	Major fire, evacuation at sea
			4,0%		0%							0,00000000	0,0	safe
					100%	17%	83%					0,00065734	0,0	safe
			NO				18%	30%	73%			0,00003054	1,0	Local fire
									27%	57%	95%	0,00000612	1,0	Local fire
			YES								5%	0,00000032	2,0	Local fire, evacuation at shore
										43%	90%	0,00000437	1,0	Local fire
											10%	0,00000049	3,1	Local fire, evacuation at sea
								70%	18%			0,00001757	2,0	Local fire, major fire
									82%	44%	95%	0,00003346	2,0	Local fire, major fire
											5%	0,00000176	3,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00002869	2,0	Local fire, major fire
											36%	0,00001614	3,9	Major fire, evacuation at sea
						83%	68%					0,00262585	0,0	safe
							33%	30%	73%			0,00027688	1,0	Local fire
									27%	57%	95%	0,00005545	1,0	Local fire
											5%	0,00000292	2,0	Local fire, evacuation at shore
										43%	90%	0,00003963	1,0	Local fire
											10%	0,00000440	3,1	Local fire, evacuation at sea
								70%	18%			0,00015930	2,0	Local fire, major fire
									82%	44%	95%	0,00030335	2,0	Local fire, major fire
											5%	0,00001597	3,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00026009	2,0	Local fire, major fire
											36%	0,00014630	3,9	Major fire, evacuation at sea
		33,33%	96,0%	65%								0,07311607	0,0	safe

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Drencher failure	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
											36%	0,00014630	3,9	Major fire, evacuation at sea
		33,33%	96,0%	65%								0,07311607	0,0	safe
		10.5		35%	0%							0,00000000	0,0	safe
					100%	17%	65%					0,00435041	0,0	safe
							35%	30%	73%			0,00051301	1,0	Local fire
									27%	57%	95%	0,00010275	1,0	Local fire
											5%	0,00000541	2,0	Local fire, evacuation at shore
										43%	90%	0,00007343	1,0	Local fire
											10%	0,00000816	8,2	Local fire, evacuation at sea
								70%	18%			0,00029516	3,0	Local fire, major fire
									82%	44%	95%	0,00056205	3,0	Local fire, major fire
											5%	0,00002958	4,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00048191	3,0	Local fire, major fire
											36%	0,00027107	9,7	Major fire, evacuation at sea
						83%	35%					0,01143704	0,0	safe
							65%	30%	73%			0,00465161	1,0	Local fire
									27%	57%	95%	0,00093163	1,0	Local fire
											5%	0,00004903	2,0	Local fire, evacuation at shore
										43%	90%	0,00066582	1,0	Local fire
											10%	0,00007398	8,2	Local fire, evacuation at sea
								70%	18%			0,00267627	3,0	Local fire, major fire
									82%	44%	95%	0,00509621	3,0	Local fire, major fire
											5%	0,00026822	4,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00436957	3,0	Local fire, major fire
											36%	0,00245788	9,7	Major fire, evacuation at sea
			4,0%		0%							0,00000000	0,0	safe
					100%	17%	83%					0,00065734	0,0	safe
			NO				18%	30%	73%			0,00003054	1,0	Local fire
									27%	57%	95%	0,00000612	1,0	Local fire
			YES								5%	0,00000032	2,0	Local fire, evacuation at shore
										43%	90%	0,00000437	1,0	Local fire
											10%	0,00000049	8,2	Local fire, evacuation at sea
								70%	18%			0,00001757	3,0	Local fire, major fire
									82%	44%	95%	0,00003346	3,0	Local fire, major fire
											5%	0,00000176	4,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00002869	3,0	Local fire, major fire
											36%	0,00001614	9,7	Major fire, evacuation at sea
						83%	68%					0,00262585	0,0	safe
							33%	30%	73%			0,00027688	1,0	Local fire
									27%	57%	95%	0,00005545	1,0	Local fire
											5%	0,00000292	2,0	Local fire, evacuation at shore
										43%	90%	0,00003963	1,0	Local fire
											10%	0,00000440	8,2	Local fire, evacuation at sea
								70%	18%			0,00015930	3,0	Local fire, major fire
									82%	44%	95%	0,00030335	3,0	Local fire, major fire
											5%	0,00001597	4,0	Local fire, major fire, evacuation at shore
										56%	64%	0,00026009	3,0	Local fire, major fire
											36%	0,00014630	9,7	Major fire, evacuation at sea
		33,33%	96,0%	65%								0,07311607	0,0	safe
		10.5		35%	0%							0,00000000	0,0	safe

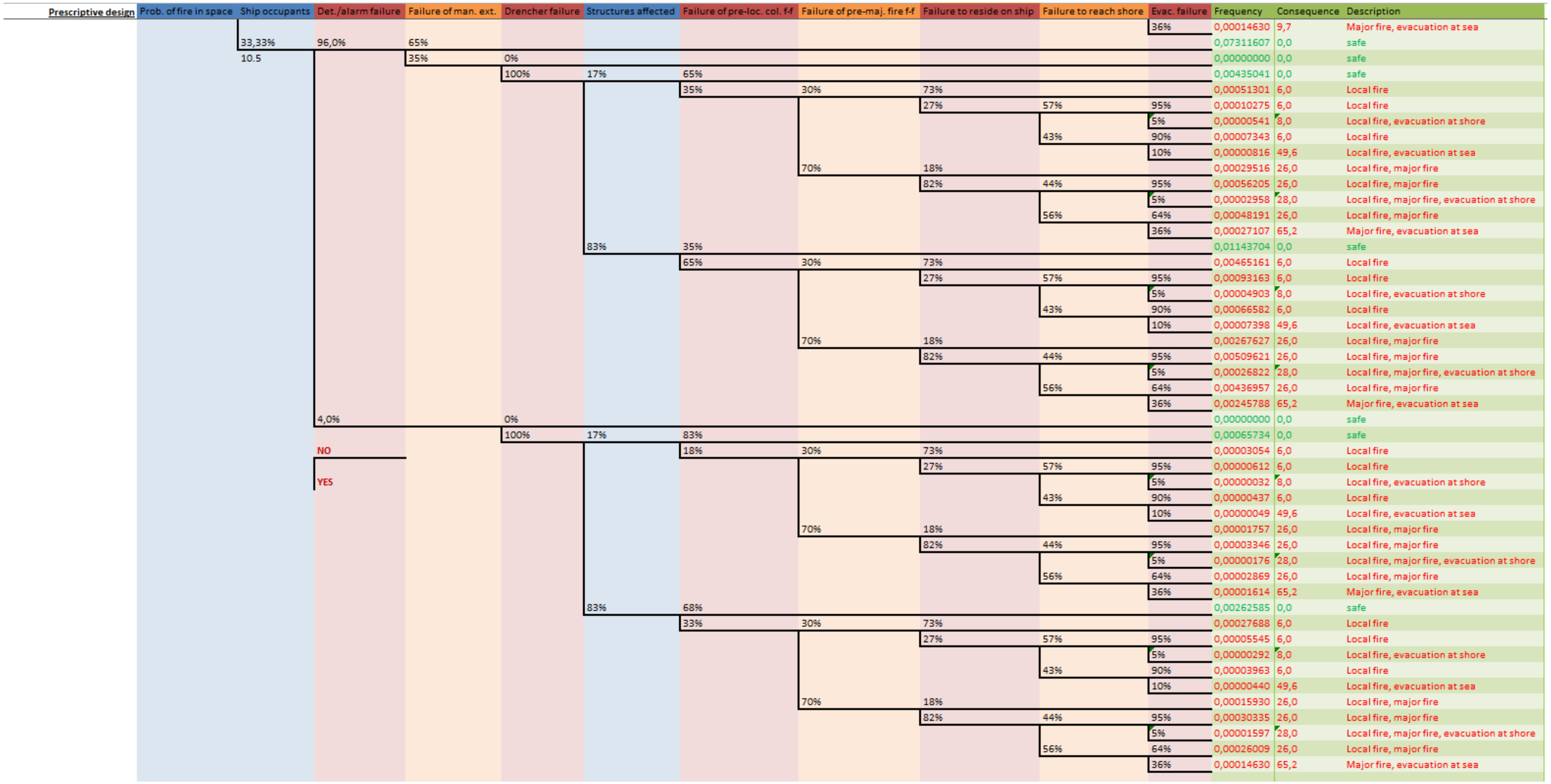


Figure O11. Event tree for the ro-ro deck in the prescriptive design.

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Drencher failure	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	21,41%	33,33%	96,0%	65%								0,07311607	0,0	safe
Significant fire	Ro-ro deck	10.5		35%	0%							0,00000000	0,0	safe
					100%	17%	65%					0,00435041	0,0	safe
							35%	10%	62%			0,00014524	4,0	Local fire
									38%	30%	95%	0,00002537	4,0	Local fire
											5%	0,00000134	5,0	Local fire, evacuation at shore
										70%	80%	0,00004985	4,0	Local fire
											20%	0,00001246	5,4	Local fire, evacuation at sea
								90%	3%			0,00006325	6,0	Local fire, major fire
									97%	10%	95%	0,00019428	6,0	Local fire, major fire
											5%	0,00001023	7,0	Local fire, major fire, evacuation at shore
										90%	50%	0,00092026	6,0	Local fire, major fire
											50%	0,00092026	7,0	Major fire, evacuation at sea
						83%	15%					0,00490159	0,0	safe
							85%	10%	62%			0,00172209	4,0	Local fire
									38%	30%	95%	0,00030081	4,0	Local fire
											5%	0,00001583	5,0	Local fire, evacuation at shore
										70%	80%	0,00059107	4,0	Local fire
											20%	0,00014777	5,4	Local fire, evacuation at sea
								90%	3%			0,00074994	6,0	Local fire, major fire
									97%	10%	95%	0,00230358	6,0	Local fire, major fire
											5%	0,00012124	7,0	Local fire, major fire, evacuation at shore
										90%	50%	0,01091167	6,0	Local fire, major fire
											50%	0,01091167	7,0	Major fire, evacuation at sea
			4,0%		0%							0,00000000	0,0	safe
					100%	17%	83%					0,00065734	0,0	safe
			NO				18%	10%	62%			0,00000865	4,0	Local fire
									38%	30%	95%	0,00000151	4,0	Local fire
			YES								5%	0,00000008	5,0	Local fire, evacuation at shore
										70%	80%	0,00000297	4,0	Local fire
											20%	0,00000074	5,4	Local fire, evacuation at sea
								90%	3%			0,00000376	6,0	Local fire, major fire
									97%	10%	95%	0,00001156	6,0	Local fire, major fire
											5%	0,00000061	7,0	Local fire, major fire, evacuation at shore
										90%	50%	0,00005478	6,0	Local fire, major fire
											50%	0,00005478	7,0	Major fire, evacuation at sea
						83%	58%					0,00223684	0,0	safe
							43%	10%	62%			0,00010251	4,0	Local fire
									38%	30%	95%	0,00001791	4,0	Local fire
											5%	0,00000094	5,0	Local fire, evacuation at shore
										70%	80%	0,00003518	4,0	Local fire
											20%	0,00000880	5,4	Local fire, evacuation at sea
								90%	3%			0,00004464	6,0	Local fire, major fire
									97%	10%	95%	0,00013712	6,0	Local fire, major fire
											5%	0,00000722	7,0	Local fire, major fire, evacuation at shore
										90%	50%	0,00064950	6,0	Local fire, major fire
											50%	0,00064950	7,0	Major fire, evacuation at sea
		33,33%	96,0%	65%								0,07311607	0,0	safe
		10.5		35%	0%							0,00000000	0,0	safe

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Drencher failure	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
											50%	0,00064950	7,0	Major fire, evacuation at sea
		33,33%	96,0%	65%								0,07311607	0,0	safe
		10.5		35%	0%							0,00000000	0,0	safe
					100%	17%	65%					0,00435041	0,0	safe
							35%	10%	62%			0,00014524	4,0	Local fire
									38%	30%	95%	0,00002537	4,0	Local fire
											5%	0,00000134	5,0	Local fire, evacuation at shore
										70%	80%	0,00004985	4,0	Local fire
											20%	0,00001246	10,5	Local fire, evacuation at sea
								90%	3%			0,00006325	8,0	Local fire, major fire
									97%	10%	95%	0,00019428	8,0	Local fire, major fire
											5%	0,00001023	9,0	Local fire, major fire, evacuation at shore
										90%	50%	0,00092026	8,0	Local fire, major fire
											50%	0,00092026	13,6	Major fire, evacuation at sea
						83%	15%					0,00490159	0,0	safe
							85%	10%	62%			0,00172209	4,0	Local fire
									38%	30%	95%	0,00030081	4,0	Local fire
											5%	0,00001583	5,0	Local fire, evacuation at shore
										70%	80%	0,00059107	4,0	Local fire
											20%	0,00014777	10,5	Local fire, evacuation at sea
								90%	3%			0,00074994	8,0	Local fire, major fire
									97%	10%	95%	0,00230358	8,0	Local fire, major fire
											5%	0,00012124	9,0	Local fire, major fire, evacuation at shore
										90%	50%	0,01091167	8,0	Local fire, major fire
											50%	0,01091167	13,6	Major fire, evacuation at sea
			4,0%		0%							0,00000000	0,0	safe
					100%	17%	83%					0,00065734	0,0	safe
			NO				18%	10%	62%			0,00000865	4,0	Local fire
									38%	30%	95%	0,00000151	4,0	Local fire
			YES								5%	0,00000008	5,0	Local fire, evacuation at shore
										70%	80%	0,00000297	4,0	Local fire
											20%	0,00000074	10,5	Local fire, evacuation at sea
								90%	3%			0,00000376	8,0	Local fire, major fire
									97%	10%	95%	0,00001156	8,0	Local fire, major fire
											5%	0,00000061	9,0	Local fire, major fire, evacuation at shore
										90%	50%	0,00005478	8,0	Local fire, major fire
											50%	0,00005478	13,6	Major fire, evacuation at sea
						83%	58%					0,00223684	0,0	safe
							43%	10%	62%			0,00010251	4,0	Local fire
									38%	30%	95%	0,00001791	4,0	Local fire
											5%	0,00000094	5,0	Local fire, evacuation at shore
										70%	80%	0,00003518	4,0	Local fire
											20%	0,00000880	10,5	Local fire, evacuation at sea
								90%	3%			0,00004464	8,0	Local fire, major fire
									97%	10%	95%	0,00013712	8,0	Local fire, major fire
											5%	0,00000722	9,0	Local fire, major fire, evacuation at shore
										90%	50%	0,00064950	8,0	Local fire, major fire
											50%	0,00064950	13,6	Major fire, evacuation at sea
		33,33%	96,0%	65%								0,07311607	0,0	safe
		10.5		35%	0%							0,00000000	0,0	safe

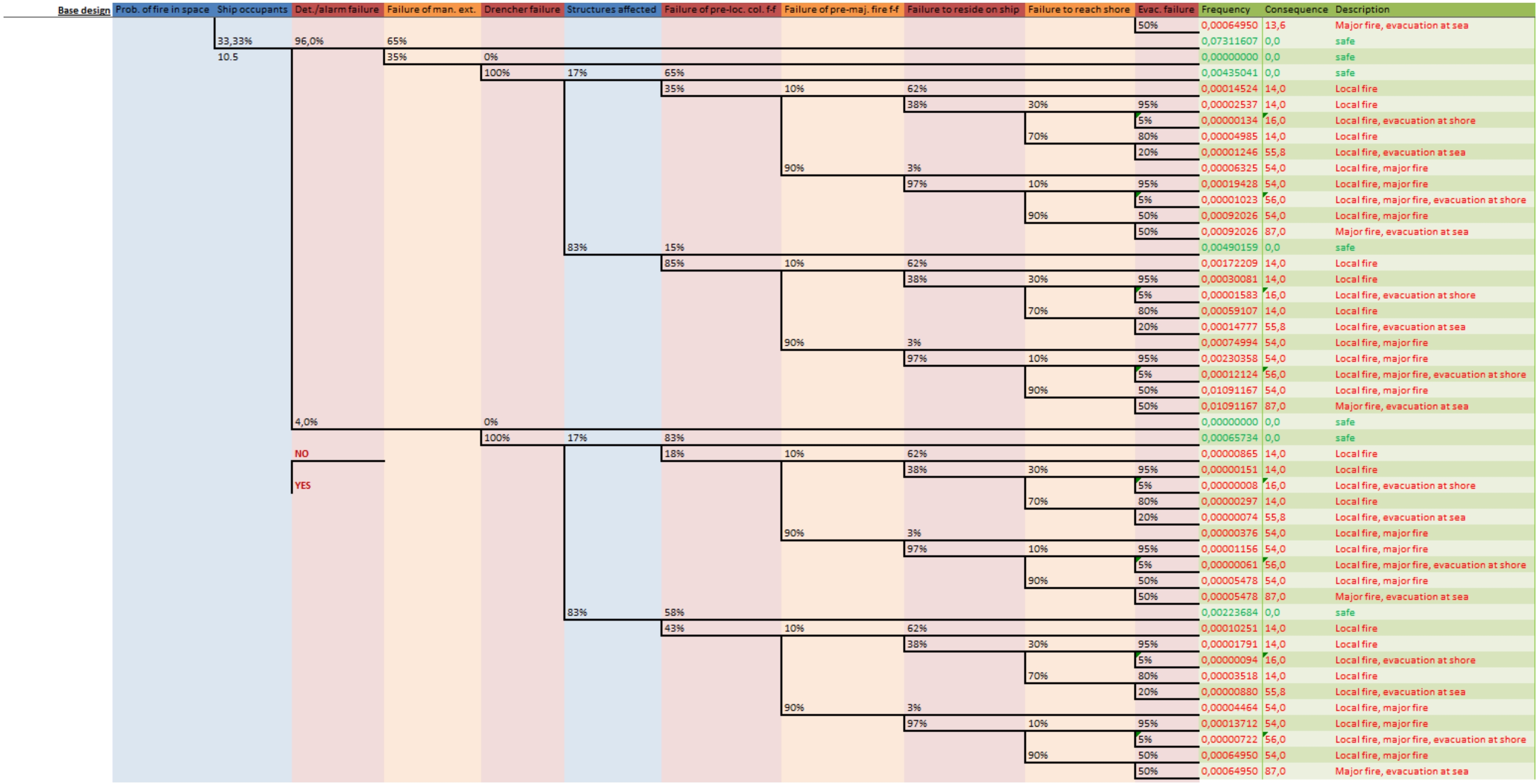


Figure O12. Event tree for the ro-ro deck in the base design.

Stairway space event trees

The event trees for the stairways in the prescriptive design and the base design are presented in Figures O13 and O14 below.

Prescriptive design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	3,72%	33,33%	96,0%	35%								0,00684203	0,0	safe
Significant fire	Stairways	10.5		65%	91%							0,01156303	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	60%					0,00003431	0,0	safe
							40%	27%	73%			0,00000451	0,0	safe
									27%	57%	95%	0,00000090	0,0	safe
											5%	0,00000005	1,0	Evacuation at shore
										43%	90%	0,00000065	0,0	safe
											10%	0,00000007	2,3	Evacuation at sea
								73%	18%			0,00000301	2,0	Major fire
									82%	44%	95%	0,00000572	2,0	Major fire
											5%	0,00000030	3,0	Major fire, evacuation at shore
										56%	64%	0,00000491	2,0	Major fire
											36%	0,00000276	3,9	Major fire, evacuation at sea
			4,0%		91%							0,00074122	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	60%					0,00000220	0,0	safe
							40%	27%	73%			0,00000029	0,0	safe
									27%	57%	95%	0,00000006	0,0	safe
											5%	0,00000000	1,0	Evacuation at shore
										43%	90%	0,00000004	0,0	safe
											10%	0,00000000	2,3	Evacuation at sea
								73%	18%			0,00000019	2,0	Major fire
									82%	44%	95%	0,00000037	2,0	Major fire
											5%	0,00000002	3,0	Major fire, evacuation at shore
										56%	64%	0,00000031	2,0	Major fire
											36%	0,00000018	3,9	Major fire, evacuation at sea
		34,67%	96,0%	35%								0,00711571	0,0	safe
		33.6		65%	91%							0,01202555	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	60%					0,00003568	0,0	safe
							40%	27%	73%			0,00000469	0,0	safe
									27%	57%	95%	0,00000094	0,0	safe
											5%	0,00000005	1,0	Evacuation at shore
										43%	90%	0,00000067	0,0	safe
											10%	0,00000007	7,4	Evacuation at sea
								73%	18%			0,00000313	2,0	Major fire
									82%	44%	95%	0,00000595	2,0	Major fire
											5%	0,00000031	3,0	Major fire, evacuation at shore
										56%	64%	0,00000510	2,0	Major fire
											36%	0,00000287	9,0	Major fire, evacuation at sea
			4,0%		91%							0,00077087	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	60%					0,00000229	0,0	safe
							40%	27%	73%			0,00000000	0,0	safe
									27%	57%	95%	0,00000000	0,0	safe
											5%	0,00000000	1,0	Evacuation at shore
										43%	90%	0,00000000	0,0	safe
											10%	0,00000000	7,4	Evacuation at sea
								73%	18%			0,00000000	2,0	Major fire
									82%	44%	95%	0,00000000	2,0	Major fire
											5%	0,00000000	3,0	Major fire, evacuation at shore
										56%	64%	0,00000000	2,0	Major fire
											36%	0,00000000	9,0	Major fire, evacuation at sea
		32,00%	96,0%	35%								0,00656835	0,0	safe
		204		65%	91%							0,01110051	0,0	safe

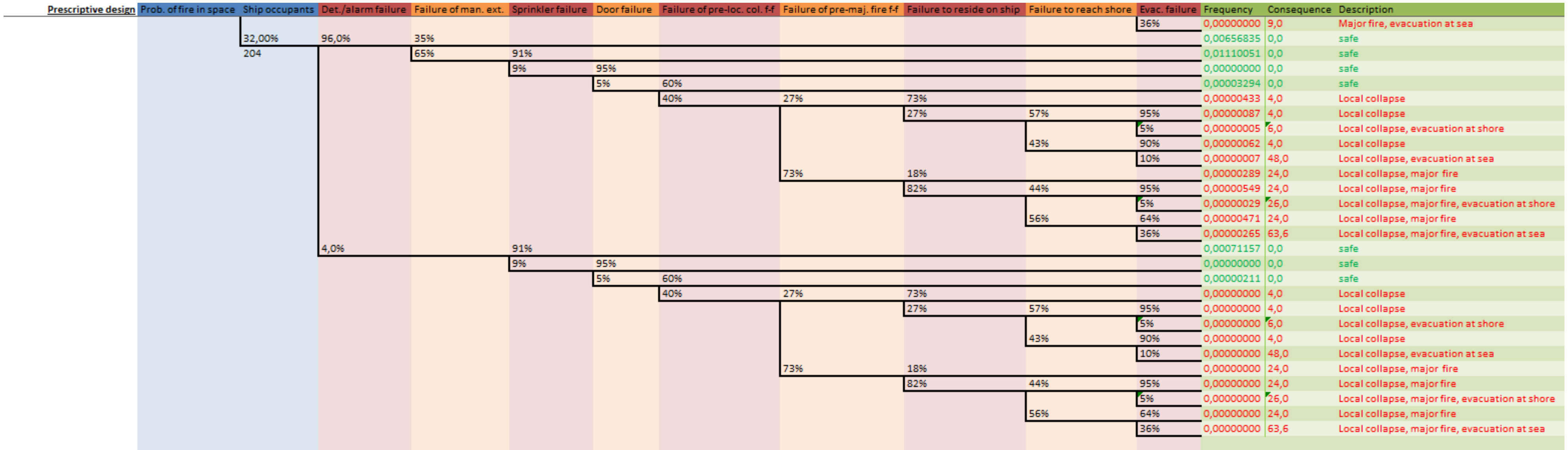


Figure O13. Event tree for the stairways in the prescriptive design.

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	3,72%	33,33%	96,0%	35%								0,00684203	0,0	safe
Significant fire	Stairways	10.5		65%	91%							0,01156303	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	35%					0,00002001	0,0	safe
							65%	8%	62%			0,00000190	1,0	Local collapse
									38%	30%	95%	0,00000033	1,0	Local collapse
											5%	0,00000002	2,0	Local collapse, evacuation at shore
										70%	80%	0,00000065	1,0	Local collapse
											20%	0,00000016	3,1	Local collapse, evacuation at sea
								92%	3%			0,00000102	3,0	Local collapse, major fire
									97%	10%	95%	0,00000314	3,0	Local collapse, major fire
											5%	0,00000017	4,0	Local collapse, major fire, evacuation at shore
										90%	50%	0,00001488	3,0	Local collapse, major fire
											50%	0,00001488	4,7	Local collapse, major fire, evacuation at sea
			4,0%		91%							0,00074122	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	35%					0,00000128	0,0	safe
							65%	8%	62%			0,00000012	1,0	Local collapse
									38%	30%	95%	0,00000002	1,0	Local collapse
											5%	0,00000000	2,0	Local collapse, evacuation at shore
										70%	80%	0,00000004	1,0	Local collapse
											20%	0,00000001	3,1	Local collapse, evacuation at sea
								92%	3%			0,00000007	3,0	Local collapse, major fire
									97%	10%	95%	0,00000020	3,0	Local collapse, major fire
											5%	0,00000001	4,0	Local collapse, major fire, evacuation at shore
										90%	50%	0,00000095	3,0	Local collapse, major fire
											50%	0,00000095	4,7	Local collapse, major fire, evacuation at sea
		34,67%	96,0%	35%								0,00711571	0,0	safe
		33.6		65%	91%							0.01202555	0.0	safe

Base design	Prob. of fire in space	Ship occupants	Det./alarm failure	Failure of man. ext.	Sprinkler failure	Door failure	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
		34,67%	96,0%	35%								0,00711571	0,0	safe
		33.6		65%	91%							0,01202555	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	35%					0,00002081	0,0	safe
							65%	8%	62%			0,00000198	1,0	Local collapse
									38%	30%	95%	0,00000035	1,0	Local collapse
											5%	0,00000002	2,0	Local collapse, evacuation at shore
										70%	80%	0,00000068	1,0	Local collapse
											20%	0,00000017	8,2	Local collapse, evacuation at sea
								92%	3%			0,00000106	4,0	Local collapse, major fire
									97%	10%	95%	0,00000327	4,0	Local collapse, major fire
											5%	0,00000017	5,0	Local collapse, major fire, evacuation at shore
										90%	50%	0,00001548	4,0	Local collapse, major fire
											50%	0,00001548	10,5	Local collapse, major fire, evacuation at sea
			4,0%		91%							0,00077087	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	35%					0,00000133	0,0	safe
							65%	8%	62%			0,00000000	1,0	Local collapse
									38%	30%	95%	0,00000000	1,0	Local collapse
											5%	0,00000000	2,0	Local collapse, evacuation at shore
										70%	80%	0,00000000	1,0	Local collapse
											20%	0,00000000	8,2	Local collapse, evacuation at sea
								92%	3%			0,00000000	4,0	Local collapse, major fire
									97%	10%	95%	0,00000000	4,0	Local collapse, major fire
											5%	0,00000000	5,0	Local collapse, major fire, evacuation at shore
										90%	50%	0,00000000	4,0	Local collapse, major fire
											50%	0,00000000	10,5	Local collapse, major fire, evacuation at sea
		32,00%	96,0%	35%								0,00656835	0,0	safe
		204		65%	91%							0,01110051	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	35%					0,00001921	0,0	safe
							65%	8%	62%			0,00000183	12,0	Local collapse
									38%	30%	95%	0,00000032	12,0	Local collapse
											5%	0,00000002	14,0	Local collapse, evacuation at shore
										70%	80%	0,00000063	12,0	Local collapse
											20%	0,00000016	54,2	Local collapse, evacuation at sea
								92%	3%			0,00000098	52,0	Local collapse, major fire
									97%	10%	95%	0,00000302	52,0	Local collapse, major fire
											5%	0,00000016	54,0	Local collapse, major fire, evacuation at shore
										90%	50%	0,00001429	52,0	Local collapse, major fire
											50%	0,00001429	85,4	Local collapse, major fire, evacuation at sea
			4,0%		91%							0,00071157	0,0	safe
					9%	95%						0,00000000	0,0	safe
						5%	35%					0,00000123	0,0	safe
							65%	8%	62%			0,00000000	12,0	Local collapse
									38%	30%	95%	0,00000000	12,0	Local collapse
											5%	0,00000000	14,0	Local collapse, evacuation at shore
										70%	80%	0,00000000	12,0	Local collapse
											20%	0,00000000	54,2	Local collapse, evacuation at sea
								92%	3%			0,00000000	52,0	Local collapse, major fire
									97%	10%	95%	0,00000000	52,0	Local collapse, major fire
											5%	0,00000000	54,0	Local collapse, major fire, evacuation at shore
										90%	50%	0,00000000	52,0	Local collapse, major fire
											50%	0,00000000	85,4	Local collapse, major fire, evacuation at sea

Figure O14. Event tree for the stairways in the base design.

Open deck space event trees

The event trees for the open deck in the prescriptive design and the base design are presented in Figures O15 and O16 below.

Prescriptive design	Prob. of fire in space	Ship occupants	Failure of man. ext.	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	6,84%	33,33%	30%							0,01122805	0,0	safe
Significant fire	Open deck	10.5	70%	52%	85%					0,01362337	0,0	safe
					15%	60%	73%			0,00089506	0,0	safe
							27%	57%	95%	0,00017926	0,0	safe
									5%	0,00000943	1,0	Evacuation at shore
								43%	90%	0,00012812	0,0	safe
									10%	0,00001424	2,3	Evacuation at sea
						40%	18%			0,00014713	1,0	Major fire
							82%	44%	95%	0,00028017	1,0	Major fire
									5%	0,00001475	2,0	Major fire, evacuation at shore
								56%	64%	0,00024022	1,0	Major fire
									36%	0,00013513	3,1	Major fire, evacuation at sea
				48%	75%					0,00943156	0,0	safe
			NO		25%	60%	73%			0,00137701	0,0	safe
							27%	57%	95%	0,00027579	0,0	safe
			YES						5%	0,00001452	1,0	Evacuation at shore
								43%	90%	0,00019710	0,0	safe
									10%	0,00002190	2,3	Evacuation at sea
						40%	18%			0,00022636	1,0	Major fire
							82%	44%	95%	0,00043104	1,0	Major fire
									5%	0,00002269	2,0	Major fire, evacuation at shore
								56%	64%	0,00036958	1,0	Major fire
									36%	0,00020789	3,1	Major fire, evacuation at sea
		34,67%	30%							0,01167717	0,0	safe
		33.6	70%	52%	85%					0,01416830	0,0	safe
					15%	60%	73%			0,00093086	0,0	safe
							27%	57%	95%	0,00018643	0,0	safe
									5%	0,00000981	1,0	Evacuation at shore
								43%	90%	0,00013324	0,0	safe
									10%	0,00001480	7,4	Evacuation at sea
						40%	18%			0,00015302	1,0	Major fire
							82%	44%	95%	0,00029138	1,0	Major fire
									5%	0,00001534	2,0	Major fire, evacuation at shore
								56%	64%	0,00024983	1,0	Major fire
									36%	0,00014053	8,2	Major fire, evacuation at sea
				48%	75%					0,00980883	0,0	safe
			NO		25%	60%	73%			0,00000000	0,0	safe
							27%	57%	95%	0,00000000	0,0	safe
			YES						5%	0,00000000	1,0	Evacuation at shore
								43%	90%	0,00000000	0,0	safe
									10%	0,00000000	7,4	Evacuation at sea
						40%	18%			0,00000000	1,0	Major fire
							82%	44%	95%	0,00000000	1,0	Major fire
									5%	0,00000000	2,0	Major fire, evacuation at shore
								56%	64%	0,00000000	1,0	Major fire
									36%	0,00000000	8,2	Major fire, evacuation at sea
		32,00%	30%							0,01077893	0,0	safe

Prescriptive design	Prob. of fire in space	Ship occupants	Failure of man. ext.	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
									36%	0,00000000	8,2	Major fire, evacuation at sea
		32,00%	30%							0,01077893	0,0	safe
		204	70%	52%	85%					0,01307843	0,0	safe
					15%	60%	73%			0,00085925	1,0	Local fire
							27%	57%	95%	0,00017209	1,0	Local fire
									5%	0,00000906	3,0	Local fire, evacuation at shore
								43%	90%	0,00012299	1,0	Local fire
									10%	0,00001367	45,7	Local fire, evacuation at sea
						40%	18%			0,00014125	11,0	Local fire, major fire
							82%	44%	95%	0,00026897	11,0	Local fire, major fire
									5%	0,00001416	13,0	Local fire, major fire, evacuation at shore
								56%	64%	0,00023062	11,0	Local fire, major fire
									36%	0,00012972	53,5	Major fire, evacuation at sea
				48%	75%					0,00905430	0,0	safe
			NO		25%	60%	73%			0,00000000	1,0	Local fire
							27%	57%	95%	0,00000000	1,0	Local fire
			YES						5%	0,00000000	3,0	Local fire, evacuation at shore
								43%	90%	0,00000000	1,0	Local fire
									10%	0,00000000	45,7	Local fire, evacuation at sea
						40%	18%			0,00000000	11,0	Local fire, major fire
							82%	44%	95%	0,00000000	11,0	Local fire, major fire
									5%	0,00000000	13,0	Local fire, major fire, evacuation at shore
								56%	64%	0,00000000	11,0	Local fire, major fire
									36%	0,00000000	53,5	Major fire, evacuation at sea

Figure O15. Event tree for the open deck space in the prescriptive design.

Base design	Prob. of fire in space	Ship occupants	Failure of man. ext.	Structures affected	Failure of pre-loc. col. f-f	Failure of pre-maj. fire f-f	Failure to reside on ship	Failure to reach shore	Evac. failure	Frequency	Consequence	Description
1,64209	6,84%	33,33%	30%							0,01122805	0,0	safe
Significant fire	Open deck	10.5	70%	52%	85%					0,01362337	0,0	safe
					15%	15%	62%			0,00019005	1,0	Local fire
							38%	30%	95%	0,00003320	1,0	Local fire
									5%	0,00000175	2,0	Local fire, evacuation at shore
								70%	80%	0,00006523	1,0	Local fire
									20%	0,00001631	3,1	Local fire, evacuation at sea
						85%	3%			0,00005211	2,0	Local fire, major fire
							97%	10%	95%	0,00016006	2,0	Local fire, major fire
									5%	0,00000842	3,0	Local fire, major fire, evacuation at shore
								90%	50%	0,00075819	2,0	Local fire, major fire
									50%	0,00075819	3,9	Major fire, evacuation at sea
				48%	60%					0,00754525	0,0	safe
			NO		40%	15%	62%			0,00046781	1,0	Local fire
							38%	30%	95%	0,00008172	1,0	Local fire
			YES						5%	0,00000430	2,0	Local fire, evacuation at shore
								70%	80%	0,00016056	1,0	Local fire
									20%	0,00004014	3,1	Local fire, evacuation at sea
						85%	3%			0,00012827	2,0	Local fire, major fire
							97%	10%	95%	0,00039400	2,0	Local fire, major fire
									5%	0,00002074	3,0	Local fire, major fire, evacuation at shore
								90%	50%	0,00186632	2,0	Local fire, major fire
									50%	0,00186632	3,9	Major fire, evacuation at sea
		34,67%	30%							0,01167717	0,0	safe
		33,6	70%	52%	85%					0,01416830	0,0	safe

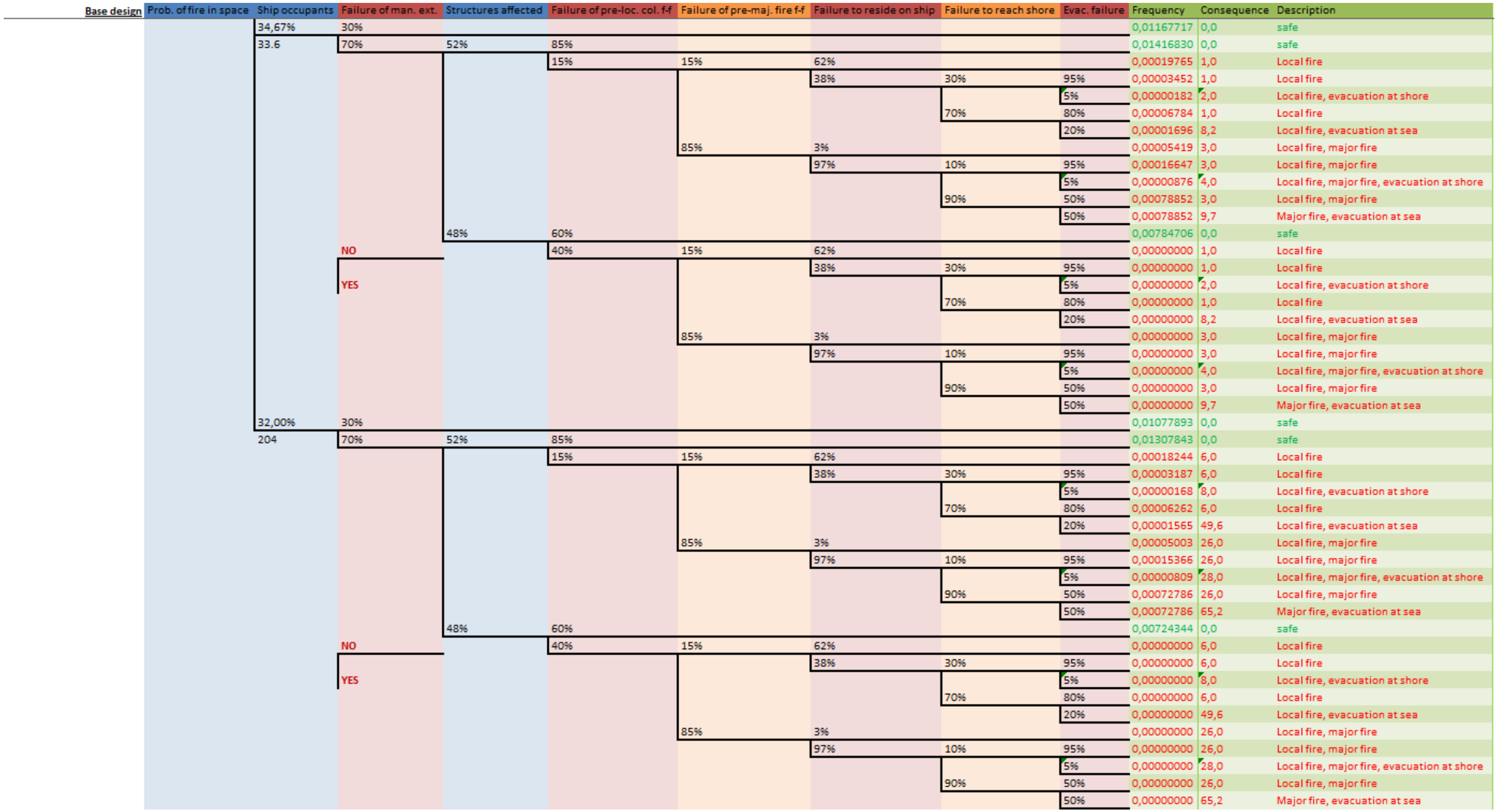


Figure O16. Event tree for the open deck space in the base design.

Summarized input data

All probabilities and consequences used in the fire risk model are summarized in the table below. The first column contains assessments for the prescriptive design (PD), the second column for the base design (BD), the third for the base design with RCO A (trial alternative design A), the fourth for trial alternative design B etc. Note that differences are signified by bold numbers.

Probabilities	PD	BD	TAD A	TAD B	TAD C	TAD D	TAD E	TAD F	TAD G	TAD H	TAD I	TAD J	TAD K	TAD L	TAD M	TAD N	TAD O	TAD P	TAD Q	TAD R	TAD S	TAD T	TAD U
Probability of 7.5 persons in the accommodation space	**33,3%**	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%	33,3%
Probability of 30 persons in the accommodation space	**34,7%**	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%	34,7%
Probability of full occupancy in accommodation space	**32,0%**	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%	32,0%
Probability of failure in detection and alarm system	**4,0%**	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%
Probability of failure of manual detection in the wheelhouse in case automatic detection and alarm system fails	**10,0%**	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%
Probability of failure of manual extinguishment in accommodation space in case of 7,5% occupancy and detection	**56,3%**	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%	56,3%
Probability of failure of manual extinguishment in accommodation space in case of 7,5% occupancy and detection failure	**69,0%**	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%	69,0%
Probability of failure of manual extinguishment in accommodation space in case of 30% occupation and detection	**35,8%**	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%	35,8%
Probability of failure of manual extinguishment in accommodation space in case of 30% occupation and detection failure	**49,5%**	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%	49,5%
Probability of failure of manual extinguishment in accommodation space in case of full occupancy and detection	**29,8%**	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%	29,8%
Probability of failure of manual extinguishment in accommodation space in case	**32,9%**	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%	32,9%

of full occupancy and detection failure																							
Probability of failure of manual extinguishment in wheelhouse in case of detection	**95,0%**	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%
Probability of failure of manual extinguishment on ro-ro deck in case of detection	**35,0%**	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%
Probability of failure of manual extinguishment in stairway in case of detection	**65,0%**	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%
Probability of failure of manual extinguishment on open deck	**70,0%**	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%
Probability of failure of sprinkler system	**9,0%**	9,0%	**3,6%**	**0,8%**	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	9,0%	**3,6%**	**3,6%**	**3,6%**	**3,6%**	**3,6%**
Probability of failure of water mist detection, alarm and extinguishing system	**23,2%**	23,2%	23,2%	23,2%	**5,4%**	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%	23,2%
Probability of failure of doors in the accommodation space in case of low or medium occupancy	**10,0%**	**100,0%**	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	**10,0%**	100,0%	**10,0%**	**10,0%**	**10,0%**	**10,0%**	**10,0%**
Probability of failure of doors in the accommodation space in case of full occupancy	**15,0%**	**100,0%**	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	**15,0%**	100,0%	**15,0%**	**15,0%**	**15,0%**	**15,0%**	**15,0%**
Probability of failure of doors in the accommodation space detection and alarm system fails	**100,0%**	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%
Probability of failure of doors in an engine room	**2,0%**	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	2,0%	0,2%	2,0%	2,0%	2,0%	2,0%	2,0%
Probability of failure of hatch in an auxiliary machinery space	**4,0%**	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	0,4%	4,0%	4,0%	4,0%	4,0%	4,0%
Probability of failure of hatch in an void space	**0,0%**	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Probability of failure of doors or windows in the wheelhouse in case of low or mid seasons	**1,0%**	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%	1,0%
Probability of failure of doors or windows in the wheelhouse in case of high seasons	**10,0%**	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%	10,0%
Probability of failure of door in the stairway	**5,0%**	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%
Probability of failure of drencher system	**100,0%**	100,0%	100,0%	100,0%	100,0%	**9,0%**	**4,0%**	100,0%	100,0%	**20,0%**	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	**9,0%**	**9,0%**	**9,0%**
Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are closed in the accommodation space	**90,0%**	**85,0%**	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	**90,0%**	85,0%	**90,0%**	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%
Probability of failure of fire-fighting before potential	**95,0%**	**92,0%**	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	**95,0%**	92,0%	**95,0%**	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%	92,0%

window breakage and local collapse in case doors are open in the accommodation space																							
Probability of failure of windows in case fire develops and doors are closed in the accommodation space	**60,0%**	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%
Probability of failure of windows in case fire develops and doors are open in the accommodation space	**85,0%**	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%
Probability of failure of windows in case fire develops and doors are closed in the wheelhouse	**30,0%**	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%
Probability of failure of windows in case fire develops and doors are open in the wheelhouse	**90,0%**	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%
Probability of failure of pre-local fire fire-fighting in case of engine room fire and doors are open	**80,0%**	**70,0%**	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%
Probability of failure of pre-major collapse fire-fighting in case of doors closed in accommodation space	**0,0%**	**95,0%**	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	**40,0%**	95,0%	**0,0%**	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%	95,0%
Probability of failure of pre-major collapse fire-fighting in case of doors open in accommodation space	**0,0%**	**98,0%**	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	**70,0%**	98,0%	**0,0%**	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%	98,0%
Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system functions	**30,0%**	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%	30,0%
Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system fails	**50,0%**	**60,0%**	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%
Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are closed	**70,0%**	**85,0%**	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	70,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%
Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are open	**50,0%**	**60,0%**	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	**50,0%**	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%	60,0%
Probability of failure of pre-local collapse fire-fighting in staircase	**40,0%**	**65,0%**	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	**65,0%**	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%	65,0%

Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was not ventilated	**40,0%**	**70,0%**	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	**47,5%**	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%
Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was ventilated	**70,0%**	**90,0%**	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	**75,0%**	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%
Probability of failure of pre-major collapse fire-fighting in staircase	**55,0%**	**45,0%**	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%	45,0%
Probability of developed ro-ro deck fire to affect structures	**83,0%**	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%	83,0%
Probability of developed open deck fire to affect structures	**48,0%**	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%	48,0%
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides	**50,0%**	**94,4%**	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	**20,0%**	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%	94,4%
Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are not affected	**35,0%**	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%	35,0%
Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are affected	**65,0%**	**85,0%**	85,0%	85,0%	85,0%	85,0%	85,0%	**20,0%**	**20,0%**	85,0%	**75,0%**	**72,0%**	85,0%	85,0%	85,0%	**15,0%**	85,0%	85,0%	**20,0%**	**15,0%**	**75,0%**	**72,0%**	**15,0%**
Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection failure and structures are not affected	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%	67,5%
Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection failure and structures are affected	82,5%	92,5%	92,5%	92,5%	92,5%	92,5%	92,5%	**35,0%**	**35,0%**	92,5%	82,5%	92,5%	92,5%	92,5%	92,5%	**25,0%**	92,5%	92,5%	**35,0%**	**25,0%**	92,5%	**92,5%**	**25,0%**
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are affected	**25,0%**	**40,0%**	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%	40,0%
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are not affected	**15,0%**	**15,0%**	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%	15,0%
Probability of failure of pre-major external fire fire-fighting for all fires initiated on ro-ro deck	**50,0%**	**90,0%**	90,0%	90,0%	90,0%	90,0%	90,0%	**70,0%**	**70,0%**	90,0%	**70,0%**	**64,0%**	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	**70,0%**	90,0%	**70,0%**	**64,0%**	**64,0%**

Probability of failure of pre-major external fire fire-fighting for all fires except for those initiated on ro-ro deck	**40,0%**	**85,0%**	85,0%	85,0%	85,0%	85,0%	85,0%	**62,5%**	**62,5%**	85,0%	85,0%	85,0%	85,0%	85,0%	85,0%	**51,3%**	85,0%	85,0%	**62,5%**	**51,3%**	85,0%	85,0%	**51,3%**
Probability of abandonment in case fire is contained	**27,0%**	**38,0%**	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%	38,0%
Probability of abandonment in case fire is not contained	**82,0%**	**97,0%**	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%	97,0%
Probability of ship being at sea when abandoning in case fire is not escalating	**43,0%**	**70,0%**	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%	70,0%
Probability of ship being at sea when abandoning in case fire is escalating	**56,0%**	**90,0%**	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%	90,0%
Probability of casualties when abandoning ship at shore	**5,0%**	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%	5,0%
Probability of casualties when abandoning ship at sea and fire is not escalating	**10,0%**	**20,0%**	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%	20,0%
Probability of casualties when abandoning ship at sea and fire is escalating	**36,0%**	**50,0%**	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%	50,0%
Consequences																							
Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system and door closing devices function	**0**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system functions but door closing device fails	**44**	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44	44
Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system (and door closing devices) fails	**66**	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66	66
Fatalities from fire scenarios in the accommodation space with local collapse during mid and low seasons	**0**	**1**	1	1	1	1	1	1	1	1	1	1	**0**	1	**0**	1	1	1	1	1	1	1	1
Fatalities from fire scenarios in the accommodation space with local collapse during high season	**0**	**5**	5	5	5	5	5	5	5	5	5	5	**0**	5	**0**	5	5	5	5	5	5	5	5
Fatalities from fire scenarios in the wheelhouse with local collapse durning high season	**0**	**2**	2	2	2	2	2	2	2	2	2	2	2	**0**	2	2	2	2	2	2	2	2	2

Fatalities from fire scenarios in the stairway with local collapse durning high season	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Fatalities from local collapse due to the engine room fire with doors open in case of low or mid seasons	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fatalities from local collapse due to the engine room fire with doors open in case of high season	0	5	5	5	5	5	5	5	5	5	5	0	5	5	5	5	5	5	5	5	5	5	5
Fatalities from local fire on outboard sides due to collapse in case of high season	1	4	4	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	4	4
Fatalities from local fire on outboard sides due to smoke in case of high season	2	4	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	4	4
Fatalities (total) from local fire on outboard sides in case of high season	*3*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*3*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	*8*	8	8
Fatalities from local fire on outboard sides due to collapse in case of low or mid seasons	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Fatalities from local fire on outboard sides due to smoke in case of low or mid seasons	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Fatalities (total) from local fire on outboard sides in case of low or mid seasons	*0*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*0*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	2	2
Fatalities from local fire on ro-ro deck due to collapse in case of high season	2	6	6	6	6	6	6	6	6	6	3	2	6	6	6	4	6	6	6	4	3	2	2
Fatalities from local fire on ro-ro deck due to smoke in case of high season	4	8	8	8	8	8	8	8	8	8	5	4	8	8	8	6	8	8	8	6	5	4	4
Fatalities (total) from local fire on ro-ro deck in case of high season	*6*	*14*	*14*	*14*	*14*	*14*	*14*	*14*	*14*	*14*	*9*	*6*	*14*	*14*	*14*	*10*	*14*	*14*	*14*	*10*	*9*	6	6
Fatalities from local fire on ro-ro deck due to collapse in case of low or mid seasons	1	2	2	2	2	2	2	2	2	2	1	1	2	2	2	1	2	2	2	1	1	1	1
Fatalities from local fire on ro-ro deck due to smoke in case of low or mid seasons	1	2	2	2	2	2	2	2	2	2	1	1	2	2	2	1	2	2	2	1	1	1	1
Fatalities (total) from local fire on ro-ro deck in case of low or mid seasons	*1*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*2*	*1*	*4*	*4*	*4*	*3*	*4*	*4*	*4*	*3*	*2*	1	1
Fatalities from local fire on open deck due to collapse in case of high season	1	5	5	5	5	5	5	5	5	5	5	1	5	5	5	5	5	5	5	5	5	5	5
Fatalities from local fire on open deck due to smoke in case of high season	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1

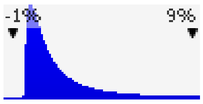
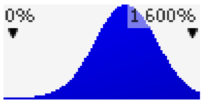
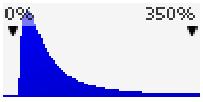
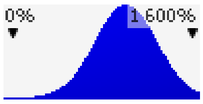
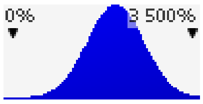
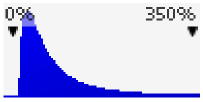
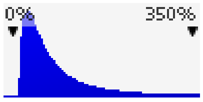
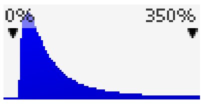
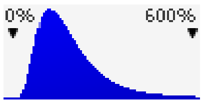
Fatalities (total) from local fire on open deck in case of high season	*1*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*1*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	6	6
Fatalities from local fire on open deck due to collapse in case of low or mid seasons	**0**	**1**	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
Fatalities from local fire on open deck due to smoke in case of low or mid seasons	**0**	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatalities (total) from local fire on open deck in case of low or mid seasons	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*0*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	1	1
Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is divided	**0**	**1**	1	1	1	1	1	1	1	1	1	1	**1**	1	**0**	1	1	1	1	1	1	1	1
Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is divided	**0**	**2**	2	2	2	2	2	2	2	2	2	2	**1**	2	**0**	2	2	2	2	2	2	2	2
Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is divided	**20**	**40**	40	40	40	40	40	40	40	40	40	40	**30**	40	**20**	40	40	40	40	40	40	40	40
Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is not divided	**1**	**2**	2	2	2	2	2	2	2	2	2	2	**2**	2	**1**	2	2	2	2	2	2	2	2
Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is not divided	**2**	**4**	4	4	4	4	4	4	4	4	4	4	**3**	4	**2**	4	4	4	4	4	4	4	4
Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is not divided	**40**	**80**	80	80	80	80	80	80	80	80	80	80	**60**	80	**40**	80	80	80	80	80	80	80	80
Fatalities due to major fire initiated in the wheelhouse at low or mid seasons	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fatalities due to major fire initiated in the wheelhouse at high season	**10**	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Fatalities due to major fire initiated by ro-ro deck fire in case of low season	**1**	**2**	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Fatalities due to major fire initiated by ro-ro deck fire in case of mid season	**2**	**4**	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

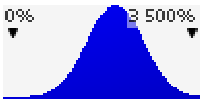
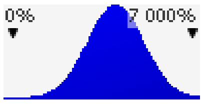
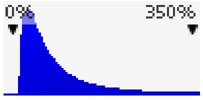
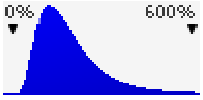
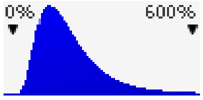
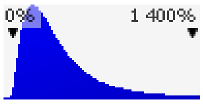
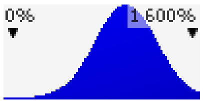
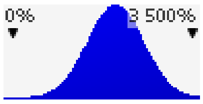
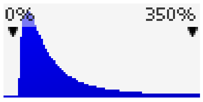
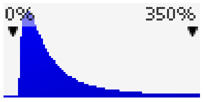
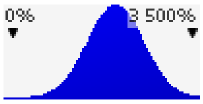
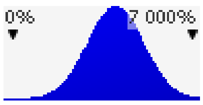
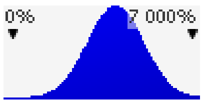
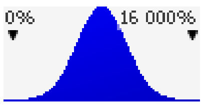
Fatalities due to major fire initiated by ro-ro deck fire in case of high season	**20**	**40**	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40
Fatalities due to major fire initiated by open deck fire in case of low season	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fatalities due to major fire initiated by open deck fire in case of mid season	**1**	**2**	2	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	2	2	2	2
Fatalities due to major fire initiated by open deck fire in case of high season	**10**	**20**	20	20	20	20	20	20	20	20	20	10	20	20	20	20	20	20	20	20	20	20	20
Fatalities due to major fire initiated by stairway fire in case of low or mid seasons	**1**	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fatalities due to major fire initiated by stairway fire in case of high season	**10**	**20**	20	20	20	20	20	20	20	20	20	10	20	20	20	20	20	20	20	20	20	20	20
Fatalities due to major collapse in an auxiliary machinery space in case of mid or low seasons	**0**	**1**	1	1	1	1	1	1	1	1	1	**0**	1	1	1	1	1	1	1	1	1	1	1
Fatalities due to major collapse in an auxiliary machinery space in case of high season	**0**	**10**	10	10	10	10	10	10	10	10	10	**0**	10	10	10	10	10	10	10	10	10	10	10
Fatalities from evacuation at shore in case of low or mid seasons	**1**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Fatalities from evacuation at shore in case of high season	**2**	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Fatalities from evacuation at sea	**0**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fatalities due to abandonment at sea in case LSA are unavailable in low season	**11**	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Fatalities due to abandonment at sea in case LSA are unavailable in mid season	**34**	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34	34
Fatalities due to abandonment at sea in case LSA are unavailable in high season	**204**	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204	204

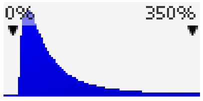
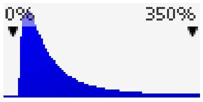
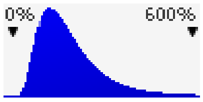
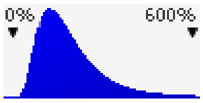
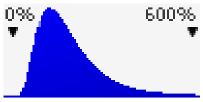
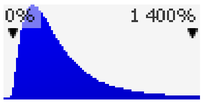
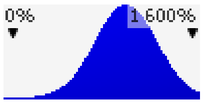
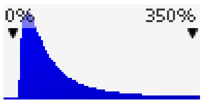
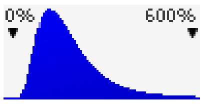
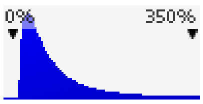
Uncertainty and sensitivity analysis

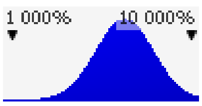
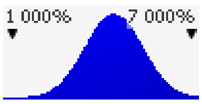
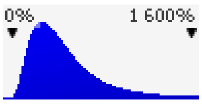
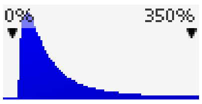
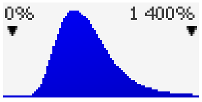
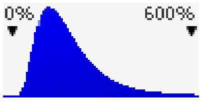
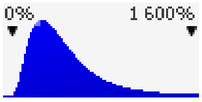
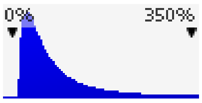
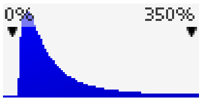
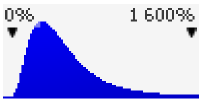
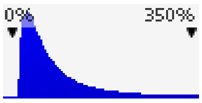
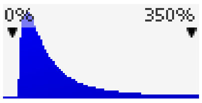
All estimated probabilities and consequences summarized in *Appendix P. Summarized input data* were, based on the discussions in the quantification above, assigned probability distributions. Thereby the uncertainties of the estimations and assumptions made in the quantification processes were managed. With these distributions as input, Monte Carlo simulations were performed in the program @RISK. The input distributions were also correlated so that input parameters which are related had similar effects. The simulations gave results of the mean risk with confidence intervals as well as an analysis of the most sensitive input parameters. The input data as well as the results are presented below.

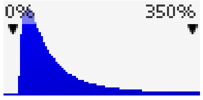
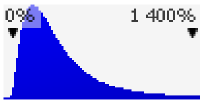
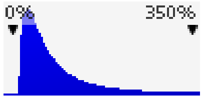
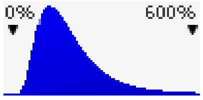
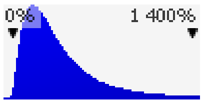
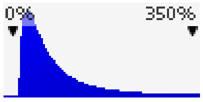
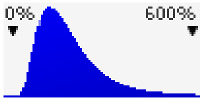
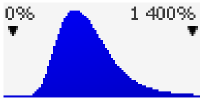
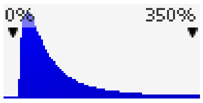
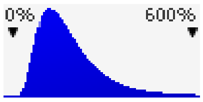
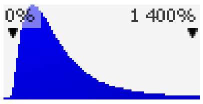
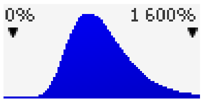
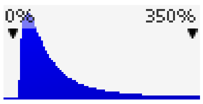
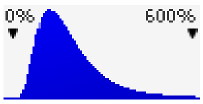
Input distributions

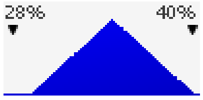
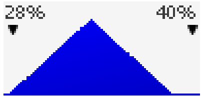
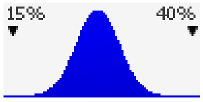
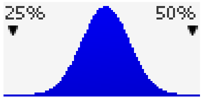
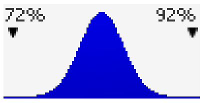
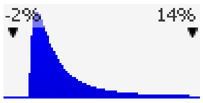
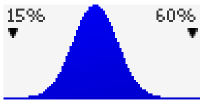
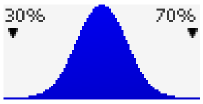
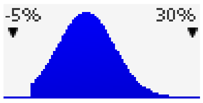
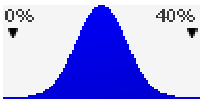
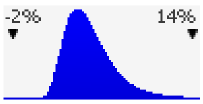
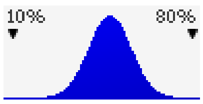
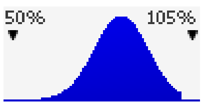
	Name	Cell	Graph	Function	Mean
	Fatalities from fire scenarios in the stairway with local collapse durning high season / PD	B113		RiskLognorm(2,75;1;RiskShift(0,25);RiskStatic(3))	3,00
	Probability of failure of pre-major collapse fire-fighting in case of doors open in accommodation space / BD	C79		RiskLognorm(0,02;0,03;RiskTruncate(0;1);RiskStatic(0,02))	0,02
Category: Fatalities due to major collapse in an auxiliary machinery space in case of high season					
	Fatalities due to major collapse in an auxiliary machinery space in case of high season / BD	C151		RiskNormal(10;2,5;RiskTruncate(0;);RiskStatic(10);RiskName(A151&" / "&C43))	10,00
Category: Fatalities due to major collapse in an auxiliary machinery space in case of mid or low seasons					
	Fatalities due to major collapse in an auxiliary machinery space in case of mid or low seasons / BD	C150		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A150&" / "&C43))	1,00
Category: Fatalities due to major fire initiated by open deck fire in case of high season					
	Fatalities due to major fire initiated by open deck fire in case of high season / PD	B147		RiskNormal(10;2,5;RiskTruncate(0;);RiskStatic(10);RiskName(A147&" / "&B43))	10,00
	Fatalities due to major fire initiated by open deck fire in case of high season / BD	C147		RiskNormal(20;5;RiskTruncate(0;);RiskStatic(20);RiskName(A147&" / "&C43))	20,00
Category: Fatalities due to major fire initiated by open deck fire in case of low season					
	Fatalities due to major fire initiated by open deck fire in case of low season / PD	B145		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A145&" / "&B43))	1,00
	Fatalities due to major fire initiated by open deck fire in case of low season / BD	C145		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A145&" / "&C43))	1,00
Category: Fatalities due to major fire initiated by open deck fire in case of mid season					
	Fatalities due to major fire initiated by open deck fire in case of mid season / PD	B146		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A146&" / "&B43))	1,00
	Fatalities due to major fire initiated by open deck fire in case of mid season / BD	C146		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A146&" / "&C43))	2,00
Category: Fatalities due to major fire initiated by ro-ro deck fire in case of high season					

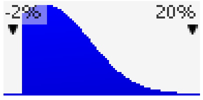
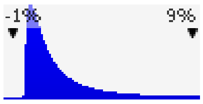
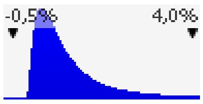
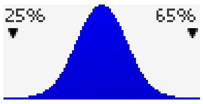
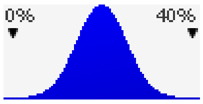
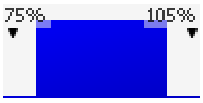
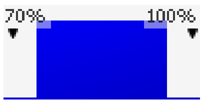
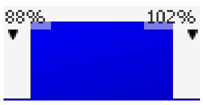
	Fatalities due to major fire initiated by ro-ro deck fire in case of high season / PD	B144		RiskNormal(20;5;RiskTruncate(0;);RiskStatic(20);RiskName(A144&" / "&B43))	20,00
	Fatalities due to major fire initiated by ro-ro deck fire in case of high season / BD	C144		RiskNormal(40;10;RiskTruncate(0;);RiskStatic(40);RiskName(A144&" / "&C43))	40,00
Category: Fatalities due to major fire initiated by ro-ro deck fire in case of low season					
	Fatalities due to major fire initiated by ro-ro deck fire in case of low season / PD	B142		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A142&" / "&B43))	1,00
	Fatalities due to major fire initiated by ro-ro deck fire in case of low season / BD	C142		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A142&" / "&C43))	2,00
Category: Fatalities due to major fire initiated by ro-ro deck fire in case of mid season					
	Fatalities due to major fire initiated by ro-ro deck fire in case of mid season / PD	B143		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A143&" / "&B43))	2,00
	Fatalities due to major fire initiated by ro-ro deck fire in case of mid season / BD	C143		RiskLognorm(3,75;3;RiskShift(0,25);RiskStatic(4);RiskName(A143&" / "&C43))	4,00
Category: Fatalities due to major fire initiated by stairway fire in case of high season					
	Fatalities due to major fire initiated by stairway fire in case of high season / PD	B149		RiskNormal(10;2,5;RiskTruncate(0;);RiskStatic(10);RiskName(A149&" / "&B43))	10,00
	Fatalities due to major fire initiated by stairway fire in case of high season / BD	C149		RiskNormal(20;5;RiskTruncate(0;);RiskStatic(20);RiskName(A149&" / "&C43))	20,00
Category: Fatalities due to major fire initiated by stairway fire in case of low or mid seasons					
	Fatalities due to major fire initiated by stairway fire in case of low or mid seasons / PD	B148		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A148&" / "&B43))	1,00
	Fatalities due to major fire initiated by stairway fire in case of low or mid seasons / BD	C148		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A148&" / "&C43))	1,00
Category: Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is divided					
	Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is divided / PD	B136		RiskNormal(20;5;RiskTruncate(0;);RiskStatic(20);RiskName(A136&" / "&B43))	20,00
	Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is divided / BD	C136		RiskNormal(40;10;RiskTruncate(0;);RiskStatic(40);RiskName(A136&" / "&C43))	40,00
Category: Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is not divided					
	Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is not divided / PD	B139		RiskNormal(40;10;RiskTruncate(0;);RiskStatic(40);RiskName(A139&" / "&B43))	40,00
	Fatalities due to major fire initiated in the accommodation space at high season in case accommodation space is not	C139		RiskNormal(80;20;RiskTruncate(0;140);RiskStatic(80);RiskName(A139&" / "&C43))	79,91

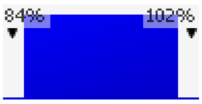
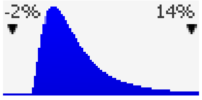
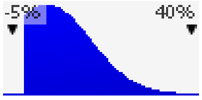
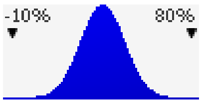
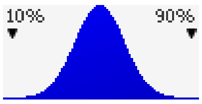
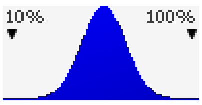
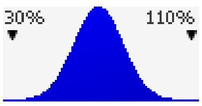
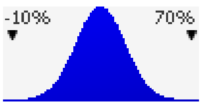
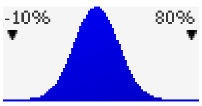
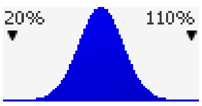
	divided / BD				
Category: Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is divided					
	Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is divided / BD	C134		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A134&" / "&C43))	1,00
Category: Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is not divided					
	Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is not divided / PD	B137		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A137&" / "&B43))	1,00
	Fatalities due to major fire initiated in the accommodation space at low season in case accommodation space is not divided / BD	C137		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A137&" / "&C43))	2,00
Category: Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is divided					
	Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is divided / BD	C135		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A135&" / "&C43))	2,00
Category: Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is not divided					
	Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is not divided / PD	B138		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A138&" / "&B43))	2,00
	Fatalities due to major fire initiated in the accommodation space at mid season in case accommodation space is not divided / BD	C138		RiskLognorm(3,75;3;RiskShift(0,25);RiskStatic(4);RiskName(A138&" / "&C43))	4,00
Category: Fatalities due to major fire initiated in the wheelhouse at high season					
	Fatalities due to major fire initiated in the wheelhouse at high season / PD	B141		RiskNormal(10;2,5;RiskTruncate(0;);RiskStatic(10);RiskName(A141&" / "&B43))	10,00
Category: Fatalities due to major fire initiated in the wheelhouse at low or mid seasons					
	Fatalities due to major fire initiated in the wheelhouse at low or mid seasons / PD	B140		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A140&" / "&B43))	1,00
Category: Fatalities from evacuation at shore in case of high season					
	Fatalities from evacuation at shore in case of high season / PD	B153		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A153&" / "&B43))	2,00
Category: Fatalities from evacuation at shore in case of low or mid seasons					
	Fatalities from evacuation at shore in case of low or mid seasons / PD	B152		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A152&" / "&B43))	1,00
Category: Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system (and door closing devices) fails					

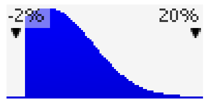
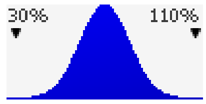
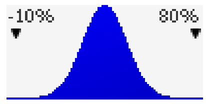
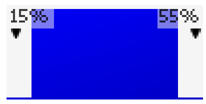
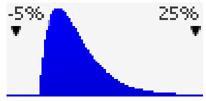
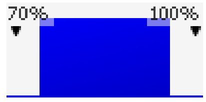
Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system (and door closing devices) fails / PD	B109		RiskNormal(66;13,2;RiskTruncate(0;);RiskStatic(66);RiskName(A109&" / "&B43);RiskCorrmat(AccEscape;2))	66,00
Category: Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system functions but door closing device fails				
Fatalities from fire scenarios in the accommodation space in case of full occupancy and the detection and alarm system functions but door closing device fails / PD	B108		RiskNormal(44;8,8;RiskTruncate(0;);RiskStatic(44);RiskName(A108&" / "&B43);RiskCorrmat(AccEscape;1))	44,00
Category: Fatalities from fire scenarios in the accommodation space with local collapse during high season				
Fatalities from fire scenarios in the accommodation space with local collapse during high season / BD	C111		RiskLognorm(4,75;3;RiskShift(0,25);RiskStatic(5);RiskName(A111&" / "&C43))	5,00
Category: Fatalities from fire scenarios in the accommodation space with local collapse during mid and low seasons				
Fatalities from fire scenarios in the accommodation space with local collapse during mid and low seasons / BD	C110		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A110&" / "&C43))	1,00
Category: Fatalities from fire scenarios in the stairway with local collapse durning high season				
Fatalities from fire scenarios in the stairway with local collapse durning high season / BD	C113		RiskLognorm(5,75;2;RiskShift(0,25);RiskStatic(6);RiskName(A113&" / "&C43))	6,00
Category: Fatalities from fire scenarios in the wheelhouse with local collapse durning high season				
Fatalities from fire scenarios in the wheelhouse with local collapse durning high season / BD	C112		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A112&" / "&C43))	2,00
Category: Fatalities from local collapse due to the engine room fire with doors open in case of high season				
Fatalities from local collapse due to the engine room fire with doors open in case of high season / BD	C115		RiskLognorm(4,75;3;RiskShift(0,25);RiskStatic(5);RiskName(A115&" / "&C43))	5,00
Category: Fatalities from local collapse due to the engine room fire with doors open in case of low or mid seasons				
Fatalities from local collapse due to the engine room fire with doors open in case of low or mid seasons / BD	C114		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A114&" / "&C43))	1,00
Category: Fatalities from local fire on open deck due to collapse in case of high season				
Fatalities from local fire on open deck due to collapse in case of high season / PD	B128		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A128&" / "&B43))	1,00
Fatalities from local fire on open deck due to collapse in case of high season / BD	C128		RiskLognorm(4,75;3;RiskShift(0,25);RiskStatic(5);RiskName(A128&" / "&C43))	5,00
Category: Fatalities from local fire on open deck due to collapse in case of low or mid seasons				
Fatalities from local fire on open deck due to collapse in case of low or mid seasons / BD	C131		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A131&" / "&C43))	1,00
Category: Fatalities from local fire on open deck due to smoke in case of high season				
Fatalities from local fire on open deck due to smoke in case of high season / BD	C129		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A129&" / "&C43))	1,00

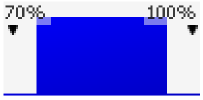
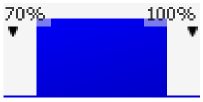
Category: Fatalities from local fire on outboard sides due to collapse in case of high season				
Fatalities from local fire on outboard sides due to collapse in case of high season / PD	B116		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A116&" / "&B43))	1,00
Fatalities from local fire on outboard sides due to collapse in case of high season / BD	C116		RiskLognorm(3,75;3;RiskShift(0,25);RiskStatic(4);RiskName(A116&" / "&C43))	4,00
Category: Fatalities from local fire on outboard sides due to collapse in case of low or mid seasons				
Fatalities from local fire on outboard sides due to collapse in case of low or mid seasons / BD	C119		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A119&" / "&C43))	1,00
Category: Fatalities from local fire on outboard sides due to smoke in case of high season				
Fatalities from local fire on outboard sides due to smoke in case of high season / PD	B117		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A117&" / "&B43))	2,00
Fatalities from local fire on outboard sides due to smoke in case of high season / BD	C117		RiskLognorm(3,75;3;RiskShift(0,25);RiskStatic(4);RiskName(A117&" / "&C43))	4,00
Category: Fatalities from local fire on outboard sides due to smoke in case of low or mid seasons				
Fatalities from local fire on outboard sides due to smoke in case of low or mid seasons / BD	C120		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A120&" / "&C43))	1,00
Category: Fatalities from local fire on ro-ro deck due to collapse in case of high season				
Fatalities from local fire on ro-ro deck due to collapse in case of high season / PD	B122		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A122&" / "&B43))	2,00
Fatalities from local fire on ro-ro deck due to collapse in case of high season / BD	C122		RiskLognorm(5,75;2;RiskShift(0,25);RiskStatic(6);RiskName(A122&" / "&C43))	6,00
Category: Fatalities from local fire on ro-ro deck due to collapse in case of low or mid seasons				
Fatalities from local fire on ro-ro deck due to collapse in case of low or mid seasons / PD	B125		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A125&" / "&B43))	1,00
Fatalities from local fire on ro-ro deck due to collapse in case of low or mid seasons / BD	C125		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A125&" / "&C43))	2,00
Category: Fatalities from local fire on ro-ro deck due to smoke in case of high season				
Fatalities from local fire on ro-ro deck due to smoke in case of high season / PD	B123		RiskLognorm(3,75;3;RiskShift(0,25);RiskStatic(4);RiskName(A123&" / "&B43))	4,00
Fatalities from local fire on ro-ro deck due to smoke in case of high season / BD	C123		RiskLognorm(7,75;2,5;RiskShift(0,25);RiskStatic(8);RiskName(A123&" / "&C43))	8,00
Category: Fatalities from local fire on ro-ro deck due to smoke in case of low or mid seasons				
Fatalities from local fire on ro-ro deck due to smoke in case of low or mid seasons / PD	B126		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A126&" / "&B43))	1,00
Fatalities from local fire on ro-ro deck due to smoke in case of low or mid seasons / BD	C126		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A126&" / "&C43))	2,00
Category: Probability of 30 persons in the accommodation space				

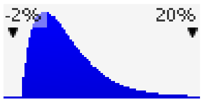
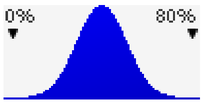
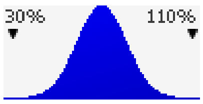
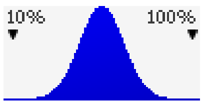
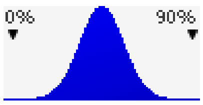
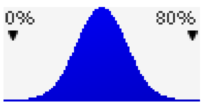
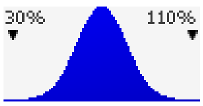
	Probability of 30 persons in the accommodation space / PD	B45		RiskTriang(0,2967;0,3467;0,3967;RiskStatic(0,3467))	0,35
Category: Probability of 7.5 persons in the accommodation space					
	Probability of 7.5 persons in the accommodation space / PD	B44		RiskTriang(0,2833;0,3333;0,3833;RiskStatic(0,3333))	0,33
Category: Probability of abandonment in case fire is contained					
	Probability of abandonment in case fire is contained / PD	B99		RiskNormal(0,27;0,027;RiskTruncate(0;1);RiskStatic(0,27);RiskCorrmat(Abandonment;1))	0,27
	Probability of abandonment in case fire is contained / BD	C99		RiskNormal(0,38;0,03;RiskTruncate(0;1);RiskStatic(0,38);RiskCorrmat(Abandonment;2))	0,38
Category: Probability of abandonment in case fire is not contained					
	Probability of abandonment in case fire is not contained / PD	B100		RiskNormal(0,82;0,022;RiskTruncate(0;1);RiskStatic(0,82);RiskCorrmat(Abandonment;3))	0,82
	Probability of abandonment in case fire is not contained / BD	C100		RiskLognorm(0,03;0,04;RiskTruncate(0;1);RiskStatic(0,03);RiskCorrmat(Abandonment;4))	0,03
Category: Probability of casualties when abandoning ship at sea and fire is escalating					
	Probability of casualties when abandoning ship at sea and fire is escalating / PD	B105		RiskNormal(0,36;0,05;RiskTruncate(0;1);RiskStatic(0,36);RiskName(A105&" / "&B43);RiskCorrmat(EvacCasualties;3))	0,36
	Probability of casualties when abandoning ship at sea and fire is escalating / BD	C105		RiskNormal(0,5;0,05;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A105&" / "&C43);RiskCorrmat(EvacCasualties;4))	0,50
Category: Probability of casualties when abandoning ship at sea and fire is not escalating					
	Probability of casualties when abandoning ship at sea and fire is not escalating / PD	B104		RiskNormal(0,097;0,05;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A104&" / "&B43);RiskCorrmat(EvacCasualties;1))	0,10
	Probability of casualties when abandoning ship at sea and fire is not escalating / BD	C104		RiskNormal(0,2;0,05;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A104&" / "&C43);RiskCorrmat(EvacCasualties;2))	0,20
Category: Probability of casualties when abandoning ship at shore					
	Probability of casualties when abandoning ship at shore / PD	B103		RiskLognorm(0,05;0,02;RiskTruncate(0;1);RiskStatic(0,05))	0,05
Category: Probability of developed open deck fire to affect structures					
	Probability of developed open deck fire to affect structures / PD	B89		RiskNormal(0,48;0,075;RiskTruncate(0;1);RiskStatic(0,483);RiskName(A89&" / "&B43))	0,48
Category: Probability of developed ro-ro deck fire to affect structures					
	Probability of developed ro-ro deck fire to affect structures / PD	B88		RiskNormal(0,83;0,075;RiskTruncate(0;1);RiskStatic(0,83);RiskName(A88&" / "&B43))	0,83

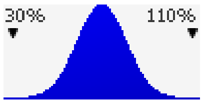
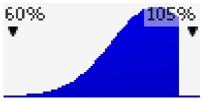
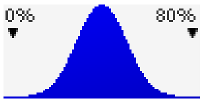
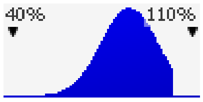
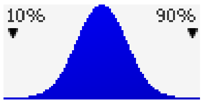
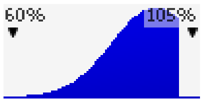
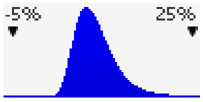
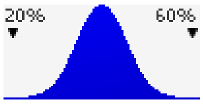
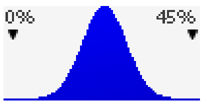
Category: Probability of failure in detection and alarm system					
	Probability of failure in detection and alarm system / PD	B47	X	RiskGamma(3;0,01;RiskShift(0,01);RiskTruncate(0;1);RiskStatic(0,04))	0,04
Category: Probability of failure of door in the stairway					
	Probability of failure of door in the stairway / PD	B69		RiskNormal(0,025;0,05;RiskTruncate(0;1);RiskStatic(0,05))	0,05
Category: Probability of failure of doors in an engine room					
	Probability of failure of doors in an engine room / PD	B64		RiskLognorm(0,02;0,03;RiskTruncate(0;1);RiskStatic(0,02))	0,02
Category: Probability of failure of doors in the accommodation space in case of full occupancy					
	Probability of failure of doors in the accommodation space in case of full occupancy / PD	B62		RiskUniform(0,05;0,25;RiskStatic(0,15);RiskName(A62&" / "&B43))	0,15
Category: Probability of failure of doors in the accommodation space in case of low or medium occupancy					
	Probability of failure of doors in the accommodation space in case of low or medium occupancy / PD	B61		RiskUniform(0;0,2;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A61&" / "&B43))	0,10
Category: Probability of failure of doors or windows in the wheelhouse in case of high seasons					
	Probability of failure of doors or windows in the wheelhouse in case of high seasons / PD	B68		RiskUniform(0;0,2;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A68&" / "&B43))	0,10
Category: Probability of failure of doors or windows in the wheelhouse in case of low or mid seasons					
	Probability of failure of doors or windows in the wheelhouse in case of low or mid seasons / PD	B67		RiskLognorm(0,01;0,01;RiskTruncate(0;1);RiskStatic(0,01);RiskName(A67&" / "&B43))	0,01
Category: Probability of failure of drencher system					
	Probability of failure of drencher system / TAD D	G70		RiskNormal(0,45;0,05;RiskTruncate(0;1);RiskStatic(0,45))	0,45
	Probability of failure of drencher system / TAD H	K70		RiskNormal(0,2;0,05;RiskTruncate(0;1);RiskStatic(0,2))	0,20
Category: Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are closed in the accommodation space					
	Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are closed in the accommodation space / PD	B71		RiskUniform(0,8;1;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A71&" / "&B43);RiskCorrmat(Prelocolffinacc;1))	0,90
	Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are closed in the accommodation space / PD	C71		RiskUniform(0,75;0,95;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A71&" / "&B43);RiskCorrmat(Prelocolffinacc;2))	0,85
Category: Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are open in the accommodation space					
	Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are open in the accommodation space / PD	B72		RiskUniform(0,9;1;RiskTruncate(0;1);RiskStatic(0,95);RiskName(A72&" / "&B43);RiskCorrmat(Prelocolffinacc;3))	0,95

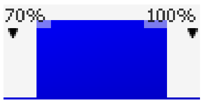
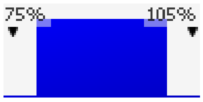
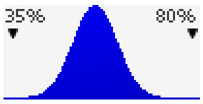
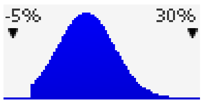
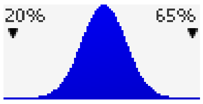
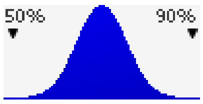
	Probability of failure of fire-fighting before potential window breakage and local collapse in case doors are open in the accommodation space / BD	C72		RiskUniform(0,86;1;RiskTruncate(0;1);RiskStatic(0,92);RiskName(A72&" / "&C43);RiskCorrmat(Prelocolffinacc;4))	0,93
Category: Probability of failure of hatch in an auxiliary machinery space					
	Probability of failure of hatch in an auxiliary machinery space / PD	B65		RiskLognorm(0,04;0,03;RiskTruncate(0;1);RiskStatic(0,04);RiskName(A65&" / "&B43))	0,04
Category: Probability of failure of manual detection in the wheelhouse in case automatic detection and alarm system fails					
	Probability of failure of manual detection in the wheelhouse in case automatic detection and alarm system fails / PD	B48		RiskNormal(0,05;0,1;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A48&" / "&B43))	0,10
Category: Probability of failure of manual extinguishment in accommodation space in case of 30% occupation and detection					
	Probability of failure of manual extinguishment in accommodation space in case of 30% occupation and detection / PD	B51		RiskNormal(0,358;0,1;RiskTruncate(0;1);RiskStatic(0,358);RiskName(A51&" / "&B43))	0,36
Category: Probability of failure of manual extinguishment in accommodation space in case of 30% occupation and detection failure					
	Probability of failure of manual extinguishment in accommodation space in case of 30% occupation and detection failure / PD	B52		RiskNormal(0,495;0,1;RiskTruncate(0;1);RiskStatic(0,495);RiskName(A52&" / "&B43))	0,49
Category: Probability of failure of manual extinguishment in accommodation space in case of 7,5% occupancy and detection					
	Probability of failure of manual extinguishment in accommodation space in case of 7,5% occupancy and detection / PD	B49		RiskNormal(0,563;0,1;RiskTruncate(0;1);RiskStatic(0,563);RiskName(A49&" / "&B43))	0,56
Category: Probability of failure of manual extinguishment in accommodation space in case of 7,5% occupancy and detection failure					
	Probability of failure of manual extinguishment in accommodation space in case of 7,5% occupancy and detection failure / PD	B50		RiskNormal(0,69;0,1;RiskTruncate(0;1);RiskStatic(0,69);RiskName(A50&" / "&B43))	0,69
Category: Probability of failure of manual extinguishment in accommodation space in case of full occupancy and detection					
	Probability of failure of manual extinguishment in accommodation space in case of full occupancy and detection / PD	B53		RiskNormal(0,298;0,1;RiskTruncate(0;1);RiskStatic(0,298);RiskName(A53&" / "&B43))	0,30
Category: Probability of failure of manual extinguishment in accommodation space in case of full occupancy and detection failure					
	Probability of failure of manual extinguishment in accommodation space in case of full occupancy and detection failure / PD	B54		RiskNormal(0,329;0,1;RiskTruncate(0;1);RiskStatic(0,329);RiskName(A54&" / "&B43))	0,33
Category: Probability of failure of manual extinguishment in stairway in case of detection					
	Probability of failure of manual extinguishment in stairway in case of detection / PD	B57		RiskNormal(0,65;0,1;RiskTruncate(0;1);RiskStatic(0,65);RiskName(A57&" / "&B43))	0,65
Category: Probability of failure of manual extinguishment in wheelhouse in case of detection					

	Probability of failure of manual extinguishment in wheelhouse in case of detection / PD	B55		RiskNormal(0,025;0,05;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A55&" / "&B43))	0,05
Category: Probability of failure of manual extinguishment on open deck					
	Probability of failure of manual extinguishment on open deck / PD	B58		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7))	0,70
Category: Probability of failure of manual extinguishment on ro-ro deck in case of detection					
	Probability of failure of manual extinguishment on ro-ro deck in case of detection / PD	B56		RiskNormal(0,35;0,1;RiskTruncate(0;1);RiskStatic(0,35);RiskName(A56&" / "&B43))	0,35
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are affected					
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are affected / PD	B95		RiskUniform(0,15;0,35;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A95&" / "&B43);RiskCorrmat(PreLocExtFF;4))	0,25
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are affected / BD	C95		RiskUniform(0,2;0,5;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A95&" / "&C43);RiskCorrmat(PreLocExtFF;5))	0,35
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are not affected					
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck when structures are not affected / PD	B96		RiskUniform(0,05;0,25;RiskTruncate(0;1);RiskStatic(0,15);RiskName(A96&" / "&B43);RiskCorrmat(PreLocExtFF;6))	0,15
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides					
	Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / PD	B90		RiskUniform(0,4;0,6;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A90&" / "&B43))	0,50
	Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / BD	C90		RiskGamma(2;0,028;RiskTruncate(0;1);RiskStatic(0,056);RiskName(A90&" / "&C43))	0,06
	Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / TAD G	J90		RiskUniform(0,7;0,9;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A90&" / "&J43))	0,80
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are affected					
	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are affected / PD	B92		RiskUniform(0,55;0,75;RiskTruncate(0;1);RiskStatic(0,65);RiskName(A92&" / "&B43);RiskCorrmat(PreLocExtFF;2))	0,65
	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are affected / BD	C92		RiskUniform(0,75;0,95;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A92&" / "&C43);RiskCorrmat(PreLocExtFF;3))	0,85
	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are affected / TAD G	J92		RiskUniform(0,7;0,9;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A92&" / "&J43))	0,80

	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are affected / TAD N	Q92		RiskUniform(0,75;0,95;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A92&" / "&Q43))	0,85
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are not affected					
	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection and structures are not affected / PD	B91		RiskUniform(0,25;0,45;RiskTruncate(0;1);RiskStatic(0,35);RiskName(A91&" / "&B43);RiskCorrmat(PreLocExtFF;1))	0,35
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection failure and structures are affected					
	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection failure and structures are affected / TAD G	J94		RiskUniform(0,55;0,75;RiskTruncate(0;1);RiskStatic(0,65);RiskName(A94&" / "&J43))	0,65
	Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-ro deck, detection failure and structures are affected / TAD N	Q94		RiskUniform(0,65;0,85;RiskTruncate(0;1);RiskStatic(0,75);RiskName(A94&" / "&Q43))	0,75
Category: Probability of failure of pre-local collapse fire-fighting in staircase					
	Probability of failure of pre-local collapse fire-fighting in staircase / PD	B84		RiskUniform(0,3;0,5;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A84&" / "&B43);RiskCorrmat(PreLocFF;9))	0,40
	Probability of failure of pre-local collapse fire-fighting in staircase / PD	C84		RiskUniform(0,55;0,75;RiskTruncate(0;1);RiskStatic(0,65);RiskName(A84&" / "&B43);RiskCorrmat(PreLocFF;10))	0,65
Category: Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are closed					
	Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are closed / PD	B82		RiskUniform(0,6;0,8;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A82&" / "&B43);RiskCorrmat(PreLocFF;5))	0,70
	Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are closed / BD	C82		RiskUniform(0,75;0,95;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A82&" / "&C43);RiskCorrmat(PreLocFF;6))	0,85
Category: Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are open					
	Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are open / PD	B83		RiskUniform(0,4;0,6;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A83&" / "&B43);RiskCorrmat(PreLocFF;7))	0,50
	Probability of failure of pre-local collapse fire-fighting in wheelhouse in case ventilation openings are open / PD	C83		RiskUniform(0,5;0,7;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A83&" / "&B43);RiskCorrmat(PreLocFF;8))	0,60
Category: Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system fails					
	Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system fails / PD	B81		RiskUniform(0,4;0,6;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A81&" / "&B43);RiskCorrmat(PreLocFF;3))	0,50

Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system fails / PD	C81		RiskUniform(0,5;0,7;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A81&" / "&B43);RiskCorrmat(PreLocFF;4))	0,60
Category: Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system functions				
Probability of failure of pre-local fire fire-fighting in auxiliary machinery space in case detection and alarm system functions / PD	B80		RiskUniform(0,2;0,4;RiskTruncate(0;1);RiskStatic(0,3);RiskName(A80&" / "&B43))	0,30
Category: Probability of failure of pre-local fire fire-fighting in case of engine room fire and doors are open				
Probability of failure of pre-local fire fire-fighting in case of engine room fire and doors are open / PD	B77		RiskUniform(0,7;0,9;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A77&" / "&B43);RiskCorrmat(PreLocFF;1))	0,80
Probability of failure of pre-local fire fire-fighting in case of engine room fire and doors are open / PD	C77		RiskUniform(0,6;0,8;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A77&" / "&B43);RiskCorrmat(PreLocFF;2))	0,70
Category: Probability of failure of pre-major collapse fire-fighting in case of doors closed in accommodation space				
Probability of failure of pre-major collapse fire-fighting in case of doors closed in accommodation space / BD	C78		RiskGamma(2;0,025;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A78&" / "&C43))	0,05
Probability of failure of pre-major collapse fire-fighting in case of doors closed in accommodation space / TAD K	N78		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A78&" / "&N43))	0,40
Category: Probability of failure of pre-major collapse fire-fighting in case of doors open in accommodation space				
Probability of failure of pre-major collapse fire-fighting in case of doors open in accommodation space / TAD K	N79		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A79&" / "&N43))	0,70
Category: Probability of failure of pre-major collapse fire-fighting in staircase				
Probability of failure of pre-major collapse fire-fighting in staircase / PD	B87		RiskNormal(0,55;0,1;RiskTruncate(0;1);RiskStatic(0,55);RiskName(A87&" / "&B43);RiskCorrmat(PreMajFFStairs;1))	0,55
Probability of failure of pre-major collapse fire-fighting in staircase / BD	C87		RiskNormal(0,45;0,1;RiskTruncate(0;1);RiskStatic(0,45);RiskName(A87&" / "&C43);RiskCorrmat(PreMajFFStairs;2))	0,45
Category: Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was not ventilated				
Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was not ventilated / PD	B85		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A85&" / "&B43);RiskCorrmat(PreMajFFWheelh;1))	0,40
Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was not ventilated / PD	C85		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A85&" / "&B43);RiskCorrmat(PreMajFFWheelh;2))	0,70
Category: Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was ventilated				

	Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was ventilated / PD	B86		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A86&" / "&B43);RiskCorrmat(PreMajFFWheelh;3))	0,70
	Probability of failure of pre-major collapse fire-fighting in wheelhouse in case initial fire was ventilated / BD	C86		RiskNormal(0,95;0,1;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A86&" / "&C43);RiskCorrmat(PreMajFFWheelh;4))	0,90
Category: Probability of failure of pre-major external fire fire-fighting for all fires except for those initiated on ro-ro deck					
	Probability of failure of pre-major external fire fire-fighting for all fires except for those initiated on ro-ro deck / PD	B98		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A98&" / "&B43);RiskCorrmat(PreMajExtFF;3))	0,40
	Probability of failure of pre-major external fire fire-fighting for all fires except for those initiated on ro-ro deck / BD	C98		RiskNormal(0,85;0,1;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A98&" / "&C43);RiskCorrmat(PreMajExtFF;4))	0,84
Category: Probability of failure of pre-major external fire fire-fighting for all fires initiated on ro-ro deck					
	Probability of failure of pre-major external fire fire-fighting for all fires initiated on ro-ro deck / PD	B97		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A97&" / "&B43);RiskCorrmat(PreMajExtFF;1))	0,50
	Probability of failure of pre-major external fire fire-fighting for all fires initiated on ro-ro deck / BD	C97		RiskNormal(0,95;0,1;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A97&" / "&C43);RiskCorrmat(PreMajExtFF;2))	0,90
Category: Probability of failure of sprinkler system					
	Probability of failure of sprinkler system / PD	B59		RiskLognorm(0,09;0,03;RiskTruncate(0;1);RiskStatic(0,09))	0,09
	Probability of failure of sprinkler system / TAD A	D59		RiskNormal(0,4;0,05;RiskTruncate(0;1);RiskStatic(0,4))	0,40
Category: Probability of failure of water mist detection, alarm and extinguishing system					
	Probability of failure of water mist detection, alarm and extinguishing system / PD	B60		RiskNormal(0,2315;0,05;RiskTruncate(0;1);RiskStatic(0,2315);RiskName(A60&" / "&B43))	0,23
Category: Probability of failure of windows in case fire develops and doors are closed in the accommodation space					
	Probability of failure of windows in case fire develops and doors are closed in the accommodation space / PD	B73		RiskUniform(0,5;0,7;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A73&" / "&B43);RiskCorrmat(WinFailAcc;1))	0,60
Category: Probability of failure of windows in case fire develops and doors are closed in the wheelhouse					
	Probability of failure of windows in case fire develops and doors are closed in the wheelhouse / PD	B75		RiskUniform(0,2;0,4;RiskTruncate(0;1);RiskStatic(0,3);RiskName(A75&" / "&B43);RiskCorrmat(WinFailWheelh;1))	0,30
Category: Probability of failure of windows in case fire develops and doors are open in the accommodation space					

	Probability of failure of windows in case fire develops and doors are open in the accommodation space / PD	B74		RiskUniform(0,75;0,95;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A74&" / "&B43);RiskCorrmat(WinFailAcc;2))	0,85
Category: Probability of failure of windows in case fire develops and doors are open in the wheelhouse					
	Probability of failure of windows in case fire develops and doors are open in the wheelhouse / PD	B76		RiskUniform(0,8;1;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A76&" / "&B43);RiskCorrmat(WinFailWheelh;2))	0,90
Category: Probability of ship being at sea when abandoning in case fire is escalating					
	Probability of ship being at sea when abandoning in case fire is escalating / PD	B102		RiskNormal(0,56;0,05;RiskTruncate(0;1);RiskStatic(0,56);RiskName(A102&" / "&B43);RiskCorrmat(AtSea;3))	0,56
	Probability of ship being at sea when abandoning in case fire is escalating / BD	C102		RiskNormal(0,097;0,05;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A102&" / "&C43);RiskCorrmat(AtSea;4))	0,10
Category: Probability of ship being at sea when abandoning in case fire is not escalating					
	Probability of ship being at sea when abandoning in case fire is not escalating / PD	B101		RiskNormal(0,43;0,05;RiskTruncate(0;1);RiskStatic(0,43);RiskName(A101&" / "&B43);RiskCorrmat(AtSea;1))	0,43
	Probability of ship being at sea when abandoning in case fire is not escalating / BD	C101		RiskNormal(0,7;0,05;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A101&" / "&C43);RiskCorrmat(AtSea;2))	0,70

Correlations

@RISK Correlations	Relative area on open deck in category 2. Sparsely furnished and few fuels / PD in B26	Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD in B27
Relative area on open deck in category 2. Sparsely furnished and few fuels / PD in B26	1	
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD in B27	-0,3	1

@RISK Correlations	Probability of no one present in cabin / PD in B28	Probability of awake person present in cabin / PD in B29
Probability of no one present in cabin / PD in B28	1	
Probability of awake person present in cabin / PD in B29	-0,3	1

@RISK Correlations	Probability of failure of sprinkler system / PD in B80	Probability of failure of fully redundant interior sprinkler system / PD in B81	Probability of failure of redundant balcony sprinkler system / TAD B in E83	Probability of failure of drencher system / TAD C in F84
Probability of failure of sprinkler system / PD in B80	1			
Probability of failure of fully redundant interior sprinkler system / PD in B81	0,95	1		
Probability of failure of redundant balcony	0,7	0,7	1	

sprinkler system / TAD B in E83				
Probability of failure of drencher system / TAD C in F84	0,5	0,5	0,8	1

@RISK Correlations	Probability of failure to hinder fire development on open deck area of category 1 / PD in B91	Probability of failure to hinder fire development on open deck area of category 1 / BD in C91
Probability of failure to hinder fire development on open deck area of category 1 / PD in B91	1	
Probability of failure to hinder fire development on open deck area of category 1 / BD in C91	0,25	1

@RISK Correlations	Probability of failure to hinder fire development on open deck area of category 2 / PD in B92	Probability of failure to hinder fire development on open deck area of category 2 / BD in C92
Probability of failure to hinder fire development on open deck area of category 2 / PD in B92	1	
Probability of failure to hinder fire development on open deck area of category 2 / BD in C92	0,5	1

@RISK Correlations	Probability of failure to hinder fire development on open deck area of category 3 / PD in B93	Probability of failure to hinder fire development on open deck area of category 3 / BD in C93
Probability of failure to hinder fire development on open deck area of category 3 / PD in B93	1	
Probability of failure to hinder fire development on open deck area of category 3 / BD in C93	0,8	1

@RISK Correlations	Probability of failure to prevent outboard fire spread from cabin / PD in B119	Probability of failure to prevent outboard fire spread from cabin / BD in C119	Probability of failure to prevent outboard fire spread from lounge / PD in B120	Probability of failure to prevent outboard fire spread from lounge / BD in C120	Probability of failure to prevent outboard fire spread from restaurant / PD in B121	Probability of failure to prevent outboard fire spread from restaurant / BD in C121	Probability of failure to prevent outboard fire spread from technical space / PD in B122	Probability of failure to prevent outboard fire spread from technical space / BD in C122	Probability of failure to prevent outboard fire spread from machinery space / PD in B123	Probability of failure to prevent outboard fire spread from machinery space / BD in C123
Probability of failure to prevent outboard fire spread from cabin / PD in B119	1									
Probability of failure to prevent outboard fire spread from cabin / BD in C119	0,5	1								
Probability of failure to prevent outboard fire spread	0	0	1							

from lounge / PD in B120										
Probability of failure to prevent outboard fire spread from lounge / BD in C120	0	0	0,5	1						
Probability of failure to prevent outboard fire spread from restaurant / PD in B121	0	0	0	0	1					
Probability of failure to prevent outboard fire spread from restaurant / BD in C121	0	0	0	0	0,5	1				
Probability of failure to prevent outboard fire spread from technical space / PD in B122	0	0	0	0	0	0	1			
Probability of failure to prevent outboard fire spread from technical space / BD in C122	0	0	0	0	0	0	0,5	1		
Probability of failure to prevent outboard fire spread from machinery space / PD in B123	0	0	0	0	0	0	0	0	1	
Probability of failure to prevent outboard fire spread from machinery space / BD in C123	0	0	0	0	0	0	0	0	0,5	1

@RISK Correlations	Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / PD in B124	Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / BD in C124
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / PD in B124	1	
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / BD in C124	0,5	1

@RISK Correlations	Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / PD in B126	Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / BD in C126
Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / PD in B126	1	
Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / BD in C126	0,5	1

@RISK Correlations	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / PD in B128	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / BD in C128	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2 / PD in B129	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2 / BD in C129	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3 / PD in B130	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3 / BD in C130
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / PD in B128	1					
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / BD in C128	0,3	1				
Probability of failure of pre-local collapse fire-fighting in	0	0	1			

case of fire development on open deck area of category 2 / PD in B129						
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2 / BD in C129	0	0	0,3	1		
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3 / PD in B130	0	0	0	0	1	
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3 / BD in C130	0	0	0	0	0,3	1

@RISK Correlations	Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / PD in B132	Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / BD in C132
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / PD in B132	1	
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / BD in C132	0,15	1

@RISK Correlations	Probability of abandonment in case of internal fire and fire-fighting success / PD in B134	Probability of abandonment in case of internal fire and fire-fighting success / BD in C134	Probability of abandonment in case of internal fire and fire-fighting failure / PD in B135	Probability of abandonment in case of internal fire and fire-fighting failure / BD in C135
Probability of abandonment in case of internal fire and fire-fighting success / PD in B134	1			
Probability of abandonment in case of	0,7	1		

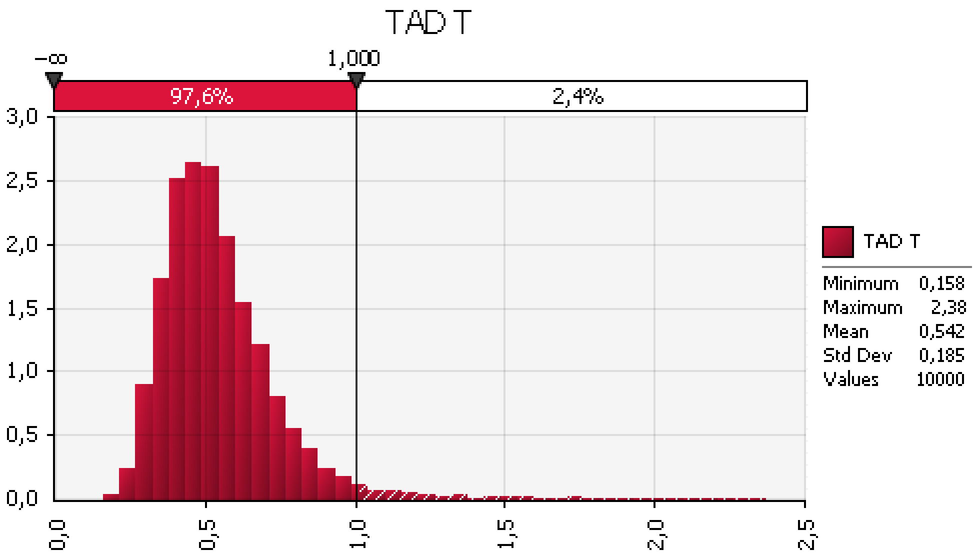
internal fire and fire-fighting success / BD in C134				
Probability of abandonment in case of internal fire and fire-fighting failure / PD in B135	0	0	1	
Probability of abandonment in case of internal fire and fire-fighting failure / BD in C135	0	0,7	0	1

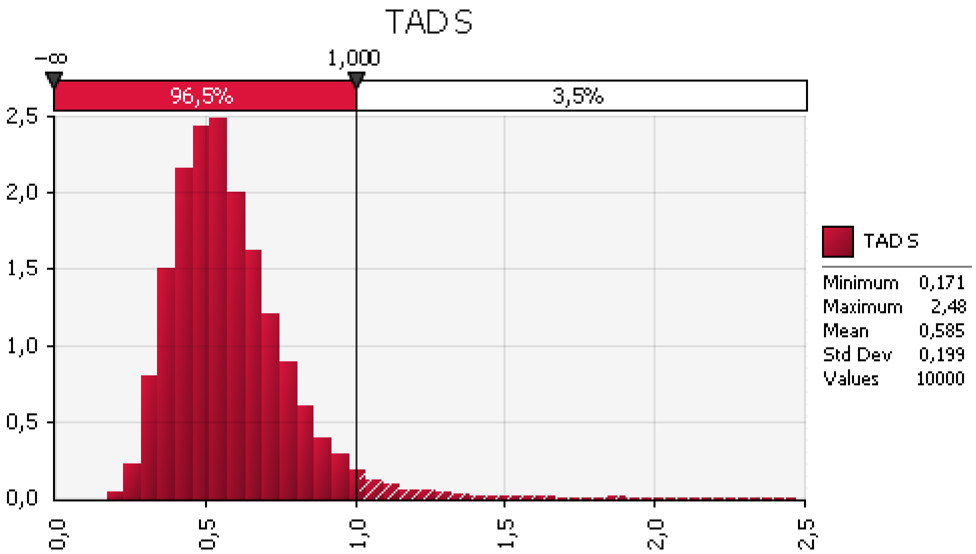
@RISK Correlations	Fatalities from local collapse due to collapse on outboard sides / PD in B152	Fatalities from local collapse due to collapse on outboard sides / BD in C152	Fatalities from local collapse due to smoke on outboard sides / PD in B153	Fatalities from local collapse due to smoke on outboard sides / BD in C153
Fatalities from local collapse due to collapse on outboard sides / PD in B152	1			
Fatalities from local collapse due to collapse on outboard sides / BD in C152	0,25	1		
Fatalities from local collapse due to smoke on outboard sides / PD in B153	0	0	1	
Fatalities from local collapse due to smoke on outboard sides / BD in C153	0	0	0,25	1

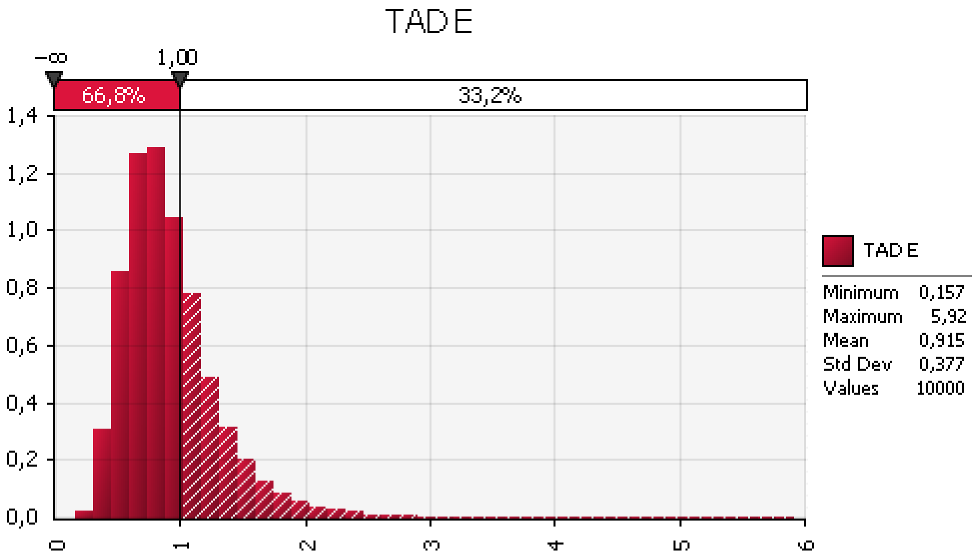
@RISK Correlations	Fatalities from collapse in case of local collapse on open deck / PD in B155	Fatalities from collapse in case of local collapse on open deck / BD in C155	Fatalities from smoke in case of local collapse on open deck / PD in B156	Fatalities from smoke in case of local collapse on open deck / BD in C156
Fatalities from collapse in case of local collapse on open deck / PD in B155	1			
Fatalities from collapse in case of local collapse on open deck / BD in C155	0,25	1		
Fatalities from smoke in case of local collapse on open deck / PD in B156	0	0	1	
Fatalities from smoke in case of local collapse on open deck / BD in C156	0	0	0,25	1

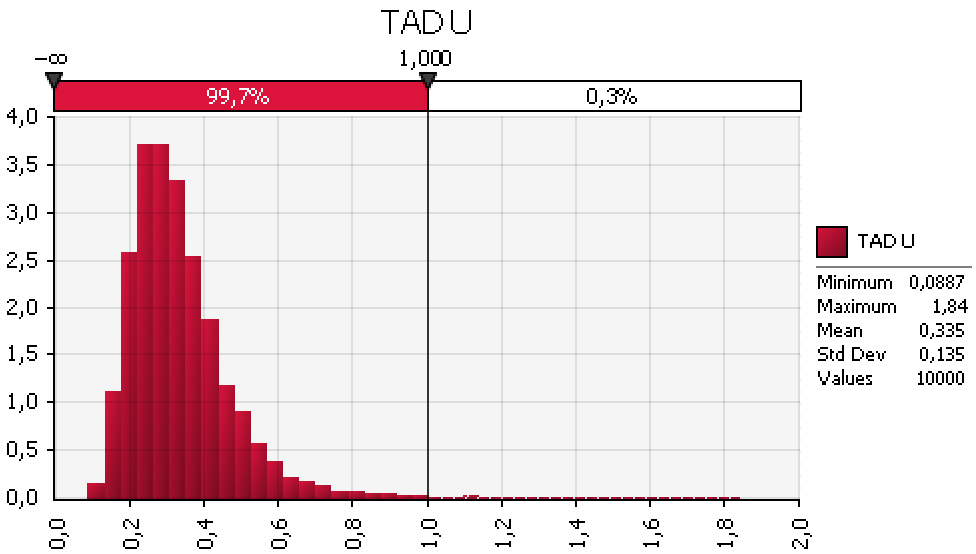
@RISK Correlations	Fatalities due to major collapse on outboard sides in case of evacuation / PD in B160	Fatalities due to major collapse on outboard sides in case of evacuation / BD in C160	Fatalities due to major collapse on open deck in case of evacuation / PD in B161	Fatalities due to major collapse on open deck in case of evacuation / BD in C161
Fatalities due to major collapse on outboard sides in case of evacuation / PD in B160	1			
Fatalities due to major collapse on outboard sides in case of evacuation / BD in C160	0,5	1		
Fatalities due to major collapse on open deck in case of evacuation / PD in B161	0	0	1	
Fatalities due to major collapse on open deck in case of evacuation / BD in C161	0	0	0,5	1

Confidence of relative risk estimations






TAD E
−∞
1,00
66,8%
33,2%
TAD E
Minimum 0,157
Maximum 5,92
Mean 0,915
Std Dev 0,377
Values 10000


TAD U
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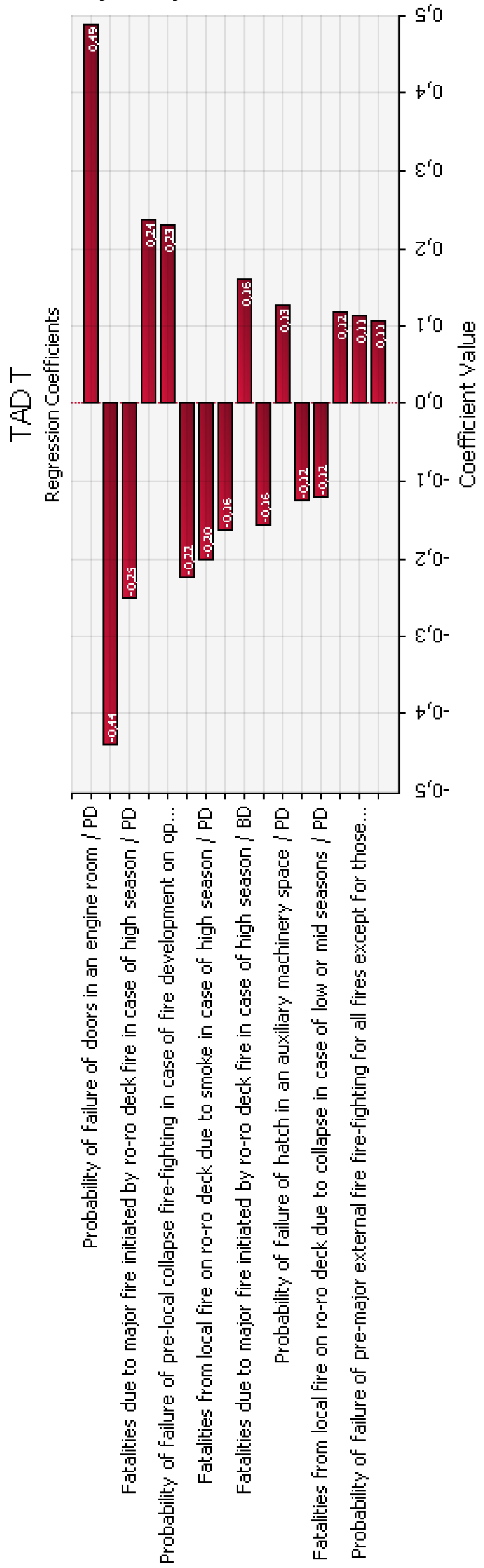
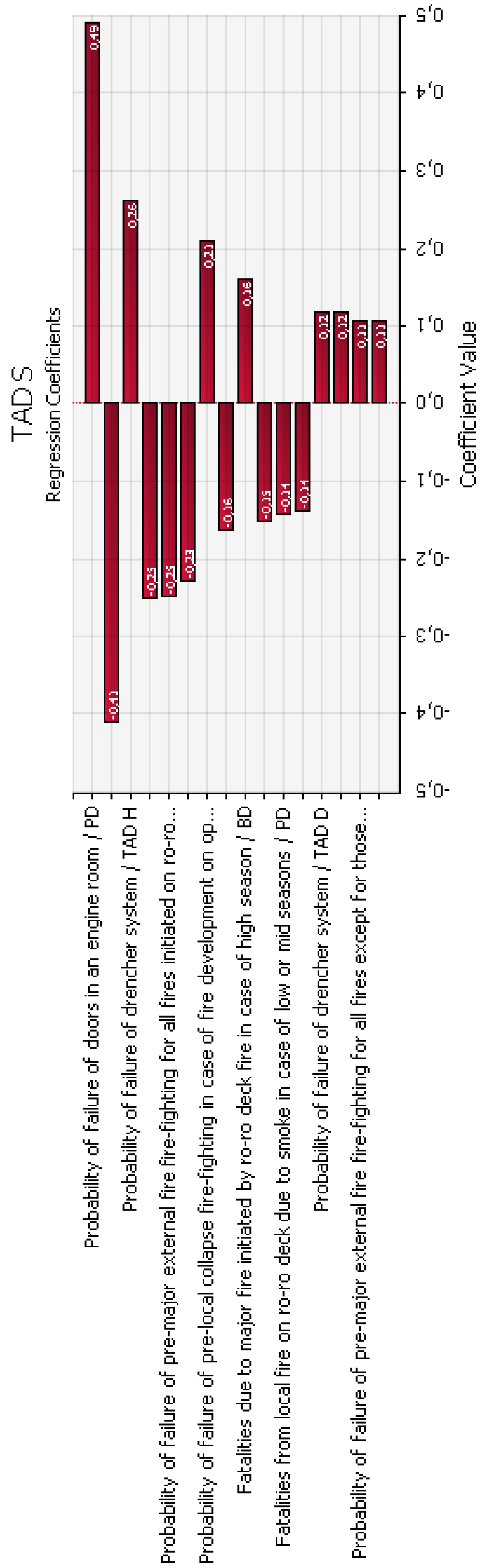
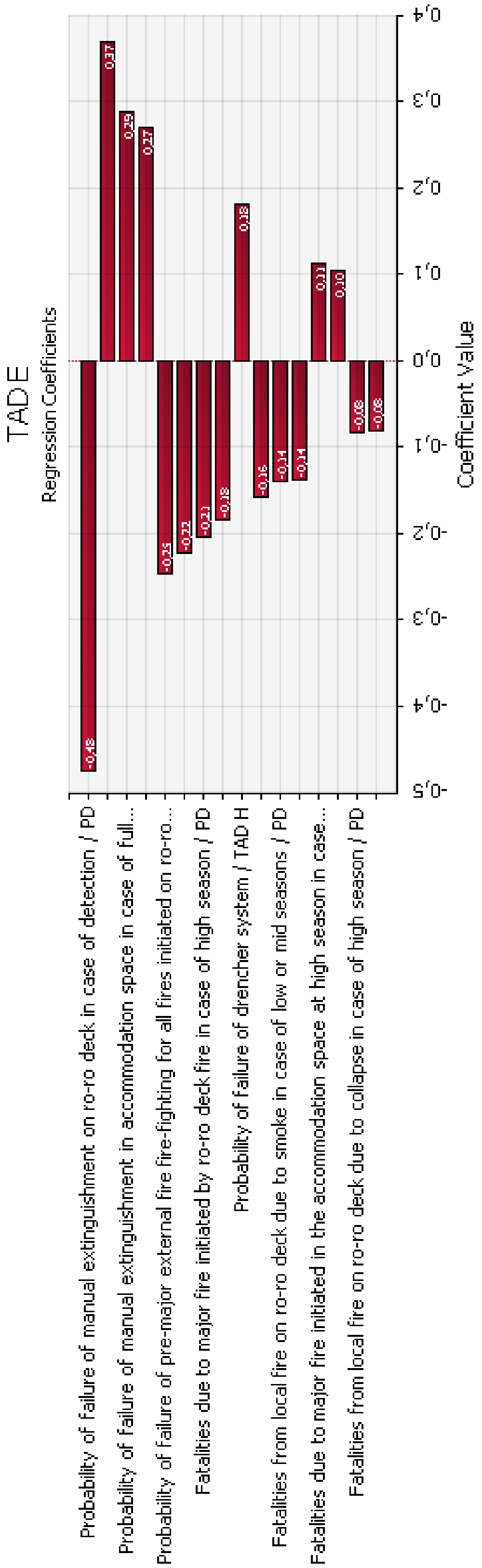
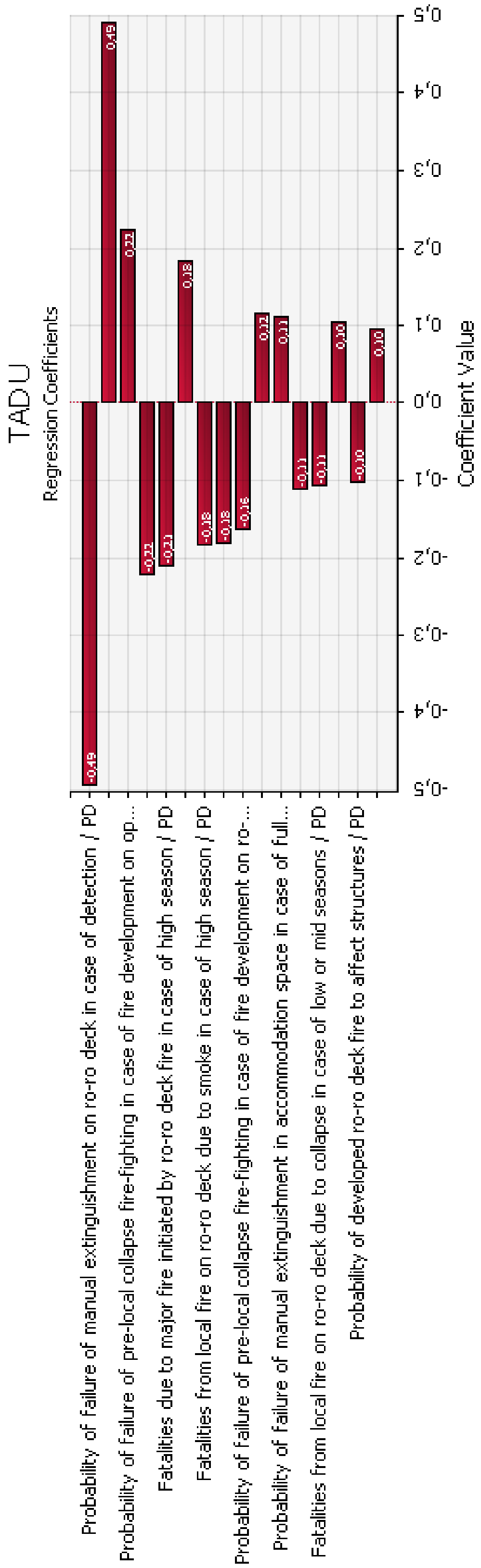
1,000
99,7%
0,3%
TAD U
Minimum 0,0887
Maximum 1,84
Mean 0,335
Std Dev 0,135
Values 10000

Sensitivity analysis






TADE
Regression Coefficients
Probability of failure of manual extinguishment on ro-ro deck in case of detection / PD
Probability of failure of manual extinguishment in accommodation space in case of full...
Probability of failure of pre-major external fire fire-fighting for all fires initiated on ro-ro...
Fatalities due to major fire initiated by ro-ro deck fire in case of high season / PD
Probability of failure of drencher system / TAD H
Fatalities from local fire on ro-ro deck due to smoke in case of low or mid seasons / PD
Fatalities due to major fire initiated in the accommodation space at high season in case...
Fatalities from local fire on ro-ro deck due to collapse in case of high season / PD
Coefficient Value


TADU
Regression Coefficients
Probability of failure of manual extinguishment on ro-ro deck in case of detection / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on op...
Fatalities due to major fire initiated by ro-ro deck fire in case of high season / PD
Fatalities from local fire on ro-ro deck due to smoke in case of high season / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on ro-...
Probability of failure of manual extinguishment in accommodation space in case of full...
Fatalities from local fire on ro-ro deck due to collapse in case of low or mid seasons / PD
Probability of developed ro-ro deck fire to affect structures / PD
Coefficient Value

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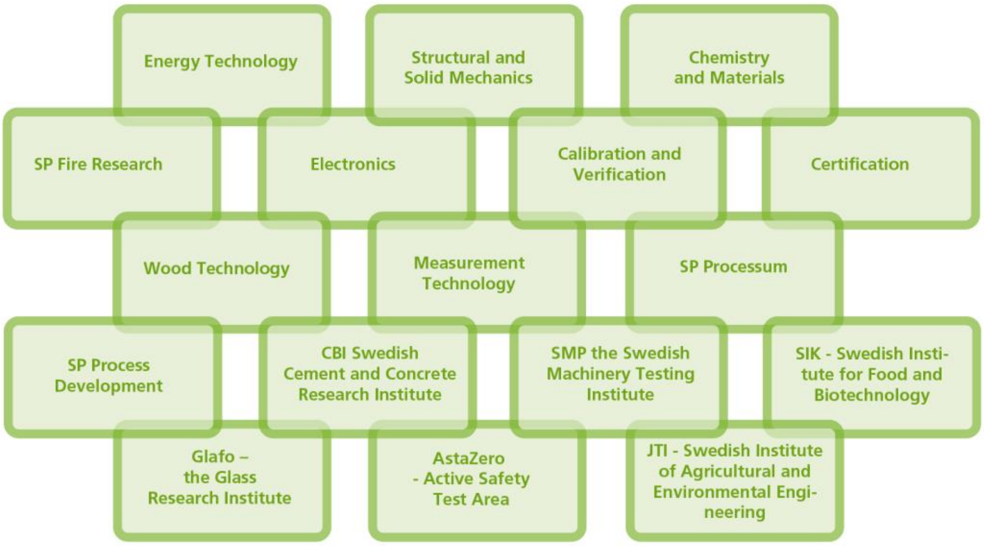

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