Engineering analysis report - Norwegian Future

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Abstract

This report contains the engineering analysis in accordance with SOLAS chapter II-2 regulation 17 for the panamax cruise vessel the Norwegian Future. The five upper decks were redesigned in FRP composite. A prerequisite was that thermal insulation was provided to all interior surfaces in order to achieve 60 minutes of fire protection. Fire development on open 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. A number of deviations to prescriptive requirements were identified. The deviations particularly concern the fact that FRP composite is combustible. This although has effects on a number of 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 representative space groups. Different combinations of risk control measures, forming 21 trial alternative designs, were quantified. In conclusion, the base design was shown to pose a risk almost five times as high as the prescriptive design. A performance criterion with a safety factor of 100% provided four acceptable trial alternative designs.

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 panamax cruise vessel the Norwegian Future. The five upper decks were redesigned in FRP composite. A risk-approach to performance-based design involved a fire hazard identification process based on workshops held by a designated design team of 28 people, 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. A prerequisite was that thermal insulation was provided to all interior surfaces in order to achieve 60 minutes of fire protection. In particular fire development on open deck and fire spread through openings and vertically along the outboard sides of the ship were although identified as fire scenarios where differences in fire safety would be significant. Furthermore, 11 space groups with similar conditions for fire scenarios were identified.

With regards to the base design, where steel structures had simply been replaced by thermally insulated FRP composite, a number of deviations to prescriptive requirements were identified. The deviations particularly concern the fact that FRP composite is combustible. This although has effects on a number of 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 almost five times as high as the prescriptive design. A performance criterion with a safety factor of 100% provided four acceptable trial alternative designs. All of these design solutions include a fully redundant sprinkler system in interior spaces in the superstructure. An acceptable design could additionally involve structural redundancy in divisions facing exteriors in combination with LEO system on exterior surfaces. In case structural redundancy is not provided, drencher system on open deck is required, either in combination with LEO or in combination with balcony sprinkler. 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 that a confidence of 80% is sufficient showed that a it would be sufficient with a fully redundant sprinkler system in interior spaces of the superstructure in combination with drencher on open deck. Considering the uncertainties also showed that structural redundancy in combination with LEO, balcony sprinkler and drencher over openings facing exteriors could provide sufficient safety. The latter design hence is the only potentially acceptable design which does not include a redundant sprinkler system in all interior spaces.

1. Scope of the analysis

This report documents an evaluation of fire safety for the cruise vessel the Norwegian Future, which is part of the EU research project BESST. The scope of the current analysis is given subsequently, commencing with a note on its part of the BESST project and brief descriptions of the ship and the reasons why it 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 required when making claim to this regulation.

1.1. The BESST project

The EU project BESST (Breakthrough in European Ship and Shipbuilding Technologies) is a large scale integrating research collaboration aiming to further develop European shipbuilding industry’s competitive advantage on the global market. The main focus of the project is holistic life cycle performance assessment on ship level, which is meant to guide the technical developments on system level. The results are then integrated in virtual show cases (ship concepts) demonstrating the technical solutions as well as the life cycle impact compared to current designs of passenger ships, ferries and mega-yachts, even if the results to a large extent will be applicable also to other ships.

Load-bearing structures on large ships are traditionally built in steel, which is the most cost-efficient shipbuilding material in the construction phase. Life cycle cost assessments have although shown that shipping companies can increase profits by investing in a lightweight ship design, since the lower fuel consumption per ton-km payload may make additional manufacturing costs pay off in short time of operation [1]. Furthermore, environmental life cycle assessments have shown that usage of fossil fuel has the greatest impact to surroundings throughout the ship life cycle, which could lowered by a lightweight ship design [1].

The hypothetical panamax cruise vessel M/S Norwegian Future was selected as an application case to demonstrate and evaluate use of lightweight materials in large passenger ships. The aim was to provide a cruise vessel where the lower decks carry all global stresses and the load-bearing structures of the upper decks are designed in lightweight Fibre Reinforced Polymer (FRP) composite instead of in steel. The main introduced difference in fire safety is that the material is combustible, as opposed to steel which by definition is non-combustible.

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 [2]. 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 Norwegian Future including a FRP composite superstructure is hence an alternative design and arrangements.

1.3. Required procedure

When laying claim to Regulation 17, an engineering analysis is required which follows the method summarized in SOLAS [2] and described in more detail in MSC/Circ.1002 [3] (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.

1.4. 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 [4]. 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 [4], 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 [5]. The methods used in the preliminary analysis in qualitative terms and the quantitative analysis are succinctly delineated throughout the processes. More detailed explanations of the preliminary analysis in qualitative terms are given in *Appendix A. The revised approach*.

2. Description of the alternative design and arrangement

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 safety level. This chapter describes the scope of the current alternative design and arrangements, which involves use of FRP composite instead of steel in load-bearing structures. FRP composite constructions is a novel feature in merchant ships and are therefore give general descriptions below, primarily from a fire safety point of view. Finally a base design, on which all trial alternative designs are based, is described in more detail.

2.1. Scope of the alternative design and arrangements

The panamax cruise vessel Norwegian Gem was used as reference when Meyer Werft formed the conceptual design of a new ship, the Norwegian Future. The reference ship was manufactured out of steel and some aluminium components on the top decks. The reference ship and the Norwegian Future are described below, with focus on differences and the decks subject to alternative design and arrangements.

2.1.1. The reference ship

Figure 2.1. The reference ship and the structures intended in FRP composite (from deck 11 and up) marked by the dashed line.

Table 2.1.General characteristics of the reference ship in comparison with its new design

	Reference ship	*Norwegian Future*
Tonnage, gt	93,500	96,500
Decks	15	16
Length, *m* (*ft*)	294 (965)	294 (965)
Beam, *m* (*ft*)	32 (106)	32 (106)
Draught, *m (ft)*	8.6 (28)	8.6 (28)
Cruise speed, *knots*	25	25
Capacity (max. persons)	4130	4350
Passengers (max.)	3130	3330

2.1.2. Changes made to form the Norwegian Future

The starting point for the design of the Norwegian Future was to gain new spaces by making the upper structures in FRP composite, but with the prerequisite to keep the same centre of gravity (fulfilling stability criteria). The result was a design where decks 1-10 are identical to the ones on the reference ship, except that they were reinforced to manage global stresses. Thereby all load-bearing structures of the remaining upper decks could be designed in FRP composite. The proportion of the FRP composite construction intended on the Norwegian Future is shown in Figure 2.1. Thanks to the lightweight properties of the material it was possible to expand the layout of the remaining upper decks by adding a third of a deck. It was inserted in the position of the previous front third of deck 12. The modifications imply that the front third of all previous decks above deck 11 are shifted upwards, as illustrated in Figure 2.2.

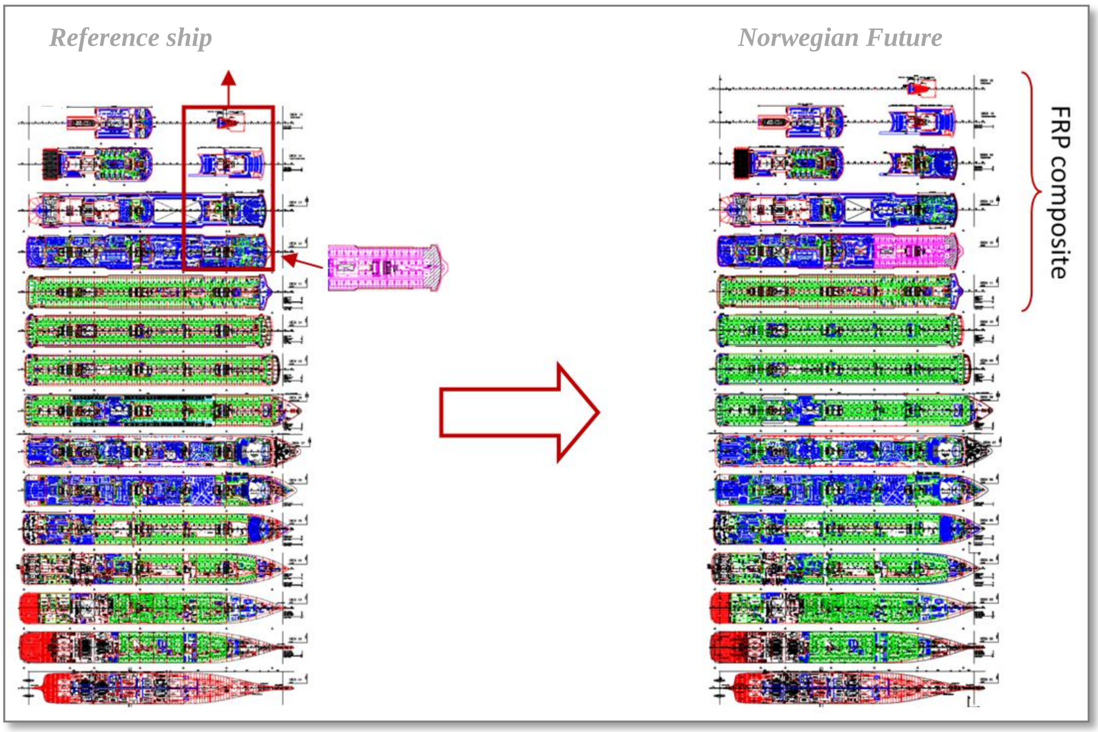

Figure 2.2. Illustration of the design changes made to the reference ship (general arrangement: Meyer Werft) to constitute the novel design of the Norwegian Future.

The added third of a deck increases the tonnage (volume) by 3 000 gt and gives possibility to add 87 cabins, accommodating another 200 passengers and 20 crew, as presented in Table 2.1. The shifting of decks and the greater number of passengers also called for some further layout adjustments. To increase the capacity of the spa the new front third of deck 12 includes a new spa lounge in the front. Repositioning the pool on deck 12 to deck 13 will open up for a few more cabins on the underlying deck 11, as shown in Figure 2.3. Furthermore, moving the previous deck 12 upwards will imply a slightly smaller opening over the main pool area (see Figure 2.3). Other than those layout changes the upper decks will simply be shifted upwards.

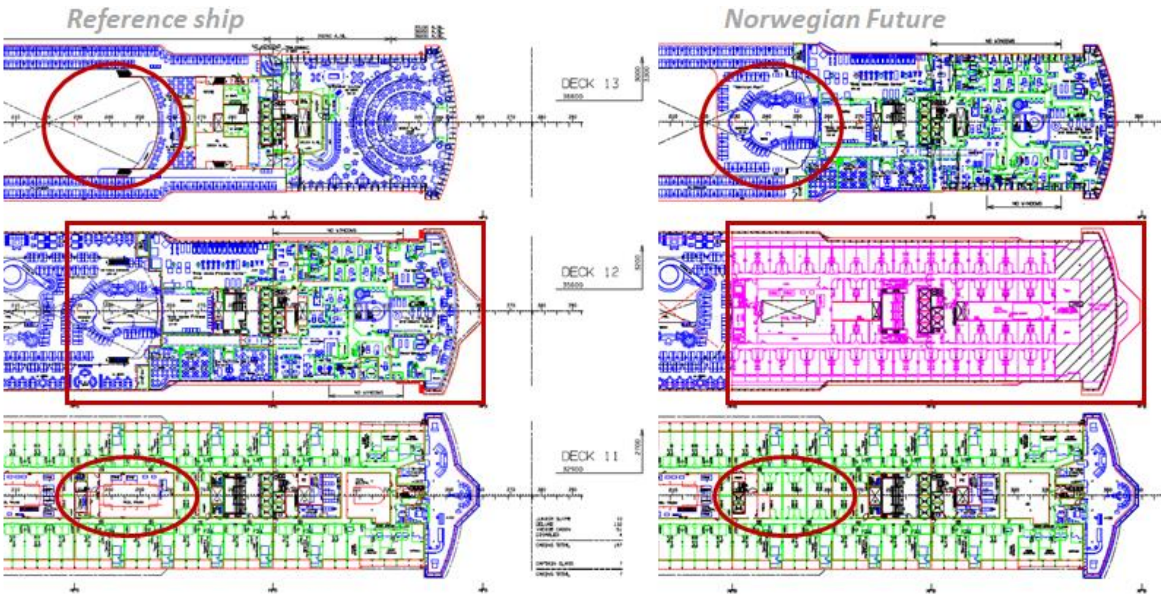

Figure 2.3. The front third of decks 11-13 on the reference ship and the Norwegian Future.

2.1.3. Layout of FRP composite decks

The scope of the alternative design and arrangements is to make the load-bearing structures from deck 11 in FRP composite. Those decks are therefore reviewed subsequently, along with deck plans. The general arrangement for the whole ship is presented in *Appendix B. General arrangement for the Norwegian Future*.

2.1.3.1. Deck 16

Deck 16 only comprises a small part in the fore, containing yet another sun deck and the radar mast (see Figure 2.4).

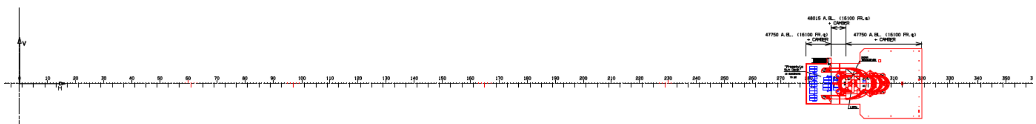

Figure 2.4. General plan for deck 16, consisting of a sun deck and the radar mast.

2.1.3.2. Deck 15

From the aft deck 15 begins with the funnel, in front of which there are mainly sun decks, private ones for the suites below and one public with 95 sun chairs (335 m^2). There are also two large suites (111 m^2 each) before the opening for the pool area, as seen in Figure 2.5.

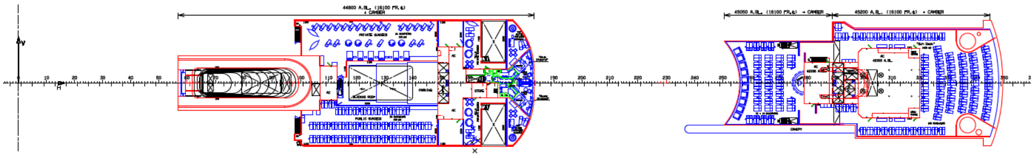

Figure 2.5. General plan for deck 15, mainly consisting of different sun decks.

After the opening amidships there is another large sun deck in the fore with 248 sun chairs as well as some large compartments for air conditioning and electronics.

2.1.3.3. Deck 14

This deck begins with some seats (48) and sun chairs (48) in the aft around the funnel, overlooking the sports court. The space in front of the funnel is occupied by ten 10 two-room suites (approx. 47 m^2) and two 465 m^2 grand villas, as seen in Figure 2.6.

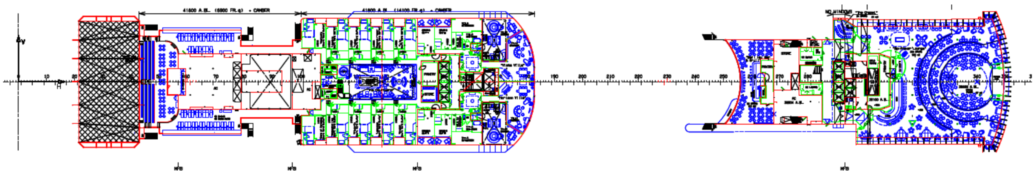

Figure 2.6. Layout of deck 14 with sun chairs around the funnel, some suites and a great lounge in the fore.

Amidships there is a large opening followed by a small bar (Bali Hai Bar & Grill, 95 seats on 161 m^2). After some storage rooms, elevators and toilets a great lounge is situated in the bow of the ship (Spinnaker Lounge, 360 seats, 998 m^2).

2.1.3.4. Deck 13

This deck is mainly an outdoor deck where a combination of sports court, which also works as a helicopter platform, is found on the aft deck. Large rooms for ventilation and other machineries also take up a lot of the space in the stern and are followed by two restaurants and a bar (Steak House, 106 seats on 274 m^2; Cagney´s Steakhouse, 62 seats on 100 m^2; Star Bar, 48 seats on 116 m^2). Around these arrangements there is also a running track. This is followed by a large open space amidships surrounded merely by sun chairs (306) and some pools in front of the opening, as seen in Figure 2.7.

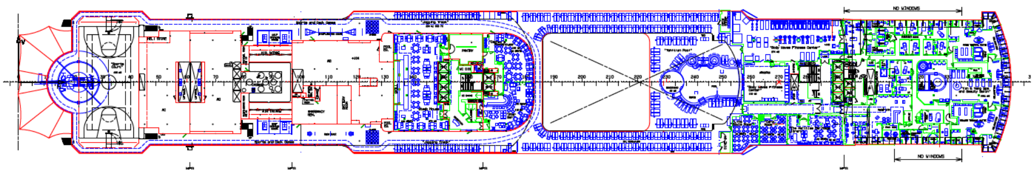

Figure 2.7. Deck 13 with a helicopter platform/sports court in the aft, a large open space amidships and spa & beauty salons in the bow.

After the outdoors follows a gym (274 m^2 + 110 m^2) with various machines on port side and on starboard side a couple of spaces for games and a library (in total 84 seats on 201 m^2). In the bow there is a considerable spa area with beauty salons, hair salon, relaxation area, saunas and numerous treatment rooms.

2.1.3.5. Deck 12

Two thirds of deck 12 is a pure leisure deck, as can be seen in Figure 2.8. Beginning from the aft there is an outdoor restaurant (The great Outdoors, 248 seats on 633 m^2) on the aft deck, followed by a restaurant on starboard side (La Cucina Italian Restaurant, 98 seats on 231 m^2) and a dining area for the main buffet on port side (Garden Café, 101 seats on 190 m^2), which continues through another two main vertical zones (134+192 seats, 249+655 m^2). The latter area also comprises the actual food court buffet. A large pantry interconnecting the three dining areas is found towards the middle of the ship, as well as some bathrooms and elevators. Port side contains the main galley and some storage rooms of cold and normal temperatures. Thereafter follow two children's lounges; The Leopard Lounge with games, dance floor, "bar", cinema and video arcade, as well as the Tree Tops Kid´s Club with areas for art and play.

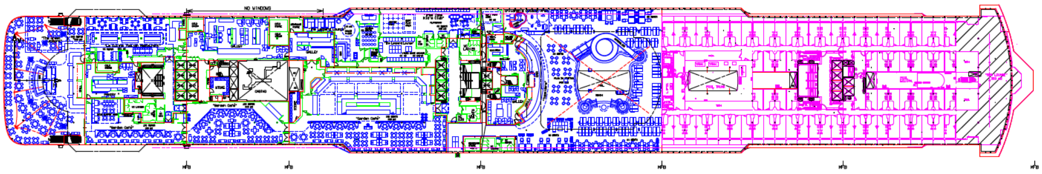

Figure 2.8. The general plan for deck 12 with restaurants in the aft, the main pool area amidships and mainly cabins in the front third.

The main pool area (Tahitian Pool, approximately 1250 m^2) begins amidships on this deck with a waterslide, pools, a bar, 92 sun chairs and 180 seats. An opening connects it with other pools and sundecks on the deck above. The front third of deck 12 contains 24 Inside Staterooms (13.3 m^2) and 52 Balcony Staterooms (26.5 m^2) and it also contains a spa lounge in the bow as well as some rooms with tanks and equipment for the pools penetrating from the deck above.

2.1.3.6. Deck 11

The joint between steel and FRP composite will be situated in the bulkheads on this deck. It is a pure housing facility with 52 Inside Staterooms (13.3 m^2), 132 Balcony Staterooms (26.5 m^2) and ten two-room suites (approx. 47 m^2). The bridge is found in the bow of this deck and the cabins closest to the bridge belong to the crew, as customary. Altogether 7 cabins are for crew and 197 cabins are for passengers. This deck also holds several storage rooms and elevators and some rooms with tanks and equipment for the pools penetrating amidships from the deck above (see Figure 2.9).

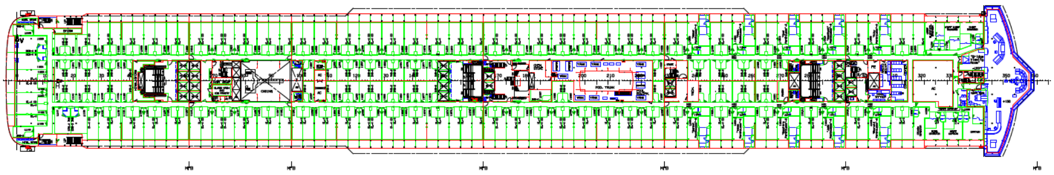

Figure 2.9. Layout of deck 11, mainly with cabins and the bridge in the front.

2.1.3.7. Deck 10

This deck is situated below the FRP composite superstructure but is briefly reviewed due to its proximity to the same. Similar to deck 11 this deck is also mainly for accommodation, even if most of the cabins (except for a few larger suites) are slightly smaller than the cabins on deck 11. In total there are 271 cabins and other than that there are several storage rooms for hotel services and a number of elevators (see Figure 2.10).

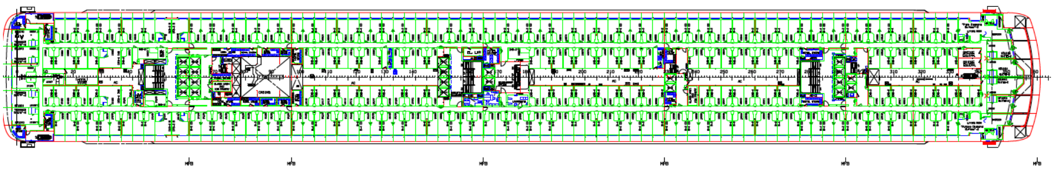

Figure 2.10. General plan for deck 10, only containing cabins.

2.2. FRP composite and fire performance

The structures which otherwise would have been made in steel or equivalent material on the aforementioned decks were designed in FRP composite. Below follow general descriptions of FRP composite and the most important fire performance features necessary to consider.

2.2.1. A FRP composite panel

A FRP composite panel essentially consists of a lightweight core separating two stiff and strong fibre reinforced polymer laminates, as is illustrated in Figure 2.11. 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*.

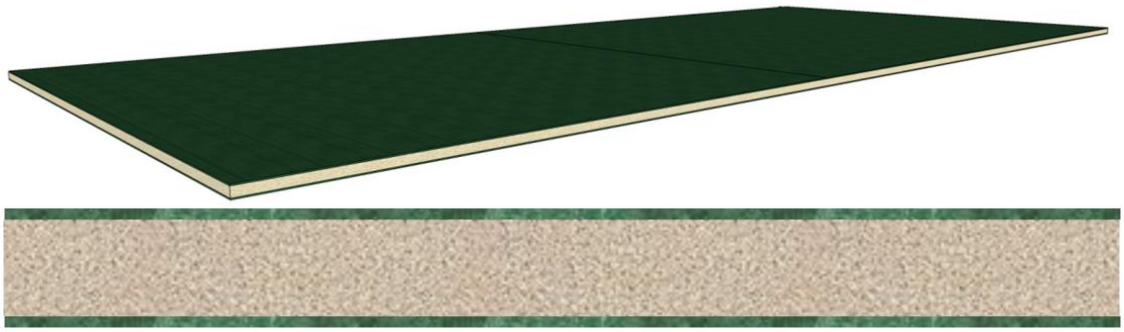

Figure 2.11. Illustration of a FRP composite panel (top) and a close-up on the lightweight core and the rigid and strong fibre reinforced laminates (bottom).

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.

2.2.2. Fire performance of FRP composite panels

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 a significant fire [6]. In addition, Figure 2.12 shows that the material *ignites* 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 [7-9], 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*.

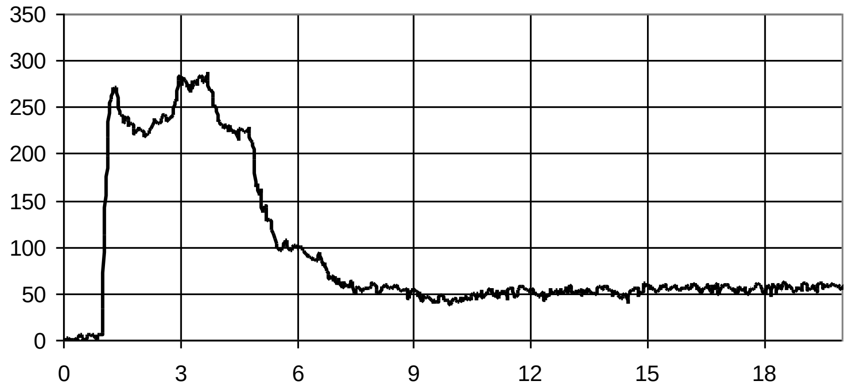

Figure 2.12. Heat release rate (kW/m^2) on the y-axis vs. time (minutes) on the x-axis, from FRP composite material when exposed to an irradiation of 50 kW/m^2 in the Cone Calorimeter.

2.2.3. 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 in a large furnace (represented by a temperature rise according to the standard temperature-time curve as defined by ISO [10]) without letting hot gas or flames pass to the side unexposed to fire, in accordance with IMO Resolution A.754(18) [10]. Depending on the following number, "A-X" (X = 0, 15, 30 or 60) requires a temperature increase less than 140°C after X minutes on the side of the construction that is unexposed to fire. The fundamental condition for the FRP composite to achieve A-class standard is hence not so much the temperature requirement on the unexposed side but that integrity is maintained for 60 minutes. To achieve this the FRP composite divisions could be insulated sufficiently to not deteriorate from a 60 minute fire. Such construction is illustrated in Figure 2.13. However, the requirement on non-combustible construction material would still be deviated.

In the International Code of Safety for High-Speed Crafts [11] (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) [12] 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[1]. However, at the same time as a loading requirement was added, the exposure time was reduced for some constructions. A-class divisions must achieve 60 minutes of fire integrity regardless of the heat transfer requirement, i.e. even an A-0 division must be capable of preventing the passage of smoke and flame for 60 minutes. For FRD divisions these requirements on fire integrity correspond with the requirement on heat transfer, i.e. a FRD-30 division must achieve both fire integrity and heat transfer criteria for 30 minutes. A FRD-60 construction thus prevents the passage of smoke and flame corresponding to an A-class construction.

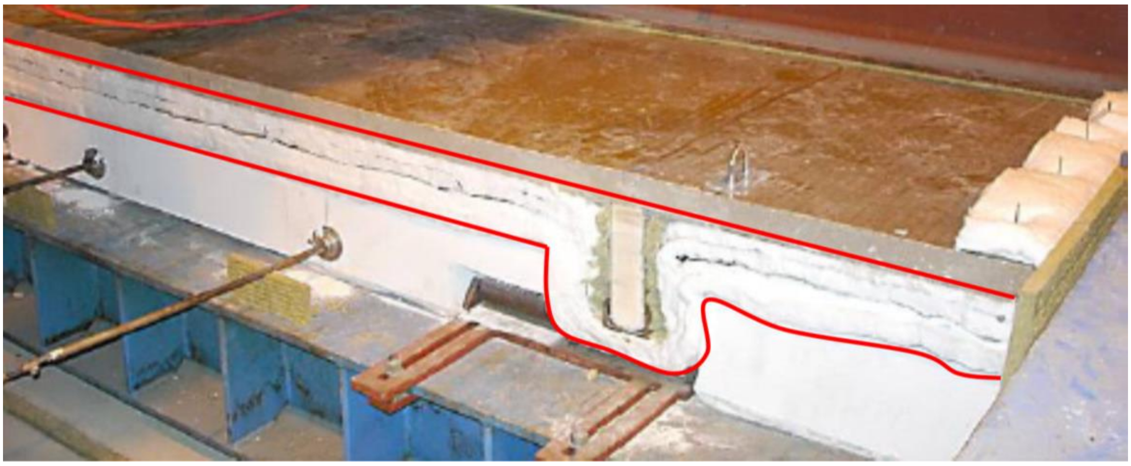

Figure 2.13. FRP composite deck with 60 minutes of thermal insulation, tested according to MSC.45 (65) [12].

The FRP composite structures could also be protected by combinations of other passive and active risk control measures (RCMs) to provide sufficient fire resistance, e.g. surface treatment (achieving fire restricting material or low flame-spread characteristics according to the FTP code [13]) or limited insulation in combination with sprinkler redundancy. The RCMs intended on the Norwegian Future are further described below.

2.3. Definition of 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 the different trial alternative designs.

The base design is defined subsequently by descriptions of the intended construction and the presupposed fire safety arrangements. Identified additional RCMs and considered trial alternative designs are described in the following chapter along with other results of the preliminary analysis in qualitative terms.

2.3.1. Current FRP composite construction

The hull construction and structural divisions in the upper decks will be made in FRP composite and since all constructions will be load-bearing structures they should meet applicable load-bearing requirements. The novel material is, however, not intended for

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[1] The load-bearing requirement was implemented when introducing aluminium constructions. By demonstrating strength whilst withstanding the standard fire test aluminium constructions are regarded equivalent to steel.

any other structures prescribed to be made in “steel or equivalent material”, such as stairways, ladders or doors. Deck 11 will be made in steel and the joint of steel and FRP composite will be located in the bulkheads of that deck. The joint is a so called crutch joint developed by the Kockums shipyard where the steel bulkhead plate ends in a U profile, a fork. The FRP composite panel is placed and glued in this fork and insulated properly. The above is all illustrated in Figure 2.14. More information on the suggested joint and its mechanical properties are found in [14].

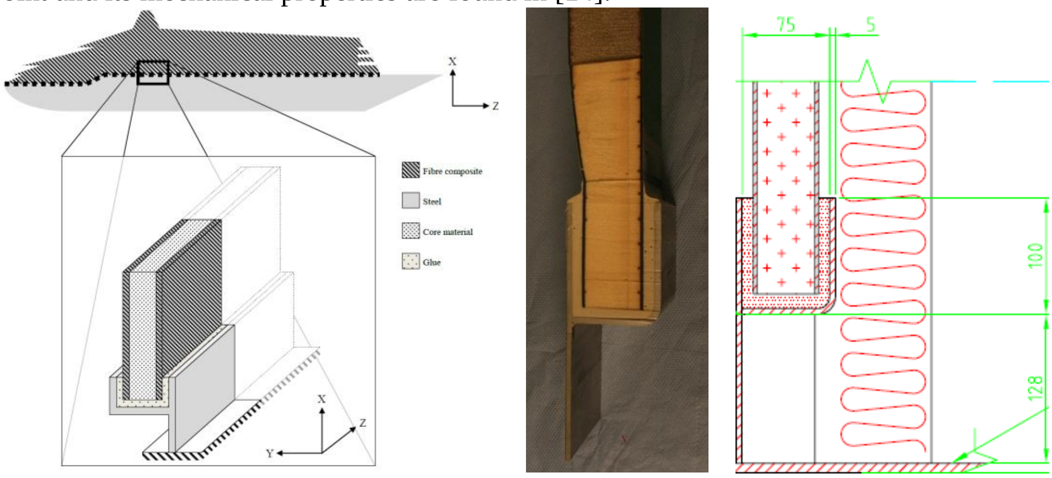

Figure 2.14. Illustrations of the joint between steel and FRP composite with its location, actual appearance and technical description with insulation [14].

Furthermore, a technical FRP composite deck solution was developed within BESST which is intended on the ship. The construction was developed to get sufficient width between load-bearing elements and to minimize the height of the deck (including stiffeners). It consists of rather thick FRP composite panels fitted on steel beams (which also work as stiffeners), which are supported by pillars, as illustrated in Figure 2.15.

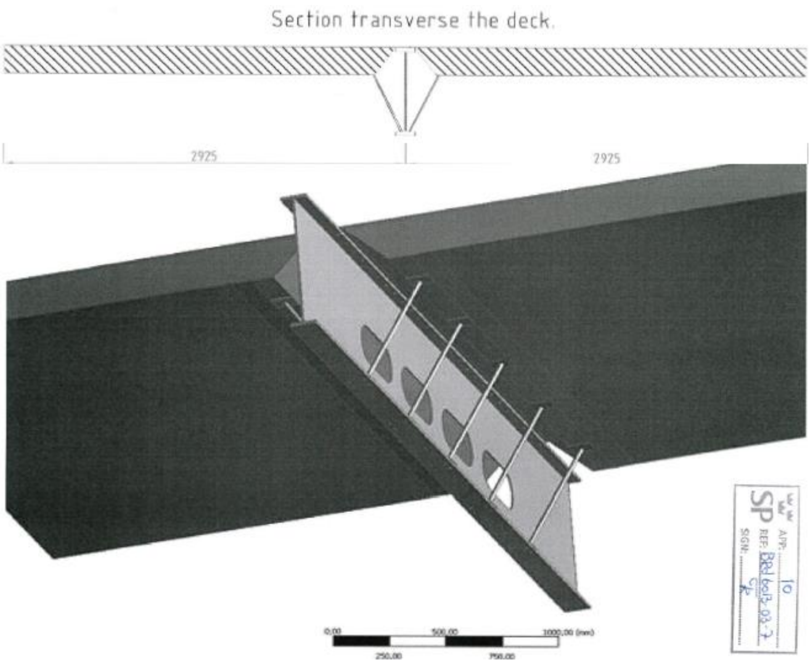

Figure 2.15. FRP composite deck solution intended on the ship.

The intended FRP composite panels consist of glass fibre reinforced laminates on a PVC foam core. The used thickness and properties of laminates and cores depend on the required strength in the particular application of the ship. The thickness of the core may although be as much as 200 mm and the laminates of about 1,3 mm. A the assembly location to the stiffener the thickness of the laminate is although significantly thicker, about 20 mm. The core material consists of glass fibre reinforced polyester face laminates and cross linked PVC foam core designated Divinycell H80 with a density of 80 kg/m^3. The laminate consisted of armed fibre glass Reichhold polylite 480-622 or 720-691. The stiffener was constructed of a steel plate with the dimension (height x thickness) 650 x 65 mm with two steel flanges welded to the upper and lower sides, with the dimension (height x width) 15 x 120 mm. The stiffener is mounted along the underside of the panel in a longitudinal direction. The stiffener is also attached and stabilized with outriggers between the deck and the stiffener.

The FRP composite construction is a good thermal barrier and has demonstrated good ability to contain a fire on its own [7-9]. However, since it makes the construction combustible and because of the predominant benefits in risk reduction compared to cost, some further mitigating efforts will be implemented on a general basis. Below follow descriptions of the most important arrangements to protect the FRP composite.

2.3.2. Fundamental arrangements of the current FRP composite construction

A fundamental condition for the current base design is that nowhere in the interior of the ship will a composite deck or bulkhead surface be allowed without protective insulation. The FRP composite divisions are insulated sufficiently to be classified as Fire Resisting Divisions that maintain fire resistance for 60 minutes (FRD-60), according to the International Code of Safety for High-Speed Crafts [11]. Even if the intended FRD-60 construction does not achieve the requirement on non-combustibility it will thereby fulfil the SOLAS requirements on fire resistance for an A-60 division.

In order to make up an FRD60 construction, the FRP composite construction described above was insulated with four layers of 25 mm thick insulation designated FireMaster Marine Plus Blanket. Layers one and two ended up against the stiffener while the two outer layers went down to the flange at the bottom of the stiffener. The nominal density of the inner layer of insulation was 64 kg/m^3 and the nominal thickness of the three outer layers of insulation was 70 kg/m^3. Between insulation layers one and two/two and three/three and four respectively there was one layer of aluminium foil. The actual technical insulation solution is illustrated in Figure 2.16.

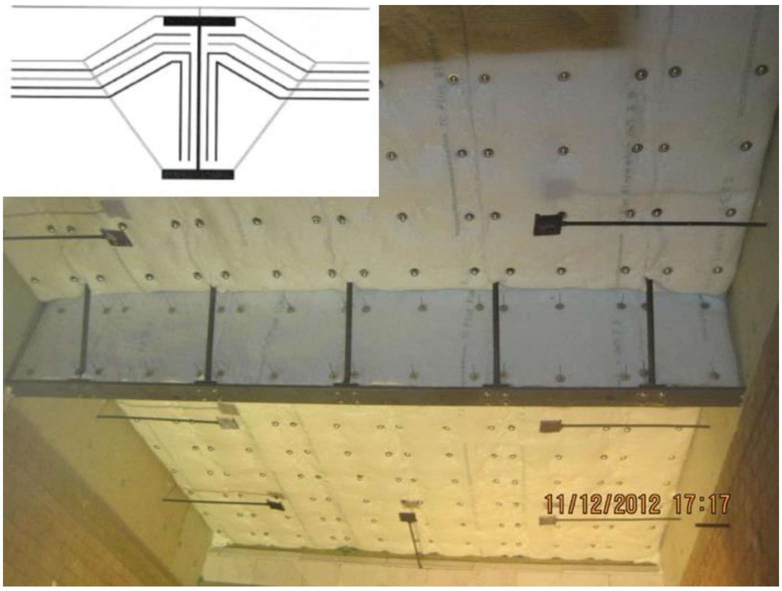

Figure 2.16. Insulated FRD60 deck solution intended on the ship.

According to SOLAS requirements, insulation is generally to be applied on the side of the division with the greatest risk of fire. An “A” class division is for example generally allowed with insulation only on one side of the bulkhead. The FRP composite has, however, been designed with insulation on both sides of the structure. Insulation on both sides of the bulkhead is generally an acceptable solution when using aluminium structures in fire zone divisions (where “steel or equivalent material” is required). It is regarded to make up for that aluminium deteriorates at relatively low temperatures [15].

Furthermore, from the above discussion on critical temperature for softening of the FRP laminate-core interface, it is clear that such insulation must keep the temperature at the interface on the side exposed to fire below ~130°C. The temperature on the unexposed side will, down to the high insulation capacity of the composite and the insulation on the unexposed side, therefore 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.

Important to note regarding the FRP composite construction is also that FRD-60 structures will be used ubiquitously and not only where A-60 divisions are required. That includes low risk spaces and when the adjacent space is an open deck. In some areas this will provide a higher level of fire safety than what is required by SOLAS II-2/9.2.2.3. For example, if a fire occurs where unprotected steel divisions are required (A-0), the backside (unexposed to fire) will become hot very quickly and could cause fire spread.

The fact that an interior surface will not be allowed without 60 minutes of protective insulation is essential for the composite base design. Preventing propagation of fire to the deck above for this time proposes that each deck becomes a “fire division”. The deck areas between bulkheads of the same category would then become “structural fire zones”, if no other than fire resistance requirements would apply. This should be compared with the A-class divisions that often have much less requirements on thermal insulation, typically A-0 or A-15.

The arrangement with insulation internally will leave the exterior combustible surfaces unprotected. 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 fire-fighting crew in and around a fire in a FRP composite structure.

2.3.3. Fire protection of the base design

The fire safety organization and fire-fighting routines on the ship will follow the requirements in SOLAS II-2. The fire protection systems and equipment will also be in agreement with these requirements. Together with the above described construction with FRD-60, this makes up the base design of the ship. The base design will likely need additional risk control measures (RCMs) in order to provide sufficient safety, which is further described in the following chapter.

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 were then incorporated in fire scenarios, which were developed by firstly identifying and tabulating fire hazards. The fire hazards were then enumerated and rated in different ways to form the basis for a selection, which made up the fire scenarios. 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 novel superstructure on Norwegian Future

	Name	***Organisation***	***Competence***
1	Erwan Juin	Center of Marine Technologies (CMT)	Lightweight structures, FE analysis
2	Christian Lundén	CL Specialglas	Glass constructions
3	Lars Molter	CMT	Ship design and constructions
4	Luis Felipe Sanchez Heres	Chalmers (CTH)	Mechanical properties
5	Jonas Ringsberg	Chalmers (CTH)	Mechanical properties
6	Roger Jansson	DIAB	Composite structures
7	Philippe Noury	DNV	Composite structures, risk analysis and maritime regulations
8	Kristoffer Brinchmann	DNV	Composite structures, risk analysis, FE analysis
9	Marcel Elenbaas	DSNS	Shipyard representative and composites
10	Markus Brinkmann	FSG	Naval architect
11	Henrik Johansson	Kockums	Naval architect and composite ship construction
12	Walter Nilsson	Kockums	Composite ship construction
13	Sven-Erik Hellbratt	Kockums	Shipyard representative, naval architect, composite structures. Coordinator of project WP.
14	Anna Hedlund-Åström	KTH	LCC and LCA
15	Hanno Buss	Meyer Werft	Ship construction
16	Markus Meyendriesch	Meyer Werft	Naval architect
17	Thomas Thon	Rhebergen Composites	Composite ship construction
18	Lars Strandén	SP Electronics	Risk analysis
19	Carl Bergenhem	SP Electronics	Risk analysis
20	Tommy Hertzberg	SP Fire Technology	Fire technology, especially composite materials and fire protection at sea
21	Petra Andersson	SP Fire Technology	Fire technology and risk analysis
22	Magnus Arvidson	SP Fire Technology	Fire technology and fire protection at sea
23	Michael Försth	SP Fire Technology	Fire technology
24	Michael Rahm	SP Fire Technology	Fire technology and risk analysis.
25	Franz Evegren	SP Fire Technology	Fire technology and risk analysis. Primary contact person regarding the report
26	Erland Johnsson	SP/CTH	Mechanical properties

27	Hans Larsson	Specialglasteknik	Glass constructions
28	Henrik Nordhammar	Stena	Ship owner
29	David Mattson	Swerea/Sicomp	Mechanical properties

3.2. Description of the trial alternative designs being evaluated

As mentioned in section *2.3. Definition of the base design*, a base design usually needs additional risk control measures (RCMs) for the ship to provide sufficient safety[2]. 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.

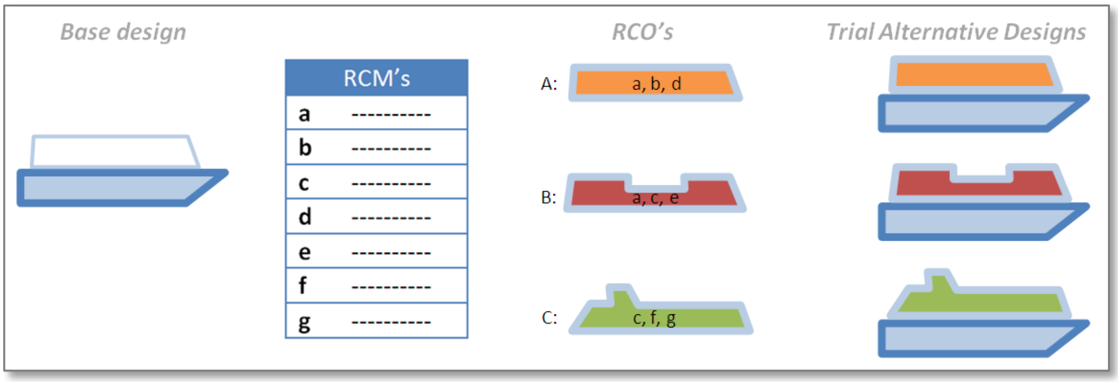

Figure 3.1. Illustration of the relation between the base design, RCMs, RCOs and trial alternative designs.

The ship superstructure 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 I. 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. Yet, even if not specified in the preliminary analysis report, the most relevant RCMs were distinguished prior to the quantitative analysis. RCMs which were suggested to be included in all RCOs (and hence could have been included in the base design) are the following:

k1 New fire-fighting routines/resources to manage fires in FRP composite and on open deck (see *4.1.3. Fire-fighting*)

j2 Use of fire-rated (LFS) deck coverings in accommodation spaces (primarily cabins)

Furthermore, the following RCMs were suggested to be included in different combinations:

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[2] 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.

a3 Drencher system covering all large vertical hazardous external composite surfaces (e.g. over 1 m high or covering more than 50% of a surface more than 1 m^2) on open deck
a5 Sprinkler system in balconies (redundant from cabin sprinkler system)
a6 Drencher system over openings (windows, doors, etc.) to exteriors on outboards sides of the ship
c2 Fully redundant sprinkler system in all internal spaces in the superstructure
j3 LEO system on external surfaces
j4 Structural redundancy

The RCOs that were then crystallized in the quantitative analysis are described subsequently. Applied to the base design, these RCOs form the primary trial alternative designs evaluated in the quantitative analysis.

- RCO A: c2 (redundant interior sprinkler system in superstructure)
- RCO B: a5 (balcony sprinkler)
- RCO C: a5 + a6 (balcony sprinkler + drencher over openings facing exteriors)
- RCO D: a5 + a6 + a3 (balcony sprinkler + drencher over openings facing exteriors + drencher on open deck)
- RCO E: c2 + a5 (redundant interior sprinkler system in superstructure + balcony sprinkler)
- RCO F: c2 + a5 + a3 (redundant interior sprinkler system in superstructure + balcony sprinkler + drencher on open deck)
- RCO G: c2 + a5 + a6 + a3(redundant interior sprinkler system in superstructure + balcony sprinkler + drencher over openings facing exteriors + drencher on open deck)
- RCO H: j3 (LEO)
- RCO I: j3 + c2 (LEO + redundant interior sprinkler system in superstructure)
- RCO J: j3 + a5 + a6 + a3 (LEO[3] + balcony sprinkler + drencher over openings facing exteriors + drencher on open deck)
- RCO K: c2 + a3 (redundant interior sprinkler system in superstructure + drencher on open deck)
- RCO L: j3 + c2 + a3 (LEO + redundant interior sprinkler system in superstructure + drencher on open deck)
- RCO M: j3 + c2 + a5 (LEO + redundant interior sprinkler system in superstructure + balcony sprinkler)
- RCO N: j3 + c2 + a5 + a6 (LEO + redundant interior sprinkler system in superstructure + balcony sprinkler + drencher over openings facing exteriors)
- RCO O: j4 (structural redundancy)
- RCO P: j4 + a5 (structural redundancy + balcony sprinkler)
- RCO Q: j4 + c2 (structural redundancy + redundant interior sprinkler system in superstructure)
- RCO R: j4 + j3 (structural redundancy + LEO)
- RCO S: j4 + j3 + a5 (structural redundancy + LEO + balcony sprinkler)
- RCO T: j4 + j3 + a5 + a6 (structural redundancy + LEO + balcony sprinkler + drencher over openings facing exteriors)
- RCO U: j4 + j3 + c2(structural redundancy + LEO + redundant interior sprinkler system in superstructure)

Hence, applied to the base design the above listed risk control options RCO A, RCO B, …, RCO T and RCO U form Trial Alternative Design A, TAD B, …, TAD T and TAD U.

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[3] LEO is a treatment to the FRP composite giving low-flame spread characteristics which is further described in *4.3.4.5. LEO system*.

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 determine how the deviations may have an effect on safety. This evaluation is presented subsequently, commencing with a background to and overview of the investigation. 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 D. 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.

2.3.1 Background to the 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[4]. Thereafter follow prescriptive requirements.

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[4] 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.

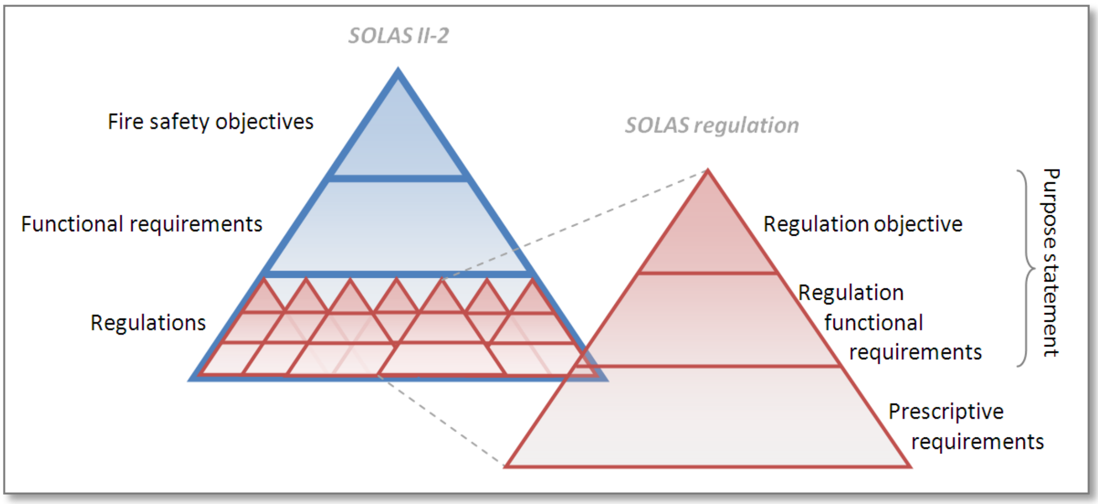


Figure 3.2. Each regulation in SOLAS II-2 consists of a purpose statement and prescriptive requirements. The purpose statements comprise regulation functional requirements and an individual regulation objective which sets out the objective of the functional requirements.

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 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 performing better 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 the 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. Identified deviations to prescriptive requirements are summarized in table 2.2 along with associated regulation functional requirements and regulation objectives. The deviations to regulations are thereafter described in the following paragraphs.

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 base design affects the regulation*
Part B	**Prevention of fire and explosion**		
Reg. 4 Probability of ignition	Prevent the ignition of combustible materials or flammable liquids	(1) Control leaks of flammable liquids; (2) Limit the accumulation of flammable vapours; (3) Restrict ignitability of combustible materials; (4) Restrict ignition sources; (5) Separate ignition sources from combustible materials and flammable liquids; (6) The atmosphere in cargo tanks shall be maintained out of the explosive range.	The base design **complies with prescriptive require-ments**. Unprotected external FRP composite surfaces could be argued to challenge RFR 3. However, FRP composite is not easily ignited, even if combustible.
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.	**Prescriptive requirements are generally complied with** and also RFRs regarding internal spaces. However, if open deck is considered a space, unprotected external surfaces challenge RFR 3. Similarly, combustible material constructions with unprotected surfaces on balconies are not fully in line with Reg. 5.3.1.3.2.
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.	**Compliance with prescriptive requirements** and with RFR. Risks associated with generation and toxicity of smoke will not likely be significantly affected.
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.	Even if structural and integrity properties are achieved by a FRP composite divisions, the construction material is combustible, which **deviates from the definitions of A and B class divisions**.

Reg. 10 Fire-fighting	Suppress and swiftly extinguish fire in the space of origin.	(1) Install fixed fire-extinguishing systems, having due regard to the fire growth potential of the spaces; and (2) have fire-extinguishing appliances readily available.	**Prescriptive requirements are complied with**. However, in in order to meet the RFRs additional fire-extinguishing systems or appliances may be proved necessary.
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 (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.	**Prescriptive requirements are complied with** and conditions for escape may be improved.

3.3.1. Regulation 4: Probability of ignition

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 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.

3.3.2. Regulation 5: Fire growth potential

This regulation oversees materials in spaces with the intention to limit the fire growth potential. All prescriptive requirements of regulation 5 considering enclosures are considered complied with but the ship 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 functional requirement must although be taken into concern 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. For example vinyl ester, which is often used as resin in FRP composite, will give rise to pyrolysis gases above 500°C and it could therefore be argued that the amount of combustible material is increased when exchanging steel with FRP composite.

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 and other loose fittings. All of those materials are of the same approved type in the base design as in a traditional (prescriptive) design. In this sense, a ship with FRP composite constructions can be claimed to comply with all prescriptive requirements and not increase the fire growth potential in spaces.

Behind any insulation or wall construction the material is nevertheless exchanged from non-combustible steel to combustible FRP composite. However, this regulation covers fire growth and the first stages of a fire and it may therefore not be relevant to stipulate requirements for the bulkhead plate behind a wall construction or insulation. There are although requirements which could be relevant. 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. If FRP composite surfaces are left uncovered it can be argued that the surface laminate in fact represents the surface of the wall construction. As a result of the above requirements low flame-spread characteristics apply to the surfaces. That is also in line with the purpose of this regulation.

In the current design case the combustible FRP composite surfaces are although covered with thermal insulation representing 60 minutes of fire protection. The FRP composite will thus not add to the fire growth potential in a space within the first hour of fully developed fire. The amount of combustible materials should certainly be restricted, but combustible material is then only added to the construction behind the insulation. Since the purpose of the regulation is to control the fire **in** spaces and during its first stages of development, and the insulated construction in no way will affect the fire load in the space until the fire is allowed to spread to adjacent spaces after 60 minutes, the fire growth potential could be connoted unaffected in this case.

The base design will, hence, not add to the fire growth potential of any internal space within the first hour of fully developed fire, on account of the thermal insulation. However, if open deck is considered a space, the unprotected combustible external surfaces would give reason to assert that the third regulation functional requirement is challenged. Since external surfaces on ships are typically made up of painted steel there has not been any reason to regulate this matter. This is another example of where the FRP composite construction goes beyond the steel-based regulations. One exception although exists. Since balcony fires made news headlines, requirements have been implemented which oblige ceilings and linings of balconies to be made in non-combustible material (Reg. 5.3.1.3.2). The ship does formally not have any ceilings or linings on the balconies but, once again, then the regulation assumes that there are painted steel surfaces. The same applies to the rest of the ships' exterior surfaces. Making exterior surfaces in combustible FRP composite will affect the fire growth potential and could cause e.g. fire growth on a balcony or vertical fire spread between decks, which are hazards which must be addressed on these ships. Hazardous exterior surfaces could for example be protected by achieving low flame-spread characteristics or by protection with a drencher system. An indirect way to manage the problem is to use fire rated windows, which could avoid fire spread.

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, respectively. 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 increased fire growth potential is increased smoke production. This, however, is not as relevant of a problem to consider for external fires where 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. 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 required, which are also used in a ship with FRP composite constructions.

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 are 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 core 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 [16], 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. Furthermore, if a fire spreads to an adjacent space there will not be a significant increase in smoke generation and toxicity if the fire also involves a FRP composite division. It is also hard to predict whether the smoke generation and toxicity at a given time would be worse in a ship with FRP composite constructions depending on the insulating capacity of the construction. If thermal insulation is used to protect the FRP composite, fire spread will likely be delayed. Important to note is also that when a fire starts to involve such protected FRP composite divisions, conditions in nearby spaces will already have been uninhabitable for long.

Fires on open deck and involving exterior surfaces in FRP composite could also affect the smoke generation and toxicity. This, however, is not as relevant of a problem to consider for external fires (compared to the actual fire spread) since smoke management is not a problem.

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. Reg. 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. 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 this definition.

The base design achieves equal structural properties 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 (which can be a weak link in prescriptive designs). The base design will thereby in many cases contain a fire in its origin better than a prescriptive design. However, even if structural and integrity properties in divisions are achieved and fire rated penetrations are used, FRP composite is combustible and thereby poses a deviation.

3.3.5. Regulation 10: Fire-fighting

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 may need to be taken into account when designing the fire extinguishing systems. In internal spaces the fire growth potential will although not be affected since the FRP composite is thermally protected. It may, however, be necessary to consider fire extinguishing systems and equipment in additional places of the ship. Exterior surfaces are made of unprotected FRP composite and it could be useful to fix an additional sprinkler above doors, so that an enclosure fire will not spread to the exteriors if the door is left open. Additional sprinklers may also be useful above windows facing the outside to prevent fire to spread through an open or broken window to other decks via the exteriors vertical FRP composite surfaces. It may also be relevant to install drencher systems covering hazardous parts of the hull, if made in FRP composite, where there is a significant risk of fire spread. Additional equipment for manual fire-fighting should also be considered, e.g. on open deck spaces surrounded by unprotected FRP composite surfaces. Hence, fire extinguishing systems and appliances should be readily available regardless of the construction material of the ship.

Regarding prescriptive requirements, Regulation 10.2.1.1 requires to use a materials in piping which are not readily rendered ineffective by heat, unless adequately protected. It could be relevant to make piping in FRP but if using sufficient insulation this seems acceptable.

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 with tools such as Fog Spear or Cutting Extinguisher 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.

3.3.6. Regulation 11: Structural integrity

This regulation intends to ensure 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 be achieved at the end of the applicable exposure to the standard fire test since the FRP composite is sufficiently insulated. However, unlike the requirements on structural and integrity properties, the requirement for non-combustibility is not time-limited. It may be argued that steel 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. Yet, the fact that FRP composite constructions are combustible may not be overlooked. A prolonged fire could involve and deteriorate a FRP composite structure when the thermal insulation is no longer enough to keep the temperatures sufficiently low. A worst-case scenario fire could bring about a local collapse when the FRP laminates detach from the core. Good structural behaviour of unprotected FRP composite in a real fire, even with local delamination occurring in the composite due to high temperature, was although documented in a full scale cabin fire test carried out at SP Technical Research Institute of Sweden [16]. In this context it is also worth remembering that also steel constructions suffer from strength deterioration and particularly deformation problems when heated enough. Generally steel loses its structural strength at about 400-600°C and a sandwich FRP composite laminate may lose its bonding between core and laminate, and thereby structural performance, when heated to about 150°C. Still, steel ships have proved to be able to survive fire for several days without progressive structural collapse occurring.

3.3.7. 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). Looking at the prescriptive requirements, 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. Such constructions are although not considered in other materials than steel, which is generally the case also on ships in FRP composite.

In order to achieve safe escape routes Regulation 13 requires fire integrity and insulation in several places, referring to values in Regulation 9 (tables 9.1 to 9.4). It may be argued that steel is therefore implicitly required. However, since it is only referred to fire integrity and insulation values and not to the class of the divisions, a sufficiently insulated FRP composite division could be claimed to achieve these requirements.

Furthermore, from the discussions above on critical temperature for softening of the FRP laminate-core interface, it is clear that the provided insulation must keep the temperature at the interface on the side exposed to fire below ~130°C to achieve sufficient structural integrity in case of fire. The temperature on the unexposed side will, down to the high insulation capacity of the composite construction, therefore 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. In addition, more crew could help with the evacuation since there is no need for boundary cooling and the time available for escape and evacuation could thereby be increased.

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 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, e.g. since they do not consider combustible exterior surfaces. It was judged that the high level of novelty in the present design case invokes further evaluations of how the base design affects the implicit level of fire safety in the regulations [4]. FRP composite in shipbuilding is still relatively new and has limited field history regarding effects on fire safety. In addition the scope of the design case is rather large and the deviations are deeply rooted. For these reasons, investigations were carried out to reveal effects on the prescriptive level of fire safety from different perspectives. The general fire safety objectives and functional requirements stated in SOLAS II-2/2 were investigated as they set out the safety targets for the whole chapter. Effects on the structure of the fire safety prescribed in regulations was also investigated as well as effects on different properties represented in the current requirements. This way innate effects on the implicit level of fire safety in regulations were intended to be identified. These investigations were complimented with a general evaluation of how the novel structural material may affect a fire development at different stages. These additional regulation and fire evaluations are documented in *Appendix D. Additional regulation and fire safety evaluations* and the results are summarized below.

3.3.9. Summary of additional regulation and fire safety evaluations

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 investigation 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 from steel to FRD-60. In case the circumstances allow a fire to progress, it will reasonably be better contained in the structure within the first 60 minutes. In case of fire, that ability could e.g. give the advantage of an increased time for escape as a result of significantly lower temperatures in staircases and escape routes. 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 involves external surfaces, which will 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 two separate Hazid workshops held at SP Technical Research Institute of Sweden. 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. However, since the layout for the Norwegian Future was not finished, deck plans for the reference ship were used in both sessions. The differences between the ships are reviewed in paragraph *2.1.2. Changes* *made to form the Norwegian Future* which makes it clear that the hazard identifications performed for the reference ship are applicable also to the Norwegian Future. 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.

Two slightly different approaches were used on the two occasions. In the workshop held in November 2008, members from the design team met to identify the specific fire hazards introduced by the new design using a "What-if" analysis method. The team was divided into four groups that worked their way through the concerned spaces of the ship, starting from four different positions (top, bottom, aft and fore). The outcome from this hazard identification is documented in *Appendix E. Data from the first hazard identification* and was concluded in event trees, presented in *Appendix F. Summary of the first hazard identification*. In general, this first hazard identification provided information on possible fire developments in different spaces and gave an idea of the potential fire scenarios.

The data from the first hazard identification worked as input when performing the second hazard identification, under somewhat different conditions. This time a new method had been developed, which was introduced to the participants before splitting up for group sessions. Each group identified fire hazards of different categories on one of the five considered decks. Thereafter the results were presented for the whole design team, which provided opportunity to give input on each other's work. The outcome from this second hazard identification is presented in *Appendix G. Data from the second 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. [17]. 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 will be of significantly different probability. The difference in risk depends on how the safeguards affect the probability of a hazard converging into actual damage or loss [17]. Hence, it is rather the probability of functioning safeguards and the potential consequences which together constitute the possible outcomes, i.e. what is generally called 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 F. 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 6th 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. A summarized rating of the fire risks in each space in the new superstructure was therefore estimated, based on the performed identification of hazards. The rating particularly considered the amount of combustibles and the potential fire growth rate in the concerned space. The spaces were considered individually, i.e. even if spaces of a certain kind is common, this did not affect the risk index. Probability is included only in a qualitative sense, when appraising the reasonableness in different consequences. The risk ratings were made from 1 to 3 and are found in Table 3.3 below and in the rightmost column in *Appendix G. Data from the second hazard identification*, where they are also given a comment.

Table 3.3. Fire risk indices (R_i) of the spaces in the FRP composite superstructure

Space on deck 11	R_i	***Space on deck 12***	R_i	***Space on deck 13***	R_i	***Space on deck 14***	R_i	***Space on deck 15***	R_i
Void space	1	Void space	1	Void space	1	Void space	1	Funnel	2
Cabin	3	Sundeck mid	3	Sundeck	3	Sundeck	3	Private Sundeck	2
Void space below bridge floor	2	Sundeck stern	2	Steakhouse	3	Villas/ suites	3	Private Villa Sundeck	3
AC	2	AC	2	AC	2	AC	2	AC	2
Lifts and shaft	1	Lifts and shaft	1	Lift Machinery	2	Lift Machinery	2	Lift Machinery	2
Store	2	Store	2	Store	2	Store	2	Store	2
Pool chemical store	2	Staircases	2	Pantry	3	Pantry	3	Freestyle Sundeck	2
Staircases	2	WC etc	2	Staircases	2	Staircases	2	Diamond/Pearl suites	3
Communication centre etc.	1	Spa area	2	WC	2	WC etc	2	Public Sundecks	2
Lift Machinery	2	Gym area	1	Lifts and shaft	1	The courtyard	3		
Pantry	3	Library and Card Room	2	Spinnaker Lounge	3	Radar tranceiver	1		
Casing	3	Children's area	2	Emergency generator	2				
Balcony	3	Pantry	3	Battery room	2				
Bridge	2			Sports Court	2				
Corridors	2			Switchboard Room	2				

The rating of fire hazards given in Table 3.3 serves the purpose of the prescribed enumeration of fire hazards in Circular 1002. Particularly when performing a more elaborated fire risk assessment where fire hazards are selected to form design fires and event trees, which will define the fire scenarios. The rating although describes the conditions for a fire in the concerned spaces. The Hazid therefore included identification of fire hazards with regards to fire spread, which also influences the selection of fire hazards.

3.5.3. Collection and rating in a Procon list

The different investigations documented in this report have revealed much information regarding differences in fire safety between the novel 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 hazards induced by the use of FRP composites is related to the exposure of combustible external surface areas. This is particularly critical due to the numerous balconies connecting cabin enclosures to the external areas. A cabin fire might produce an intense flashover fire due to used standard combustible cabin materials [16] in combination with a possibly high degree of ventilation through an open balcony door (it seems reasonable that on a cruise vessel many people will enjoy sitting on the balconies with doors open). Consequently, the possibility of having well-ventilated cabin fires connected with the exterior will allow for fire spread between fire zones which induces a significant fire hazard. There is also a large open atrium and other outdoor areas accessible for leisure activities, 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 after 60 minutes (provided that FRD-60 is used) and, even if it would only fuel an already uncontrolled fire, it would lead to failure 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 (2 hours or 2 days?) has been proven, this risk will be considered significant. In this context, also the safe return to port requirement will put a demand on the ship, which needs to be taken into account in the design.

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

3.6. Selection of fire hazards

All of the previously identified fire hazards (*Appendix E. Data from the first hazard identification*, *Appendix F. Summary of the first hazard identification* and *Appendix G. Data from the second hazard identification*) were reviewed with help from the Procon list (*Appendix G. 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 is elaborated in the following subsections and the quantification needs are thereafter concluded.

3.6.1. Ignitability of surfaces

More combustible materials will be visible on external surfaces. However, the surfaces on the hull are generally of rather restricted size due to the many windows. Furthermore, combustible exterior surfaces on open deck is simply another combustible material amongst the many combustible surfaces and numerous other combustible materials on deck (sun chairs, upholstered couches, towels, trashcans, small composite structures, wood or plastic deck surfaces etc.). What is prescribed for these combustible materials is 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 with worse ignitability than painted steel; FRP composites does 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 will not affect people in an escape situation/evacuation and will not affect people on the embarkation deck at least four decks below after more than one hour. When 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. 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 and 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. Now, smoke is what causes fatalities in a fire and smoke management is not a problem in case of an external fire. I 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 cabin spreading to vertical FRP composite surfaces. In case the initiating fire is situated on open deck it is important to remember that a deck on a cruise vessel is not a stripped painted steel deck. On the contrary, as seen in Figure 4.1 there are numerous plastic chairs, sunbeds and matrasses, upholstered furniture, plastic bushes and other vegetation, umbrellas, 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 [16] 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

Containment of fire is in the case of FRD60 structures all about building decks and bulkheads with sufficient fire resistance. The ship does not comply with the definition of A-class 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 and 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. Containment is equal or better thanks to double-sided insulation and insulation provided by the FRP composite itself (structural integrity is evaluated separately). The benefits of better containment could be useful to account for to show on sufficient safety for the ship as a whole, in accordance with the revised approach.

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 external surfaces are restricted based on the above comparisons.

From a life safety perspective the most dangerous part of fire growth is smoke production. For external surfaces the smoke production will be increased, in comparison with a prescriptive ship, if FRP composite surfaces at vertical surfaces and on open deck take part in the 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 on 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 in anywhere on open deck or a space with an opening towards the exteriors this hazard was recommended to 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. cabin fire leads to fire spread on vertical 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.

Better containment of fire for internal FRD enclosures was discussed above. Containing heat in a space will however cause higher temperatures and could give potential for faster fire growth. It therefore needs to be established whether this effect needs to be accounted for and if it may diminish the positive effects from improved insulation, i.e. will the fire actually be better contained if the fire growth is significantly accelerated, what is the total outcome? If there is a difference depending on the differences in construction this should be included in the overall fire scenarios for the whole ship.

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)). 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.

Strength deterioration is although 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.

In case of an internal fire, structural integrity is maintained by a FRD60 structure until the end of the applicable fire test and, as discussed above, 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. It will thereby have a lower probability of collapse than the exposed combustible FRP composite structure after 60 minutes, even if RCM's could be provided to improve the probability of collapse in the new structure. No one should although reside in the relevant compartments at this stage except the fire-fighting crew. The risk of collapse will therefore need to be considered from this perspective. 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 need to be accounted for in the overall fire scenarios for the ship as a whole.

Furthermore, looking at exterior surfaces, the FRP composite is worse than both steel and aluminium since the FRP composite bulkheads are load-bearing and non-insulated, i.e. a fire could lead to structural collapse 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. balcony/cabin 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.

For internal fires there are two further issues: (1) Heat may be conducted to the steel-composite joint from a fire on deck below unless sufficient insulation is provided to solve the problem, and (2) Fire on internal deck may spread downwards unless decks are insulated on the upper side (60 minutes of thermal insulation has been a prerequisite in the preliminary analysis but such a solution does not exist at the moment and no standardized test exists).

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. It is suggested that a qualitative evaluation is performed and if possible a quantification is made where the probability of failure of manual extinguishment is evaluated.

Fire-fighting may furthermore be affected through the risk of collapse after 60 minutes. 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 two ships.

3.6.7. Evacuation

Improved conditions within the first 60 minutes and potentially worsened conditions after 60 minutes in case of a major fire could affect evacuation. It is 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 combustible material is restricted.
- To establish how the probability of successful fire-fighting is affected by usage of the new material.
- To establish if and how risks associated with the joint should be managed (heat may be conducted to the steel-composite joint from a fire on deck below unless sufficient insulation is provided).
- To establish if and how risks associated with fires on internal decks should be managed (fire could spread downwards unless decks are insulated on the upper side).

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 the consequences are increased due to the increased amount of fuel which is made available to an uncontrolled fire after 60 minutes.
- To establish how the probability for flashover is affected by the alternative design and arrangements.
- To establish how the probability for containing a fire in the alternative design and arrangements is affected.
- To establish how the probability of involving exterior vertical surfaces in a fire is affected due to their combustibility.
- To establish how the probability of involving combustible surfaces on open deck in a fire is affected by the added FRP composite structures.
- To establish how the consequences are affected from an uncontrolled fire for more than 60 minutes due to potential internal 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 open deck are increased due to the risk of collapse.
- To establish how the probability of successful fire-fighting is affected by usage of the new material.
- To establish how the probability for a fire-fighting fatality is affected by the alternative design and arrangements.
- To account for the consequences associated with evacuation, which may be more likely in the alternative design and arrangements.

3.7. Description of design fire scenarios

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 G. Procon list*) to distinguish the fire hazards differing between the designs and the ones with great potential to affect a fire development. Concurrently, fire hazards affecting failure modes were recognized for all spaces. As in the previous process, priority was to distinguish fire hazards differing between the base design and the reference design.

In this process, groups of spaces are formed which have similar characteristics and conditions for fire development. This is done to narrow down the number of fire scenarios and simplify the following quantitative analysis. Design fires will be developed for the 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 were 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, twelve groups of spaces were distinguished:

1. Cabins (cabins, rooms of suites and spa treatment rooms);
2. Corridors;
3. Stairways (staircases, lifts and shafts, WC localized in the same fire zone as a stairway);
4. Open deck spaces (all deck exterior areas on decks 12-16);
5. Galleys (galleys and pantries);
6. Lounges (small inside seating areas, such as Cinema, Card Room, Life Style Room, The Library, Thermal Suites, Leopard Lounge, Children's area, Cagney's Steakhouse and Star Bar);
7. Restaurants (large inside seating areas, such as Garden Café, La Cucina Italian Restaurant, Steak House and Spinnaker Lounge);
8. Store-rooms (store, hotel store, laundrette, linen store);
9. Technical spaces (Bridge, Comm. Centre, Radio room, Arcade);
10. Machinery spaces (Emergency Generator, Pool Management spaces, AC);
11. Funnel and Casing; and
12. Void spaces.

The spaces in 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. Considerations were also made to include potential effects of fire spread from other areas, which could affect the fire development. Furthermore, conservative assumptions were made regarding target locations, in order to select the most 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 analysis for each trial alternative design. However, due to instructions in the circular, examples of fire scenarios in the representative spaces are documented below. Hence, they only represent one scenario in the distribution of fire scenarios for each representative space and not design fire scenarios (i.e. worst-case scenarios).

3.7.1. Cabins

There is a large number of different sized cabins in the novel superstructure. This category includes small cabins and rooms of larger suites and similar spaces. All cabins along the sides of the ship have balconies which pose a special challenge since the fire can spread to the outside of the ship. As fire spreads more easily upwards, a worst case fire scenario could occur if a spreads from deck 11, which could lead to the following fire scenario:

> *Electric equipment or lighter in combination with carelessness ignites combustible disposal materials, blankets and duvet in bed and spreads to textiles and eventually furniture. Door to corridor is closed but balcony door is open, which leads to exterior propagation of fire through the balcony and to the exterior surfaces.*

Except the mentioned conditions, this scenario is possible if e.g. the sprinkler system fails to release and detection, first-aid, extinguishment by crew and a possible drencher system fails to release. Time of the day and if the cabin is occupied/anyone is present will affect the consequences and possibilities for detection, as well as the likelihood of fire. The people in the cabin could be disabled, affected by alcohol or deep asleep when the fire occurs which could affect the consequences.

3.7.2. Corridors

Corridors exist in many of the decks but mainly on deck 11 and 12 where they interconnect cabins. They should generally be empty from combustible materials but an extended cabin fire (or if a cabin door is kept open) could lead to propagation of fire to this space. A cleaning wagon could also work as fuel but that would also imply that personnel will be present for first-aid. A fire scenario involving a corridor is the following:

Arsonist sets combustible disposal material in a cleaning wagon on fire with flammable liquids and cleaning products. Fire spreads to include linen, towels and other materials on the wagon. Cleaning personnel is trapped in adjacent cabin with door closed. Fire is detected and fire alarm goes off which brings nearby personnel to the scenery. Smoke spreads to nearby stairways but sprinkler system and first-aid by personnel put out the fire.

This scenario depends on a number of conditions or failure modes. Failure of keeping doors to cabins closed, first-aid, sprinkler system, available personnel and time of the day will affect the probability and consequences of this fire scenario.

3.7.3. Stairways

There are three main stairways running vertically through the ship, in the aft, mid and forward. Many times these in connection with WC, as for example in the aft of deck 12. A fire in a space connected with the staircase could lead to smoke spread to the staircase and evacuating passengers. One fire scenario in the stairways could be the following:

Undisturbed arsonist sets combustible disposal material, plastic covers and flammable liquids on fire in WC. Temporary furniture and surface linings in the staircase ignite and fire is detected but first-aid fails. Alarm goes off as smoke spreads upwards in the staircase. Evacuating people are affected by toxic smoke.

If the door to the WC is jammed open this will affect the consequences of the fire scenario. The material in surface linings and function of detection and sprinkler system will also affect the fire scenario as well as the crew organization.

3.7.4. Open deck spaces

The deck and exterior surfaces are made of combustible material and this risk must be addressed. The worst consequences may occur if a fire starts on deck 12 and spread upwards through e.g. flames reaching the bottom of deck 13. An outdoor fire could also spread to parts inside of the ship through e.g. balconies. One of the fire scenarios representing the fire risk in the open deck is thereby:

Cigarette, barbeque or electrical equipment ignites combustible disposal material or pillows and spreads to include upholstered furniture/sun beds in a corner. The fire spreads to surfaces of bulkhead or composite structures and propagates to adjacent spaces.

For this to occur, possible measures for slow flame spread must fail as well as first-aid and possible extinguishing systems. The fire could be affected by an unfortunate wind and other weather conditions. This and the time of the day will affect the consequences and detection of fire but most likely also the occurrence of fire.

3.7.5. Galleys

Galleys and pantries are placed on several decks but mainly on deck 12 in the novel superstructure. The initial fires in galleys are similar to the ones in a traditionally built ship and not until after 60 minutes major differences could appear fire resistance. If the sprinkler system fails in such enclosure the following fire scenario could be necessary to consider:

Hot surface ignites paper, plastics and grease which makes the fire spread to surface linings and bags and boxes of try foods. Evacuation of crew is initiated and fire is left to fire-fighting crew. The fire becomes ventilation controlled but gets enough air to progress. Fire reaches fully the fully developed stage and eventually decays as *cutting extinguishers are used to put it out before it reaches the combustible FRP composite.*

The above fire scenario requires failure of first-aid and sprinkler system. However, detection and crew evacuation functions as planned and doors to the enclosure are closed, even if leakages keep the fire burning and smoke escaping. Function of thermal insulation and manual extinguishment controls the fire.

3.7.6. Lounges

The Library, Cinema are Life Style Room are examples of inside seating areas which all fall in this category, according to the section above. These are public areas with the same kind of combustible materials but where a major fire could be limited by the available ventilation. However, one of the fire scenarios in lobbies, in this case in the Card room, could be the following:

Electrical failure ignites dust, cables and paper materials in the middle of the night. Detection system fails and fire spreads to ignite surface linings, books and furniture. Smoke propagates through leakage in door. The fire is detected and fire-fighting crew arrives soon after lack of oxygen controls the fire, which can be extinguished.

For the above fire scenario to occur the sprinkler system needs to fail, as well as detection system. Windows and doors, however, need to last until the oxygen is consumed and fire-fighting routines need to be in place.

3.7.7. Restaurants

Fire scenarios in this type of space are similar to those in a traditional ship, with the main difference in fire spread to the outside of the ship. Since there is a big supply of oxygen a fire could develop for a long time:

Stage lights ignite electrical insulation material and cables, and fire spreads to cushions and boxes. Evacuation is initiated and eventually the fire includes surface linings, carpets, packing material and furniture. Fire continues and eventually breaks window even though fire-fighting crew makes attempts to extinguish fire. Smoke propagates through leakage in doors and through window. Exterior propagation to deck above and manual extinguishment is necessary by the windows and exterior surfaces to control vertical fire spread.

This fire scenario is possible if first-aid and sprinkler system fails. The success of evacuation will determine the consequences in human casualties and the failure of window and doors will determine fire and smoke propagation possibilities. The effectiveness of fire-fighting crew is crucial to extinguish the fire.

3.7.8. Store-rooms

There are several kinds of storage rooms all over the ship. Some of these are adjacent to exteriors and many of them contain cable and pipe penetrations. Weaknesses in maintenance or poorly insulated new penetrations could imply weaknesses in the divisions' ability to contain a fire. The following fire scenario could then occur:

Electrical failure in combination with carelessness causes plastics and cleaning products to start a smouldering fire. Detection fails and smoke mainly stays in the enclosure until door is opened and smoke pours out. Door closer functions but the ventilation gives the fire a rebirth at the same time as smoke is detected in the corridor. Fire alarm goes off and evacuation is initiated. Linings and stored equipment is involved in the fire and a weakness in the thermal insulation by new penetrations causes parts of FRP composite structure to burn and fire to spread to *an adjacent unoccupied cabin. Fire develops in the adjacent compartment but is controlled by a sprinkler system. Fire-fighting crew arrives and puts out the cabin fire and controls the storage room with a cutting extinguisher.*

If detection fails, a smouldering fire can go on for quite some time without being notices. A potential sprinkler system in the store-room also has to fail for the above fire scenario to occur. The functioning door closer contains the fire at the same time as intact thermal insulation is important for this reason. Effective fire-fighting depends on training and organization of the crew.

3.7.9. Technical spaces

The difference from a traditional ship is the possibility of a fire spread on the outside through broken windows or from the balcony underneath the bridge. This fire hazard is estimated as local or major.

A fire in a cabin below the bridge spreads through a balcony and to the exterior combustible sides of deck 11. Windows on bridge breaks soon after bridge is evacuated. Fire on bridge includes books, papers, plastics and electrical equipment. The whole fore section is evacuated and the ship is controlled through an emergency control station. Fire continues to spread vertically but cabin fire is controlled before 60 minutes has passed and vertical spread to further decks is controlled. Bridge and exterior fire is controlled after a massive fire-fighting operation.

The above fire scenario is possible if sprinkler system, fire-fighting and balcony door of the cabin below fails. Furthermore, the fire must be of such degree that the bridge windows fail and allows fire to propagate into the bridge and vertically on exterior surfaces. For a fire to progress inside the bridge both manual and automatic extinguishing systems must fail. Control of the ship requires a functioning emergency control station. In order to control the initiating cabin fire a well-functioning fire-fighting crew and intact thermal insulation is necessary. A functioning drencher system or low flame spread characteristics on exterior surfaces could help controlling a propagating exterior fire.

3.7.10. Machinery spaces

The spaces classified in this category contain pipes, motors and pumps, except cables and electrical equipment. A fire in such enclosure could continue for quite some time provided that there is enough oxygen but if ventilation of the fire is restricted the following scenario could be likely:

Overheating of bearings ignite dust and cable insulation material. Fire spreads to oil and electrical equipment. The space is unoccupied when the fire is initiated but fire is detected through detection system and sprinkler system activates, which controls the fire. Fire-fighting crew arrives and puts out the rest of the fire.

Except controlled ventilation, this requires that the detection system the sprinkler system are functioning. The thermal insulation on divisions, and particularly around penetrations, is also plays an important role. The design of how the AC spreads smoke and fire dampers are critical if adjacent spaces (if not outdoors) are to be kept free from toxic gases.

3.7.11. Funnel and casing

The funnel and casing will be made in lightweight material and require special attention. The funnel will not spread fire vertically but could release glowing particles to the adjacent combustible exterior surfaces. The casing could heat up and ignite nearby constructions. Another scenario is the following:

An explosion in the engine room causes flame spread through the casing, which heats up the surrounding constructions. Soot, grease and weaknesses in the thermal insulation causes FRP composite to ignite which leads to smoke leakage and eventually continued fire spread to an adjacent cabin on deck 11.

Except from the improbable event of an explosion in the engine room, maintenance in the casing must be insufficient and the insulation integrity severely damaged. Otherwise the fire must progress for over 60 minutes to cause fire spread to adjacent spaces.

3.7.12. Void spaces

Around cabins and several other areas there are void spaces with cables, pipes, electrical equipment and dust. An electric failure in a void space above a cabin on deck 11 could lead to the following fire scenario.

Fire in dust, cable covers and pipe insulation stays undetected until it spreads to the cabins below. The fire has then been going on for a while and affects several compartments. Manual fire extinguishment is possible before 60 minutes has passed.

For the above scenario to occur the detection system in the void space, or persons in the adjacent spaces, must fail to detect the fire. It also needs sufficient oxygen to sustain. Failure of the cabin sprinkler systems is necessary for the fire to get out of control but function of the thermal insulation to the deck above gives the fire-fighting crew 60 minutes to work on the fire.

After the delivery of the preliminary analysis report it was decided to remove the twelfth space group. It was considered more reasonable to account for fire scenarios in void spaces in the fire scenarios for the space which the void belongs to.

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 and argued for throughout the process; for transparency they are although also be reprinted in a summarized list (see paragraph *4.3.5. Summarized input data*). Amount and composition of fire load were described when using a design fires in the quantification but in general the differences in fire safety had to be quantified well beyond the traditional fire safety engineering (ASET-RSET) approach. 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 individually

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 individually, 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 Cone Calorimeter test data in Figure 2.12. 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 (15-20 kW/m^2 towards the floor is often referred to as a criteria for when flashover is determined). Fire spread may consequently be a problem but ignition of FRP composite surfaces from an ignition source is not.

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 BESST. 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 use of combustible materials

- To establish whether the introduced use of combustible material is restricted.

SOLAS II-2/5.1.3 requires that combustible materials are restricted. This is particularly considered an issue on exterior surfaces where the added combustible materials are uncovered and available for combustion. A comparison was therefore made where the exterior surfaces replaced by FRP composite were compared with amount of combustibles already existing on open deck. An open deck space on a cruise vessel is not a stripped painted steel deck. To accommodate the passengers' needs for amusement and relaxation they are often quite packed with facilities constructed in combustible materials, as illustrated in Figure 4.1. In many areas on open deck the surfaces replaced by FRP composite may therefore be considered quite limited in comparison with all the other combustible materials. However, in other areas on open deck the replacement of steel with FRP composite will provide almost the only available combustible materials. On outboard sides of the ship the replaced surfaces are of rather restricted size due to all the windows.

Figure 4.1. Example of open deck spaces with many combustibles.

As further described in *4.2.4. External fire* , an inventory was made to account for different categories of outdoor areas, partly with respect to amount of combustibles. The first category covers areas where with very few combustibles on the prescriptive ship but where using FRP composite on outboard surfaces will imply a large relative increase of combustible materials. The second category of spaces are areas where the amount of combustibles is limited and mainly represented by the FRP composite surfaces in the trial alternative designs, e.g. sundecks with metal-based sunbeds. The third category covers spaces where the amount of combustibles is large in general and the addition made by FRP composite surfaces is relatively small. These areas are typically spaces with outdoor seating areas, upholstered furniture, bar serving etc., as pictured in Figure 4.1. The final category represents outboard sides of the ship in the considered superstructure. The representation of spaces of the different categories on the ship as well as the amount of combustibles in the different kinds of areas are summarized in Table 4.1.

Table 4.1. The representation of different kinds of exterior areas and the increase of combustibles in these areas

Outboard space category and keywords	***Relative representation on the ship***	***FRP composite in relation to all combustibles***
1. Bare areas	27%	60%
2. Sparsely furnished areas	20%	40%
3. Areas with many combustibles	20%	5%
4. Outboard sides	33%	60%

Altogether the replacement of steel by FRP composite surfaces are assessed to increase the amount of combustible materials on exterior surfaces by 45% of what already exists on the prescriptive ship. This cannot be 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. See in particular *4.2.4. External fire* .

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 probability for a fire-fighting fatality is affected by the alternative design and arrangements.

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. Furthermore, the risks for fire-fighters could also be affected due to the risk of collapse after 60 minutes. It was therefore decided to look in to these issues 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] followed by the implications for the Norwegian Future.

4.1.3.1. Scope and method of study

The purpose of the study was to evaluate fire-fighting on the Norwegian Future from the following 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.

Make 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.

4.1.3.2. 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.

4.1.3.3. 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.

4.1.3.4. 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 requires 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.

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.

4.1.3.5. 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 4.2, 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.

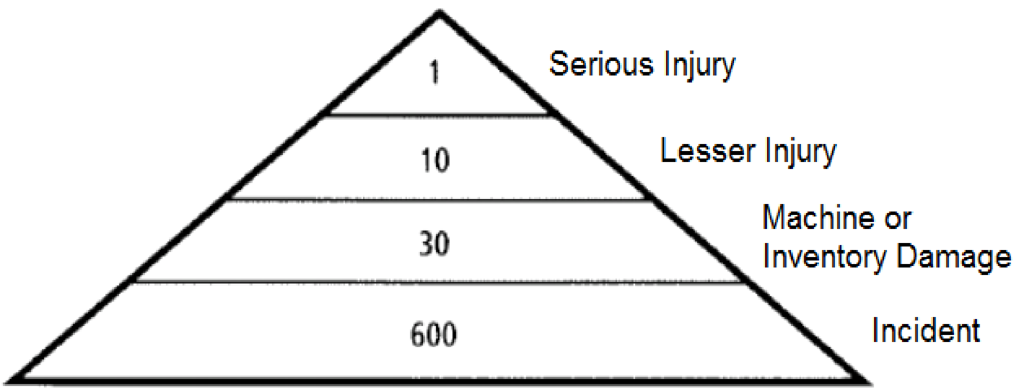


Figure 4.2. Ice-berg model example.

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.

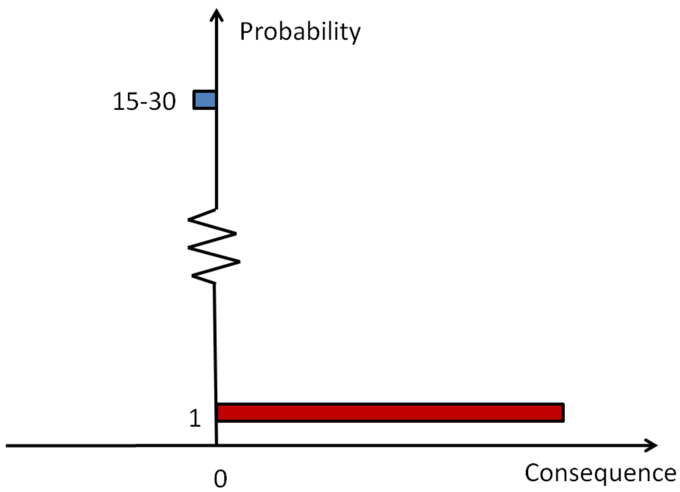


Figure 4.3. Illustration of how different scenarios may affect the RR; if the beneficial scenarios each reduce fire-fighters' absolute personal risk by an amount that corresponds to at least 1/30 - 1/15 of the personal risk increase caused by one detrimental scenario, the consequence is zero or negative, which indicates that the RR is at the most 1.

The different scenarios' consequences for the RR comparison are again illustrated in Figure 4.3. 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.

4.1.3.6. Implications for the Norwegian Future

The conclusions of the study on fire-fighting effectiveness and efficiency as well as personal risks for fire-fighters [18] shows that, with the recommended changes, it is possible to fight fires as safe and as efficient in the insulated FRP composite superstructure on the Norwegian Future as in a prescriptive design. This presupposes that the crew gets sufficient education and training in the new routines. However, the study has certain limitations which must be taken into account. Particularly the study 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 be valid.

4.1.4. Sufficient fire protection of joint

- To establish if and how risks associated with the joint should be managed (heat may be conducted to the steel-composite joint from a fire on deck below unless sufficient insulation is provided).

In the BESST-project the fire performance of a so called crutch joint developed by Kockums shipyard was analysed.

The main identified hazard associated with steel-composite joints is the possibility of conduction of fire induced heat in the steel structure to the actual adhesive joint. If the adhesive reaches a critical temperature the joint might fail. This hazard can easily be avoided if requirements of insulation of the steel deck is added. However, this is not a preferred solution since the insulation will add weight and the design of the ship will be more complex since the spaces below cannot be designed only according to prescriptive requirements.

The problem was addressed in two steps. First FEM-simulations were performed by CMT to evaluate the temperature rise in the steel joint in case of a fire in a compartment below the joint with worst case insulation setup. The details from these simulations are found in *Appendix J. FEM simulation of the joint in the fire test for BESST II.2* and the results indicate that after 120 minutes of fire according to the standard fire curve the steel temperature of U profile of the joint does not exceed 140°C. After 60 minutes the temperature is approximately 100-110°C. This indicates that the adhesive joint will not fail due to heat conduction in the steel before 60 minutes of fire exposure.

A fire resistance test was performed at SP Fire Technology to verify the load carrying ability during fire of this joint design [19]. The test failed after 49 minutes due to buckling of the composite bulkhead. At this point the peak steel temperature of the U profile of the joint was 91°C. This indicates that the result of the simulations performed by CMT are reasonable and that the joint design is not very sensitive to heat conduction into the joint. However, the test failed after 49 minutes and does not validate load carrying capability for 60 minutes of fire exposure. To validate this a design update (e.g. added insulation or stiffeners) must be done and a new test performed.

When the fire performance of a steel-composite joint is validated the joint is not considered a weak link in the fire protection of the base design. Hereafter in this this report, a validated joint design is assumed.

4.1.5. Sufficient fire protection of FRD60 floor

- To establish if and how risks associated with fires on internal decks should be managed (fire could spread downwards unless decks are insulated on the upper side).

There are no standardized IMO fire resistance tests for floor constructions (exposed too fire from above) since insulation is always fitted under the deck if e.g. A-60 is required. The same insulating capacity is hard to achieve in a floor construction since the floor needs to resist point loads. However, taking into account that temperatures are normally lower at the floor in a real worst-case fire, a floor construction with sufficient fire protection can be achieved.

4.1.5.1. Floor construction exposed to full scale fire tests

Full scale fire tests [16] were performed in a passenger cabin at SP Technical Research Institute of Sweden. Two cabins and a corridor were constructed within a section of thermally insulated FRP composite decks and bulkheads (as the FRP composite intended in the base design). The tests were carried out in order to evaluate the behaviour of a FRP composite structure under realistic fire conditions, also with all active fire safety systems out of order. The construction and cabins were hence made of realistic materials, furnishings and fittings. Based on calculations accounting for the lower temperatures at floor level, a floor construction was designed that was believed to achieve sufficient fire protection.

A floating floor system was installed on the FRP composite deck consisting of a single layer of 1200 mm by 600 mm Rockwool® floor plates, having a nominal thickness of 20 mm. These were covered by 2000 mm by 1000 mm aluminium plates with a nominal thickness of 2 mm. The aluminium plates were installed edge-to-edge and glued to 90 mm wide steel strips, having a nominal thickness of 1.5 mm, which were centred underneath the gap. The insulation material had a nominal density of 150 kg/m^3, a heat transfer coefficient (λ) of 0.037 W/mK and thermal resistance (R) of 0.50 m^{2}K/W.

The floating floor in the cabins and the corridor was covered by a homogenous floor carpet, fulfilling SOLAS requirements. It was made from Polyvinylchloride (PVC), reinforced by Polyurethane (PU). The covering had an overall thickness of 2.0 mm and an area weight of 3.1 kg/m^2. The carpet was denoted “Granit 2.0 mm”, the colour was light grey and it was provided by Tarkett AB.

4.1.5.2. The fire exposure

One fire scenario was performed with an uncontrolled fire (the water mist nozzles inside the cabin as well as the nozzles inside the corridor were disconnected). In this scenario the door was also left open but the window to the cabin was closed.

The fire was ignited using a standardized wood crib, wood crib No. 7 according to BS 5852:Part 2 [20] and its ignition instructions. The crib was placed in direct contact with a bed mattress in one of the cabins and was ignited by a small torch. To enhance the fire spread, the bedding material of the head end of the bed was removed and the fabric of the foam mattress was exposed to the ignition source.

The conditions for the uncontrolled and ventilated fire allowed it to develop to a very intense flashover. Unfortunately, the measurement system partially malfunctioned at 09:33 and was not possible to re-start until 56:30. Therefore, some measurement data was lost. The system crash problem affected almost all temperature measurements, however, the heat release rate measurements were not affected and due to the time delay associated with the move of the heat wave, the peak heat temperatures could be determined when the measurement system was re-started.

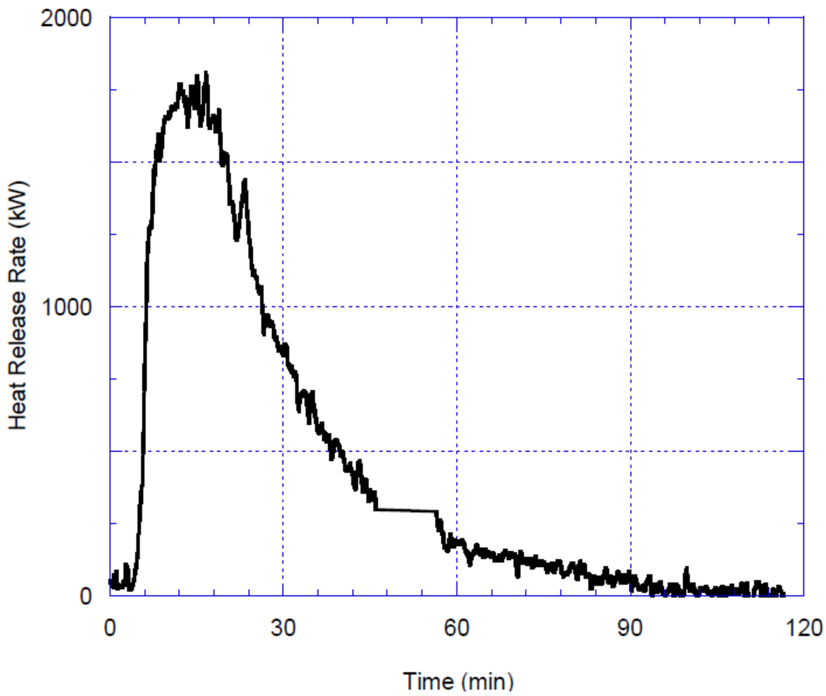


Figure 4.4. Heat release rate in the uncontrolled fire scenario.

The total heat release exceeded 1.5 MW for a period of over twelve minutes, as shown in Figure 4.4. In reality, the fire size was larger, but smoke escaped the hood of the calorimeter and the fire size was therefore underestimated. Calculations although indicate that the losses should have been limited.

A Plate Thermometer (C39) positioned at the floor of the cabin with the fire gave readings as illustrated in Figure 4.5. The temperature peaked at 813°C just prior to the malfunction of the measurement system. This corresponds to a heat radiation flux of approximately 80 kW/m^2. This is a high reading, considering that a criterion for fully developed fire is a radiation towards the floor of 15-20 kW/m^2 [21]. After the re-start of the measurement system, none of these measurement channels showed any reliable readings due to the deformation and long exposure to severe heat.

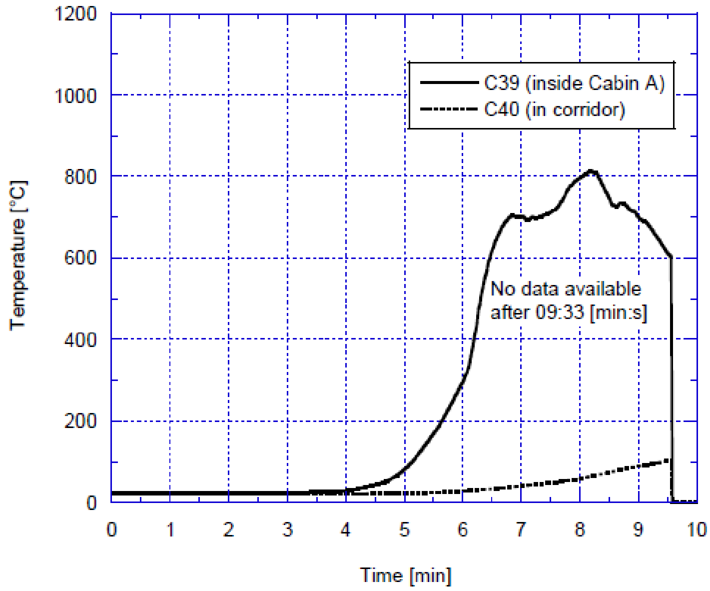


Figure 4.5. The temperatures at the Plate Thermometers at the floor in the uncontrolled fire.

Temperatures measured at inside the structure of the top deck reached to levels associated with standard furnace tests. However, it was shown that the temperature exposure varied a lot with the distance from the fire.

4.1.5.3. Damage

The fire involved all combustible interior materials and floor covering of the cabin where the fire was started as well as in the corridor. Afterwards it was observed that all cabin panels were more or less deformed and two ceiling panels had fallen to the floor. The aluminium floor plates at the floor of the cabin had melted over a large area and were completely consumed in the area between the two beds in the cabin. The overall size of the damage was approximately 2 m^2. Additionally, the aluminium floor plates had melted in an area of approximately 0.2 m^2 in front and under the position of a table top and in two smaller spots close to the doorway opening. The underlying fire insulation was damaged in a corresponding area.

Figure 4.6. Damages to the FRP composite deck as a result of the uncontrolled fire, after the floor construction had been removed.

After the removal of the aluminium floor plates and the underlying insulation, it could be concluded that the composite deck was blackened and burnt in a rectangular pattern that was approximately 2700 mm in length and 2100 mm wide (5.7 m^2). This is show in Figure 4.6. The core was damaged in a pattern that was 1500 mm in length and 1300 mm in width (2 m^2).

4.1.5.4. Conclusions and recommendations for sufficient fire protection

The fire protection given by the floating floor in the construction above was insufficient, which led to damage to the composite deck below. The aluminium plates that were lain on top of the 20 mm Rockwool® layer of fire insulation had partly melted, which means that the temperatures of the floor reached at least 660°C. Together with the radiation levels, which were shown to be in the order of 80 kW/m^2 already after less than four minutes of fully developed fire, this shows that the fire exposure corresponded to a severe fire scenario. Furthermore, the temperatures measured inside the structure of the top deck reached to levels associated with standard furnace tests. Altogether the above argues for that for a the construction was exposed to a sufficient trial.

Based on the fire tests described above it could be concluded that, in order to achieve sufficient fire protection, the thermal resistance of the floor construction must be improved. Based on the fire tests, calculations were carried out by SP Fire Technology (unpublished) which indicate that an increase of the thickness of the insulation material from 20 mm to 30 mm could give sufficient fire protection, if desiring a similar floor construction to the one used in the tests. In a real case, this would have to be verified by trial, which has although not been carried out within BESST. For that reason, henceforth this was assumed managed and applied to the base design in this risk assessment.

4.2. Quantification of fire hazards affecting the risk assessment

The following quantification needs were identified necessary to include in the overall fire scenarios for the whole ship:

4.2.1. More fuel internally after 60 minutes

- To establish how the consequences are increased due to the increased amount of fuel which is made available to an uncontrolled fire after 60 minutes.

As mentioned above, 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 and their neighbouring spaces long ago. At this stage people should be on the embarkation deck at least four decks below the superstructure. 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.

In the large scale tests reviewed above [16], in which two cabins and a corridor were enclosed in a FRP composite superstructure and a standard cabin was later 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 an high temperatures were maintained for over 90 minutes. Only minor parts of the floor construction were involved in the fire and this was due to insignificant fire protection, which would be improved on the Norwegian Future.

Nevertheless there will eventually be more fuel available to the already uncontrolled fire. This may not have direct consequences for people who are already long gone. However, the fact that a fire in a FRP composite superstructure may be even harder to get under control, due to the potential refuel of the fire, could have an effect on a decision to abandon the ship. Hence, knowing that a fire will not likely get under control within 60 minutes may cause an earlier decision to abandon a ship with a FRP composite superstructure. In a prescriptive ship there may instead be a possibility to await further fire-fighting efforts or to avoid abandoning ship in bad weather. Hence, the consequences of the increased amount of fuel made available to an uncontrolled fire after 60 minutes may have an impact for the probability for evacuation. It is although assessed that the effect on such a decision due to the increased amount of fuel would be very limited if it was not for the associated risk for collapse. The joint effect on a decision to abandon ship is hence further evaluated in paragraph *4.2.5. Internal collapse*.

4.2.2. Flashover

- To establish how the probability for flashover is affected by the alternative design and arrangements

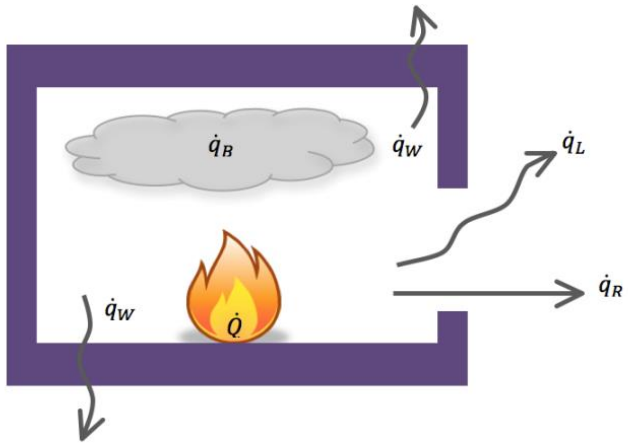
An insulated construction can trap the heat from a fire and prevent the fire from spreading. In general many spaces in the base design have more thermal insulation than the prescriptive design. The FRD60 construction has insulation on both sides of the FRP composite, which is also thermally insulated in itself. In the cases where non-insulated steel structures are replaced by FRD60 constructions the increase of thermal insulation is significant. This will lead to a higher probability of containing a fire in the space within 60 minutes. However, there was also an uncertain fear that this may also cause higher temperatures, a faster fire growth and a shorter time to flashover in the fire compartment. It was therefore decided to establish whether this effect needs to be accounted for and if it may diminish the positive effects from improved insulation, i.e. will the fire actually be better contained if the fire growth is significantly accelerated, what is the total outcome? This was done as part of a thesis [22] on the initiative of SP Technical Research Institute of Sweden by a student concluding her fire safety engineering degree at Lund University. Below follows a summary of this study followed by the implications for the Norwegian Future.

4.2.2.1. Scope and theoretical background of study

The purpose of the study was to create an understanding of how increased thermal insulation can affect the fire development in a compartment. It was also of interest to investigate the suitability of the use of hand calculation methods and simulations when carrying out the comparison between the fire development in an insulated compartment to a non-insulated compartment. The work was based on four research questions:

- Does increased thermal insulation lead to a significantly higher gas temperature in a fire compartment?
- Will increased thermal insulation lead to a significantly larger and quicker heat release rate of a fire?
- Is it plausible that the condition flashover is reached earlier in an insulated compartment than in a non-insulated compartment?
- Do hand calculations and simulations give similar results to full scale experiments when comparing the fire behaviour in an insulated compartment to the fire behaviour in a non-insulated compartment?

The fire development in a compartment consists of four stages; incipient, growth, fully developed and decay. The phase between fire growth and fully developed fire is referred to as flashover.



$\dot{Q}$ = Energy release rate due to combustion

$\dot{q}_W$ = Heat lost to compartment boundaries

$\dot{q}_L$ = Heat lost due to replacement of hot gases by cold

$\dot{q}_R$ = Heat lost by radiation through openings

$\dot{q}_B$ = Heat stored in the gas volume

Figure 4.7. Energy balance in a fire compartment.

How the fire develops depends on a number of factors. Most important for this study has been the law of conservation of energy that can be applied on a fire compartment. Energy is released by the fire and later transferred away from the compartment in a number of different ways. The temperature in a fire compartment depends on the balance between the heat produced by the fire and the heat losses to its surroundings. The energy balance in a fire compartment is described in Figure 4.7.

4.2.2.2. Worst-case test arrangement

A test arrangement was designed with the aim of identifying potential differences in the development of a fire depending on thermal insulation. In order to find all potential differences a worst-case scenario was sought, where the differences were as large as possible.

The flames themselves are not affected by the thermal insulation behind the surrounding boundaries. The main heat transfer from the fire will take place between the smoke layer (i.e. the upper part of the air volume with a significantly higher temperature and content of fire products than the lower of the horizontally divided volumes) and the ceiling and walls. The formation of a smoke layer is therefore necessary for the above impact on the HRR to occur.

If the fire room is small, with relatively large openings at a relatively short distance from the ceiling, then the impact on the fire development will be insignificant since most of the heat will leave with the evacuating smoke. The impact will also be small if the fire room is large. In a large space it will take much longer time for a hot smoke layer to form since the fire first needs to heat the large surfaces (mainly the ceiling). For well-insulated boundaries to have an impact on fire development in a large space, the fire needs to be considerable. It will in other words take longer for effects on the fire development to occur. It is also more reasonable to believe that heat will escape with smoke ventilated through some opening in a large space, which may or may not have been caused by the significant fire.

Hence, the largest impact on fire development will potentially occur in a small space with relatively small openings (no openings will extinguish the fire due to lack of oxygen); keeping as much as possible of the hot smoke in the fire compartment but letting enough air in for the fire to develop as much as possible. The worst static size of the opening in relation to the space and the fire size for the whole fire development was investigated in a study of its own prior to this project and summarized in an unpublished internship report by Stéphanie Görsün. In a real case scenario this could for example be a cabin with a balcony door left partially open.

4.2.2.3. Full scale experiments and simulations

The evaluation was partly made through experiments, where full scale experiments were carried out at SP Technical Research Institute of Sweden, in Borås. Furthermore, pre- and post-experiment hand calculations (using the MQH, Magnusson and Thelandersson and EUROCODE methods [23]) and simulations using Fire Dynamics Simulator [24] (computational fluid dynamics tool for fire simulations) were carried out. To represent the worst-case scenario above, a standard 20 feet (6.1 m) steel container was used in experiments and calculations. The container which provided the fire room in the tests was either not insulated at all or insulated with mineral wool on the outside, as shown in Figure 4.8. In the experiments the insulation was provided by Rockwool and the thickness of the FlexiBatts® was about 0.1 m. This thickness was not based on the insulation capacity of a FRD60 construction. It was rather estimated to give a sufficiently large difference in thermal inertia between the cases to represent a worst-case effect on the fire development.

Figure 4.8. The insulated steel container, ready to be used in the experiments.

Two types of fire sources were used in order to represent distinctly different types of fires:

1. combustible organic material, in the form of a wood crib; and
2. a pool fire, in the form of a tray filled with heptane.

The heptane pool fire can be said to represent an oil or chemical spill fire in a machinery or technical space and the wood crib fire a represents organic wood and plastic materials in an ordinary room.

Parameters measured during the tests included the gas temperatures in the container and the heat release rate from the fires. The test arrangements are illustrated in Figure 4.9.

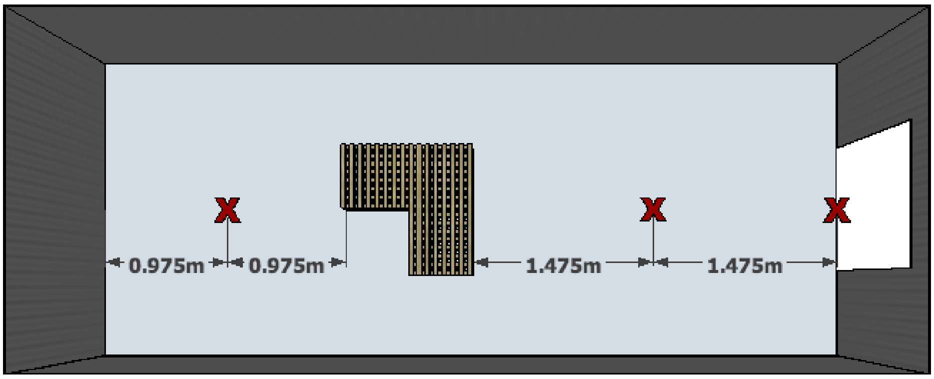


Figure 4.9. Arrangement of the fire source (in this case a wood crib) and the thermo couple trees for measuring the gas temperature.

The same arrangements were used in experiments, FDS simulations and hand calculations, as far as allowed by the models.

4.2.2.4. Results

In the experiments the fire development was affected by the increased thermal insulation, but the magnitude depended on the type of fire source. In the case with the wood crib, the heat release rate curve has the same shape both for the insulated and non-insulated compartment, as shown in Figure 4.10. There was although a "delay" in the fire growth in the non-insulated compartment. This delay in the early fire development more likely depends on stochastic variation of a fire and uncertainties associated with how the test was set up than on the insulation. Deducting the delay the fire growth was only insignificantly faster in the insulated case. The differences were hence considered to fall within the uncertainties of the test and did not show on any significant difference in fire development depending on the thermal insulation of the compartment.

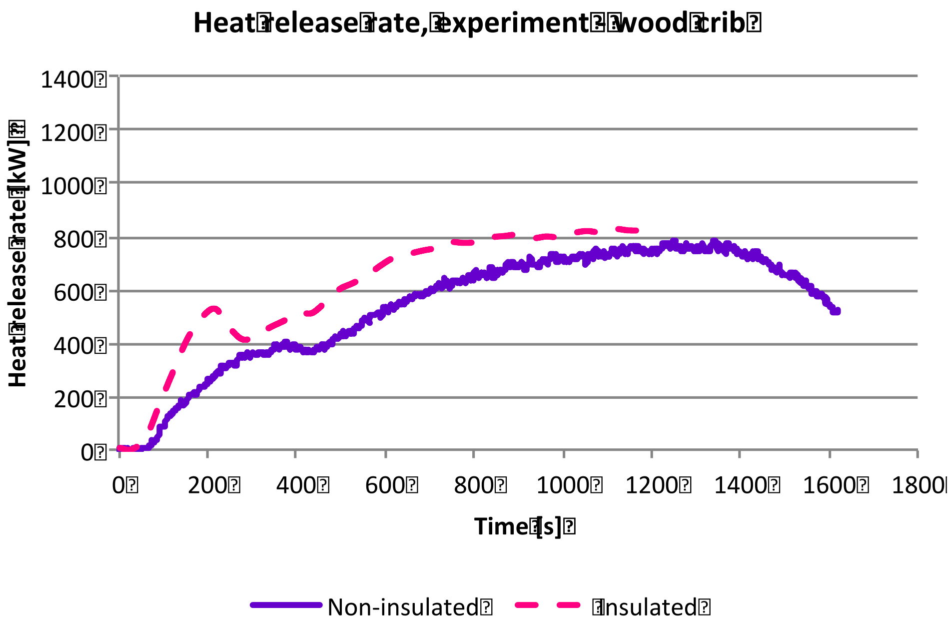


Figure 4.10. The heat release rate recorded in the wood crib fire experiments.

For the heptane fires, however, the effect of the insulation was more noticeable, as seen in Figure 4.11. Fire growth in the insulated container was more rapid and as the heat release rate increased, flashover was also reached in this compartment after about 400 s (in the non-insulated compartment flashover was never reached).

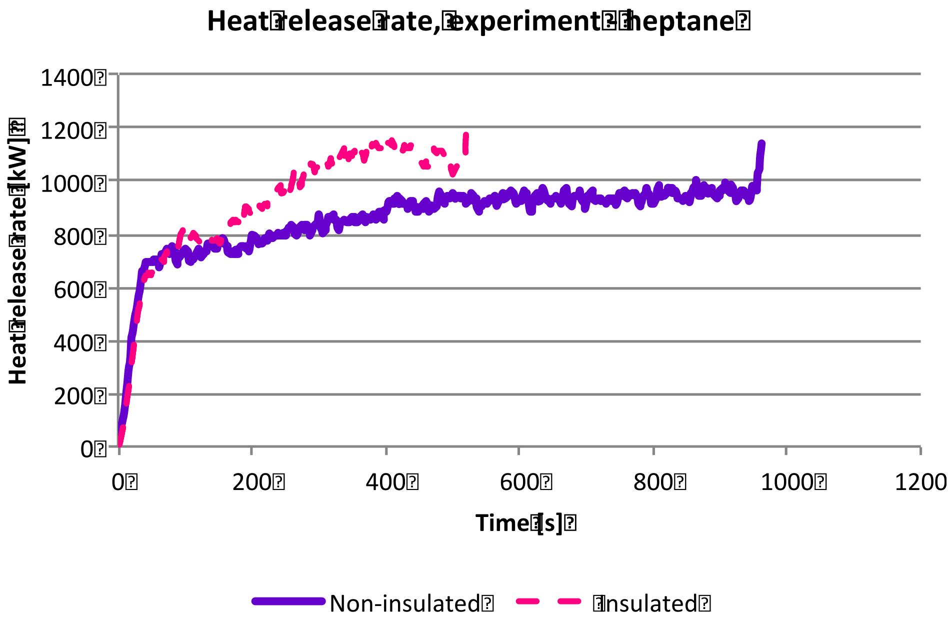


Figure 4.11. The heat release rate recorded in the heptane pool fire experiments (the peak at the end of each curve is a result of extinguishment).

The faster progress in the case with the pool fire is due to the fact that heptane easily evaporates into flammable gases when heated, while wood must be thermally broken down before flammable gases are generated. Increased combustion resulted in higher temperatures, further increasing combustion, resulting in gas temperatures in the insulated container several hundred degrees higher than in the non-insulated container.

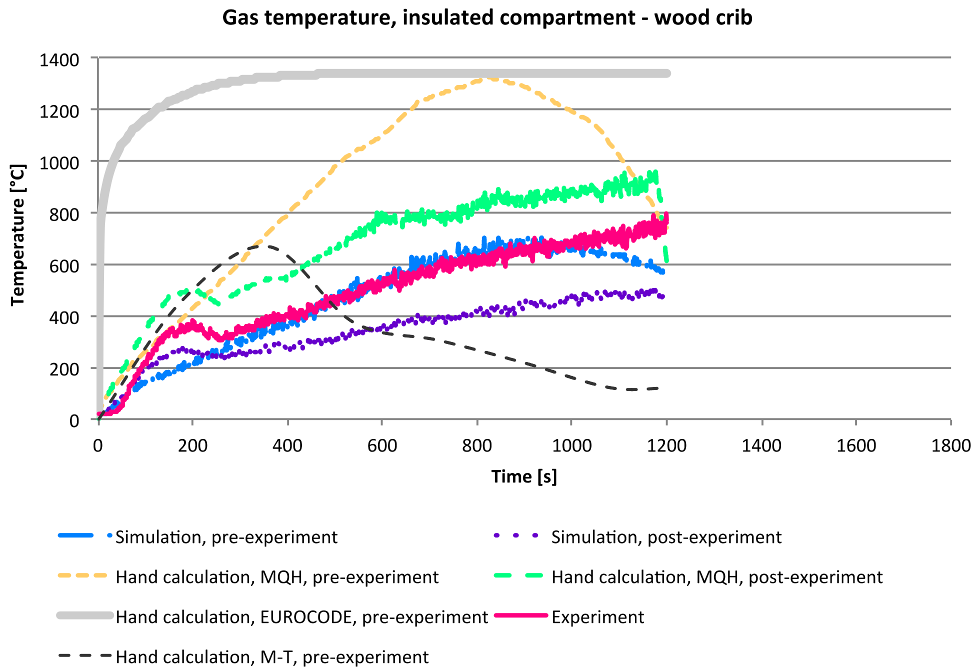


Figure 4.12. The gas temperature calculated by different common methods as well as recorded for the wood crib fire in the insulated compartment.

Calculations and computer simulations of the fire developments were also performed, both before and after the tests, as illustrated in Figure 4.12. However, both manual calculations and computer simulations are very sensitive to the quality of the input data, to the extent that the results generally failed to agree with those from the experiments. Many of the available models require a heat release rate curve as an input parameter, but even with the correct curve many models failed to deliver satisfactory results. For many parameters manual calculation based on the MQH method gave equally good results as FDS simulations (which are considerably more time consuming) when the values for heat release rate and material properties were uncertain. In purely general terms, the modelled results showed themselves to be incapable of representing complex fire spread and fire growth behaviours of the kinds encountered in this experiment.

4.2.2.5. Effect on safety on the Norwegian Future

When in the above study [22] purposely creating the worst-case scenario to promote insulation of the construction to affect the fire development some effects appeared which may be necessary to consider. The worst-case scenario was arranged in order to determine if there were any effects at all to consider. However, as was discussed above, these effects are only likely under certain conditions. It is only if the space is rather small with a relatively small opening not too far up towards the ceiling and if the fire is relatively large. Furthermore, as shown in the experiments, the effect is only likely to appear if the pyrolysis of the fuel is easily affected by the surrounding heat.

There are many spaces on the Norwegian Future which comply with the above descriptions, even if the relevant fuel may not be as common. However, looking at the actual spaces where non-insulated steel has been replaced by FRD60 that list decreases drastically. Spaces with B-class divisions in the prescriptive design namely also have B-class divisions in the base design and spaces where FRD60 replace A60 divisions will not give any significant effect. Cabins for example, come in modules with B-class walls and inner ceilings. At the most two steel divisions could be said to be replaced by FRD60 and this is not believed enough to give the effect that was seen in the experiments. Furthermore, in many cases these divisions are already A60 divisions since they are found in main vertical zones on the Norwegian Future. The spaces which could although fit better into the requirements are the spaces which in the report are group under Machinery spaces, i.e. emergency generator spaces, AC spaces, technical spaces, chemical storages etc. It was assessed that a quarter of these spaces may contain fluid liquids sufficient to fuel a pool fire with effects as seen in the experiments. Some of the spaces are although already divided by A60 divisions which will diminish any differences in fire development. Furthermore, some spaces are too large to give any likely effects and these will only show if a door is left open. Some of these conditions are evaluated below and summarized and considered further in *4.3.2.10. Machinery space fire scenarios*.

4.2.3. Containment of fire

- To establish how the probability for containing a fire in the alternative design and arrangements is affected.

Containment of fire is, in the case of FRD60 structures, all about achieving fire resistance. After 60 minutes it is possible for a still on-going large fire to reach the combustible structure, which can lead to collapse and failure of containment. For an A-60 (steel) division, containment will fail after 60 minutes due to excessive heat transfer through the construction. However, in many places the FRD60 construction will replace non-insulated steel structures which will spread a fire soon after it establishes.

Based on the general arrangement (*Appendix B. General arrangement for the Norwegian Future*) and the integrity requirements in SOLAS it is possible to account for all the non-insulated (A-0) divisions in the prescriptive design which were replaced by FRD60 divisions in the base design. For the improved containment by FRD60 divisions to make a difference in the horizontal direction, all surrounding bulkheads were considered necessary to be of FRD60 and to replace non-insulated steel divisions (A-0). In the vertical upwards direction the FRD60 deck was considered necessary to replace an A-0 deck. An inventory was made for the areas of improved containment in the vertical (V) and horizontal (H) directions for each of the 11 groups of spaces referred to in section *3.7. Description of design fire scenarios* individually:

1. Cabins
   H: Typically subdivided horizontally by B-class divisions => 0 %
   V: 75% are under another space and about 90% of these have A-0 decks above => 67,5 %
2. Corridors
   H: As for cabins
   V: As for cabins
3. Stairways
   H: Typically subdivided horizontally by A-60 divisions => 0 %
   V: -
4. Open deck spaces
   H: -
   V: -
5. Galleys
   H: Typically subdivided horizontally by A-60 divisions => 0 %
   V: Typically subdivided vertically by A-60 divisions => 0 %
6. Lounges
   H: Typically at least partly subdivided horizontally by B-class divisions => 0 %
   V: A-0 in the deck division above is found in very few locations => 4%
7. Restaurants
   H: Typically subdivided horizontally by A-60 divisions => 0 %
   V: A-0 in the deck division above is only found in a few locations => 9%
8. Store-rooms
   H: Typically subdivided horizontally by A-0 divisions => 95 %
   V: In most cases subdivided vertically by A-60 divisions => 10 %
9. Technical spaces
   H: Typically subdivided horizontally by A-60 divisions => 0 %
   V: In most cases subdivided vertically by A-60 divisions => 20 %
10. Machinery spaces
    H: Typically subdivided horizontally by A-0 divisions => 95 %
    V: Typically subdivided vertically by A-0 divisions but only 50 % are under another space => 50 %
11. Funnel and Casing
    H: Typically subdivided horizontally by A-60 divisions => 0 %
    V: -
12. Void spaces
    H: Included in the considerations above, as noted in paragraph *3.7.12. Void spaces*.
    V: Included in the considerations above, as noted in paragraph *3.7.12. Void spaces*.

The benefits of better containment will imply a reduced probability for fire spread in the horizontal and vertical directions respectively, which may also affect the potential getting the fire under control. It may although be argued that 60 minutes of thermal fire protection is not prescribed since it has not been considered necessary in divisions of low risk spaces. Hence, one would not be able to account for a significant risk reduction as a result of improved fire protection in this way. However, this is considered in the event tree by accounting for the reduced probability of a fire starting and developing in some spaces and thus the probability to reach a fire scenario where the improved containment is useful.

From the above inventory it can be concluded that containment is improved in one of three different ways in the different spaces on the ship. In in the groups denominated Cabins, Corridors, Lounges, Restaurants and Technical spaces the horizontal divisions are not improved whilst the vertical division in some cases is made FRD60 instead of A-0. These spaces generally also have an inner ceiling which subdivides the A-class or fire resisting division from the fire in the beginning of a fire development. This may hence somewhat decrease the potential benefit associated with replacing the steel division by insulated FRP composite. In all, fire-fighting within 60 minutes was assessed to have a success rate which is improved from 32% to 55% in the locations with improved vertical possibilities for containment of fire. In the group denominated Store-rooms the horizontal divisions are generally made A-0 whilst this is only the case in a few locations in the vertical direction. In the 95% of the locations with improved possibilities for containment of fire in the horizontal direction the probability of successful fire-fighting within 60 minutes was assessed to be increased from 48% to 75%. In the group denominated Machinery spaces the horizontal divisions are generally made A-0 and this is the case also in the vertical direction. However, only about half of the spaces have a space above it. In the 95% of the locations with improved possibilities for containment of fire in the horizontal direction the probability of successful fire-fighting within 60 minutes was on average assessed to be increased from 32% to 75%.

The above assessments were based on the layout of divisions and that A-0, A-60, B-class and FRD60 divisions give different protection against fire spread. In spaces with inner (B-class) ceilings the upper horizontal structural division was assumed to account for a third of the protection, the inner ceiling for a third and the vertical division for a third of the protection. In spaces without inner ceiling the upper horizontal division was assumed to be 75% more important for the protection against fire spread than the vertical divisions. In this assessment the A-0, A-60, B-class and FRD60 divisions were assumed to give protection against fire spread in relation to their fire integrity requirements (A-0 was although assumed to give 10 minutes of fire integrity, B-class was assumed to give 30 minutes of fire integrity).

4.2.4. External fire development

- To establish how the probability of involving exterior vertical surfaces in a fire is affected due to their combustibility.
- To establish how the probability of involving combustible surfaces on open deck in a fire is affected by the added FRP composite structures.

The exteriors of the ship contain a lot of combustible materials and the base design particularly have combustible exterior FRP composite surfaces since these are not possible to protect with thermal insulation (due to weather conditions). When identifying quantification needs it was decided to evaluate how the probability for fire development was affected from the having FRP composite as exterior surface material. Two fire scenarios were distinguished representative to evaluate the potential for fire development due to the existence of FRP composite surfaces: (1) Outboard fire development (e.g. cabin fire leads to fire development on vertical combustible external surfaces), and (2) Fire development on open deck (how much more likely is fire development due to the larger areas of combustible external surfaces). In both cases the fire development for which a probability is sought is a self-fuelled fire which is large and long enough to compromise structural integrity of adjacent structures. In the prescriptive design it is mainly aluminium balcony structures and in the trial alternative designs is balcony structures as well as the FRP composite hull structures. It should be noted that an on-going fire is assumed from the previous fire scenario, e.g. involving combustibles on open deck or in a cabin fire spreading to vertical FRP composite surfaces. This is due to that FRP composite is not considered to be a first fuel since it is not easily ignited, as established above. These two fire scenarios are evaluated subsequently.

4.2.4.1. Probability of outboard fire development

The probability of fire development on outboard sides of the ship is assessed below, with starting point in fire development on a prescriptive ship and then with focus on the differences with the base design. Tests carried out on fire growth on FRP composite surfaces gives support in quantifying this probability and suggests ways to manage such a fire.

Fire development on a prescriptive ship

On a prescriptive ship there are not much combustible materials above balconies and windows in the considered superstructure. As seen in Figure 4.13, the sides of the ship mainly consist of glass and steel and may therefore not be considered susceptible to flame spread.

Figure 4.13. Pictures of the sides of the reference ship with the bottom of deck 11 marked.

However, the fire on Star Princess [25] indeed showed that the probability of outboard fire spread exists also on prescriptive ships. The damage on the ships port side are illustrated in Figure 4.14. The presence of combustible materials on balconies on the outside of the hull is a potential fire hazard which can fuel a fire sufficiently to produce enough heat to break the glass door and spread to the adjacent cabin. This is how the fire developed on the Star Princess [25]. Since then new requirements have been adopted which restrict the amount of combustible materials on the balconies unless a sprinkler is provided specifically for the balcony. The combustible materials on the balconies of the reference ship, illustrated in Figure 4.13, are supposed to be rather restricted as the ship lacks balcony sprinkler.

Figure 4.14. Extent of damage on port side of the Star Princess after outboard fire spread [25].

The initial fire may not be initiated on the balcony but in the cabin and could spread to the balcony and expose the surfaces above the balcony to heat. This could spread the fire to a balcony above or break the windows on the deck above and cause fire spread that way.

Fire growth on FRP composite surfaces

The potential for fire development should be larger in the base design due to the added FRP composite surfaces on the sides of the ship. Large scale tests have shown that an unprotected FRP composite panel is susceptible to quick flame spread along its surface when ignited and exposed to flames from a cabin window [16] or larger opening, e.g. a balcony door [26, 27]. In fact, when exposed to a fire representing a fully developed cabin fire with open balcony door, the fire growth rate on a vertical FRP composite surface was faster than that denominated Ultrafast in Fire Safety Engineering after being exposed to a large fire for some minutes, as illustrated in Figure 4.15.

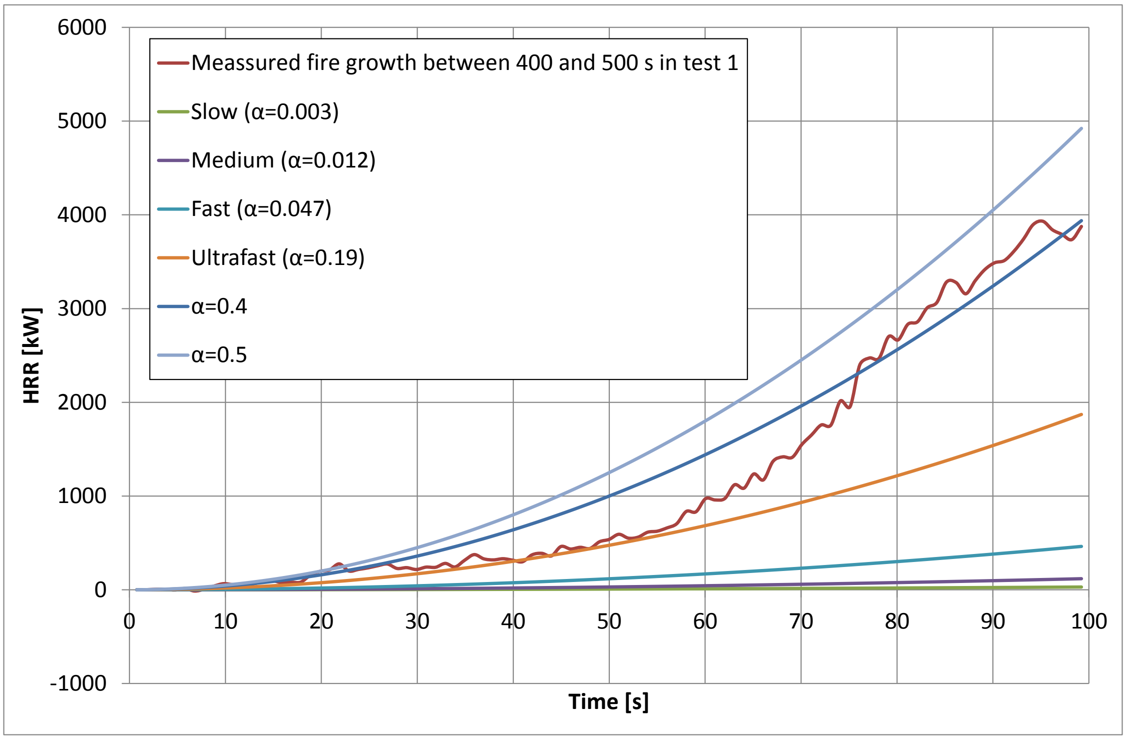


Figure 4.15. Heat release rate from fire growth on a vertical unprotected FRP composite surface when exposed to a 1.7 MW Heptane pool fire (excluded) 400-500 seconds after ignition [26].

Performed tests also showed that a drencher system is very effective for preventing fire development on FRP composite surfaces as well as for extinguishing an already established fire on these surfaces [16, 26]. Furthermore, a surface treated with LEO managed to prevent fire spread and additional heat release from the FRP composite panel the first 10 minutes. After the end of the test a total increase in heat release of 10% was produced by the LEO treated FRP composite panels [26]. In a cruise ship balcony set up the tests also showed that a balcony sprinkler prevented a fully developed cabin fire from spreading to FRP composite surfaces on the balcony and on outboard sides of the ship [27].

Effects on fire growth for the particular design case

The steel areas that will be replaced by FRP composite will although not be anywhere near the 6.5 m of height as the vertical panel in the considered test. The (white) steel areas on the outboard sides of the ship superstructure are namely quite limited, as can be seen above the balconies on deck 11 and deck 14 in Figure 4.13. Above the balconies on deck 14 there is only a rail and above the balconies on deck 11 there is only a wide strip of steel before deck 12, which is mainly covered by glass on the sides. Thereafter follows an open deck area on deck 13 before the deck house continues in the vertical direction. This is representative also for the rest of the ship, except in the aft where there are some slightly larger areas of uninterrupted steel by the balconies, which can be seen in Figure 4.16. In all the FRP composite areas above balconies and windows on the outboard sides of the base design were appreciated to have a maximum height of about 1 m. The significantly smaller areas of FRP composite in the real case application also reduces the potential heat released from the FRP composite in comparison with the performed experiments.

Figure 4.16. The reference ship from the aft (note the white area on the aft/starboard side corner of deck 11).

The FRP composite areas of limited height but significant width will nevertheless affect the potential for fire development on outboard surfaces. When trying to appreciate how much the added combustible exterior vertical surfaces will affect the potential for fire growth it is useful to refer to the tests carried out on fire spread from a cabin window and balcony opening. Representative fire exposures when a fully developed cabin fire spreads through a window and a balcony opening are illustrated in Figure 4.17. No addition is given from combustible surfaces in these cases.

Figure 4.17. Representative fire exposure to outboard surfaces when a cabin fire spreads through a window [16] or a balcony opening [26] (exterior surfaces are non-combustible).

It was shown in the tests that fire spread is fast in the vertical direction and that lateral fire spread if rather slow (in idealized conditions). Furthermore, looking at Figure 4.17 one can argue that the addition of 1 m of combustible material above the opening will not make such a big difference. The fire exposure to a window, balcony or other structure further up the ship side will be significant regardless of the addition of 0.5-1 m of FRP composite. However, it is necessary to recognize less idealized conditions, particularly the fact that it is usually windy at sea. When there is a fire on the outboard side of a ship, fire development may be either assisted or hindered by the weather. 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 (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 effect on fire spread from the wind makes it clear that the combustible surfaces must be accounted for also in the lateral direction. A fire scenario where large areas of FRP composite could be involved is then not hard to imagine. For example if a cabin fire spreads through a balcony in the forward part of deck 10. As illustrated in Figure 4.18, in case of a wind from the front/port side it is not hard to imagine a fire scenario with involvement of large areas of FRP composite. This would mainly be due to the fact that the surfaces are combustible.

In the above discussions, no account was taken to the fact that the “non-combustible” steel surfaces generally have layers of combustible paint. However, since no tests have yet been performed in comparison with painted steel surfaces this will not be directly considered.

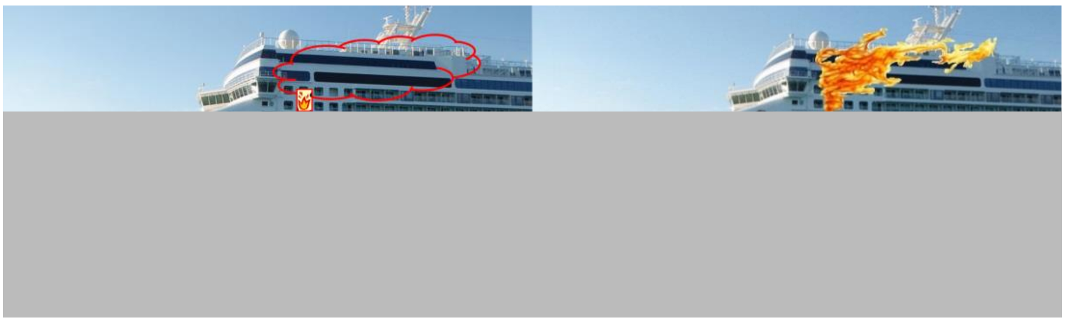


Figure 4.18. Potential fire involvement of FRP composite surfaces in case of an unfortunate wind.

Quantification of fire development on outboard sides

In assessing the probability for fire development on outboard sides of the ship the presumed scenario is a fire which is self-fuelled on the outboard side of the ship and continues to a large fire, sufficient to cause a local structural collapse. Except what has been discussed above, consideration was also made to the following conditions when estimating the probability for fire development on outboard surfaces:

- Opening to exteriors; only spaces with an opening to an outboard side of the ship are relevant.
- Potential for fire spread; in case of insignificant wind, fire spread is assumed only if there is a space above the fire compartment and in case of unfortunate winds, lateral fire spread was assumed to be relevant.
- Fire size variation; the likelihood for fire spread depends on the size of the fire.

The likelihood for winds which would promote fire spread affected by the FRP composite surfaces extending laterally was given the probability of 75%.

An inventory was made to account for the relative number of spaces in each group which have a space above it and the ones that are located by exteriors and have openings to an outboard side. The result is presented in Table 4.2.

Table 4.2. Inventory of factors affecting the probability for outboard fire development

Space group	***Opening to exteriors***	***Space above***
Cabins	70%	75%
Corridors	0%	-
Stairways	0%	-
Open deck spaces	-	-
Galleys	0%	-
Lounges	90%	10%
Restaurants	100%	90%
Store-rooms	0%	-
Technical spaces	80%	100%
Machinery spaces	10%	50%
Funnel and casing	-	-

Given that there is a fire in a space where outboard fire spread is relevant, the likelihood of fire development was assessed based on the preceding fire development, as determined by the failure modes and the expected fire size. However, the likelihood for fire development was assumed to be independent of whether the door to the fire compartment was open or closed from the beginning; a closed door could lead to more likely fire spread since all the smoke evacuates through the window but it could also be a limiting factor for the fire development since less ventilation (oxygen) is provided. The window is likely to break before any serious attempts for fire-fighting and the cases it doesn't are included in the probability for successful fire-fighting (see paragraph *0. Ventilation*). Hence, the window or balcony door is always assumed open or broken. Furthermore, if manual extinguishment has failed (which is a requirement for the fire to develop), fire-fighting efforts will be successful depending on the fire development. If such efforts fail, the growth rate and size of the preceding fire development will also affect the likelihood of exterior fire development. Accounting for the variation that these aspects will imply as well as the discussions above, the probability for a fire development which could compromise structural integrity on the prescriptive ship in case of no wind was estimated to 40% and if windy to 45 %. For the base design the corresponding probabilities were estimated to 50% and 90%, respectively [27]. Hence, more importantly, the probability for vertical fire spread in case of no wind is increased by 25% (relatively) in the base design and the probability for fire spread in case of unfortunate wind conditions is doubled. This relation was based on the discussions above regarding the areas replaced by FRP composite and their proneness to fire involvement [27].

Concluding, the probabilities for outboard fire development as a result of a fire on a balcony or in a space adjacent to exteriors in the prescriptive and base design are summarized in Table 4.3.

Table 4.3. Probability of outboard fire development in the different space groups on the prescriptive ship as well as in the base design (BD)

Space group	***P(fire development | Presc.)***	***P(fire development | BD)***
Cabins	29%	55%
Corridors	-	-
Stairways	-	-
Open deck spaces	-	-
Galleys	-	-
Lounges	33%	66%
Restaurants	43%	79%
Store-rooms	-	-
Technical spaces	35%	64%
Machinery spaces	4%	8%
Funnel and casing	-	-

Prevention of fire development on outboard sides

It was shown in [16, 26] that fire may spread quickly on a FRP composite surface. It was also shown not to be difficult to extinguish an external with a water spray, in other words e.g. with a regular fire hose for a trained crew member. However, there are some circumstances that reduce the probability of successful manual fire-fighting:

1. Detection may be delayed for a fire originating outside; and
2. Fire-fighters may be preoccupied with an internal fire if it propagates from a compartment;
3. It may be hard to reach a fire with a fire hose, particularly in case of unfortunate winds;
4. Structural integrity may be jeopardized soon after a fire develops on exterior surfaces;

Points two and three are considered managed through new fire-fighting routines and training with less focus on boundary cooling and a larger focus on external fire-fighting. However, the evaluation of fire-fighting efficiency [18] assumed that exterior surfaces were protected either with low-flame spread characteristics or with drencher. As mentioned above, tests [26] have shown that this is quite necessary, with regards to the fourth point, since structural integrity may be lost a few minutes after a FRP composite surface ignites when exposed to a large 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 is based on the above discussion assumed to be very low in the based design of the ship, 5%. In a prescriptive design the corresponding probability is estimated to 50%, based on a fire scenario screening and lessons learned from the Star Princess. Note that such a scenario in the prescriptive design are associated with considerably lower consequences.

There are although ways to manage outboard fires in FRP composite surfaces in a safer way. The tests mentioned above showed that a drencher system or a balcony sprinkler is very effective for preventing fire development on the FRP composite surface as well as for extinguishing an already established fire on these surfaces. They also showed that a surface treated with LEO system managed to prevent fire development and additional heat release from the FRP composite panel the first 10 minutes. A drencher system or balcony sprinkler could hence be sufficient to prevent fire from developing on the FRP composite surfaces. The former system could also extinguish an already established fire if activation is “too late”. As mentioned in point one above, detection may be a problem. Exterior detection, e.g. with use of flame detectors, could solve this problem and provide for early activation of such systems. A problem with only using a drencher system is that insides of balconies will not be reached. With balcony sprinklers a fire starting in a cabin or on a balcony will activate the system and thereby the fire and alarm system which solves early detection. Furthermore, the LEO system could be very useful as it provides additional time for the fire-fighting crew to arrange 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 *4.3.4. Quantification of risk control measures*.

4.2.4.2. Probability of fire development on open deck

The probability of fire development on open deck is assessed below, with starting point in the potential for fire development on a prescriptive ship and then with focus on the differences with the base design. Distinguishing spaces with different amounts of combustibles helps in quantifying this probability. Safety functions effecting such an event are also evaluated.

Spaces with different amounts of combustibles

Most modern cruise ships such as the reference ship have several open deck spaces. In case the initiating fire is located on open deck it is important to remember that an open deck space on a cruise vessel is not a stripped painted steel deck. To accommodate the passengers’ needs for amusement and relaxation they are often quite packed with facilities constructed in combustible materials. As seen in Figure 4.1 and Figure 4.19 there are numerous plastic chairs, sunbeds and matrasses, upholstered furniture, plastic bushes and other vegetation, bars and their structures and content, umbrellas, wooden deck and polymeric teak deck imitations, FRP composite pool, rails and other structures as well as many other combustible materials, as identified in *Appendix G. Data from the second hazard identification*. All of these materials could be involved in a fire.

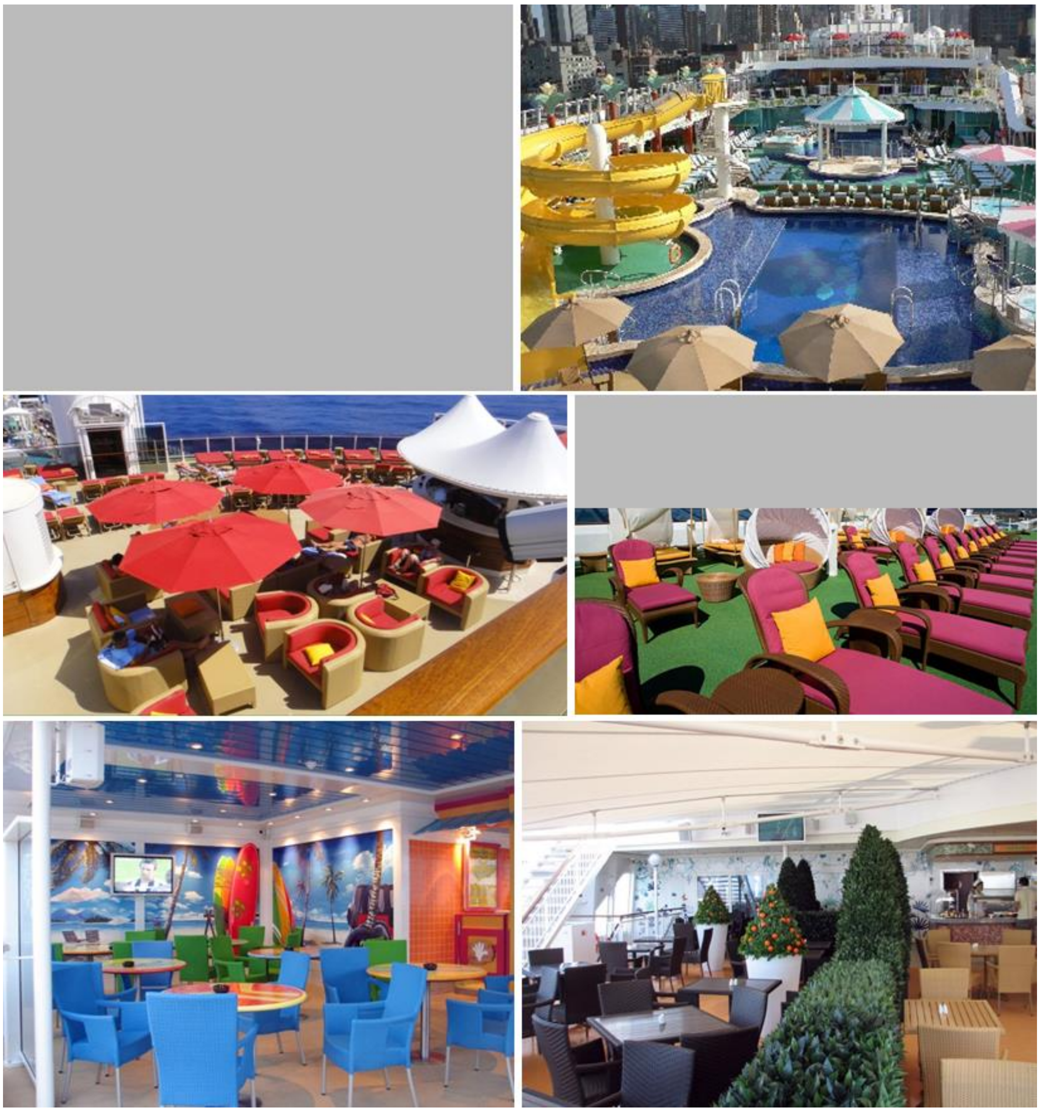


Figure 4.19. Photo collage of open deck areas with a lot of combustibles.

All of the furniture and fittings on open deck spaces are assumed to be the same on the Norwegian Future as on the reference ship. The floor construction is also assumed to be the same. It is only the deck house side walls and other vertical surfaces facing the open deck spaces where painted steel surfaces have been replaces by combustible FRP composite material. In many areas on open deck, such as those presented in Figure 4.19, these surfaces may be considered quite limited in comparison with all the other combustible materials. Particularly as many areas, as in the outdoor serving areas, have surfaces covered with additional panels for better finish and the FRP composite is therefore not exposed. However, in other areas on open deck the replacement of steel with FRP composite will provide almost the only available combustible materials. Such areas are illustrated in Figure 4.20. The probability for an initiated fire in these areas is although much lower than in the areas with a lot of other combustibles.

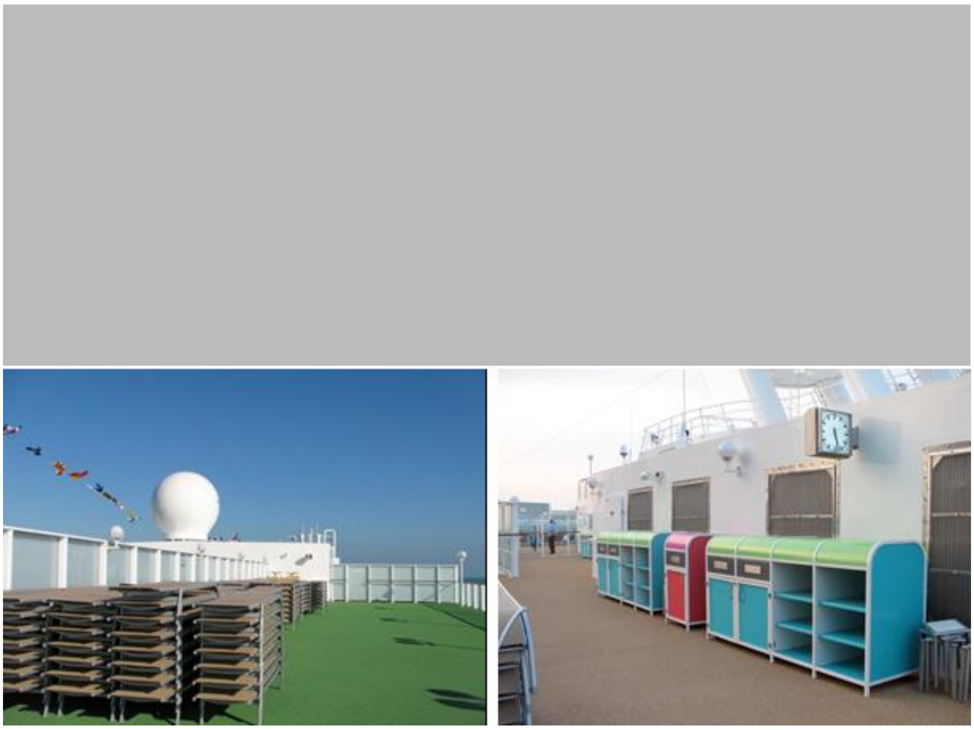


Figure 4.20. Photo collage of open deck areas with not so many combustibles.

A fire could although be initiated in the areas with a relatively large increase if combustible materials as well as in the areas with a relatively small addition of combustible materials. Particularly the fact that the replaced surfaces are vertical gives potential for fire spread in case a fire is initiated. For example, a fire starting in a bar on deck 12, as illustrated in Figure 4.21, could be further developed partly as a result of the added combustible FRP composite surfaces.

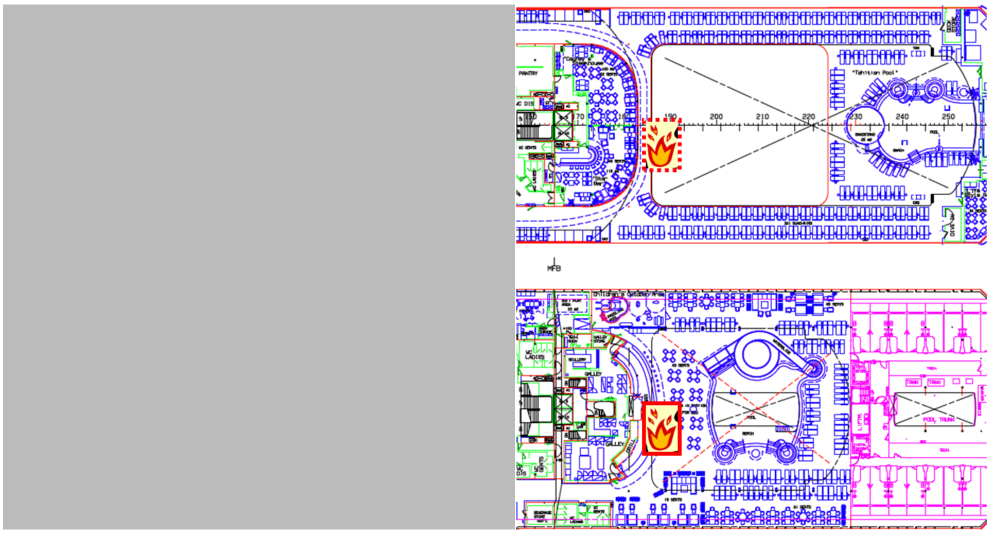


Figure 4.21. Example of a fire scenario where fire spread could be promoted by exterior FRP composite surfaces.

Quantification of fire development in different areas

In assessing the probability for fire development on open deck the presumed scenario is a fire which is self-fuelled and continues to a large fire, sufficient to cause a local structural collapse. With consideration to the above discussion, an inventory was made to account for different categories of outdoor areas with respect to previous discussions on potential for fire spread with consideration to the added FRP composite areas. The properties of the different kinds of areas on outboard decks are summarized in Table 4.4.

The first category was described as areas where the probability for ignition is very low since people normally do not occupy these areas and since there are very few other ignition sources. Furthermore, in these areas potential first fuels are very sparse but the amount of combustibles were significantly increased, relatively, as a result of the use of FRP composite on exterior surfaces. These areas are typically empty deck areas where people normally don't reside. These areas were assessed to represent 40% of all outboard areas.

The second category of spaces are spaces where the probability for ignition and the amount of first fuels are limited but where people are frequently occupied. These spaces are typically sundecks with metal-based sunbeds and where no other activity than sunbathing normally takes place; hence the first fuels are basically limited to what people bring along and a few other fixed materials. The secondary fuels are still mainly represented by the FRP composite surfaces. This category was assessed to account for another 30% of the open deck spaces.

The third and final category covers spaces where people are normally present for sunbathing, barbeque, music entertainment, dining and other activities. Ignition sources are hence not limited and neither are the first fuels. The amount of combustibles is large in general and the addition made by FRP composite surfaces is relatively small. These areas are typically spaces with outdoor seating areas, upholstered furniture, bar serving etc., as pictured in Figure 4.19. These spaces were assessed to represent about 30% of the open deck spaces.

Table 4.4. Properties of different kinds of areas on open deck on the prescriptive design and the base design (BD)

Outboard space category and keywords	***Relative deck area***	***P(fire est.)***	***P(fire dev.|Presc.)***	***P(fire dev.|BD)***
1. Unfurnished and bare	40%	5%	1%	25%
2. Sparsely furnished and few fuels	30%	10%	5%	30%
3. Upholstered furniture and many combustibles	30%	85%	40%	50%

The three categories of spaces have different probabilities for ignition, which will be considered in the event trees depending on their areas and on their probability of fire establishment. Not considering the relative deck areas between the different kinds of outboard deck spaces, the relative probability for a fire establishing was assessed depending on the availability of ignition sources, first fuels and critical factors, as identified in *Appendix G. Data from the second hazard identification*. Based on investigations of pictures of the spaces and previous discussions, the individual probability for a fire establishing in the spaces of category 1, 2 and 3 were assessed to 5%, 10% and 85%, respectively.

If a fire on an outboard space has established sufficiently to involve first fuels, the probability for further development, i.e. inclusion of secondary fuels, was assessed based on the relative increase of combustible materials provided by the FRP composite surfaces. In spaces of categories 1, 2 and 3 the probability for further fire development was assessed to 1%, 5% and 40%, respectively, in the prescriptive design and to 25%, 30% and 50%, respectively, in the base design. These estimations were made based on investigations of pictures of the spaces, the areas intended in FRP composite and on previous discussions.

The above assessed probabilities are summarized in Table 4.4. Concluding, provided that a fire has established somewhere on open deck, the resulting average probability for fire development sufficient to cause local collapse on a prescriptive ship is 34% and in the base design the corresponding probability is 46%. Hence there is a 36% overall increase in probability of fire development on open deck spaces in the base design in comparison with the prescriptive design.

Prevention of fire development on open deck

In the above paragraphs the discussions have only accounted for the physical conditions of the spaces and their potential effects on a fire developing. However, such a scenario could also be hindered by manual extinguishment or organized fire-fighting efforts. As mentioned above in paragraph *4.2.4.1. Probability of outboard fire development*, it was shown in [16, 26] that a fire on FRP composite surfaces may be relatively simple to extinguish. However, potential late detection and quick fire spread on FRP composite surfaces may reduce the probability of successful fire-fighting. In comparison with fire spread on outboard sides of the ship the layout of the open deck areas, being outdoors and mostly open, speaks in favor of the likelihood of a rather swift and effective fire-fighting effort.

As also was mentioned above, the evaluation of fire-fighting efficiency [18] assumed that exterior surfaces were protected either with low-flame spread characteristics or with a drencher system. This has been shown to be quite important since structural integrity may be lost a few minutes after a FRP composite surface ignites when exposed to a large fire [26]. Considering the potential for late detection and the fire growth potential of vertical FRP composite surfaces when a fire has established it could be difficult to perform fire-fighting in the base design. Due to inherent differences with regards to these aspects in different areas on the ship, the probability for successful fire-fighting on open deck was assessed depending on the kind of exposed area. The evaluations assume that a fire has established and considered the possibilities for successful fire-fighting before a first local collapse in a FRP composite structure in the base design and an aluminium structure in the prescriptive design. Aluminium is used in almost all decks and bulkheads facing open deck spaces on the reference ship, as illustrated in Figure 4.22. Aluminium is a commonly used material in cruise ship superstructures, which is further discussed in *4.2.5. Internal collapse*.

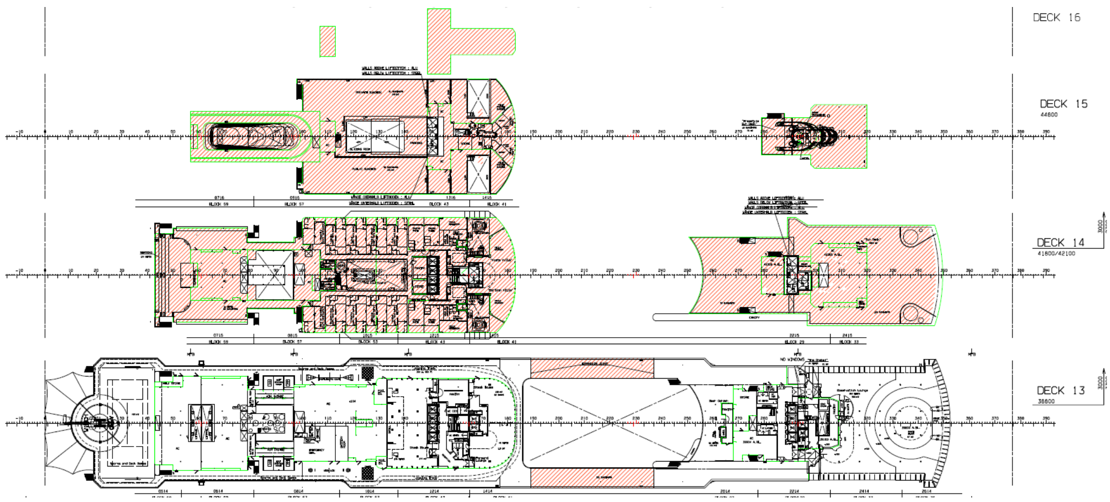


Figure 4.22. Areas in aluminium in the prescriptive design of the reference ship.

In a space of the first category the potentials for early detection and manual extinguishment were assumed to be quite low since there are no automatic detectors and people are not common in these areas. Based on the discussion above, the probability for successful fire-fighting before local collapse was estimated to 15% in the base design. In the prescriptive design the probability for a fire developing in this kind of area is almost insignificant, basically only to account for a potential arsonist. Hence, the probability for successful fire-fighting before significant fire development was estimated to only 60%.

If a fire establishes in a space of the second category the probability for manual detection is increased since people are frequently present. In the base design it is although assumed that the probability for a successful fire-fighting effort before loss of structural integrity is quite low, estimated to 30%. In a prescriptive design the probability for a fire to establish is still rather low. In case that happens the success rate of fire-fighting is assumed to 80% due to the longer time available until critical conditions.

A fire established in a space of the third category will be hard to extinguish due to the amount of combustibles. These spaces are typically occupied (except in the night time), which could be good for manual detection and potential manual extinguishment of a fire. The latter is although not considered since the combustibles generally have poor fire properties and are of large amounts, i.e. if a fire has established it takes the fire-fighting crew to extinguish it. The FRP composite surfaces will thus not have such a large relative impact in this category. In the base design the probability for successful fire-fighting was estimated to 25%, which is also affected by that FRP composite may not always be involved. In the prescriptive design the corresponding probability was assessed to 60%. The above figures were based on [18] and on the above discussions.

Concluding, given that a fire has established and continues to develop somewhere on open deck, the above probabilities for fire-fighting results in a probability of fire development of 14% in the prescriptive design and of 35% in the base design. Due to the potential difficulties in fighting a fire in a FRP composite structure, accounting for the restricted available time, the probability of fire development is thus more than two and a half times more common (2.58) in the base design than in the prescriptive design.

4.2.5. Internal collapse

- To establish how the consequences are affected from an uncontrolled fire for more than 60 minutes due to potential internal collapse.

The particular FRP composite sandwich panels that are intended for the base design were put on trial in fire resistance tests conducted at SP Fire Technology [19]. The tests show that it is possible to reach the requested goal of 60 minutes resistance to temperatures that represent a fully developed fire, as required by paragraph 8.3.1 in IMO Resolution A.754 [10]. This is achieved through insulation that is capable of keeping the temperatures in the laminate under the threshold value, keeping the bonding intact for the duration of the test.

The panels were loaded and after 60 minutes of fire exposure the heat in the furnace caused structural collapse. However, except for the obligation of being non-combustible, that is also all the regulations require from a FRD60 division; 60 minutes of fire resistance. Structures can namely be made in aluminium according to prescriptive requirements if insulation is provided on both sides of the division. Comparing FRP composite structures with aluminium structures there is no difference with regards to collapse since it may occur at this time also in aluminium structures. Some of the structures in the intended FRP composite superstructure are in fact made in aluminium and not in steel on the reference ship, as illustrated in Figure 4.22.

Thereby, risks associated with collapse as a result of heat exposure can be argued to happen also in the prescriptive design. Regulations are however made up for steel designs and aluminium structures can be said to be an exception. The general knowledge is that a steel structure, even if not classified fire resistant, may stand far longer than an hour. The history of fires shows that a passenger ships built in steel is normally not susceptible to serious collapse as a result of a fire. Accidents such as the fire on board the Scandinavian Star [28] have shown that even if fires rage for several days on steel passenger ships, the structure may become deformed but progressive collapse is unlikely. This difference was identified necessary to account for when comparing safety levels.

4.2.5.1. Time until collapse

Structural fire resistance of differently dimensioned FRD60 panels relevant for the Norwegian Future were tested in furnace tests according to the FTP Code [13], with reference from the HSC Code [11]. The 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 4.23. The test sample is normally subjected to a static or dynamic load during the test. However, in the current tests the sandwich panels were not exposed to nominal loading but to realistic loading, depending on the load the panel was designed to carry.

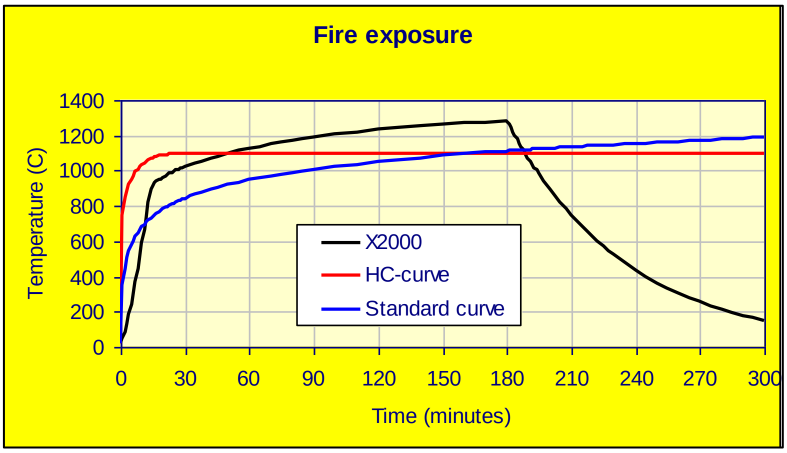


Figure 4.23. Time-temperature curves used for testing of structural resistance.

The applicable time for fire exposure in the fire test is 60 minutes. After 60 minutes of fire exposure, the heat wave may reach the FRP composite sufficiently to cause structural collapse. With regards to this it should be noted that in actuality it may be somewhat conservative to assume sudden collapse after this time due to the following reasons:

- In most places an additional thermal barrier exists between the fire seat and the load-bearing structure. The inner ceiling and walls separate most interior spaces on-board from the FRP composite 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. This reduces the thermal load to the load-bearing construction.
- In the furnace test, 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 [16] as well as the incident report from Star Princess [25] and lessons learned from the fire on HMS Ledbury [7, 29].

Furthermore, when a division is tested for structural resistance in the aforementioned test it is done with no support from surrounding structures. In a different unpublished international military research project called Convince, global FEM-studies were carried out 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 following 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. This implies that if FRD60 is used for all divisions there is no global collapse until after at least 120 minutes.

The above are good arguments for a longer time until collapse than the reference time of the structural fire resistance tests. However, at this time passengers will not be present in the same fire zone as the fire (unless already incapacitated) and the risks posed to fire-fighters after 60 minutes were managed under paragraph *4.1.3. Fire-fighting*. 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 consequences due to internal collapse will be assessed subsequently but the potential extra time until collapse will not be accounted for in the proceeding analysis. Hence, collapse as a result of lost load-bearing capacity in structures exposed to fire is assumed to occur after 60 minutes. Since FRD60 structures are used throughout the ship, collapse as a result of internal fire exposure is although not relevant before this time.

4.2.5.2. Collapse propagation and consequences

When it comes to evaluating the consequences of structural collapses, all on-board fires will be different and the dangers they imply will vary from case to case. For instance, a weakened bulkhead in the bottom of the FRP composite superstructure may compromise all 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 is 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. Thereafter, as the fire spreads to involve adjacent spaces and added FRP composite structures a collapse propagation may occur and cause a major or global collapse in the superstructure. The time frame from local collapse until a global collapse may occur in the superstructure is case dependant and hard to estimate. The conservative figure would be to say after 60 minutes of fire exposure, but even local collapse is unlikely to occur momentarily after 60 minutes. In any case, passengers should be on deck 7 at this time, prepared to disembark the ship if not in the life boats already. A local or even global collapse is therefore unlikely to affect the passengers inside the ship a minimum of four decks down the hull girder. A global collapse in the superstructure is hence not likely to cause collapse where passengers reside. The only identified possible direct consequence that an internal collapse could have for passengers would be if the internal collapse causes structural parts to fall down in the area of disembarkation. Depending on how early or if a decision has been made to abandon ship before collapse occurs, there could hence be direct consequences for disembarking passengers. It should be possible to move away and to make a decision to not use the life safety appliances in the same main vertical zone as the very significant fire at this time. This is likely a precautionary decision also in a prescriptive ship if a fire has been raging in an area for over an hour. Nevertheless, if passengers are not yet safely in life safety appliances at this time there could be additional consequences for the disembarking passengers below due to the increased probability of collapse. Either the disembarking passengers could be directly struck by falling objects or a decision not to use all of the life boats could make the rest of the boats overcrowded and cause consequences that way.

Furthermore, 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 may have an effect on the decision to abandon ship. Hence, a decreased likelihood of getting the fire under control and increased risks in case abandonment is delayed may cause an earlier decision to abandon 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.

4.2.5.3. Quantified consequences

A scenario leading to involvement of additional fuel and potential internal collapse is assumed to occur in the base design if a fire is not under control fire after 60 minutes. The potential for this scenario may lead to a higher probability of abandonment of the ship. An internal collapse may in some cases also cause consequences e.g. in case people are affected by collapsing structures when disembarking. As for consequences, they are assumed to be represented by the result of structures collapsing in the area for disembarkation. This is assumed to give fatalities in relation to the capacity of the life boats in the same main vertical zone. On each side of the ship there are 10 life boats which each normally takes 150 people. The overall ship was counted to have six main vertical zones (the front zone which only covers the bow was excluded). That gives three and a third life boats per main vertical zone. Assuming that the average consequences by an internal collapse are represented by falling objects sufficient to cause untenable conditions for the people on one life boat in 20% of the cases gives an average of 25 fatalities in case of internal collapse.

In both the base design and the prescriptive ship another 11 persons are assumed affected by untenable conditions in all cases a fire lasts for more than 60 minutes only due to effects of the long-lasting fire. This accounts for people who may have been reluctant or unable to evacuate in the first place and have been residing in a temporary safe place which is now inhabitable. The figure also accounts for fire-fighters who may also have been affected by untenable conditions at this stage. Consequences associated with evacuation after reaching the disembarkation deck are further quantified in paragraph *4.2.7. Evacuation*.

4.2.6. External 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 open deck are increased due to the risk of collapse.

The increased probability for fire development on outboard sides and on open deck spaces due to the use of FRP composite on exterior surfaces was assessed above in paragraph *4.2.4. External fire* . The fact that these surfaces are not protected increases the likelihood of a fire developing but it also has an effect for the possible consequences when FRP composite structures are involved. As for the probabilities, this was evaluated though two fire scenarios: (1) Outboard fire spread and (2) Fire development on open deck.

4.2.6.1. Consequences of outboard fire development

As established in paragraph *4.2.4.1. Probability of outboard fire development*, a fire on outboard sides of the ship could spread to balconies and other decks and even other main vertical zones, as happened on Star Princess. What also occurred in this accident was collapse of exterior balcony structures, which were mainly made in aluminium. The potential consequences from external fire development could although be larger in the base design as a result of using load-bearing FRP composite structures which are unprotected from the outside. The potential consequences are elaborated subsequently, divided on different stages. The probability of reaching major consequences is thereafter also discussed.

Consequences of the first stages of a fire on outboard sides

In case outboard sides of the prescriptive ship are exposed to a large fire development, minor structures on the sides of the ship may eventually collapse and smoke and fire may spread to adjacent decks and cause inhabitable conditions. These conditions can be compared with the Star Princess where the final damage was much greater and many balconies and outboard structures collapsed. On Star Princess 14 persons were exposed to dangerous conditions out of which one was deceased [25]. The consequences on the prescriptive ship at this stage of the fire scenario are therefore estimated to 9 people exposed to critical conditions (i.e. counted as “fatalities”), out of which only 2 due to collapse.

When it comes the base design of the ship, large scale tests showed that an unprotected FRP composite panel is susceptible to quick flame spread along its surface (see Figure 4.15) when exposed to such a fire [16, 26]. In *4.2.4.1. Probability of outboard fire development* it was concluded that the FRP composite surfaces in the base design are although rather limited on the sides of the ship in comparison with the experiments. Nevertheless, the combustible surfaces were assessed to promote fire spread with a certain probability.

Based on [26], 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. The fire could in other words result in direct consequences for evacuating and hesitating passengers. The people in the superstructure will need to be evacuated instantly and in a worst-case scenario many of the passengers in the effect zone will be exposed to smoke. 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 formed a triangle with almost the same width as the opening and a height higher than the 6.5 meter panel, probably about 8-9 meters, which may be distinguished in Figure 4.24. Even if the loss of structural integrity would be local in the early stages it could thus affect a large vertical area over several decks.

Figure 4.24. Fire damage on a FRP composite panel after a two minute fire exposure, representing a cabin fire through a balcony opening (structural integrity was lost throughout the whole height of the 6.5 m panel).

A worst-case scenario where the sides of the ship collapse locally early after fire exposure could in other words result in direct consequences for evacuating and hesitating passengers. If structural redundancy is not provided this could result in many casualties. In addition, detection may be delayed for a fire originating outside, which could give an even worse effect to the above consequences. 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. Therefore, and based on the discussions above, it was assessed that the consequences of this alone should be in the range of the final consequences of the Star Princess. Hence, 14 persons are assumed exposed to untenable conditions, only due to smoke spread (corresponding to 7 persons affected by untenable conditions in the prescriptive design). In the base design another 14 persons are also assumed to be affected by an early loss of structural integrity. Hence, in total 28 people will be exposed to untenable conditions during evacuation to a safe place.

Consequences of a progressing collapse

Later on, a worst-case scenario could involve large parts of the superstructure. This could give a fire on the upper deck similar to the fire on the Indonesian navy ship Kri Klewang, built in unprotected FRP composite. This could not only cause inhabitable conditions due to collapse. It could also cause an earlier decision to disembark and hinder disembarkation since structural parts of the ship may block usage of the life boats underneath, as further elaborated subsequently.

Figure 4.25. The Indonesian navy ship Kri Klewang had unprotected FRP composite surfaces on exteriors where a large fire established.

As the fire spreads to involve internal spaces and FRP composite structures on open deck, a collapse propagation may occur and cause a major or global collapse in the superstructure. 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 may be as low as 15-30 minutes, a major collapse is assumed to have potential consequences for evacuating or mustering passengers.

It is assumed that a major collapse will occur at the end of the above time frame and that it will cause affected by untenable conditions for all passengers left in the same main vertical zone. Most passengers should although not be in the effect zone at this time but rather at or on the way to deck 7, preparing to disembark the ship. A major collapse in the superstructure is hence not likely to cause collapse where most passengers reside. At this stage some passengers reluctant to evacuate may not have been accounted for, some passengers may have been hindered to evacuated due to sagging or other effects from the first local collapse and some passengers may simply not yet have made it to a safe place, e.g. due to disability. Based on information on habits at cruises on the Norwegian Cruise lines Jewel class cruise ships from personal and professional experiences in the design team it was assumed that in a 24 hour period, a third of the time all cabins are occupied with two persons and other areas are empty whilst in two thirds of the day cabins have 25% occupation and other areas 50% occupation. Inventorying a couple of the largest main vertical zones gives an average number of about 280 passengers as a likely maximum number of passengers occupying a large main vertical zone in the superstructure. Based on the above reasoning on possibilities for evacuation versus the potential available time frame it was assumed that 75% of the passengers have safely escaped the main vertical zone and that thus 70 persons are affected by untenable conditions by the global structural collapse.

To estimate the consequences of a fire on a prescriptive ship the Star Princess is once again used for reference. Within six minutes after the fire established on deck 10 on that ship, decks 11 and 12 and two main vertical fire zones were involved. After 24 more minutes the fire had spread further, involving a third main vertical fire zone. The fire spread to the cabins after the glass doors separating them from the balconies shattered from the heat. Temperatures on the balconies were high, at least 550°C since the exterior aluminium structures melted and collapsed. A total of 79 cabins were condemned by the fire and another 218 were damaged by fire, smoke or water, as shown in Figure 4.14 [25]. These are considered to be representable consequences from an unhindered fire on a prescriptive ship corresponding to the time frame on the base design. The number of passengers exposed to critical conditions on the Star Princess were 14. In the prescriptive design 9 persons have above already been assumed exposed to untenable conditions in the early events of the fire scenario. Considering that fire-fighting efforts in the prescriptive design have been ineffective, the fire would be unhindered to a larger extent. It was therefore assumed that the representative number of casualties such a fire scenario in a prescriptive design would be another 10 persons.

In case the major collapse is not hindered, effects on evacuation must also be taken into account, both for the prescriptive design and the base design. Structural parts and other debris may fall down in the area of disembarkation which could have direct consequences for disembarking passengers. The effects will depend on how early or if a decision has been made to abandon ship before collapse occurs, which will be different in the prescriptive design and base design. Increased risks in case abandonment is delayed may cause an earlier decision to abandon 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. On the Star Princess it is assumed 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 associated with disembarked passengers are further quantified in paragraph *4.2.7. Evacuation* but consequences due to falling debris should also be accounted for. It should be possible to move away and not use the life safety appliances in the same main vertical zone as the quite significant fire at this time. This would likely be a precautionary act in both ships. Nevertheless, there could be additional consequences for the disembarking passengers below. The result of collapsing structures in the area for disembarkation is assumed to give fatalities in relation to the capacity of the life boats in the same main vertical zone. On each side of the ship there are 10 life boats which each normally takes 150 people. The overall ship was counted to have six main vertical zones (the front zone which only covers the bow was excluded). That gives three and a third life boats per main vertical zone, i.e. 500 persons. For the base design it was assumed that the people on one side of the ship in this main vertical zone would be affected by untenable conditions due to the consequences from an external collapse, which gives another 250 fatalities in case evacuation is necessary. In the prescriptive design it is assumed that a number of people corresponding to 50 persons would be affected by the structural collapse on outboard sides in case of disembarkation.

Prevention of major collapse on outboard sides

The above scenarios could be limited to local collapse if fire-fighting efforts are established quickly and performed effectively. In the prescriptive design the likelihood of getting a fire in control, to not reach such large consequences, is estimated to 40%, much based on that the fire-fighting efforts on the Star Princess were performed in an unexpectedly commendable manner [18]. 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 difficulties in extinguishing a large fire established in FRP composite. Successful fire-fighting was therefore estimated to 10% in the base design.

4.2.6.2. Consequences of fire development on open deck

In *4.2.4.2. Probability of fire development on open deck* it was concluded that there are different kinds of areas on open deck in which the FRP composite surfaces make different relative additions to the amount of combustible materials. In all, a 36% overall increase in probability of a fire establishing on open deck was estimated in the based design when comparing with a prescriptive design. Taking into account the possibilities for fire-fighting, which are reduced due to the short time available until structural integrity may be compromised in the base design, the probability of fire development was estimated increased by more than one and a half times. These figures were based on an inventory of different categories of outdoor areas with respect to ignition sources, amount of first fuels, amount of FRP composite, amount of other secondary fuels, possibilities for detection, possibilities for early extinguishment, possibilities for fire-fighting and more.

The division into different categories of open deck areas was used in order to estimate the probability for fire development. However, in case a fire develops in open deck areas, the consequences were assumed to be similar, regardless of location. The generalized consequences of such a fire are elaborated below, divided on local collapse and major collapse. Thereafter the possibilities for preventing such large consequences are discussed.

Consequences of a local collapse on open deck

It was shown in [26] that 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. The prescriptive design is assumed to have aluminium structures facing all open deck spaces, based on Figure 4.22. Collapse may hence occur also in the prescriptive design. The time until collapse of an aluminium structure exposed to fire will although likely be quite a lot longer than until collapse of a FRP composite structure, which will affect the consequences.

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 an adjacent 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. The above effects may especially be 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 affected by untenable conditions. Comparing with the consequences from a local collapse on outboard sides of the ship, less people are likely affected by this scenario since a fire on open deck will generally not affect as many load-bearing bulkheads and spaces above the fire. In the prescriptive design 5 persons are assumed affected by critical conditions when local collapse occurs (mainly from smoke). The corresponding number in the base design is 5 persons affected by untenable conditions by toxic smoke and another 10.5 persons affected by untenable conditions by collapse (three quarters of the persons affected by untenable conditions by collapse on outboard sides).

Consequences of a major collapse on open deck

If the fire is left unhindered, a worst-case scenario could lead to involvement of large parts of the superstructure. As mentioned above, this could cause inhabitable conditions due to collapse and also hinder disembarkation and cause an earlier decision to abandon ship. The consequences from a similar scenario caused by fire spread on outboard surfaces were elaborated in *4.2.6.1. Consequences of outboard fire* . The considered differences to this scenario are primarily that the structures in the prescriptive design may be more prone to collapse as they are in aluminium. Furthermore, a collapse scenario is less likely to affect disembarkation as it will generally affect the upper areas of the ship than the sides.

A major collapse is will have potential consequences for evacuating or mustering passengers. Since the general alarm may be delayed due to detection problems on exterior surfaces and the fire may spread quickly, the available time for evacuation may be as low as 15-30 minutes in the base design. In the scenario used for comparison mentioned above, 25% of the persons in a main vertical zone were assumed not to have evacuated when a major collapse occurs. Since a fire on open deck would likely only affect the upper half of the superstructure, half of this number is assumed to be affected by untenable conditions, i.e. 35 persons. In the prescriptive design there will be longer time to evacuate but collapse may occur since structures are made in aluminium. The consequences from a major collapse in the prescriptive design are assumed to be 10 fatalities, also supported by comparison with the corresponding scenario on outboard sides.

When it comes to effects on evacuation, the likelihood of falling debris in the area of disembarkation is considered to be less relevant than in the outboard fire scenarios. The result of collapsing structures in the area for disembarkation was although considered to give larger consequences than associated with a major internal collapse. In all 100 people were assumed affected in the base design. In the prescriptive design it was assumed that a number of people corresponding to 25 persons could be affected by the structural collapse on open deck in case of disembarkation.

Prevention of major collapse on open deck

A major collapse as a result of an open deck fire could be limited to local collapse if fire-fighting efforts are established quickly and performed effectively. Considering the potential for early deterioration of structural integrity it may although be difficult to perform fire-fighting at this time in the base design. Furthermore, from various tests carried out at SP Fire Technology and from accidents in ships with FRP composite structures a general knowledge is that a long-lasting fire in FRP composite may be hard to extinguish since the material is prone to reignite [18]. This could further hinder successful fire-fighting. Since fire spread in the vertical and lateral directions are primarily considered it should be easier to manage a large superstructure fire initiated on open deck since it should primarily involve the upper parts of the superstructure. In comparison with fire scenarios initiated on outboard sides of the ship, the layout of the open deck areas are also easier to reach for fire-fighting. In all the probability of getting a fire under control in the base design is estimated to 20%. The likelihood of getting the fire under control in the prescriptive design was estimated to 60%.

4.2.7. Evacuation

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

It has previously been stated that conditions may be improved within the first 60 minutes thanks to the improved containment of a fire. This was accounted for when considering the potential for fire spread and the consequences thereof. Furthermore, in case of an internal fire for more than 60 minutes or and external fire could potentially affect the possibilities for evacuation. This has also been accounted for above. However, the probability for fire scenarios which will lead to abandonment of the ship may be increased in the trial alternative designs, which has not been managed so far. Risks associated with the abandonment process must thus be accounted for.

In [30], 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 fire. In this case evacuation refers to muster, assemble, disembark and abandon the ship. In case of a fire on a cruise ship, a number of events were identified which affect the likelihood of a successful evacuation process, as illustrated in Figure 4.26. These and other events affecting abandonment of a cruise ship are further discussed below, particularly with regards to likelihood and potential outcomes.

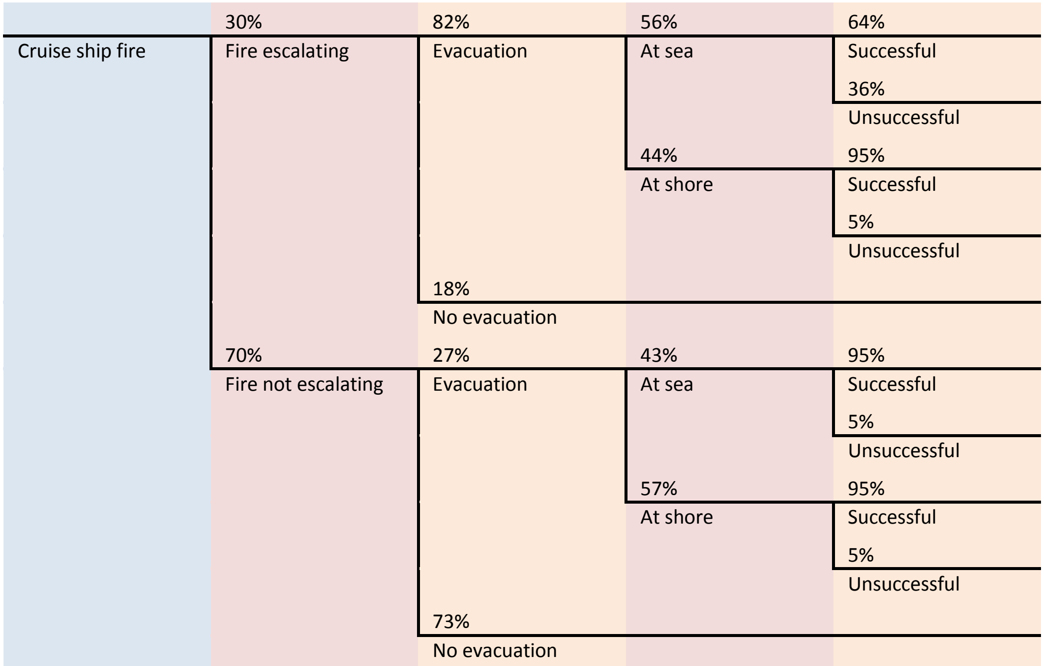


Figure 4.26. Event tree for cruise ship fires based on historical data, reproduced from [30].

4.2.7.1. Failure to reside on ship

According to [30], the probability for evacuation (abandonment of the ship) is linked to whether the fire is escalating or not. In case of an internal fire on the current prescriptive ship, the probability of a fire for more than 60 minutes depends on whether fire-fighting efforts are successful or not. This is assumed to correspond to whether a fire is said to escalate or not in the aforementioned data. Hence, if fire-fighting efforts are successful, abandonment will take place in 27% of the cases. This 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 fire-fighting efforts are not successful, evacuation will take place in 82% of the cases. 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 well beyond 60 minutes. 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 is assessed to be 90% in the base design. The corresponding probability in case fire-fighting efforts prove successful in the base design was assessed to be somewhat higher than in the prescriptive case due to the higher potential for consequences in case a decision is delayed, hence 38%.

In case of a fire on open deck or outboard sides of the ship, the fire-fighting efforts hindering a major collapse are assumed to correspond to whether a fire is said to escalate or not in the data. Thus, if pre-major collapse fire-fighting is successful the probability of abandonment is 27% and if fire-fighting fails the probability if 82%. This former probability is also judged applicable for the base design if fire-fighting is successful. However, in case fire-fighting efforts before a major collapse fail, the probability of evacuation is assumed to be higher, about 95%.

4.2.7.2. Events affecting the casualties in case of abandonment

In case a decision to abandon ship has been made, Figure 4.26 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 be at sea is 56% and if the fire does not escalate the probability is 43%. 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.

Another event affecting the potential casualties in case of abandonment is the weather. In case of evacuation at shore the weather is assumed to have no effect in this sense but if abandonment takes place at sea the weather could largely affect the number of fatalities. The probability of bad weather, such that would significantly affect the possibilities for safe evacuation, is assumed to be 20%, considering the mainly pleasant geographical location in which the ship may cruise. The above probabilities of casualties in 36% and 5% of the cases depending on the fire scenario are assumed only to be valid in case of good weather conditions. In case of bad weather casualties are assumed in 60% of the cases if the fire is not escalating and in 95% of the cases if the fire is escalating.

4.2.7.3. 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, 7 persons were therefore assumed to be affected by untenable conditions based on expert judgement, which gives an average outcome of 0,35 persons per evacuation at shore.

As for emergency evacuations due to fire at sea, this was investigated in [30, 31]. 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 accident on RoPax ships and two from accidents on cruise ships. 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 affected by untenable conditions 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 that the records from cruise ships represent the cases in good weather conditions. In other words, fatal consequences for 1% of the people on board a ship seems to be a reasonable average in case casualties occur due to evacuation in good weather. Hence, an average fatality rate of 1% was assumed in case casualties occur due to evacuation in good weather, based on an estimated distribution presented in Table 4.5. Note that since there are only casualties in 5% of the scenarios where the fire is not escalating, the expected number of fatalities in case of an evacuation at sea in good weather is 2 persons. If the fire is escalating the corresponding expected number of fatalities is 16 persons.

Table 4.5. Assumed distribution of number of fatalities (n) in case of casualties due to evacuation in good weather

Tot. population	***Relative n***	***Absolute n***	***Adjusted n***	***Probability of n***	***Risk contribution***
4350	15,00%	652,5	653	2,50%	16,325
4350	3,50%	152,25	152	9,00%	13,68
4350	1,10%	47,85	48	20,00%	9,6
4350	0,30%	13,05	13	27,00%	3,51
4350	0,03%	1,305	1	41,50%	0,415
			Total:	**100,00%**	**43,5 fatalities/s-y**

In case of bad weather the fatality distribution based on all of the statistical data found in [30] 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 in bad weather was calculated to 910 or 575 persons, depending on whether the fire is escalating or not.

4.2.7.4. Summarized event tree for evacuation

The probabilities and consequences elaborated on above were incorporated in an event tree, presented in Table 4.6. Note that the frequency of evacuation per ship year stems from all the fire scenarios in the superstructure. The same applies to the relative number of fires escalating. Hence, both of those figures are in this case examples. These figures are further elaborated in *4.3.3. Summarized data for* evacuation.

Table 4.6. Event tree with the probabilities and consequences associated with evacuation

	Fire escalating	At sea	In bad weather	Unsuccessful	Probability distr.	Frequency	Consequence	Risk contribution
0,047663	21,5%	44%		95%		0,00353019	0	0,00000000
Evacuation				5%		0,00018580	7	0,00130060
[per s-y]		56%	80%	95%		0,00359437	0	0,00000000
				5%	41,50%	0,00007851	1	0,00007851
					27,00%	0,00005108	13	0,00066401
					20,00%	0,00003784	48	0,00181610
					9,00%	0,00001703	152	0,00258795
					2,50%	0,00000473	653	0,00308832
			20%	40%		0,00037835	0	0,00000000
				60%	16,67%	0,00009459	4	0,00037835
					33,33%	0,00018918	44	0,00832381
					16,67%	0,00009459	174	0,01645844
					16,67%	0,00009459	1436	0,13582943
					16,67%	0,00009459	4046	0,38270605
	78,5%	57%		95%		0,02123609	0	0,00000000
				5%		0,00111769	7	0,00782382
		43%	80%	64%		0,00863405	0	0,00000000
				36%	41,50%	0,00201551	1	0,00201551
					27,00%	0,00131130	13	0,01704685
					20,00%	0,00097133	48	0,04662386
	NO				9,00%	0,00043710	152	0,06643900
					2,50%	0,00012142	653	0,07928484
			20%	5%		0,00016863	0	0,00000000
	YES			95%	16,67%	0,00053401	4	0,00213603
					33,33%	0,00106801	44	0,04699260
					16,67%	0,00053401	174	0,09291719
					16,67%	0,00053401	1436	0,76683383
					16,67%	0,00053401	4046	2,16059169
						Expected risk contribution:		3,84193678

4.3. Integration of quantified differences into risk model

The above quantified differences in fire safety were now incorporated in fire scenarios in order to determine their effects on safety. The previous division of the ship into representative groups of spaces was used as a starting point for the fire scenarios. In order to weigh together the risk contributions from the different spaces, a fire probability distribution was initially determined. Differences associated with the different risk control measures are quantified at the end of this section.

4.3.1. Frequency of superstructure 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 cruise ship. The data which was found was nevertheless investigated quite thoroughly in order to determine the likely frequency of a fire occurring in the superstructure of the Norwegian Future and furthermore to determine a probability distribution for the different spaces.

4.3.1.1. 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 [30]. 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 4.27 based on the statistical data.

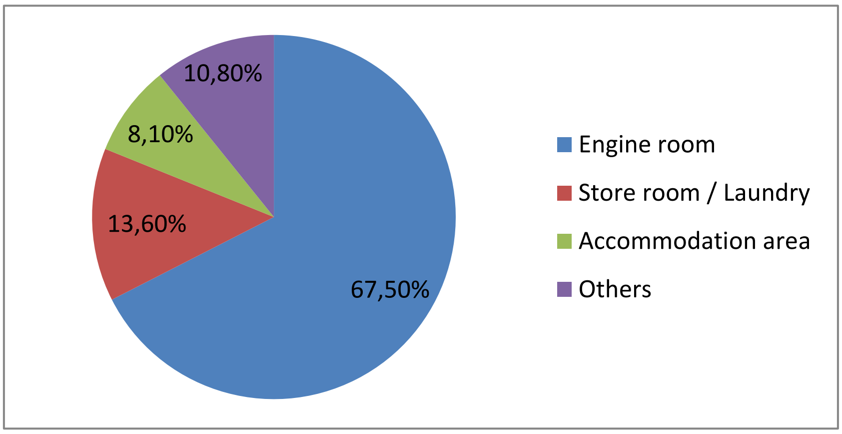


Figure 4.27. Origin of fires on cruise ships according to [30].

In the considered FRP composite superstructure on the Norwegian Future there is no engine room and additionally about two thirds of the spaces are situated in the lower ten decks. The figure should therefore be further adjusted to be applicable just for the spaces in the superstructure. However, noting that 0.012 fires per ship year is already a quite low figure gives reason to believe that what is being considered as a fire in the investigated historical data is a rather 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 which would be self-fuelled and continue to develop if left unhindered in different ways, 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 [32, 33] and Fireproof [34, 35]. In particular published data on fire frequencies per ship year for 51 different types of spaces on cruise ships were studied [35, 36]. The data stems from historical records of fire ignition in an incident database. 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 [30]. Accordingly the weighted average fire ignition frequency counts to 3.28 per ship-year. The fact that only about a third of the deck spaces on the Norwegian Future are considered in the evaluation gives an ignition frequency of 1.1 per ship-year. Even this figure was although assumed not to be sufficient to account for all the times a fire is ignited on a large cruise ship. In particular since the pure ignition of a fire may lead to a very limited fire and may therefore not find its way in to statistics, i.e. a bias in the data due to hidden statistics. It was therefore assumed that the weighted average fire ignition frequency of 1 per year is valid for one month in the superstructure on the Norwegian Future, i.e. 12 significant fires per ship-year. This best estimate figure is 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.

4.3.1.2. Fire probability distribution for the different spaces

In order to find a probability distribution for fire in the different groups of spaces in the considered superstructure, calculations were made in four ways. Firstly the fire incident data from the Fireproof project was used as starting point to assess the relative likelihood of fire in the different groups of spaces on the Norwegian Future. The data accounts for fire frequencies in 51 different types of spaces on cruise ships out of which many are applicable on the Norwegian Future. An inventory was made to account for the different kinds of spaces which make up each of the 11 space groups identified on the Norwegian Future (see section *3.7 Description of design fire scenarios*. These spaces were thereafter identified in the data and multiplied with the number of space in each space group. In some cases a matching space was not found in the data and then assumptions were made that the fire frequency was the same as in a similar space. In other cases several matches were found for one space and then a weighted average figure was determined. Furthermore, the lowest deck in the superstructure has cabins all the way around the exteriors of the ship. When determining the frequency of a fire in a cabin, the spaces adjacent to exteriors on the deck below this deck were also included in the total frequency of fire in a cabin. This was done to account for that a cabin on deck 11 will likely be involved in a fire on the deck below. Summing up the frequencies of the various spaces in each space group and dividing them by the total fire frequency for all space groups gave a relative probability distribution for fire in the different groups of spaces in the considered superstructure.

Due to a large frequency of fire associated with cabins as well as balconies in the data (in combination with the large number of cabins in the superstructure) the distribution was unreasonably overrepresented by the Cabins group (94%). A second distribution was therefore formed with consideration to the data presented in Figure 4.27. This data obviously presents a much more uncertain distribution and the validity may be questioned since only large fires are considered. However, using the Fireproof data as starting point it was used to get some contrast to the previous distribution. According to this data accommodation spaces are only involved in about 25% of the large fires whilst store rooms/laundry and other spaces account for 42% and 33% respectively. Considering that store room/laundry may not necessarily correspond particularly well with the Store-room space group the latter shares were distributed to all other spaces based on the Fireproof data. This formed a new probability distribution for fire in the space groups.

A third distribution was formed with consideration to internal company confidential data from concerning origin of fires from DNV found in [33]. Some internal studies done by DNV based on statistics from 150 fire outbreaks for a major shipping company also shows a distribution quite different from the one determined based on the data from the Fireproof fire incident database. After withdrawing spaces which do not exist in the superstructure and adding approximate values for the spaces missing in the historical statistics the data once again shows that accommodation spaces should only be involved in approximately 25% of the fires. The number of cabins in the superstructure of the Norwegian Future may although be relatively many. The data from DNV also showed on increased probabilities for fire in restaurants, store-rooms and open deck spaces than previous data.

Furthermore, traditionally in fire safety engineering, the probability of ignition in a building can be estimated based on the floor area in that building or space, e.g. [37]. 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 although 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 combustibles and in especially ignition sources. An inventory was nevertheless made which provided approximate relative floor areas for the space groups. However, these figures were multiplied by the fire risk indices provided in Table 3.3, which was judged to give a more nuanced fire ignition distribution than simply the floor area comparison. This gave a third probability distribution for fire in the space groups.

The three distributions formed as described above were summed up and averaged, which generated a final distribution, However, since the Funnel and casing space group is strongly affected by the fires in the engine rooms it was necessary to also account for the engine room fires. Based on the data above an average of 20% of all ship fires were assessed to be originated in the engine room. Adding the ignition probability distribution for the FRP composite superstructure gives the distribution presented in Table 4.7.

Table 4.7. Relative probability distribution for fire in the different groups of spaces

	Probability of fire in space	Frequency [per ship-year]
5,60319	30,40%	1,70314
Relevant fires/ship-year	Cabin	
	1,37%	0,07665
	Corridor	
	1,92%	0,10762
	Stairway	
	6,50%	0,36410
	Open deck	
	7,80%	0,43683
	Galley	
	1,53%	0,08561
	Lounges	
	3,99%	0,22340
	Restaurants	
	1,58%	0,08866
	Store-rooms	
	0,75%	0,04179
	Technical spaces	
	1,26%	0,07060
	Machinery spaces	
	42,92%	2,40478
	Funnel and Casing	

This relative probability distribution for fire in the different groups of spaces was used in the risk assessment.

4.3.2. Fire scenarios

The quantified differences in fire safety were incorporated in fire scenarios associated with the different groups of spaces, as elaborated below.

4.3.2.1. Cabin fire scenarios

The Cabin group represents the conditions in cabins, rooms of suites and spa treatment rooms. These spaces generally contain potential fuels, such as furniture, plastics, electrical equipment, linings, upholstered materials, textiles and other materials as described in *Appendix G. Data from the second hazard identification*. The identified critical factors and the associated target locations in cabins 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 a cabin 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 the spaces in this group.

For Cabins there are in particular two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs; one if an internal fire goes on for more than 60 minutes and the other one if a fire spreads to involve exterior sides of the ship. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment and their current state. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the two scenario branches which involve differences between the prescriptive design and the trial alternative designs are described.

1.1.1.1.1 Person present in Cabins

With regards to whether there is anyone present in the space it was assumed that 8.5 hours of the day (35%) persons are present but sleeping or intoxicated. In the hours that are left people were assumed to be present and awake (and sober) 2.5 hours of the time (10%). Hence, 55% of the day no one is estimated present. However, a fire in Cabins is considered to be four times as likely to occur if people are present. Furthermore, it was assumed twice as likely that persons were awake. Hence an updated probability distribution was set to 22.8%, 48.6% and 28.6% depending on whether no one is present or if someone is present and awake or present and sleeping, respectively.

1.1.1.1.2 Initial manual extinguishment in Cabins

The above affects the probability of failure of first aid with regards to manual extinguishment. In a Cabin space the occupant was estimated to provide initial manual extinguishment in 25% of the cases where a fire is ignited, if the compartment occupant was originally awake. If the compartment occupant was asleep during the development of the fire there is still a chance that he will extinguish the fire e.g. by covering it or using an extinguisher. The probability of this happening was although judged less likely and estimated to 10% for when the occupant was initially asleep. If no one was present in the fire compartment during the fire development, the probability that a fire is manually extinguished by a cabin occupant in the incipient phase was set to 0%.

All events above should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Furthermore there is a possibility that a nearby crew member or passenger, e.g. cleaning personnel, may notice and put out the fire. According to [18] the time from detection alarm until a first fire-fighter on call (without fire-fighters outfit and breathing apparatus) is at the scene can be estimated to about 2-3 minutes. The time until fire-fighters with appropriate equipment arrive is in the range of 4-5 minutes, possibly more. The entire fire-fighting crew should be assembled on site soon after. These estimations consider a large cruise vessel and the information is therefore regarded as valid. The time until detection was investigated in [16] and in the Branzfire simulations below and can be estimated to approximately one minute from ignition. The fire may then be of a size of 250-750 kW. If it is in the upper range of this interval or larger it is considered unlikely that a first effort is successful, even for a trained fire-fighter with a fire-extinguisher. Considering that a first fire-fighting effort may not occur, be delayed or not be possible at arrival the overall probability of successful fire-fighting at this early stage was estimated to 30%. Hence, the aforementioned probabilities were updated to probabilities of failure of manual extinguishment of 52.5%, 63% and 70% in case a person is present and awake, present and asleep or not present, respectively.

1.1.1.1.3 Ventilation in Cabins

The compartment door to the corridor is generally closed since all these doors are equipped with door-closing devices according to regulations. The door may although be open due to failure in the door mechanism or due to it being put open, e.g. by cleaning personnel, a passenger or an arsonist. The probability of the door being closed was also identified to be affected by whether there was a person in the cabin originally and their current state. If the person was originally asleep the likelihood of the door being open was estimated to be very low, 1%. If the person was originally awake the probability was estimated to 6%. If no one was present in the compartment of fire origin the probability was estimated to be 8% that the door is open since this is when cleaning of the rooms is generally carried out.

Regarding other potential ventilation openings, 70% of the spaces were estimated to have openings to exteriors, based on an inventory above. These are normally covered by a balcony sliding door or by windows. Furthermore, all spaces have a door to a corridor and if it is not open minor ventilation is still provided through a door ventilator. The active ventilation system is generally turned off when fire is detected. The potential ventilation openings in Cabins are summarized in further detail in Table 4.8.

Table 4.8. Potential ventilation openings in the cabin

Connecting volume	*Opening*	*Dimensions (WxH) [m]*
Corridor	Cabin door	0.7x2.0
Corridor	Cabin door ventilator	0.3x0.1*
Outside	Balcony door	0.7x2.0

*The door ventilator is located 0.2 m from the floor and its actual dimensions are 0.36x0.18 m. However, for the simulations the opening was reduced due to the fact that >50% of the opening is covered, which reduces the effective opening.

In order to determine the likelihood of window breakage, these ventilation openings were used in fire simulations using the software Branzfire [38]. In the simulations the approximate size of an inside cabin was assumed, which is about half of the size of a balcony stateroom. The dimensions of the cabin used in the simulations was 3.0 x 4.3 x 2.1 m^3, i.e. about 27 m^3. For the design fire, reference was made to the full scale cabin fire tests performed at SP Fire Technology in 2007 [16]. It was estimated that the fuels in this fire can also represent the fuels in the spaces in the Cabins group. In the uninterrupted fire test, however, an incipient phase of 4 minutes was found. The ignition source used in this test, a wood crib according to BS 5852:Part 2 [20], does not necessary represent an ignition source in the accommodation space. A 2 minute incipient phase was estimated more reasonable and 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” [21] where the heat release is expressed as:

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

Based on the large scale cabin fire tests the following values were estimated for the accommodation space design fire, as illustrated in Figure 4.28:

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

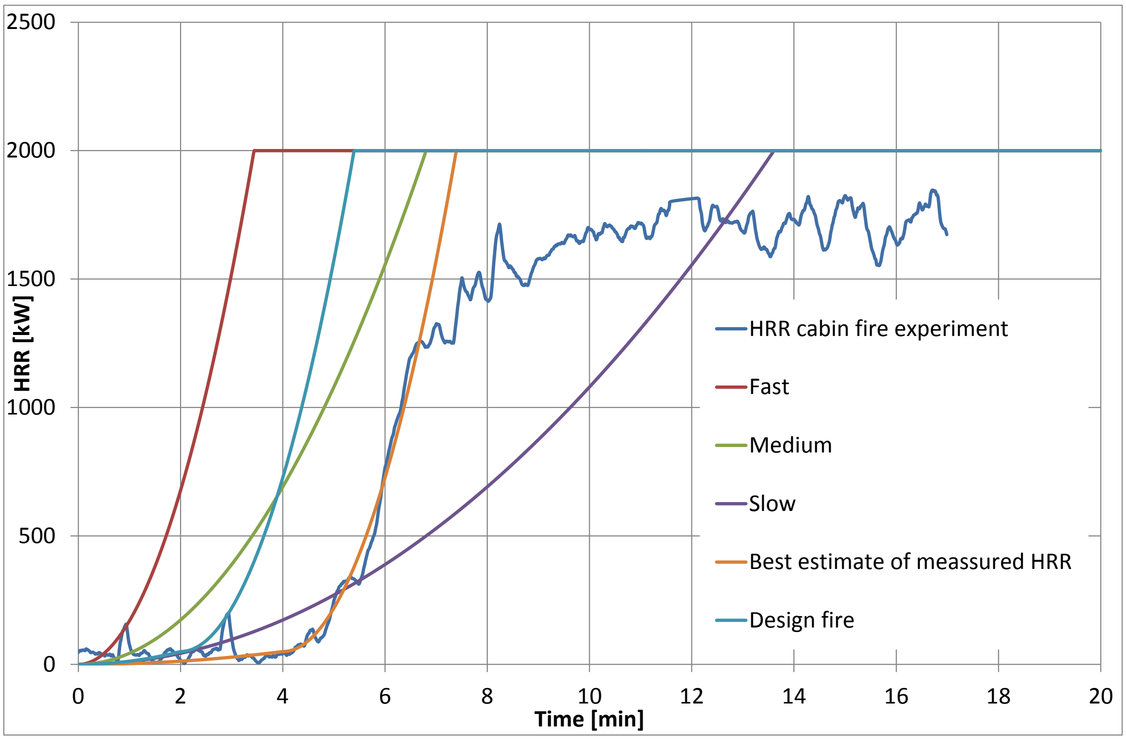


Figure 4.28. Heat Release Rate curve in the large scale cabin fire test, commonly used fire growth rates and the design fire used in the cabin fire simulations.

Based on information on the quality of the used glasses [1], 3 mm single pane glass windows were assumed. According to [“Glass breakage in fires”, Dr Babrauskas, Fire Science and Technology Inc, 2010] such a glass can be assumed to break at gas temperatures of about 360°C.

A Branzfire simulation was performed with the input data as described above. Some results of this simulation are presented in Figure 4.29 and Figure 4.30.

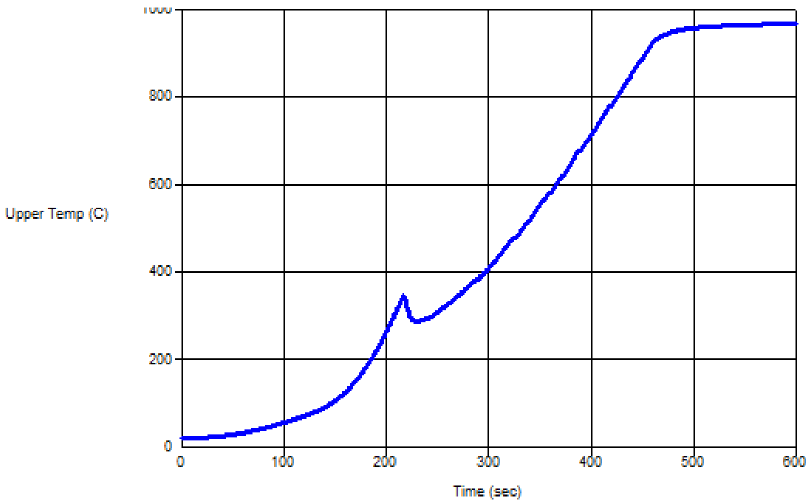


Figure 4.29. The temperature in the upper smoke layer in Branzfire simulations of an unventilated cabin with a balcony opening (with occurring window breakage).

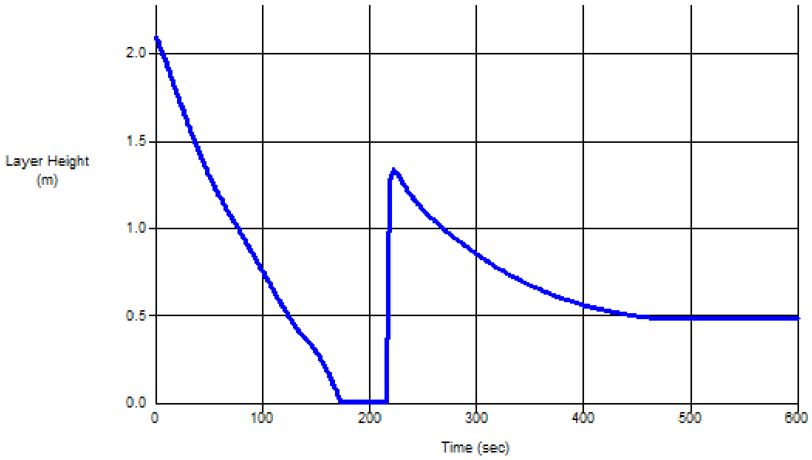


Figure 4.30. The smoke layer height in Branzfire simulations of an unventilated cabin with a balcony opening (with occurring window breakage).

Thus, an important result of the Branzfire simulations is that the balcony window will likely break before a non-ventilated cabin fire self-extinguishes. A sensitivity analysis was also carried out where one input parameter was varied at a time and simulations were also carried out with the door open. In particular the glass thicknesses was increased up to 6 mm, which according to [39] can be assumed to bread at gas temperatures of about 450°C. All simulations although gave the same general result as the simulation with the input data as described above. Therefore, if the compartment has a window it is assumed to always break in case of fire. In addition it is estimated quite likely that a balcony door is open to begin with. The cases where the window is closed and nonetheless holds up against the fire and leads to self-extinguishment are assumed accounted for in the probability for successful pre-flashover fire-fighting, as described below.

1.1.1.1.4 Sprinkler system in Cabins

According to a report from the research project Fireproof [40-42] 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-f(λ) = $e^{-(\lambda * t)}$ to 0.88-1.0. This close to one (1), the exponential function can be considered 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 [43], 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.

1.1.1.1.5 Fire-fighting before flashover in Cabins

For a so far uncontrolled cabin fire to reach flashover, there is one more safety function that must fail: fire-fighting. As mentioned above, the time from detection of a fire until the first crewmember with fire-fighters outfit is at the scene is at 4-5 minutes on a large cruise vessel, possibly more [18]. The entire fire-fighting crew should be assembled on site soon after this. According to Figure 4.28, even a fire with a 4 minute incipient phase may reach flashover 5 minutes after detection. This gives reason to believe that the potential for successful fire-fighting efforts before flashover may be quite limited. This was judged to be affected by whether the door was open or closed. An open door will make smoke and potentially fire spread out in the corridor and may require a more advanced strategy to locate and extinguish the fire and tend to passengers in adjacent cabins. If the door is closed the fire-fighting crew is estimated to be successful in extinguishing the uncontrolled fire before flashover in 40% of the cases if the door is open and in 10% of the cases if the door is closed. The probability of successful fire-fighting when the door is closed is assumed to also include the above estimated few cases where the window does not break and the fire self-extinguishes. Furthermore, note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later event for internal fire development.

1.1.1.1.6 Summarized event tree for Cabins

All the conditions and failure modes affecting the development of uncontrolled fires in Cabins are summarized in the event tree in Table 4.9.

Table 4.9. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a cabin leading to flashover (FO)

	Prob. of fire in space	Person present	Failure of man. ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	30,40%	22,8%	30%				0,11649508	safe
Significant fire	Cabin	no one	70%	92%	91%		0,22756925	safe
					9%	40%	0,00900274	safe
						60%	0,01350411	Unctrl. fire
				8%	91%		0,01978863	Safe
					9%	10%	0,00019571	Safe
						90%	0,00176141	Unctrl. fire
		48,6%	48%				0,39317088	safe
		awake	53%	94%	91%		0,37172030	safe
					9%	40%	0,01470542	safe
						60%	0,02205813	Unctrl. fire
				6%	91%		0,02372683	safe
					9%	10%	0,00023466	safe
						90%	0,00211195	Unctrl. fire
		28,6%	37%				0,18022674	safe
		sleeping	63%	99%	91%		0,27646148	safe
					9%	40%	0,01093694	safe
						60%	0,01640541	Unctrl. fire
				1%	90%		0,00279254	safe
			NO		10%	10%	0,00002762	safe
						90%	0,00024857	Unctrl. fire
			YES	Total frequency of unctrl. fires:			0,05608956	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Cabins space group there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs: internal fire development and fire development on outboard sides, which are further elaborated below.

1.1.1.1.7 Internal fire development in Cabins

Differences between the prescriptive design and the base design with regards to a fire in a space in the Cabins group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Cabins group on the prescriptive ship the event tree is presented in Table 4.10.

Table 4.10. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a cabin fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,05608956	32,5%	55%	73%	0,00731899	0	Safe
Unctrl. fire			27%	0,00270702	X	Evacuation
		45%	18%	0,00147656	11	Long-lasting fire
			82%	0,00672654	11 + X	Long-lasting fire + Evac.
	67,5%	32%	73%	0,00884420	0	Safe
			27%	0,00327114	X	Evacuation
		68%	18%	0,00463412	11	Long-lasting fire
			82%	0,02111099	11 + X	Long-lasting fire + Evac.
			Evacuation:	0,03381570		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Cabins group in the base design, for which the event tree is presented in Table 4.11.

Table 4.11. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a cabin fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,05608956	100%	55%	62%	0,01912654	0	safe
Unctrl. fire			38%	0,01172272	X	Evacuation
		45%	10%	0,00252403	11	Long-lasting fire
			90%	0,02271627	36 + X	L-l fire + Maj. col. + Evac.
			Evacuation:	0,03443899		

1.1.1.1.8 Cabin fire development on outboard sides

Differences between the prescriptive design and the base design with regards to a fire in a space in the Cabins group leading to fire development on outboard sides were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For fire development on outboard sides of the ship due to a fire in a space in the Cabins group on the prescriptive ship the event tree is presented in Table 5.9.

Table 4.12. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a cabin fire in the prescriptive design

Fire dev. on outboard side	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.	Description
0,05608956	71%				0,03982359	0	safe
Unctrl. fire	29%	50%			0,00813299	0	safe
		50%	40%	73%	0,00237483	9	Local collapse
				27%	0,00087836	9 + X	Loc. col. + Evac.
			60%	18%	0,00087836	19	Loc. + Maj. col.
				82%	0,00400143	69 + X	Loc.+Maj.col.+E.
				Evacuation:	0,00487979		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for fire development on outboard sides due to a fire in a space in the Cabins group in the base design, for which the event tree is presented in Table 5.11.

Table 4.13. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a cabin fire in the base design

Fire dev. on outb. sides	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.	Description
0,05608956	45%				0,02524030	0	safe
Unctrl. fire	55%	5%			0,00154246	0	safe
		95%	10%	73%	0,00213940	28	Local collapse
				27%	0,00079128	28 + X	Local col. + Evac.
			90%	5%	0,00131881	98	Loc. + Maj. Col.
				95%	0,02505731	348 + X	Loc.+Maj.Col.+E.
				Evacuation:	0,02584860		

4.3.2.2. Corridor fire scenarios

The Corridor group represents the conditions in corridors, which exist in many of the decks but mainly on deck 11 and 12 where they interconnect cabins. These spaces generally contain sparse potential fuels. They could nonetheless contain luggage or a cleaning wagon with its contents, except from a few electrical devices, decorations and surface linings, as described in *Appendix G. Data from the second hazard identification*. The most significant identified failure modes in a corridor 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 the spaces in this group.

For corridors there is in particular one scenario branch which was identified to imply differences between the prescriptive design and the trial alternative designs; if an internal fire goes on for more than 60 minutes. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the scenario branch which involves differences between the prescriptive design and the trial alternative designs is described.

1.1.1.1.9 Person present in Corridors

With regards to whether there is anyone present in the space it was assumed that 7 hours of the day (29%) the activity in corridors is very sparse since most people in adjacent spaces are sleeping. Furthermore, another 8 hours (33%) of the day it is assumed that people are away ashore or for activities on deck and the activity in corridors is very sparse. The rest of the day (38%) persons are assumed present in the corridor, e.g. people walking to their cabin, cleaning personnel doing their rounds or people simply walking through. However, a fire in Corridors was assumed to be twice as likely if persons are present. Hence the updated probability of a person being present in case of fire was set to 54,5%.

1.1.1.1.10 Initial manual extinguishment in Corridors

The above affects the probability of failure of first aid with regards to manual extinguishment. In a corridor a present person was estimated to provide initial manual extinguishment in 35% of the cases where a fire is ignited. If no one was present in the fire compartment during the fire development, the probability that a fire is manually extinguished in the incipient phase was set to 0%. The above events should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Based on the reasoning in paragraph *4.3.2.1. fire scenarios* and the less amount of fuel in a corridor gave an assessed overall probability of successful fire-fighting at this early stage of 40%. Hence, the aforementioned probabilities were updated to probabilities of failure of manual extinguishment of 39% in case a person is present and of 60% in case no one is present.

1.1.1.1.11 Ventilation in Corridor

The doors to the corridor are generally closed since all these doors are equipped with door-closing devices according to regulations. The doors may although be open due to failure in the door mechanism or due to it being put open, e.g. by cleaning personnel, a passenger or an arsonist. A door being open was also identified to be somewhat linked to whether there is a person present. If no one is present the probability was estimated to be quite low, 3%, that a door is open. If someone is present the likelihood of a door being open was estimated to be 6%. This accounts for that there are always at least two doors in a corridor which may be left open to a large amount of oxygen. No windows or other significant ventilation openings generally exist.

In case the doors are closed it would be likely that the fire would eventually self-extinguish. However, some of the doors to corridors are made in glass and there is also a potential for fire spread to adjacent spaces if the fire burns through. Altogether, in a fire scenario where all doors are closed, a corridor fire is estimated to self-extinguish in 75% of the cases. This is accounted for when considering the probability for fire-fighting below.

1.1.1.1.12 Sprinkler system in Corridors

The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.13 Fire-fighting before flashover in Corridor

For a so far uncontrolled Corridor fire to reach flashover, fire-fighting must also fail. Based on *4.3.2.1. fire scenarios* and the smaller amount of fuels in Corridors give reason to believe that the potential for successful fire-fighting efforts before flashover may be slightly larger than in Cabins. Fire-fighting was judged to be affected by whether a door is open or closed. If the door is closed the fire-fighting crew is estimated to be successful in extinguishing the uncontrolled fire before flashover in 35% of the cases if a door is open and in 10% of the cases if the doors are closed. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later event for internal fire development.

1.1.1.1.14 Summarized event tree for Corridors

All the conditions and failure modes affecting the development of uncontrolled fires in Corridors are summarized in the event tree in Table 4.14.

Table 4.14. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a corridor leading to flashover (FO)

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	1,37%	45,5%	40%				0,01395097	safe
Significant fire	Corridor		60%	97%	91%		0,01847178	safe
					9%	90%	0,00164419	safe
						10%	0,00018269	Unctrl. fire
				3%	91%		0,00057129	safe
					9%	35%	0,00001978	safe
						65%	0,00003673	Unctrl. fire
		54,5%	61%				0,02548352	safe
			39%	94%	91%		0,01393681	safe
		NO			9%	90%	0,00124053	safe
						10%	0,00013784	Unctrl. fire
		YES		6%	91%		0,00088958	safe
					9%	35%	0,00003079	safe
						65%	0,00005719	Unctrl. fire
				Total frequency of unctrl. fires:			0,00041444	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Corridors space group there is one scenario branch which was identified to imply differences between the prescriptive design and the trial alternative designs: internal fire development, which is further elaborated below.

1.1.1.1.15 Internal fire development in Corridors

Differences between the prescriptive design and the base design with regards to a fire in a space in the Corridors group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Corridors group on the prescriptive ship the event tree is presented in Table 4.15.

Table 4.15 Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a corridor fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00041444	32,5%	55%	73%	0,00005408	0	safe
Unctrl. fire			27%	0,00002000	X	Evacuation
		45%	18%	0,00001091	11	Long-lasting fire
			82%	0,00004970	11 + X	Long-lasting fire + Evac.
	67,5%	32%	73%	0,00006535	0	safe
			27%	0,00002417	X	Evacuation
		68%	18%	0,00003424	11	Long-lasting fire
			82%	0,00015599	11 + X	Long-lasting fire + Evac.
			Evacuation:	0,00024986		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Corridors group in the base design, for which the event tree is presented in Table 4.16.

Table 4.16 Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a corridor fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00041444	100%	55%	62%	0,00014132	0	safe
Unctrl. fire			38%	0,00008662	X	Evacuation
		45%	10%	0,00001865	11	Long-lasting fire
			90%	0,00016785	36 + X	L-l fire + Maj. col. + Evac.
			Evacuation:	0,00025446		

4.3.2.3. Stairway fire scenarios

The Stairway group represents the conditions in stairways, which interconnect many of the decks. These spaces generally contain sparse potential fuels. They could nonetheless contain luggage or passenger belongings and temporary furniture, except from a few electrical devices, decorations and surface linings, as described in *Appendix G. Data from the second hazard identification*. The stairways often also include WCs, which may contain more combustible materials, furniture etc. The most significant identified 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 the spaces in this group.

For Stairways there are only small differences in fire scenarios since they are seldom in direct connection with outboard surfaces and are generally made up by A-60 constructions. If an internal fire goes on for more than 60 minutes there may although be relevant differences between the prescriptive design and the trial alternative designs. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the scenario branch which involves differences between the prescriptive design and the trial alternative designs is described.

1.1.1.1.16 Person present in Stairways

With regards to whether there is anyone present in the space it was assumed that the activities in a stairway are more frequent than in a corridor. Based on the discussions in *0. Person present in Corridors* and the estimation that people are more frequently present in stairways, persons were assumed present in Stairways 14 hours of the day, i.e. 58%. Furthermore, a fire in Stairways was assessed to be three times as likely if persons are present, e.g. since it was judged harder for an arsonist to establish a fire unnoticed than in a corridor. Hence the updated probability of a person being present in in a Stairway in case of fire was set to 80,8%.

1.1.1.1.17 Initial manual extinguishment in Stairways

The above affects the probability of failure of first aid with regards to manual extinguishment. If a person is present in a stairway he or she was estimated to provide initial manual extinguishment in 25% of the cases where a fire is ignited. This is a somewhat lower probability than in Corridors because of the possibilities of a fire to grow rapidly on the larger vertical surfaces. If no one was present in the compartment during fire development, the probability that a fire is manually extinguished in the incipient phase was set to 0%. The above events should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Based on the reasoning in paragraph *4.3.2.1. _ fire scenarios* and the less amount of fuel in a stairway as well as the easier availability gave an assessed overall probability of successful fire-fighting at this early stage of 50%. Hence, the aforementioned probabilities were updated to probabilities of failure of manual extinguishment of 37.5% in case a person is present and of 50% in case no one is present.

1.1.1.1.18 Ventilation in Stairways

The doors to a stairway should generally be closed as they are be equipped with door-closing devices according to regulations. The doors may although be open due to failure in the door mechanism or due to it being put open, e.g. by crew to provide ventilation or because of moving, a passenger or an arsonist. A door being open was also identified to be somewhat linked to whether there is a person present. If no one is present the probability was estimated to be 5% that a door is open. If someone is present the likelihood of a door being open was estimated to be 9%. This accounts for the many doors in a stairway and also the fact that doors are often in glass and might break due to the fire. The doors are generally made of glass and the stairways are generally of rather significant volume. Hence a fire is assumed to continue even if all doors are closed.

1.1.1.1.19 Sprinkler system in Stairways

The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. _ fire scenarios*, i.e. 9%.

1.1.1.1.20 Fire-fighting before flashover in Stairways

For a so far uncontrolled Stairway fire to reach flashover, quick fire-fighting must also fail. Based on *0. Fire-fighting before flashover in Cabins* and the smaller amount of fuels and the easier availability in Stairways give reason to believe that the potential for successful fire-fighting efforts before flashover may be slightly larger than in Cabins. Fire-fighting was only judged to be slightly affected by whether a door is open or closed. If the door is closed the fire-fighting crew is estimated to be successful in extinguishing the uncontrolled fire before flashover in 50% of the cases if a door is open and in 40% of the cases if the doors are closed. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later event for internal fire development.

1.1.1.1.21 Summarized event tree for Stairways

All the conditions and failure modes affecting the development of uncontrolled fires in Corridors are summarized in the event tree in Table 4.17.

Table 4.17. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a stairway leading to flashover (FO)

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	1,92%	19,2%	50%				0,01033196	safe
Significant fire	Stairway		50%	97%	91%		0,00893198	safe
					9%	50%	0,00044169	safe
						50%	0,00044169	Unctrl. fire
				3%	91%		0,00047010	safe
					9%	40%	0,00001860	safe
						60%	0,00002790	Unctrl. fire
		80,8%	62,5%				0,05435043	safe
			37,5%	94%	91%		0,02700456	safe
		NO			9%	50%	0,00133539	safe
						50%	0,00133539	Unctrl. fire
		YES		6%	91%		0,00267078	safe
					9%	40%	0,00010566	safe
						60%	0,00015849	Unctrl. fire
				Total frequency of unctrl. fires:			0,00196346	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Stairway space group there is one scenario branch which was identified to imply minor differences between the prescriptive design and the trial alternative designs: internal fire development, which is further elaborated below.

1.1.1.1.22 Internal fire development in Stairways

Differences between the prescriptive design and the base design with regards to a fire in a space in the Stairways group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. There are no differences in the divisions ability to resist fire within the first 60 minutes but in case the fire leads to evacuation there may be difference necessary to consider. The figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Stairways group in the prescriptive design the event tree is presented in Table 4.18.

Table 4.18. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a stairway fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00196346	100%	55%	73%	0,00078833	0	safe
Unctrl. fire			27%	0,00029157	X	Evacuation
		45%	18%	0,00015904	11	Long-lasting fire
			82%	0,00072452	11 + X	L-l. fire + Evac.
			Evacuation:	0,00101609		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Corridors group in the base design, for which the event tree is presented in Table 4.19.

Table 4.19. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a stairway fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00196346	100%	55%	62%	0,00066954	0	safe
Unctrl. fire			38%	0,00041036	X	Evacuation
		45%	10%	0,00008836	11	Long-lasting fire
			90%	0,00079520	36 + X	L-l. fire + Evac.
			Evacuation:	0,00120557		

4.3.2.4. Open deck fire scenarios

The Open deck spaces group represents the conditions in all deck exterior areas on decks 12-16. As described in *Appendix G. Data from the second hazard identification*, these spaces contain a wide variety of fuels and the areas are quite differentiated, as elaborated in paragraph *4.2.4.2. Probability of fire development on open deck*. Here the most significant failure modes affecting the probability of fire development were also identified and used quantify the most relevant differences in fire safety between the prescriptive design and the base design. The probabilities of these failure modes form an event tree and in combination with the associated consequences this will determine the fire risk contribution from the spaces in this group.

All these conditions and failure modes affecting the development of fires in Open deck spaces were quantified above in paragraphs *4.2.4.2. Probability of fire development on open deck* and *4.2.6.2. Consequences of fire development on open deck*. These figures were incorporated in event trees for the prescriptive design, as presented in Table 4.20.

Table 4.20. Event tree with the conditions and failure modes (and associated probabilities) of an open deck space fire in the prescriptive design

	Prob. of fire in space	Rel. deck area	Failure to prev. est.	Failure to prev. dev.	Fail. of pre-loc. col. f-f	Fail. of pre-maj. col. f-f	Fail. to reside	Frequency	Cons.	Description
5,603189	6,50%	40,0%	95%					0,1383565	0	safe
Sign. fire	Open deck	Cat. 1	5%	99%				0,0072091	0	safe
				1%	60%			0,0000437	0	safe
					40%	60%	73%	0,0000128	5	Local collapse
							27%	0,0000047	5 + X	Loc. col. + Evac.
						40%	18%	0,0000021	15	Loc. + Maj. col.
							82%	0,0000096	40 + X	Loc.+Maj.col.+E.
		30,0%	90%					0,0983059	0	Safe
		Cat. 2	10%	95%				0,0103767	0	Safe
				5%	80%			0,0004369	0	Safe
					20%	60%	73%	0,0000478	5	Local collapse
							27%	0,0000177	5 + X	Loc. col. + Evac.
						40%	18%	0,0000079	15	Loc. + Maj. col.
							82%	0,0000358	40 + X	Loc.+Maj.col.+E.
		30,0%	15%					0,0163843	0	safe
		Cat. 3	85%	60%				0,0557067	0	safe
				40%	60%			0,0222827	0	safe
			NO		40%	60%	73%	0,0065065	5	Local collapse
							27%	0,0024065	5 + X	Loc. col. + Evac.
			YES			40%	18%	0,0010696	15	Loc. + Maj. col.
							82%	0,0048725	40 + X	Loc.+Maj.col.+E.
							Evacuation:	0,0073468		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for fire development due to a fire on open deck in the base design, for which the event tree is presented in Table 4.21.

Table 4.21. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from an open deck space fire in the base design

	Prob. of fire in space	Rel. deck area	Failure to prev. est.	Failure to prev. dev..	Fail. of pre-loc. col. f-f	Fail. of pre-maj. col. f-f	Fail. to reside	Frequency	Cons.		Description
5,603189	6,50%	40,0%	95%					0,1383565	0		safe
Sign. fire	Open deck	Cat. 1	5%	75%				0,0054614	0		safe
				25%	15%			0,0002731	0		safe
					85%	20%	73%	0,0002259	5		Local collapse
							27%	0,0000836	5	+ X	Loc. col. + Evac.
						80%	5%	0,0000619	15		Loc. + Maj. col.
							95%	0,0011760	40	+ X	Loc.+Maj.col.+E.
		30,0%	90%					0,0983059	0		Safe
		Cat. 2	10%	70%				0,0076460	0		Safe
				30%	30%			0,0009831	0		Safe
					70%	20%	73%	0,0003349	5		Local collapse
							27%	0,0001239	5	+ X	Loc. col. + Evac.
						80%	5%	0,0000918	15		Loc. + Maj. col.
							95%	0,0017433	40	+ X	Loc.+Maj.col.+E.
		30,0%	15%					0,0163843	0		safe
		Cat. 3	85%	50%				0,0464222	0		safe
				50%	25%			0,0116056	0		safe
			NO		75%	20%	73%	0,0050832	5		Local collapse
							27%	0,0018801	5	+ X	Loc. col. + Evac.
			YES			80%	5%	0,0013927	15		Loc. + Maj. col.
							95%	0,0264607	40	+ X	Loc.+Maj.col.+E.
							Evacuation:	0,0314675			

4.3.2.5. Galley fire scenarios

The Galleys group represents the conditions in galley and pantries, which are located on several of the considered decks. These spaces contain various fuels, such as boxes and bags of food, hot oils, textiles and electrical equipment as described in *Appendix G. Data from the second hazard identification*. They could also contain shelves and other combustible furniture. The most significant identified failure modes in Galley 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 the spaces in this group.

Since Galleys generally don't have any windows to exteriors there was only one scenario branch which was identified to imply differences between the prescriptive design and the trial alternative designs; if an internal fire goes on for more than 60 minutes. Up until then the fire scenarios are assumed the same. The differences are although limited since the divisions surrounding Galleys are generally made A-60, which is not very different from FRD60 from a fire spread perspective. The originating fire which could lead to a scenario where differences could come into play is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment. Assumptions and estimations are further described subsequently and then summarized in an event tree.

1.1.1.1.23 Person present in Galleys

With regards to whether there is anyone present in the space it was assumed that a third of the Galleys in the superstructure are manned around the clock. The rest were assumed to be occupied by cooking or cleaning personnel half of the day. Hence, in all persons are assumed present in Galleys 67% of the time. The probability of a fire in Galleys was although considered strongly linked to whether persons are present. A fire was assessed to be ten times as likely if persons are present in the space. Based on the above the figure was thus updated and in all it was assessed to be a 95% probability of a person present if a fire is initiated.

1.1.1.1.24 Initial manual extinguishment in Galleys

The above affects the probability of failure of first aid with regards to manual extinguishment. If persons (crew) are present in a galley they are assumed to be used to fire events and e.g. to have an idea of where fire extinguishers are located. Furthermore, there are generally several persons in the galleys which makes it difficult for a fire to go unnoticed. Based on this information it was estimated that personnel provides initial manual extinguishment in 80% of the cases where a fire is ignited if they are present. If no one was present in the compartment during fire development, the probability that a fire is manually extinguished in the incipient phase was first set to 0%. This event should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Based on the reasoning in paragraph *4.3.2.1. fire scenarios* the probability of successful fire-fighting at this early stage was assessed to 30%.

1.1.1.1.25 Ventilation in Galleys

The doors to Galleys are generally closed or put up on a magnet with door-closing devices. The doors may although be open due to failure in the door mechanism or due to it being put open, e.g. by crew to provide ventilation or because of heavy usage. A door being open was also identified to be somewhat linked to whether there is a person present. If no one is present the probability was estimated to be 10% that a door is open. If someone is present the likelihood of a door being open was estimated to be 15%. This accounts for several doors in a galley.

In case the doors are closed to a galley of pantry it is possible that the fire will eventually self-extinguish before spreading to other areas, depending on the size of the space, if there are glass panes in doors etc. Altogether, in a fire scenario where all doors are closed, a galley fire is estimated to self-extinguish in 75% of the cases. This is accounted for when considering the probability for fire-fighting below.

1.1.1.1.26 Sprinkler system in Galleys

In Galleys there are generally gas extinguishing systems. These are although placed locally in order to minimize the likelihood of a fire from a certain hazardous object. The failure rate is generally quite a bit higher for this kind of system [40] than for a regular sprinkler system. In this case it is although assumed that this works as input to the probability of a fire in space and the sprinkler system which is also present in Galleys is assumed to work independently. The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.27 Fire-fighting before flashover in Galleys

For a so far uncontrolled Galley fire to reach flashover, quick fire-fighting must also fail. Based on *0. Fire-fighting before flashover in Cabins* and the large amount of fuels and larger area, the potential for successful fire-fighting efforts before flashover was estimated to be similar as for Cabins. Fire-fighting was only judged to be only slightly affected by whether a door is open or closed. If the door is closed the fire-fighting crew is estimated to be successful in extinguishing the uncontrolled fire before flashover in 20% of the cases if a door is open and in 82,5% of the cases if the doors are closed. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later event for internal fire development.

1.1.1.1.28 Summarized event tree for Galleys

All the conditions and failure modes affecting the development of uncontrolled fires in Galleys are summarized in the event tree in Table 4.22.

Table 4.22. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a galley leading to flashover (FO)

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	7,80%	5%	30%				0,00629032	safe
Significant fire	Galley		70%	90%	91%		0,01202079	safe
					9%	82,5%	0,00098082	safe
						17,5%	0,00020805	Unctrl. fire
				10%	91%		0,00133564	safe
					9%	20%	0,00002642	safe
						80%	0,00010568	Unctrl. fire
		95%	80%				0,33268777	safe
			20%	85%	91%		0,06433350	safe
		NO			9%	82,5%	0,00524919	safe
						17,5%	0,00111346	Unctrl. fire
		YES		15%	91%		0,01135297	safe
					9%	20%	0,00022456	safe
						80%	0,00089826	Unctrl. fire
				Total frequency of unctrl. fires:			0,00232545	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Galley space group there is one scenario branch which was identified to imply minor differences between the prescriptive design and the trial alternative designs: internal fire development, which is further elaborated below.

1.1.1.1.29 Internal fire development in Galleys

Differences between the prescriptive design and the base design with regards to a fire in a space in the Galleys group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. There are no differences in the divisions ability to resist fire within the first 60 minutes but in case the fire leads to evacuation there may be difference necessary to consider. The figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Galleys group in the prescriptive design the event tree is presented in Table 4.23.

Table 4.23 Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a galley fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00232545	100%	55%	73%	0,00093367	0	safe
Unctrl. fire			27%	0,00034533	X	Evacuation
		45%	18%	0,00018836	11	Long-lasting fire
			82%	0,00085809	11 + X	L-l. fire + Evac.
			Evacuation:	0,00120342		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Galleys group in the base design, for which the event tree is presented in Table 4.24.

Table 4.24. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a galley fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00232545	100%	55%	62%	0,00079298	0	safe
Unctrl. fire			38%	0,00048602	X	Evacuation
		45%	10%	0,00010465	11	Long-lasting fire
			90%	0,00094181	36 + X	L-l. fire + Evac.
			Evacuation:	0,00142783		

4.3.2.6. Lounge fire scenarios

The Lounges group represents the conditions in moderate sized inside seating areas, such as the Cinema, Card Room, Life Style Room, The Library, Leopard Lounge and Children's area. These spaces generally contain potential fuels such as furniture, plastics, electrical equipment, linings, upholstered materials, textiles, books and other materials as described in *Appendix G. Data from the second hazard identification*. The identified critical factors and the associated target locations in Lounges 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 a lounge 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 the spaces in this group.

For Lounges there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs; one if an internal fire goes on for more than 60 minutes and the other one if a fire spreads to involve exterior sides of the ship. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment and their current state. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the two scenario branches which involve differences between the prescriptive design and the trial alternative designs are described.

1.1.1.1.30 Person present in Lounges

With regards to whether there is anyone present in the space it was assumed that half of the spaces are occupied 10 hours of the day and that half of the spaces are only occupied 4 hours of the day. In all, people were estimated present in Lounges 29% of the time. Furthermore, a fire in Lounges was assumed to be three times as likely to occur if persons are present. Hence the updated probability of a person being present in case of fire was set to 55,3%.

1.1.1.1.31 Initial manual extinguishment in Lounges

The above affects the probability of failure of first aid with regards to manual extinguishment. In a lounge a person was estimated to provide initial manual extinguishment in 35% of the cases where a fire is ignited and a person is present. This is based on that crew, whom are assumed to take greater responsibility than a passenger, will be present in some spaces and that the spaces are easily overlooked. If no one was present in the fire compartment during the fire development, the probability that a fire is manually extinguished in the incipient phase was set to 0%. The above events should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Based on the reasoning in paragraph *4.3.2.1. fire scenarios* and the less amount of fuel in a corridor gave an assessed overall probability of successful fire-fighting at this early stage of 35%. Hence, the aforementioned probabilities were updated to probabilities of failure of manual extinguishment of 42% in case a person is present and of 65% in case no one is present.

1.1.1.1.32 Ventilation in Lounges

The doors to Lounges generally lead to a corridor and are generally closed or kept open on a magnet with door-closing devices, according to regulations. The doors may although be open due to failure in the door mechanism or due to it being put open, e.g. by cleaning personnel, a passenger or an arsonist. A door being open was also identified to be somewhat linked to whether there is a person present. If no one is present the probability was estimated to be 4%, that a door is open. If someone is present the likelihood of a door being open was estimated to be 8% due to the reasons above.

Regarding other potential ventilation openings, 90% of the spaces were estimated to have openings to exteriors, based on an inventory above. These openings are normally covered by closed windows. Furthermore, the doors to these spaces often have glass panes which could potentially break in case of fire. The active ventilation system is generally turned off when fire is detected.

In order to determine the likelihood of window breakage in a cabin, fire simulations were carried out as described in *0.Ventilation in Cabins*. The results show that a cabin window will likely break before a non-ventilated cabin fire self-extinguishes. Lounges are larger and contain more oxygen than a cabin. It was therefore assumed that the simulation results are valid also for Lounges. Therefore, if the compartment has a window it is assumed to always break in case of fire. The cases where the window is closed and nonetheless holds up against the fire and leads to self-extinguishment are assumed accounted for in the probability for successful pre-flashover fire-fighting, as described below.

1.1.1.1.33 Sprinkler system in Lounges

The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.34 Fire-fighting before flashover in Lounges

For a so far uncontrolled Lounge fire to reach flashover, fire-fighting must also fail. The potential for successful fire-fighting efforts before flashover was estimated based on *0. Fire-fighting before flashover in Cabins*. The larger availability of fuels and oxygen but on the other hand a more open space and in some cases spread out fuels gave reason to believe that the probability for successful fire-fighting was similar to in Cabins in case the door is closed. For Lounges, fire-fighting was although judged to be less affected by whether a door is open or closed. If the door is closed the fire-fighting crew was estimated to be successful in extinguishing the uncontrolled fire before flashover in 45% of the cases and if a door is open in 30% of the cases. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later events.

1.1.1.1.35 Summarized event tree for Lounges

All the conditions and failure modes affecting the development of uncontrolled fires in Lounges are summarized in the event tree in Table 4.25.

Table 4.25. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a Lounge leading to flashover (FO)

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	1,53%	44,7%	35%				0,01339399	safe
Significant fire	Lounge		65%	96%	91%		0,02173040	safe
					9%	45%	0,00096712	safe
						55%	0,00118204	Unctrl. fire
				4%	91%		0,00090543	safe
					9%	30%	0,00002686	safe
						70%	0,00006268	Unctrl. fire
		55,3%	58%				0,02734081	safe
			42%	92%	91%		0,01674616	safe
		NO			9%	45%	0,00074530	safe
						55%	0,00091092	Unctrl. fire
		YES		8%	91%		0,00145619	safe
					9%	30%	0,00004321	safe
						70%	0,00010081	Unctrl. fire
				Total frequency of unctrl. fires:			0,00225645	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Lounges space group there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs: internal fire development and fire development on outboard sides, which are further elaborated below.

1.1.1.1.36 Internal fire development in Lounges

Differences between the prescriptive design and the base design concerning a fire in a space in the Lounges group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were incorporated in event trees. For internal fire development due to a fire in a space in the Lounges group on the prescriptive ship the event tree is presented in Table 4.26.

Table 4.26. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a lounge fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00225645	96%	55%	73%	0,00086973	0	Safe
Unctrl. fire			27%	0,00032168	X	Evacuation
		45%	18%	0,00017546	11	Long-lasting fire
			82%	0,00079933	11 + X	Long-lasting fire + Evac.
	4%	32%	73%	0,00002108	0	Safe
			27%	0,00000780	X	Evacuation
		68%	18%	0,00001105	11	Long-lasting fire
			82%	0,00005033	11 + X	Long-lasting fire + Evac.
			Evacuation:	0,00117913		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Lounges group in the base design, for which the event tree is presented in Table 4.27.

Table 4.27 Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a lounge fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00225645	100%	55%	62%	0,00076945	0	safe
Unctrl. fire			38%	0,00047160	X	Evacuation
		45%	10%	0,00010154	11	Long-lasting fire
			90%	0,00091386	36 + X	L-l fire + Maj. col. + Evac.
			Evacuation:	0,00138546		

1.1.1.1.37 Lounge fire development on outboard sides

Differences between the prescriptive design and the base design with regards to a fire in a space in the Lounges group leading to fire development on outboard sides were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For fire development on outboard sides of the ship due to a fire in a space in the Lounges group on the prescriptive ship the event tree is presented in Table 4.28.

Table 4.28 Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a lounge fire in the prescriptive design

Fire dev. on outboard side	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.	Description
0,00225645	67%				0,00151182	0	safe
Unctrl. fire	33%	50%			0,00037231	0	safe
		50%	40%	73%	0,00010872	9	Local collapse
				27%	0,00004021	9 + X	Loc. col. + Evac.
			60%	18%	0,00004021	19	Loc. + Maj. col.
				82%	0,00018318	69 + X	Loc.+Maj.col.+E.
				Evacuation:	0,00022339		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for fire development on outboard sides due to a fire in a space in the Lounges group in the base design, for which the event tree is presented in Table 4.29.

Table 4.29. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a lounge fire in the base design

Fire dev. on outb. sides	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.	Description
0,00225645	34%				0,02524030	0	safe
Unctrl. fire	66%	5%			0,00154246	0	safe
		95%	10%	73%	0,00213940	28	Local collapse
				27%	0,00079128	28 + X	Local col. + Evac.
			90%	5%	0,00131881	98	Loc. + Maj. Col.
				95%	0,02505731	348 + X	Loc.+Maj.Col.+E.
				Evacuation:	0,02584860		

4.3.2.7. Restaurant fire scenarios

The Restaurant group represents the conditions in large inside seating areas, i.e. Garden Café, La Cucina Italian Restaurant, Cagney's Steak House and Spinnaker Lounge. These spaces generally contain potential fuels such as furniture, decorative structures, plastics, electrical equipment, linings, upholstered materials, textiles, books and other materials as described in *Appendix G. Data from the second hazard identification*. The identified critical factors and the associated target locations in Restaurants 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 a restaurant 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 the spaces in this group.

For Restaurants there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs; one if an internal fire goes on for more than 60 minutes and the other one if a fire spreads to involve exterior sides of the ship. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment and their current state. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the two scenario branches which involve differences between the prescriptive design and the trial alternative designs are described.

1.1.1.1.38 Person present in Restaurants

With regards to whether there is anyone present in the space, the conditions are quite different in the spaces. Some spaces are occupied almost always in daytime whilst other spaces are rarely occupied other than in evenings or possibly also for lunch. It was assumed that half of the spaces are occupied 12 hours of the day and that half of the spaces are occupied 6 hours of the day. In all, people were estimated present in Restaurants 37,5% of the time. Furthermore, a fire in Restaurants was assumed to be twice as likely to occur if persons are present. Hence the updated probability of a person being present in case of fire was set to 54,5%.

1.1.1.1.39 Initial manual extinguishment in Restaurants

The above affects the probability of failure of first aid with regards to manual extinguishment. A person present in a restaurant was estimated to provide initial manual extinguishment in 65% of the cases where a fire is ignited. This is based on that many people are generally present and quite often crew, whom are assumed to take greater responsibility than passengers. If no one was present in the fire compartment when fire established, the probability that a fire is manually extinguished in the incipient phase was set to 0%. The former scenario is not judged affected by a potential fast fire-fighting effort but this is included in the estimation above. The latter scenario could although possibly be relieved by a first fire-fighter on call who may quickly attend to the fire. Based on the reasoning in paragraph *4.3.2.1. fire scenarios* and the large amount of fuel and oxygen in a restaurant, the probability of successful fire-fighting at this early stage was estimated to of 20%.

1.1.1.1.40 Ventilation in Restaurants

The doors to Restaurants have restrictions and other potential ventilation openings, such as windows or active ventilation, should always be closed or will close in case of fire. In these large spaces this although has no significant effect since there is undoubtedly enough oxygen provided in the space itself to lead to breakage of windows, which exist in all spaces in this group. The fire development in Restaurants was therefore assumed unaffected by ventilation openings provided at the initiation of a fire.

1.1.1.1.41 Sprinkler system in Restaurants

The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.42 Fire-fighting before flashover in Restaurants

For a so far uncontrolled Restaurant fire to reach flashover, fire-fighting must also fail. Flashover may in this case not be as relevant of a scenario due to the significant size of the space. Nevertheless, the potential for successful fire-fighting efforts before a large fire has developed sufficient to break windows etc. was estimated based on *0. Fire-fighting before flashover in Cabins*. The larger availability of fuels and oxygen but on the other hand a more open space, spread out fuels and higher ceiling gave reason to estimate a probability for successful fire-fighting of 20%. Note that the fact that fire-fighting efforts may prove successful after this event is accounted for in a later events.

1.1.1.1.43 Summarized event tree for Restaurants

All the conditions and failure modes affecting the development of uncontrolled fires in Restaurants are summarized in the event tree in Table 4.30.

Table 4.30. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a restaurant leading to flashover

	Prob. of fire in space	Person present	Failure of manual ext.	Sprinkler failure	Failure of pre-flashover f-f	Frequency	Description
5,603189	3,99%	45,5%	20%			0,02032917	safe
Significant fire	Restaurant		80%	91%		0,07399819	safe
				9%	20%	0,00146370	safe
					80%	0,00585480	Unctrl. fire
		54,5%	65%			0,07913857	safe
			35%	91%		0,03877790	safe
		NO		9%	20%	0,00076704	safe
					80%	0,00306814	Unctrl. fire
		YES		Total freq. of unctrl. fires:		0,00892294	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Restaurants space group there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs: internal fire development and fire development on outboard sides, which are further elaborated below.

1.1.1.1.44 Internal fire development in Restaurants

Differences between the prescriptive design and the base design with regards to a fire in a space in the Restaurants group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Restaurants group on the prescriptive ship the event tree is presented in Table 4.31.

Table 4.31. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a restaurant fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00892294	91%	55%	73%	0,00326013	0	Safe
Unctrl. fire			27%	0,00120580	X	Evacuation
		45%	18%	0,00065771	11	Long-lasting fire
			82%	0,00299624	11 + X	Long-lasting fire + Evac.
	9%	32%	73%	0,00018760	0	Safe
			27%	0,00006938	X	Evacuation
		68%	18%	0,00009830	11	Long-lasting fire
			82%	0,00044779	11 + X	Long-lasting fire + Evac.
			Evacuation:	0,00471921		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Restaurants group in the base design, for which the event tree is presented in Table 4.32.

Table 4.32. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a restaurant fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00892294	100%	55%	62%	0,00304272	0	safe
Unctrl. fire			38%	0,00186490	X	Evacuation
		45%	10%	0,00040153	11	Long-lasting fire
			90%	0,00361379	36 + X	L-l fire + Maj. col. + Evac.
			Evacuation:	0,00547869		

1.1.1.1.45 Restaurant fire development on outboard sides

Differences between the prescriptive design and the base design with regards to a fire in a space in the Restaurants group leading to fire development on outboard sides were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For fire development on outboard sides of the ship due to a fire in a space in the Restaurants group on the prescriptive ship the event tree is presented in Table 4.33.

Table 4.33. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a restaurant fire in the prescriptive design

Fire dev. on outboard side	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.	Description
0,00892294	57%				0,00508608	0	safe
Unctrl. fire	43%	50%			0,00191843	0	safe
		50%	40%	73%	0,00056018	9	Local collapse
				27%	0,00020719	9 + X	Loc. col. + Evac.
			60%	18%	0,00020719	19	Loc. + Maj. col.
				82%	0,00094387	69 + X	Loc.+Maj.col.+E.
				Evacuation:	0,00115106		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for fire development on outboard sides due to a fire in a space in the Restaurants group in the base design, for which the event tree is presented in Table 4.34.

Table 4.34. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a restaurant fire in the base design

Fire dev. on outb. sides	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.	Description
0,00892294	21%				0,00187382	0	safe
Unctrl. fire	79%	5%			0,00035246	0	safe
		95%	10%	73%	0,00048886	28	Local collapse
				27%	0,00018081	28 + X	Local col. + Evac.
			90%	5%	0,00030135	98	Loc. + Maj. Col.
				95%	0,00572565	348 + X	Loc.+Maj.Col.+E.
				Evacuation:	0,00590646		

4.3.2.8. Store-room fire scenarios

The Store-room group represents the conditions in different kinds of store-rooms (store, hotel store, laundrette, linen store, food store etc.) spread out on many of the decks. These spaces contain various fuels, such as boxes and bags of food, bed linen and many other textiles, minor electrical equipment and miscellaneous items, as described in *Appendix G. Data from the second hazard identification*. They generally also contain shelves and other combustible furniture. The most significant identified failure modes in a Store-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 the spaces in this group.

Since Store-rooms do not have any windows to exteriors there was only one scenario branch which was identified to imply differences between the prescriptive design and the trial alternative designs; if an internal fire goes on for more than 60 minutes. Up until then the fire scenarios are assumed the same. The originating fire which could lead to a scenario where differences could come into play is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment. Assumptions and estimations are further described subsequently and then summarized in an event tree.

1.1.1.1.46 Person present in Store-rooms

With regards to whether there is anyone present in the space it was assumed that people occupy a third of the spaces 20 hours a day and that the other spaces are occupied not more than an average of 4 hours per day. The probability of a fire in Store-rooms was although considered linked to whether persons are present. The initiation of a fire was assessed unaffected by whether persons are present in the space or not. Based on this assumption there was estimated to be a 39% probability of a person present if a fire is initiated.

1.1.1.1.47 Initial manual extinguishment in Store-rooms

The above affects the probability of failure of first aid with regards to manual extinguishment. In this case manual extinguishment could be to take action and close an otherwise open door or to put out the fire in the space. Only crew are supposed to occupy these kind of spaces, whom should take a greater responsibility to put out a fire than passengers. Based on the above it was estimated that personnel provides initial manual extinguishment in 65% of the cases where a fire is ignited if they are present. If no one was present in the compartment during fire development, the probability that a fire is manually extinguished in the incipient phase was first set to 0%. The above events should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Based on the reasoning in paragraph *4.3.2.1. fire scenarios* the probability of successful fire-fighting at this early stage was assessed to 30%. Hence, the aforementioned probabilities were updated to probabilities of failure of manual extinguishment of 25% in case a person is present and of 70% in case no one is present.

1.1.1.1.48 Ventilation in Store-rooms

The doors to Store-rooms are generally closed and should have door-closing devices, in accordance with regulations. The doors may although be open due to failure in the door mechanism or due to it being put open, e.g. by and arsonist or by crew to provide ventilation or because of heavy usage. A door being open was not considered to be very likely but was identified to be somewhat linked to whether there is a person present. If no one is present the probability was estimated to be 2% that a door is open. If someone is present the likelihood of a door being open was estimated to be 3%. If the door is closed the fire will self-extinguish.

1.1.1.1.49 Sprinkler system in Store-rooms

In Store-rooms there is generally a sprinkler system. The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.50 Fire-fighting before flashover in Store-rooms

For a so far uncontrolled Store-room fire to reach flashover, quick fire-fighting must also fail. Based on *0. Fire-fighting before flashover in Cabins* and the large amount of fuels and small area the potential for successful fire-fighting efforts before flashover was estimated to be somewhat higher than for Cabins if the door is open. Fire-fighting crew is estimated to be successful in extinguishing an uncontrolled Store-room fire before flashover in 30% of the cases if the door is open. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later event for internal fire development.

1.1.1.1.51 Summarized event tree for Store-rooms

All the conditions and failure modes affecting the development of uncontrolled fires in Store-rooms are summarized in the event tree in Table 4.35.

Table 4.35. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a store-room leading to flashover

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-flashover f-f	Frequency	Description
5,603189	1,58%	61,1%	30%				0,01625105	safe
Significant fire	Store-room		70%	98%			0,00000000	safe
				2%	91%		0,00069013	safe
					9%	30%	0,00002048	safe
						70%	0,00004778	Unctrl. fire
		38,9%	75,5%				0,02603848	Safe
			24,5%	96%			0,00000000	Safe
				4%	91%		0,00030756	Safe
		NO			9%	30%	0,00000913	Safe
						70%	0,00002129	Unctrl. fire
		YES			Total freq. of unctrl. fires:		0,00006907	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Store-room space group there is one scenario branch which was identified to imply minor differences between the prescriptive design and the trial alternative designs: internal fire development, which is further elaborated below.

1.1.1.1.52 Internal fire development in Store-rooms

Differences between the prescriptive design and the base design with regards to a fire in a space in the Store-rooms group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. There are no differences in the divisions ability to resist fire within the first 60 minutes but in case the fire leads to evacuation there may be difference necessary to consider. The figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Store-rooms group in the prescriptive design the event tree is presented in Table 4.36.

Table 4.36. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a store-room fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00006907	5%	75%	73%	0,00000189	0	safe
Unctrl. fire			27%	0,00000070	X	Evacuation
		25%	18%	0,00000016	11	Long-lasting fire
			82%	0,00000071	11 + X	L-l. fire + Evac.
	95%	48%	73%	0,00002299	0	safe
			27%	0,00000850	X	Evacuation
		52%	18%	0,00000614	11	Long-lasting fire
			82%	0,00002798	11 + X	L-l. fire + Evac.
			Evacuation:	0,00003789		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Store-rooms group in the base design, for which the event tree is presented in Table 4.37.

Table 4.37. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a store-room fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00006907	100%	75%	62%	0,00003212	0	safe
Unctrl. fire			38%	0,00001969	X	Evacuation
		25%	10%	0,00000173	11	Long-lasting fire
			90%	0,00001554	36 + X	L-l. fire + Evac.
			Evacuation:	0,00003523		

4.3.2.9. Technical space fire scenarios

The Technical spaces group represents the conditions in e.g. the Bridge, Communications Centre, Radio room and Arcade. These spaces generally contain a lot of electrical equipment potential fuels such as electrical equipment, cables, plastic covers, carpet and linings, furniture, books and other materials as described for these spaces in *Appendix G. Data from the second hazard identification*. The identified critical factors and the associated target locations in Technical spaces 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 a technical 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 the spaces in this group.

For Technical spaces there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs; one if an internal fire goes on for more than 60 minutes and the other one if a fire spreads to involve exterior sides of the ship. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment and their current state. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the two scenario branches which involve differences between the prescriptive design and the trial alternative designs are described.

1.1.1.1.53 Person present in Technical spaces

With regards to whether there is anyone present in the space, the conditions are quite different in the spaces in this group. Some spaces are in principle always occupied whilst other spaces are occupied mainly in day time. It was assumed that half of the spaces are occupied around the clock and that the other half of the spaces are occupied 8 hours of the day. In all, people were estimated present in Technical spaces 67% of the time. The initiation of a fire in a Technical spaces was assumed to be independent of whether people are present, mainly due to the high potential for electrical failure as an ignition source.

1.1.1.1.54 Initial manual extinguishment in Technical spaces

The above affects the probability of failure of first aid with regards to manual extinguishment. Mainly highly ranked crew will be present in the technical spaces and they are assumed to be well trained to fire events and to have an idea of where fire extinguishers are located. They are also assumed to take great responsibility in case of a fire. Based on this information it was estimated that personnel provides initial manual extinguishment in 90% of the cases where a fire is ignited if they are present. If no one was present in the compartment during fire development, the probability that a fire is manually extinguished in the incipient phase was first set to 0%. This event should although also include the possibility that a first fire-fighter on call may quickly attend to the fire or that even the fire-fighting crew may even be at the scene before it develops significantly, e.g. in case of a smouldering fire and the first fire-fighter is off duty. Based on the reasoning in paragraph *4.3.2.1. fire scenarios* the probability of successful fire-fighting at this early stage was assessed to 30%.

1.1.1.1.55 Ventilation in Technical spaces

The doors to Technical spaces generally lead to a corridor and are generally closed or kept open on a magnet with door-closing devices, according to regulations. In rare occasions a door may although be open due to failure in the door mechanism or due to it being put open, e.g. by cleaning personnel, a passenger or an arsonist. A door being open was also identified to be somewhat linked to whether there is a person present. In all it was although estimated quite unlikely that a door is open in most of the spaces in this group, considering the personnel occupying the spaces. If no one is present the probability was estimated to be 2%, that a door is open. If someone is present the likelihood of a door being open was estimated to be 3%.

Regarding other potential ventilation openings, 80% of the spaces were estimated to have openings to exteriors, based on an inventory above. These openings are normally covered by windows. The active ventilation system is generally turned off when fire is detected.

In order to determine the likelihood of window breakage in a cabin, fire simulations were carried out as described in *0.Ventilation in Cabins*. The results show that a cabin window will likely break before a non-ventilated cabin fire self-extinguishes. The spaces with windows in this group are generally larger and contain more oxygen than a cabin. It was therefore assumed that the simulation results are valid also for Technical spaces with windows. Therefore, if the compartment has a window it is assumed to always break in case of fire. The cases where the space has no windows or has windows which are closed and holds up against the fire and leads to self-extinguishment of the fire are accounted for in the probability for successful pre-flashover fire-fighting, as described below.

1.1.1.1.56 Sprinkler system in Technical spaces

The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.57 Fire-fighting before flashover in Technical spaces

For a so far uncontrolled Technical space fire to reach flashover, swift fire-fighting must also fail. The potential for successful fire-fighting efforts before flashover was estimated based on *0. Fire-fighting before flashover in Cabins*. Some of the spaces in this category were considered quite similar to a cabin whilst other spaces have larger availability of fuels and oxygen. The latter spaces are on the other hand more open and have more spread out fuels. Furthermore, 20% of the spaces have no openings except a door, which will make a fire self-extinguish if the door is closed. Many of the spaces also have very high priority which may increase the probability of swift and successful fire-fighting. In all, if the door is closed the fire-fighting crew was calculated to be successful in extinguishing the fire (or self-extinguishment occurs) before flashover in 70% of the cases and if a door is open in 25% of the cases. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later events.

1.1.1.1.58 Summarized event tree for Technical spaces

All the conditions and failure modes affecting the development of uncontrolled fires in Technical spaces are summarized in the event tree in Table 4.38.

Table 4.38. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a technical space leading to flashover

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	0,75%	33,3%	30%				0,00417851	safe
Significant fire	Tech. space		70%	98%	91%		0,00869491	safe
					9%	75%	0,00064495	safe
						25%	0,00021498	Unctrl. fire
				2%	91%		0,00017745	safe
					9%	30%	0,00000526	safe
						70%	0,00001228	Unctrl. fire
		66,7%	90%				0,02507480	safe
			10%	97%	91%		0,00245928	safe
		NO			9%	75%	0,00018242	safe
						25%	0,00006081	Unctrl. fire
		YES		3%	91%		0,00007606	safe
					9%	30%	0,00000226	safe
						70%	0,00000527	Unctrl. fire
				Total frequency of unctrl. fires:			0,00029334	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Technical spaces space group there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs: internal fire development and fire development on outboard sides, which are further elaborated below.

1.1.1.1.59 Internal fire development in Technical spaces

Differences between the prescriptive design and the base design with regards to a fire in a space in the Technical spaces group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Technical spaces group on the prescriptive ship the event tree is presented in Table 4.39.

Table 4.39. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a technical space fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,05608956	32,5%	55%	73%	0,00009422	0	Safe
Unctrl. fire			27%	0,00003485	X	Evacuation
		45%	18%	0,00001901	11	Long-lasting fire
			82%	0,00008659	11 + X	Long-lasting fire + Evac.
	67,5%	32%	73%	0,00001370	0	Safe
			27%	0,00000507	X	Evacuation
		68%	18%	0,00000718	11	Long-lasting fire
			82%	0,00003271	11 + X	Long-lasting fire + Evac.
			Evacuation:	0,00015923		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Technical spaces group in the base design, for which the event tree is presented in Table 4.40.

Table 4.40. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a technical space fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,05608956	100%	55%	62%	0,00010003	0	safe
Unctrl. fire			38%	0,00006131	X	Evacuation
		45%	10%	0,00001320	11	Long-lasting fire
			90%	0,00011880	36 + X	L-l fire + Maj. col. + Evac.
			Evacuation:	0,00018011		

1.1.1.1.60 Technical space fire development on outboard sides

Differences between the prescriptive design and the base design with regards to a fire in a space in the Technical spaces group leading to fire development on outboard sides were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For fire development on outboard sides of the ship due to a fire in a space in the Technical spaces group on the prescriptive ship the event tree is presented in Table 4.41.

Table 4.41. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a technical space fire in the prescriptive design

Fire dev. on outboard side	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.		Description
0,05608956	71%				0,00019067	0		safe
Unctrl. fire	29%	50%			0,00005133	0		safe
		50%	40%	73%	0,00001499	9		Local collapse
				27%	0,00000554	9	+ X	Loc. col. + Evac.
			60%	18%	0,00000554	19		Loc. + Maj. col.
				82%	0,00002526	69	+ X	Loc.+Maj.col.+E.
				Evacuation:	0,00003080			

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for fire development on outboard sides due to a fire in a space in the Technical spaces group in the base design, for which the event tree is presented in Table 4.42.

Table 4.42. Event tree with conditions and failure modes (and associated probabilities) of fire development on outboard sides from a technical space fire in the base design

Fire dev. on outb. sides	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.		Description
0,05608956	45%				0,00010560	0		safe
Unctrl. fire	55%	5%			0,00000939	0		safe
		95%	10%	73%	0,00001302	28		Local collapse
				27%	0,00000482	28	+ X	Local col. + Evac.
			90%	5%	0,00000803	98		Loc. + Maj. Col.
				95%	0,00015249	348	+ X	Loc.+Maj.Col.+E.
				Evacuation:	0,00015731			

4.3.2.10. Machinery space fire scenarios

The Machinery spaces group represents the conditions in e.g. emergency generator spaces, AC spaces, technical spaces, chemical storages pool management spaces etc. These spaces are generally contain HVAC equipment and various electrical equipment, cables and insulation materials, plastics, diesel, cooling media and other oils, chemicals and other materials, as described for these spaces in *Appendix G. Data from the second hazard identification*. The identified critical factors and the associated target locations in Machinery spaces 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 a 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 the spaces in this group.

For Machinery spaces there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs; one if an internal fire goes on for more than 60 minutes and the other one if a fire spreads to involve exterior sides of the ship. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled fire reaching flashover. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Failure of ventilation restriction;
- Sprinkler failure; and
- Failure of pre-flashover fire-fighting.

In the event tree for an uncontrolled fire formed based on the above failure modes, another difference was also considered between the prescriptive design and the base design. Namely the increased potential for a fire to reach flashover due to the improved thermal insulation provided when replacing non-insulated steel divisions with FRD60 divisions. Furthermore, the probability of manual extinguishment as well as of door failure are assumed to depend on whether anyone is present at the time of fire establishment and their current state. Assumptions and estimations are further described subsequently and then summarized in an event tree. Thereafter the two scenario branches which involve differences between the prescriptive design and the trial alternative designs are described.

1.1.1.1.61 Person present in Machinery spaces

With regards to whether there is anyone present in the space it was assumed that 20% of the spaces are rarely occupied (1 hour/day on average). The other spaces were assumed occupied 8 hours of the day (33%). In all people were thus assumed to occupy the spaces 20.8% of the time. The initiation of a fire in Machinery spaces was assumed to be independent of whether people are present, mainly due to the high potential for electrical failure as an ignition source.

1.1.1.1.62 Initial manual extinguishment in Machinery spaces

The above affects the probability of failure of first aid with regards to manual extinguishment. Only crew will be present in the machinery spaces and they are assumed to be well trained to fire events and to have an idea of where fire extinguishing equipment is located. They are also assumed to take responsibility in case of a fire and if they are not in the space the persons responsible of the space will likely attend the space without delay. However, considering the fire growth potential of many of the fuels in the spaces, a fire may be hard to extinguish before it is well-established. Based on the above it was estimated that personnel provides initial manual extinguishment in 35% of the cases where a fire is ignited if they are present. If no one was present in the compartment during fire development, the probability that a fire is manually extinguished in the incipient phase was first set to 0%. However, the above events should also include the possibility that a the crew responsible of the space or a first fire-fighter on call may quickly attend to a fire which is not growing as fast as some of the fuels. Based on above and on the reasoning in paragraph *4.3.2.1. fire scenarios* the probability of successful fire-fighting at this early stage was assessed to 15%. Hence, the aforementioned probabilities were updated to probabilities of failure of manual extinguishment of 55% in case a person is present and of 85% in case no one is present.

1.1.1.1.63 Ventilation in Machinery spaces

The doors to Machinery spaces generally are generally kept closed. In rare occasions a door may although be open due to failure in the door mechanism or due to it being put open, e.g. by crew to provide ventilation or by an arsonist. A door being open was also identified to be somewhat linked to whether there is a person present. If no one is present the probability was estimated to be 2% that a door is open. If someone is present the likelihood of a door being open was estimated to be 3%. Based on an inventory above 10% of the spaces in this group were estimated to have openings to exteriors, which considers the doors. No windows generally exist. In case the doors are closed, some of the spaces are although large enough to give a large fire with the oxygen provided in the space. Other spaces are small and would lead to self-extinguishment of the fire in case the doors are closed. Furthermore, some of the spaces also have some kind of air intake provided, which should although close in case of fire. In all it was assumed that a quarter of the spaces are large and the rest of them are small. For the large spaces it was assumed that a fire continue to develop with the oxygen provided by air intakes whilst the small spaces would give self-extinguishment. This is accounted for in the probability for successful pre-flashover fire-fighting, as described below.

1.1.1.1.64 Sprinkler system in Machinery spaces

The probability of sprinkler system failure is assumed to be equivalent to that determined for Cabins in paragraph *4.3.2.1. fire scenarios*, i.e. 9%.

1.1.1.1.65 Fire-fighting before flashover in Machinery spaces

For a so far uncontrolled Machinery space fire to reach flashover, swift fire-fighting must also fail. The potential for successful fire-fighting efforts before flashover was estimated based on *4.3.2.1. fire scenarios*. The size of the spaces in this group is although much more varied than in the Cabins group. Furthermore, there are many fuels with great fire growth potential and a fire may therefore be hard to extinguish before flashover. Furthermore, two thirds of the spaces were estimated to be small and to give self-extinguishment of a fire if the door is closed. In all, if the door is closed the fire-fighting crew was calculated to be successful in extinguishing the fire (or self-extinguishment occurs) before flashover in 80% of the cases and if a door is open in 20% of the cases. Note that the fact that fire-fighting efforts may prove successful after flashover is accounted for in a later events.

The above figures are valid for the prescriptive design. For the base design consideration must also be made to that a fire may faster reach flashover due to the improved thermal insulation and better containment of heat, as elaborated in *4.2.2. Flashover*. Based on inventories above it was assessed that in 95% of the spaces there are sufficient differences with regards to thermal insulation in the divisions to give this effect and 25% of the spaces in this group contain the necessary fuels. Furthermore, the considered effects are only judged relevant in case the space is small (67%) and hence if the door is open (since the fire will otherwise self-extinguish). In the total of 16% of the cases where this effect is relevant, the probability of successful fire-fighting before flashover was reduced to 0%. Hence, an overall success rate of fire-fighting before flashover of 17% in the base design (i.e. the difference is insignificant and well within the boundaries of uncertainty of the figures).

1.1.1.1.66 Summarized event tree for Machinery spaces

All the conditions and failure modes affecting the development of uncontrolled fires in Machinery spaces in the prescriptive design are summarized in the event tree in Table 4.43.

Table 4.43. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a machinery space leading to flashover in the prescriptive design

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	1,26%	72,5%	15%				0,00767802	safe
Significant fire	Mach. space		85%	98%	91%		0,03880113	safe
					9%	80%	0,00306998	safe
						20%	0,00076749	Unctrl. fire
				2%	91%		0,00079186	safe
					9%	20%	0,00001566	safe
						80%	0,00006265	Unctrl. fire
		27,5,8%	45%				0,00868852	safe
			55%	97%	91%		0,00946887	safe
		NO			9%	80%	0,00074919	safe
						20%	0,00018730	Unctrl. fire
		YES		3%	91%		0,00029285	safe
					9%	20%	0,00000579	safe
						80%	0,00002317	Unctrl. fire
				Total frequency of unctrl. fires:			0,00104061	

All the conditions and failure modes affecting the development of uncontrolled fires in Machinery spaces in the base design are summarized in the event tree in Table 4.44.

Table 4.44. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a machinery space leading to flashover in the base design

	Prob. of fire in space	Person present	Failure of manual ext.	Door failure	Sprinkler failure	Failure of pre-FO f-f	Frequency	Description
5,603189	1,26%	72,5%	15%				0,00767802	safe
Significant fire	Mach. space		85%	98%	91%		0,03880113	safe
					9%	80%	0,00306998	safe
						20%	0,00076749	Unctrl. fire
				2%	91%		0,00079186	safe
					9%	17%	0,00001317	safe
						83%	0,00006514	Unctrl. fire
		27,5,8%	45%				0,00868852	safe
			55%	97%	91%		0,00946887	safe
		NO			9%	80%	0,00074919	safe
						20%	0,00018730	Unctrl. fire
		YES		3%	91%		0,00029285	safe
					9%	17%	0,00000487	safe
						83%	0,00002409	Unctrl. fire
				Total frequency of unctrl. fires:			0,00104403	

The following events depend on the conditions in the prescriptive design and trial alternative designs. For the Machinery spaces space group there are two scenario branches which were identified to imply differences between the prescriptive design and the trial alternative designs: internal fire development and fire development on outboard sides, which are further elaborated below.

1.1.1.1.67 Internal fire development in Machinery spaces

Differences between the prescriptive design and the base design with regards to a fire in a space in the Machinery spaces group leading to internal fire development were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For internal fire development due to a fire in a space in the Machinery spaces group on the prescriptive ship the event tree is presented in Table 4.45.

Table 4.45. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a machinery space fire in the prescriptive design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00104061	5%	75%	73%	0,00002849	0	Safe
Unctrl. fire			27%	0,00001054	X	Evacuation
		25%	18%	0,00000234	11	Long-lasting fire
			82%	0,00001067	11 + X	Long-lasting fire + Evac.
	95%	32%	73%	0,00023093	0	Safe
			27%	0,00008541	X	Evacuation
		68%	18%	0,00012100	11	Long-lasting fire
			82%	0,00055123	11 + X	Long-lasting fire + Evac.
			Evacuation:	0,00065785		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal fire development due to a fire in a space in the Machinery spaces group in the base design, for which the event tree is presented in Table 4.46.

Table 4.46. Event tree with the conditions and failure modes (and associated probabilities) of internal fire development from a machinery space fire in the base design

Internal fire development	Failure of lim. fire spread	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00104403	100%	75%	62%	0,00048547	0	safe
Unctrl. fire			38%	0,00029755	X	Evacuation
		25%	10%	0,00002610	11	Long-lasting fire
			90%	0,00023491	36 + X	L-l fire + Maj. col. + Evac.
			Evacuation:	0,00053245		

1.1.1.1.68 Machinery space fire development on outboard sides

Differences between the prescriptive design and the base design with regards to a fire in a space in the Machinery spaces group leading to fire development on outboard sides were quantified above in section *4.2 Quantification of fire hazards affecting the risk* assessment. These figures were suitably incorporated in event trees. For fire development on outboard sides of the ship due to a fire in a space in the Machinery spaces group on the prescriptive ship the event tree is presented in Table 4.47.

Table 4.47. Event tree with the conditions and failure modes (and associated probabilities) of fire development on outboard sides from a machinery space fire in the prescriptive design

Fire dev. on outboard side	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.		Description
0,00104061	96%				0,00099899	0		safe
Unctrl. fire	4%	50%			0,00002081	0		safe
		50%	40%	73%	0,00000608	9		Local collapse
				27%	0,00000225	9	+ X	Loc. col. + Evac.
			60%	18%	0,00000225	19		Loc. + Maj. col.
				82%	0,00001024	69	+ X	Loc.+Maj.col.+E.
				Evacuation:	0,00001249			

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for fire development on outboard sides due to a fire in a space in the Machinery spaces group in the base design, for which the event tree is presented in Table 4.48.

Table 4.48. Event tree with conditions and failure modes (and associated probabilities) of fire development on outboard sides from a machinery space fire in the base design

Fire dev. on outb. sides	Failure to prevent outb. f.d.	Failure of pre-local col. f.f.	Failure of pre-major col. f.f.	Failure to reside on ship	Frequency	Cons.		Description
0,00104403	92%				0,00096050	0		safe
Unctrl. fire	8%	5%			0,00000418	0		safe
		95%	10%	73%	0,00000579	28		Local collapse
				27%	0,00000214	28	+ X	Local col. + Evac.
			90%	5%	0,00000357	98		Loc. + Maj. Col.
				95%	0,00006784	348	+ X	Loc.+Maj.Col.+E.
				Evacuation:	0,00006998			

4.3.2.11. Funnel and casing fire scenarios

The Funnel and casing group simply represents the conditions in the casing that runs from the engine room up vertically through the ship and ends in the funnel. This vertical space mainly contains different kinds of pipes and not much of other combustibles except potentially some rags, electrical equipment and cables, as described for in *Appendix G. Data from the second hazard identification*. The identified critical factors and the associated target locations in Funnel and casings 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 a funnel and casing 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 the spaces in this group.

For the casing there is one scenario branch which was identified to imply differences between the prescriptive design and the trial alternative designs; if an engine room fire goes on for more than 60 minutes. Up until then the fire scenarios are assumed the same. The originating fire which could lead to such scenarios is an uncontrolled engine room fire large enough to spread to and affect the casing. The probability of such a fire is determined by the probabilities of a number of failure modes which were identified as significant. These failure modes are:

- Failure of manual extinguishment;
- Sprinkler failure;
- Failure of ventilation restriction; and
- Failure of pre-flashover fire-fighting.

Assumptions and estimations are further described subsequently. Thereafter the scenario branch which involves differences between the prescriptive design and the trial alternative designs is described.

1.1.1.1.69 Initial manual extinguishment in engine rooms

In these large engine rooms crew is always attending the equipment and ready to respond to any alarms. Furthermore, the crew should have significant training for fire events and know about the fire hazards and potential fire scenarios. Nevertheless, the fires initiated in an engine room may be difficult to extinguish. In all it was estimated that 50% of the engine room fires are manually extinguished at an early stage.

1.1.1.1.70 Sprinkler system in engine room

In case manual extinguishment fails the fire may continue to develop. The installed semi-redundant automatic extinguishing system was then assumed to be functional and effective in 98% of the cases.

1.1.1.1.71 Ventilation in engine room

If the sprinkler system does not function, closure of all ventilation openings may still quench the fire. This was assumed to occur in 50% of the fires which have continued this far.

1.1.1.1.72 Early fire-fighting in engine room

For a so far uncontrolled engine room fire to continue to develop, fire-fighting must also fail. The engine rooms are rather sizable and the fuels generally consist of flammable liquids in combination with high pressure pipes etc., which may complicate fire-fighting. Nevertheless, fire-fighting was estimated to be successful at an early stage in 40% of the cases.

1.1.1.1.73 Summarized event tree for engine room fires

The above conditions and failure modes affecting the development of uncontrolled fires in engine rooms are summarized in the event tree in Table 4.49.

Table 4.49. Event tree with the conditions and failure modes (and associated probabilities) of a fire in a machinery space leading to flashover in the prescriptive design

	Probability of fire in space	Failure of manual ext.	Failure of s-r sprinkler	Failure of vent. ctrl.	Failure of early f-f	Frequency	Description
5,603188816	42,92%	50%				1,20239161	safe
Significant fire	Funnel and casing	50%	98%			1,17834378	safe
			2%	50%		0,01202392	safe
				50%	40%	0,00480957	safe
					60%	0,00721435	Unctrl. Fire

The following events affecting the FRD60 casing depend on the conditions in the prescriptive design and trial alternative designs. For the casing there was one scenario branch which was identified to possibly imply differences between the prescriptive design and the trial alternative designs: prolonged fire, which is further elaborated below.

1.1.1.1.74 Prolonged fire in casing

In addition to the assumptions above it was further assumed that only 10% of the uncontrolled fires would be extreme enough to sufficiently affect the casing in FRD60 (at least 10 decks further up). In case of such prolonged fire, fire-fighting efforts were assumed effective within 60 minutes in 70% of the continuing fires.

No significantly different consequences were identified between the prescriptive and base design. The casing is not load-bearing for any other surrounding structure and therefore there will be no major collapse due to deterioration of the casing. Fire may spread after 60 minutes in both the prescriptive design and the base design. The only potential difference in consequences may be an increased amount of toxic gases or very local collapse. After this time this is although considered to have a very small effect. In all, the consequences of this scenario were assumed to correspond to approximately 25% (2.8) of the fatalities from other internal fire scenarios. In case of a prolonged fire scenario in the base design there were assumed to be another 5% (1.2) of the casualties estimated from other prolonged internal fire scenarios leading to evacuation in the base design.

Since the potential consequences from this fire scenario were estimated essentially equal, the likelihood of abandonment was judged not to be any different on the two ships. Furthermore, the probability of abandonment of the ship in case of an extreme engine room fire scenario was assumed to stand in relation to the probability of abandonment in other fire scenarios, as elaborated in paragraph *4.2.7.1. Failure to reside on ship*. There it was assessed that if fire-fighting efforts are later proven successful, on a prescriptive ship abandonment will nevertheless take place in 27% of the cases. If fire-fighting efforts are not successful, evacuation was assessed to take place in 82% of the cases on a prescriptive ship. In the base design the corresponding figures were assessed to be 38% and 90%, respectively. Based on the above, the probability of abandonment in case of a in case of an extreme engine room fire was estimated to be 64% or 96% depending on whether fire-fighting is successful or not.

These figures were suitably incorporated in event trees. For internal engine room fire affecting the casing on the prescriptive ship the event tree is presented in Table 4.50.

Table 4.50. Event tree with the conditions and failure modes (and associated probabilities) of internal fire affecting the casing in the prescriptive design

Internal fire development	Failure of limited fire	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00721435	90,0%			0,00649291	0	safe
Unctrl. fire	10,0%	70%	37%	0,00018433	0	safe
			64%	0,00032068	X	Evacuation
		30%	9%	0,00001948	2,8	Long-lasting fire
			91%	0,00019695	2,8 + X	L-l fire + Evac.
			Evacuation:	0,00051763		

Note that where one of the outcomes of a scenario is evacuation (marked blue) the event tree presented in Table 4.6 follows. The same is the case for internal engine room fire affecting the casing in the base design, for which the event tree is presented in Table 4.51.

Table 4.51. Event tree with the conditions and failure modes (and associated probabilities) of internal fire affecting the casing in the base design

Internal fire development	Failure of limited fire	Failure of f-f within 60 min	Failure to reside on ship	Frequency	Consequence	Description
0,00721435	90,0%			0,00649291	0	safe
Unctrl. fire	10,0%	70%	37%	0,00018433	0	safe
			64%	0,00032068	X	Evacuation
		30%	9%	0,00001948	2,8	Long-lasting fire
			91%	0,00019695	4,0 + X	L-l fire + Evac.
			Evacuation:	0,00051763		

4.3.3. Summarized data for evacuation

As described in paragraph *4.2.7.4. Summarized event tree for evacuation*, the frequency of evacuation per ship year due to superstructure fire stems from all of the fire scenarios elaborated above. The frequencies of evacuation were summarized for the prescriptive design and the base design and the total relative number of escalating fires was determined. For the prescriptive design the results are presented in Table 4.52.

Table 4.52. Summarized figures working as input to the evacuation event tree in *Table 4.6* for the prescriptive design (frequencies per ship-year)

	Frequency of fire	Frequency of evacuation	Prob. of evac. in case of fire in space	Total prob. of evac. in case of fire	Tot. prob. of fire escalating
5,603189	1,70314	0,038695	2,27%	1,0209%	21,49%
Sign. fire	Cabin			Evacuation [per s-y]	78,51%
	0,07665	0,000250	0,33%		
	Corridor				
	0,10762	0,001016	0,94%		
	Stairway				
	0,36410	0,007347	2,02%		NO
	Open deck		-		
	0,43683	0,001203	0,28%		
	Galley				YES
	0,08561	0,001403	1,64%		
	Lounges				
	0,22340	0,005870	2,63%		
	Restaurants				
	0,08866	0,000038	0,04%		
	Store-rooms				
	0,04179	0,000190	0,45%		
	Techn. space				
	0,07060	0,000670	0,95%		
	Mach. space				
	2,40478	0,000518	0,02%		
	F and casing				

For the base design the fire scenarios leading to evacuation resulted in the figures presented in Table 4.53.

Table 4.53. Summarized figures working as input to the evacuation event tree in *Table 4.6* for the base design (frequencies per ship-year)

	Frequency of fire	Frequency of evacuation	Prob. of evac. in case of fire in space	Total prob. of evac. in case of fire	Tot. prob. of fire escalating
5,603189	1,70314	0,060288	3,54%	1,9659%	17,11%
Sign. fire	Cabin			Evacuation	82,89%
	0,07665	0,000254	0,33%		
	Corridor				
	0,10762	0,001206	1,12%		
	Stairway				
	0,36410	0,031468	8,64%		NO
	Open deck				
	0,43683	0,001428	0,33%		
	Galley				YES
	0,08561	0,002633	3,08%		
	Lounges				
	0,22340	0,011385	5,10%		
	Restaurants				
	0,08866	0,000035	0,04%		
	Store-rooms				
	0,04179	0,000337	0,81%		
	Techn. space				
	0,07060	0,000602	0,85%		
	Mach. space				
	2,40478	0,000518	0,02%		
	F and casing				

Noteworthy is that in conclusion about 1.0% of the fires affecting the superstructure are assessed to cause evacuation in the prescriptive design. In the base design the corresponding number is about 2.0%, which signifies an almost 100% relative increase of fire scenarios leading to evacuation. For both designs, fires in Cabins, Open deck spaces, Lounges and Restaurants lead to relatively many evacuations. These are all spaces which are in connection with exteriors. The greatest relative increases amongst the space groups are found in Open deck spaces, Lounges and Restaurants where evacuations have quadrupled or doubled. The relative number of fires escalating (of the fires initiated) has only changes marginally, from 78,5% in the prescriptive design to 82,9% in the base design.

4.3.4. 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, if effects were judged to be more or less significant in combination with others. These effects from RCMs are assessed subsequently.

4.3.4.1. Drencher on open deck (a3)

Drencher system covering all large vertical hazardous external composite surfaces (e.g. over 1 m high or covering more than 50% of a surface more than 1 m^2) on open deck is assessed to decrease the probability of failure to prevent fire development on open deck. This drencher system applies 3 l/(m^2 * min) according to [26] 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. 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.

Available statistics [43] show that a dry pipe extinguishing system reliability could be assessed to 79%. For flame detectors there was no statistics found. For this assessment it was assumed that the failure rate was somewhat improved so that the systems together give 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%.

4.3.4.2. Balcony sprinkler (a5)

As mentioned above, the reliability of a dry pipe system could be assessed to 79%. Furthermore, balcony sprinkler systems are generally extended from the cabin sprinkler system. For this balcony sprinkler it was although assumed that the system is fully redundant from the cabin sprinkler system and that the system reliability was improved to at least 90%, similar to the extinguishing system used indoors. It was thereby assumed to reduce the probability of fire spread and development on outboard sides by 90%. The efficiency of a balcony sprinkler on a ship with FRP composite surfaces was further verified in [27].

4.3.4.3. Drencher on outboard sides

The drencher system over openings (windows, doors etc.) facing exteriors on outboard sides of the ship was assumed to reduce the probability of fire spread and development on outboard sides of the ship with the same reliability as the drencher system above, i.e. 80%.

4.3.4.4. Redundant sprinkler

Fully redundant sprinkler system in all internal spaces in the superstructure is assumed to be a system totally separated from the prescriptive system. It is hence assumed to give a decreased failure probability of sprinkler function from 9% to 0.81%, as determined in paragraph *4.3.2.1. fire scenarios*.

4.3.4.5. LEO system

The LEO system consists of a special glass fibre reinforcement, infusion resin and top coat. The sandwich panels are manufactured in the same way as the standard panels, resulting in the same thicknesses, fibre fractions and resin absorption. The infusion resin behaves like standard polyester but with a slightly higher viscosity than normal infusion resins. The top coat is intumescent and the system is loaded with fire retarding additives. Fire tests performed in the BESST project [19, 26] have shown that if exposed to a worst-case external fire, the LEO system limits fire-spread, limits the composites' contribution to the heat released, 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:

- The increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides was reduced by 40 % if using LEO, i.e. from 95% in the base design to 77% (50% in the prescriptive design).
- The increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides was reduced by 40% if using LEO, i.e. from 90% to 78%.
- The increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck was reduced by 80% in all categories of areas on open deck if using LEO.
- The increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck was reduced by 50%, i.e. from 80% to 60%.
- The increased fatalities from local collapse (due to collapse) on outboard sides were reduced by 70% and the increased fatalities from local collapse (due to smoke) on outboard sides was reduced by 70%, i.e. in all from 28 to 15 fatalities.
- The increased fatalities from local collapse (due to collapse) on open deck were reduced by 75% and the increased fatalities from local collapse (due to smoke) on open deck was reduced by 50%, i.e. in all from 16 to 9 fatalities.
- The increased fatalities from major collapse on outboard sides were reduced by 40%, i.e. from 70 to 46 fatalities.
- The increased fatalities from major collapse on open deck were reduced by 60%, i.e. from 35 to 20 fatalities.
- The increased fatalities due to major collapse on outboard sides in case of evacuation were reduced by 55%, i.e. from 250 to 140 fatalities.
- The increased fatalities due to major collapse on open deck in case of evacuation were reduced by 75%, i.e. from 100 to 44 fatalities.

4.3.4.6. Structural redundancy

This RCM considers structural redundancy in divisions facing exteriors and includes different ways of making sure that a FRP structures will not collapse when a fire exposed external laminate detaches from the core. This can be achieved in a number of ways e.g.:

- Use of a triple laminate sandwich structure. Tests [19] have shown that this design provides 90 minutes of fire resistance. This design also has the potential of working two-ways if the design is symmetrical.
- Use of internal stiffeners to ensure that the inner laminate and the stiffeners have sufficient strength to prevent collapse until the inner laminate reaches critical temperatures.
- 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.

In the trial alternative designs where this RCM is included it is assumed that any of these alternatives is used and that the outer laminate and the core are not necessary to prevent collapse.

Due to the above the this RCM was assumed to have a number of effects:

- The increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides was reduced by 20 %, i.e. from 95% in the base design to 86% (50% in the prescriptive design).
- The increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides was reduced by 20%, i.e. from 90% to 84%.
- The increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck was reduced by 40% in all categories of areas on open deck.
- The increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck was reduced by 25%, i.e. from 80% to 70%.
- The increased probability of abandonment in case of internal fire and fire-fighting success was reduced by 50%, i.e. from 38% to 32.5%.
- The probability of abandonment in case of internal fire and fire-fighting failure was reduced by 50%, i.e. from 90% to 86%.
- The probability of abandonment in case of outboard fire and fire-fighting failure was reduced by 50%, i.e. from 95% to 88.5%
- The increased number of fatalities from a long-lasting engine room fire due to effects on the were reduced by 100%, i.e. from 4 to 2.75 fatalities.
- The increased fatalities from local collapse (due to collapse) on outboard sides were reduced by 100% and the increased fatalities from local collapse (due to smoke) on outboard sides was reduced by 0%, i.e. in all from 28 to 16 fatalities.
- The increased fatalities from local collapse (due to collapse) on open deck were reduced by 100% and the increased fatalities from local collapse (due to smoke) on open deck was reduced by 0%, i.e. in all from 16 to 11.5 fatalities.
- The increased fatalities from major collapse on outboard sides were reduced by 20%, i.e. from 70 to 58 fatalities.
- The increased fatalities from major collapse on open deck were reduced by 30%, i.e. from 35 to 28 fatalities.
- The increased fatalities due to major collapse on outboard sides in case of evacuation were reduced by 25%, i.e. from 250 to 200 fatalities.
- The increased fatalities due to major collapse on open deck in case of evacuation were reduced by 45%, i.e. from 100 to 66 fatalities.

4.3.4.7. Structural redundancy in combination with LEO

When considering the combination of structural redundancy and LEO, which target two main hazardous areas of FRP composite, the total effects were estimated to be greater than the two added individually in a few regards. The following effects were estimated from the combination of RCMs:

- The increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides was reduced by 80 %, i.e. from 95% in the base design to 52.25% (50% in the prescriptive design).
- The increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides was reduced by 80%, i.e. from 90% to 66%.
- The increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck was reduced by 125%, i.e. to less than in a prescriptive design, in all categories of areas on open deck. This is due to the combination of insignificant added potential for fire-spread and the improved structural integrity, particularly in comparison with aluminium structures.
- The increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck was reduced by 90%, i.e. from 80% to 44%.
- The increased probability of abandonment in case of internal fire and fire-fighting success was reduced by 75%, i.e. from 38% to 29.75%.
- The probability of abandonment in case of internal fire and fire-fighting failure was reduced by 75%, i.e. from 90% to 84%.
- The probability of abandonment in case of outboard fire and fire-fighting failure was reduced by 75%, i.e. from 95% to 85.25%
- The increased number of fatalities from a long-lasting engine room fire due to effects on the were reduced by 100%, i.e. from 4 to 2.75 fatalities.
- The increased fatalities from local collapse (due to collapse) on outboard sides were reduced by 100% and the increased fatalities from local collapse (due to smoke) on outboard sides was reduced by 70%, i.e. in all from 28 to 11 fatalities.
- The increased fatalities from local collapse (due to collapse) on open deck were reduced by 100% and the increased fatalities from local collapse (due to smoke) on open deck was reduced by 50%, i.e. in all from 16 to 8 fatalities.
- The increased fatalities from major collapse on outboard sides were reduced by 60%, i.e. from 70 to 34 fatalities.
- The increased fatalities from major collapse on open deck were reduced by 90%, i.e. from 35 to 13 fatalities.
- The increased fatalities due to major collapse on outboard sides in case of evacuation were reduced by 80%, i.e. from 250 to 90 fatalities.
- The increased fatalities due to major collapse on open deck in case of evacuation were reduced by 100%, i.e. from 100 to 25 fatalities.

4.3.5. 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 K. Summarized input data*.

4.4. Results and evaluation of trial alternative designs

The quantified outcomes from the ETA 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 accidents 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.

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: c2 (redundant interior sprinkler system in superstructure)
- TAD B: a5 (balcony sprinkler)
- TAD C: a5 + a6 (balcony sprinkler + drencher over openings facing exteriors)
- TAD D: a5 + a6 + a3 (balcony sprinkler + drencher over openings facing exteriors + drencher on open deck)
- TAD E: c2 + a5 (redundant interior sprinkler system in superstructure + balcony sprinkler)
- TAD F: c2 + a5 + a3 (redundant interior sprinkler system in superstructure + balcony sprinkler + drencher on open deck)
- TAD G: c2 + a5 + a6 + a3(redundant interior sprinkler system in superstructure + balcony sprinkler + drencher over openings facing exteriors + drencher on open deck)
- TAD H: j3 (LEO)
- TAD I: j3 + c2 (LEO + redundant interior sprinkler system in superstructure)
- TAD J: j3 + a5 + a6 + a3 (LEO + balcony sprinkler + drencher over openings facing exteriors + drencher on open deck)
- TAD K: c2 + a3 (redundant interior sprinkler system in superstructure + drencher on open deck)
- TAD L: j3 + c2 + a3 (LEO + redundant interior sprinkler system in superstructure + drencher on open deck)
- TAD M: j3 + c2 + a5 (LEO + redundant interior sprinkler system in superstructure + balcony sprinkler)
- TAD N: j3 + c2 + a5 + a6 (LEO + redundant interior sprinkler system in superstructure + balcony sprinkler + drencher over openings facing exteriors)
- TAD O: j4 (structural redundancy)
- TAD P: j4 + a5 (structural redundancy + balcony sprinkler)
- TAD Q: j4 + c2 (structural redundancy + redundant interior sprinkler system in superstructure)
- TAD R: j4 + j3 (structural redundancy + LEO)
- TAD S: j4 + j3 + a5 (structural redundancy + LEO + balcony sprinkler)
- TAD T: j4 + j3 + a5 + a6 (structural redundancy + LEO + balcony sprinkler + drencher over openings facing exteriors)
- TAD U: j4 + j3 + c2(structural redundancy + LEO + redundant interior sprinkler system in superstructure)

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

4.4.1. F-N diagrams

The F-N curves for the prescriptive design, base design, TAD A, TAD H and TAD O are presented in Figure 4.31, which shows that even promising RCMs are not sufficient if applied on their own.

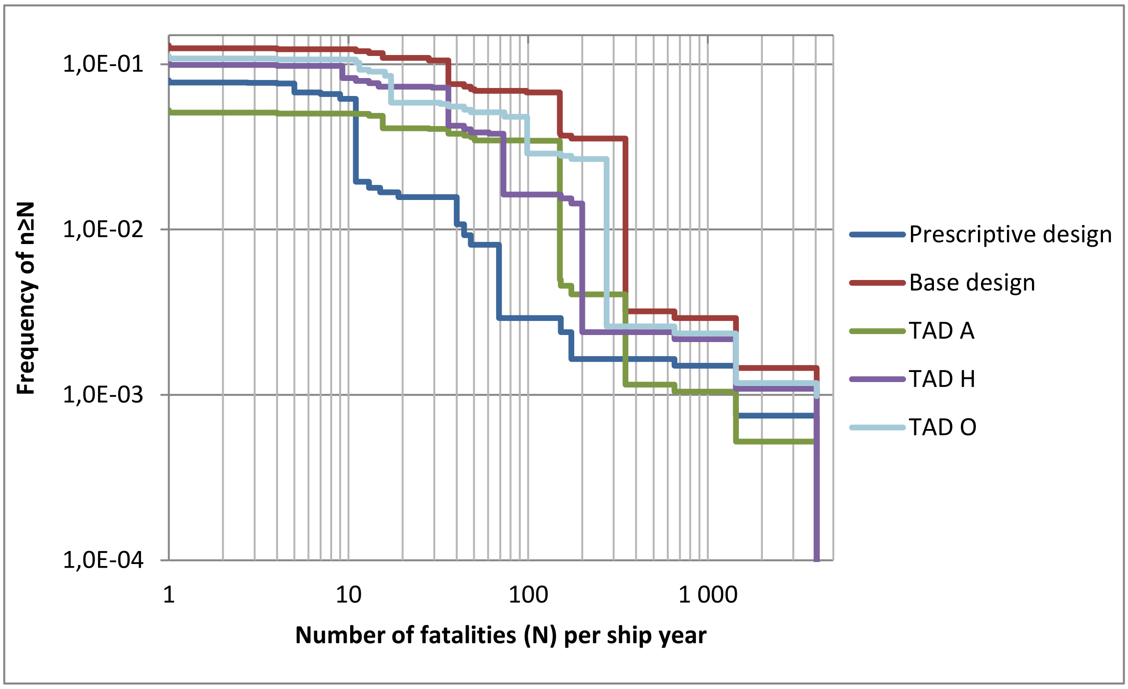


Figure 4.31. F-N diagram including single promising RCMs.

The F-N curves for the prescriptive design, base design, TAD B, TAD C and TAD D are presented in Figure 4.32, which shows the effects of different RCOs including active systems working on exteriors.

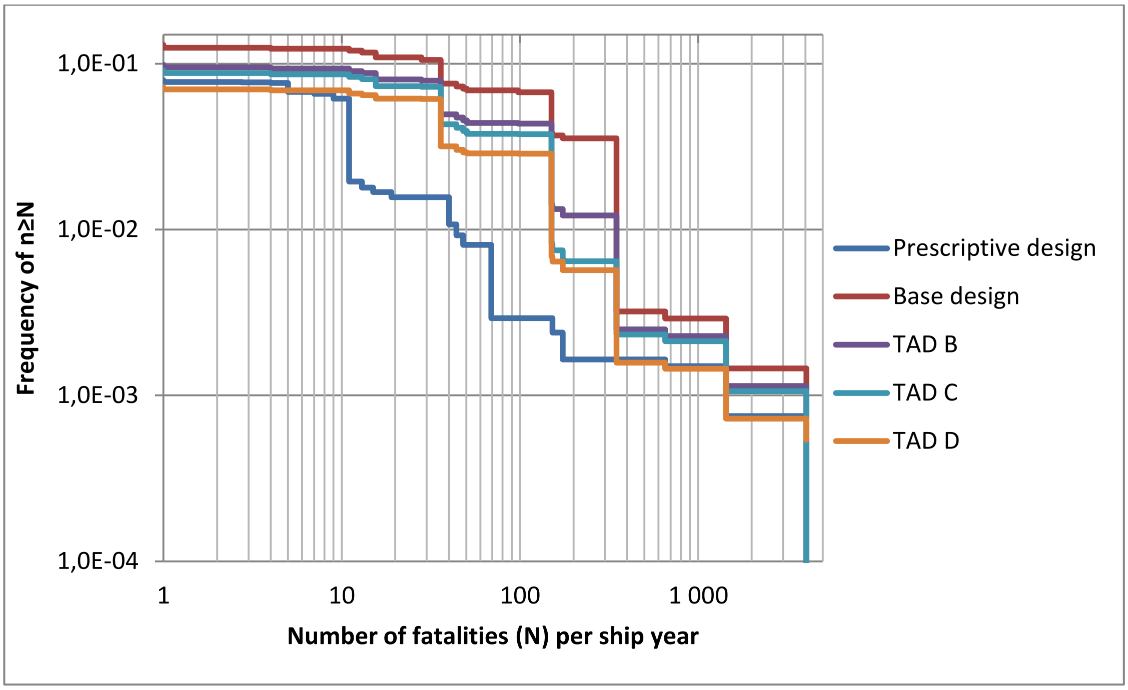


Figure 4.32. F-N diagram with different RCOs including active systems in exteriors.

The F-N curves for the prescriptive design, base design, TAD A, TAD E, TAD F, TAD G, and TAD K are presented in Figure 4.33. This shows the effects of using a redundant sprinkler system in the interior spaces of the superstructure (TAD A) and in combination with other active systems.

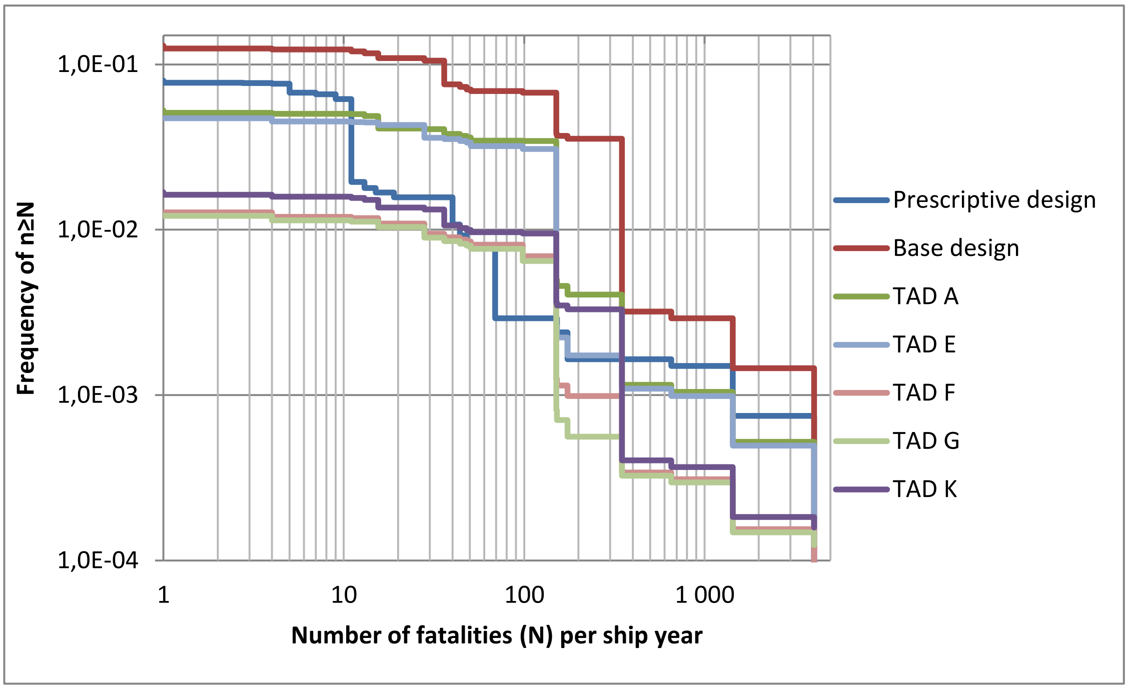


Figure 4.33. F-N diagram with different RCOs involving redundant sprinkler system in interior spaces.

The F-N curves for the prescriptive design, TAD H, TAD I, TAD J, TAD L, TAD M and TAD N are presented in Figure 4.34. This shows the effects of using a LEO on exterior surfaces (TAD H) and in combination with active systems.

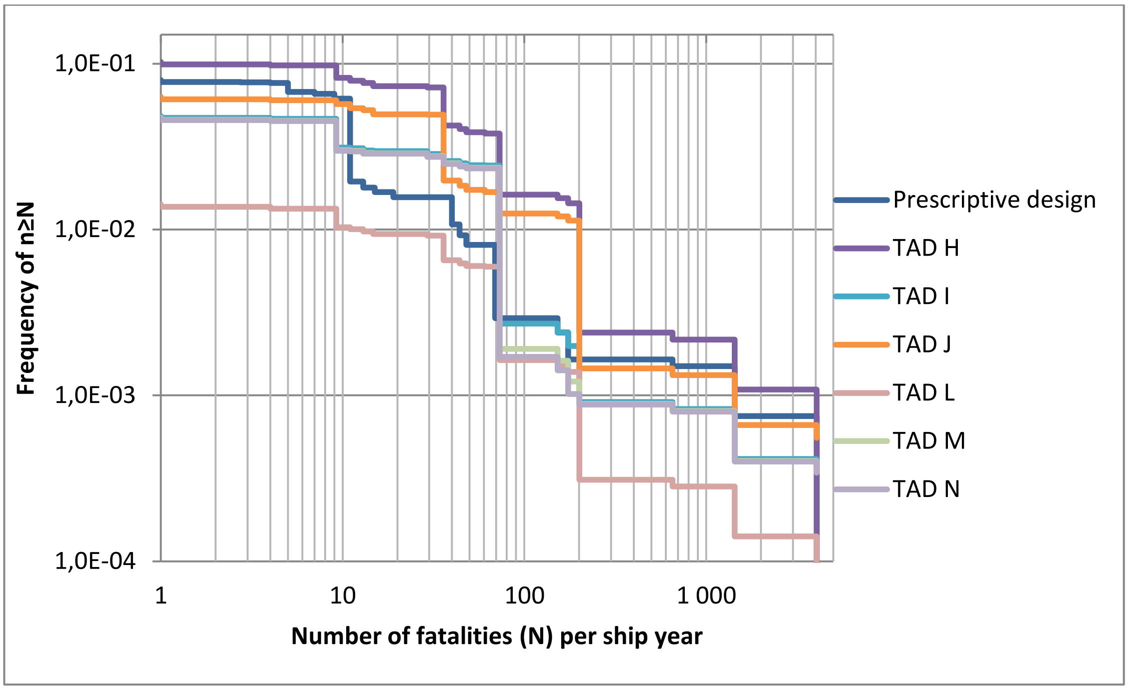


Figure 4.34. F-N diagram with different RCOs involving LEO.

The F-N curves for the prescriptive design, base design, TAD O, TAD P and TAD Q are presented in Figure 4.35. This shows the effects of constructing divisions facing exteriors with structural redundancy (TAD O) and in combination with active systems.

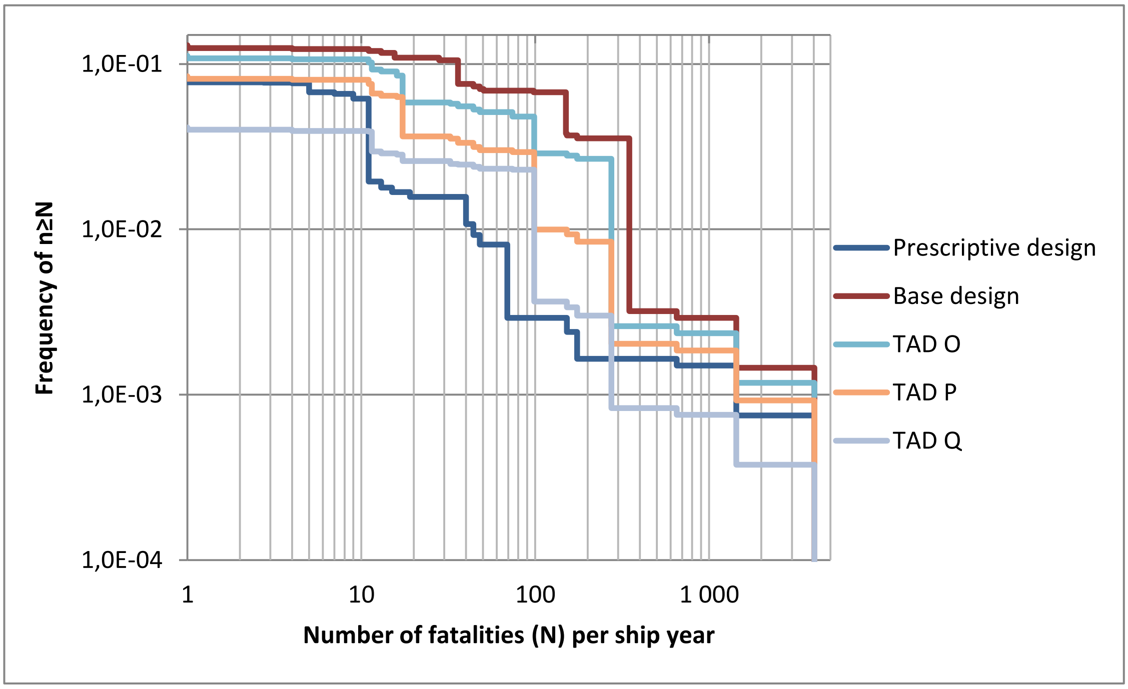


Figure 4.35. F-N diagram with different RCOs involving structural redundancy.

The F-N curves for the prescriptive design, base design, TAD R, TAD S, TAD T and TAD U are presented in Figure 4.36. This shows the effects of both LEO and constructing divisions facing exteriors with structural redundancy and (TAD R) and in combination with active systems.

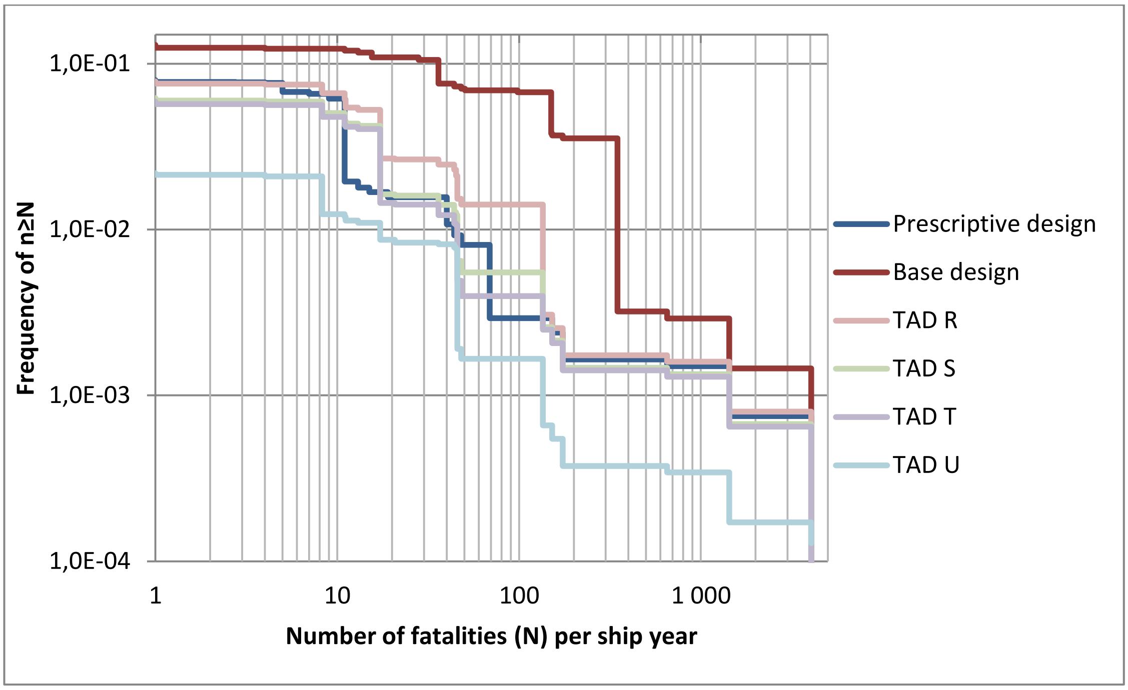


Figure 4.36. F-N diagram with different RCOs involving both structural redundancy and LEO.

The F-N curves for the prescriptive design, base design, TAD F, TAD G, TAD L and TAD U are presented in Figure 4.37. This shows the four safest combinations of risk control measures in comparison with the prescriptive design (and the base design). As visible in the diagram, TAD U is the only design which never crosses the prescriptive design (even if TAD L is also very close).

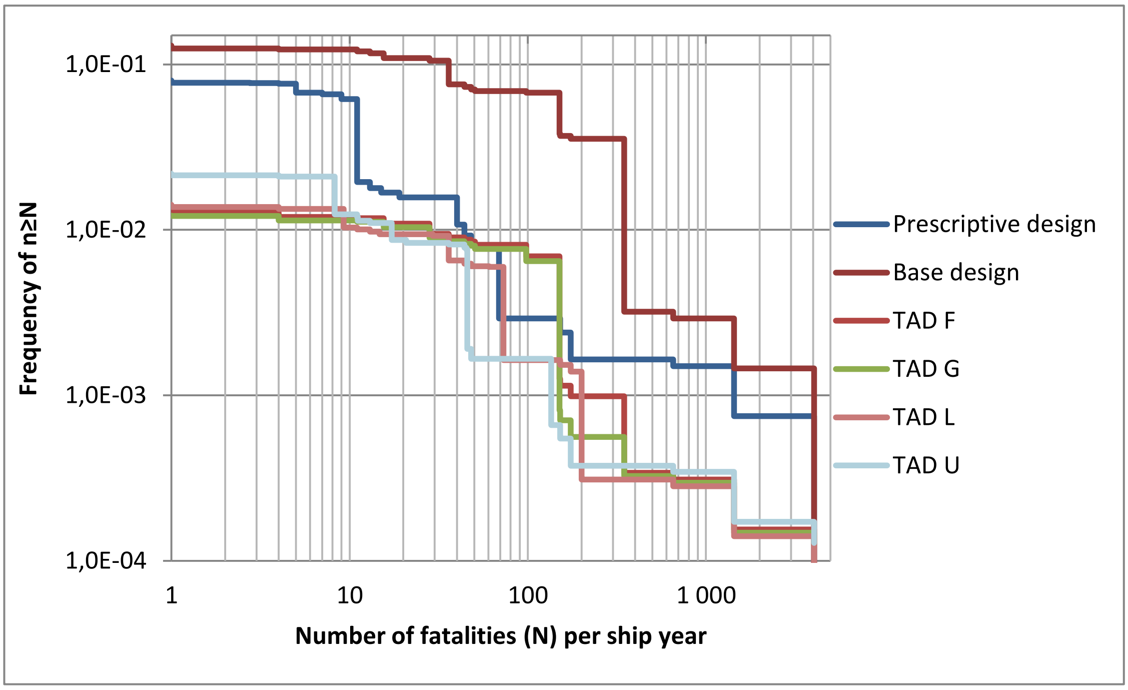


Figure 4.37. F-N diagram with the safest combinations of risk control measures.

4.4.2. 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 4.54.

Table 4.54. 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	5,71	1,00	-
BD = Base design	26,07	4,57	-
TAD A = BD + redundant sprinkler	8,95	1,57	-
TAD B = BD + balcony sprinkler	16,10	2,82	-
TAD C = BD + bal. spr. + drencher over openings	13,65	2,39	-
TAD D = BD +bal. spr. + dr.open. + dr.deck	10,28	1,80	-
TAD E = BD + red.spr. + bal.spr.	7,89	1,38	-
TAD F = BD + red.spr. + bal.spr. + dr.deck	2,27	0,40	0.999
TAD G = BD + red.spr. + bal.spr. + dr.open. + dr.deck	2,08	0,36	0.999
TAD H = BD + LEO	11,98	2,10	-
TAD I = BD + LEO + red.spr.	4,60	0,81	0.736
TAD J = BD + LEO + bal.spr. + dr.open. + dr.deck	7,55	1,32	-
TAD K = BD + red.spr. + dr.deck	3,17	0,56	0.984
TAD L = BD + LEO + red.spr. + dr.deck	1,53	0,27	1.000
TAD M = BD + LEO + red.spr. + bal.spr.	4,38	0,77	0.767
TAD N = BD + LEO + red.spr. + bal.spr. + dr.open.	4,32	0,76	0.775
TAD O = BD + structural redundancy	16,86	2,95	-
TAD P = BD + SR + bal.spr.	10,21	1,79	-
TAD Q = BD + SR + red.spr.	5,16	0,90	0.615
TAD R = BD + SR + LEO	7,42	1,30	-
TAD S = BD + SR + LEO + bal.spr.	5,43	0,95	0.732
TAD T = BD + SR + LEO + bal.spr. + dr.open.	5,07	0,89	0.923
TAD U = BD + SR + LEO + red.spr.	1,59	0,28	1.000

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 100%. Hence, based on Table 4.54, there would be four trial alternative designs which achieve this performance criteria, namely TAD F, TAD G, TAD L and TAD U, the latter of which is the only design with a F-N curve never crossing the one for the prescriptive design. What these trial alternative designs have in common is that they all include redundant sprinkler system in interior spaces. Furthermore, in case structural redundancy is not provided, drencher system on open deck is required, either in combination with LEO or in combination with balcony sprinkler.

4.4.3. Uncertainty and sensitivity analysis

All estimated probabilities and consequences summarized in *Appendix K. Summarized input data* were assigned probability distributions based on the discussions in the quantifications of fire safety above. These distributions are presented in *Appendix L. 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 4.54 and the full results are presented in *Appendix L. Uncertainty and sensitivity analysis*. This shows that the first requirement of a 100% safety margin was reasonable.

Assuming that a confidence of 80% 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 80% of the simulation iterations) also makes TAD K and TAD T sufficiently safe. TAD K includes a fully redundant sprinkler system in interior spaces in the superstructure could be sufficient in combination with drencher on open deck whilst TAD T includes structural redundancy in combination with LEO, balcony sprinkler and drencher over openings facing exteriors. Thereby TAD T is the only potentially acceptable design which does not include a redundant sprinkler system in all interior spaces. Note that TAD T is a safer design than TAD M and TAD N since these latter designs are far more uncertain, even if the average risk shows the opposite.

With regards to the sensitivity analysis it is presented for the relevant trial alternative designs in *Appendix L. Uncertainty and sensitivity analysis*. It could be concluded that the risk assessment was not very sensitive to any input parameter. Sensitive input parameters were in many cases the probability of bad weather as well as the probability of active extinguishing systems.

5. Summary and conclusions

This report contains the engineering analysis as described by the IMO/Circ.1002 for the panamax cruise vessel the Norwegian Future. The five upper decks were redesigned in FRP composite. A risk-approach to performance-based design involved a fire hazard identification process based on workshops held by a designated design team of 28 people, 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. A prerequisite was that thermal insulation was provided to all interior surfaces in order to achieve 60 minutes of fire protection. In particular fire development on open deck and fire spread through openings and vertically along the outboard sides of the ship were although identified as fire scenarios where differences in fire safety would be significant. Furthermore, 11 space groups with similar conditions for fire scenarios were identified.

With regards to the base design, where steel structures had simply been replaced by thermally insulated FRP composite, a number of deviations to prescriptive requirements were identified. The deviations particularly concern the fact that FRP composite is combustible. This although has effects on a number of 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 almost five times as high as the prescriptive design. A performance criterion with a safety factor of 100% provided four acceptable trial alternative designs. All of these design solutions include a fully redundant sprinkler system in interior spaces in the superstructure. An acceptable design could additionally involve structural redundancy in divisions facing exteriors in combination with LEO system on exterior surfaces. In case structural redundancy is not provided, drencher system on open deck is required, either in combination with LEO or in combination with balcony sprinkler. 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 that a confidence of 80% is sufficient showed that a it would be sufficient with a fully redundant sprinkler system in interior spaces of the superstructure in combination with drencher on open deck. Considering the uncertainties also showed that structural redundancy in combination with LEO, balcony sprinkler and drencher over openings facing exteriors could provide sufficient safety. The latter design hence is the only potentially acceptable design which does not include a redundant sprinkler system in all interior spaces.

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Fire Research - Fire Dynamics

Appendices

Appendix A. The revised approach
Appendix B. General arrangement for the Norwegian Future
Appendix C. FRP composite panels and fire performance
Appendix D. Additional regulation and fire safety evaluations
Appendix E. Data from the first hazard identification
Appendix F. Summary of the first hazard identification
Appendix G. Data from the second hazard identification
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Appendix I. Risk control measures
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Appendix K. Summarized input data
Appendix L. Uncertainty and sensitivity analysis

The revised approach

This appendix presents a method to assess fire safety in maritime FRP composite constructions based on [5].

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 [2], 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 [1], 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 [44] 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 [3] (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 [4].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 [4]. 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” [4]. 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 [4]. 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.

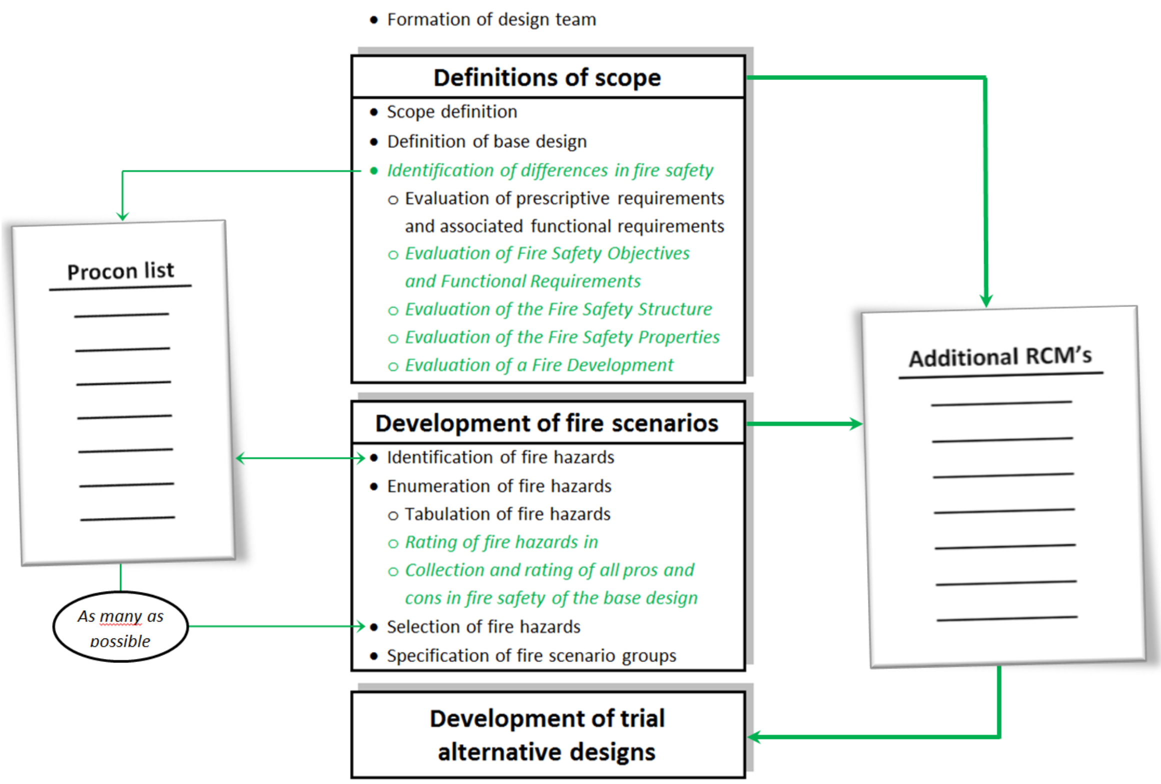


Figure A1. Procedure of the preliminary analysis in qualitative terms, where green represents introduced processes to capture the novelty of FRP composite structures.

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) [4]. 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.

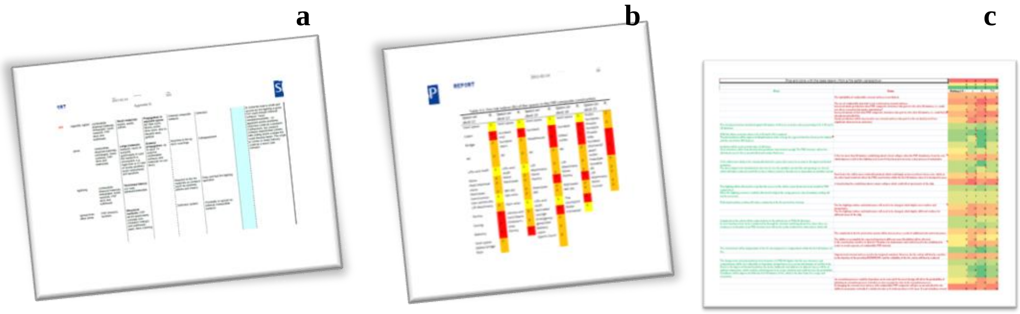


Figure A2. (a) Tabulation of the fire hazards from the hazard identification. (b) Fire hazard ratings of the spaces in the FRP composite construction. (c) A different but more useful enumeration of fire hazards where pros and cons with the base design were rated from a fire safety perspective.

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 3.1) 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.

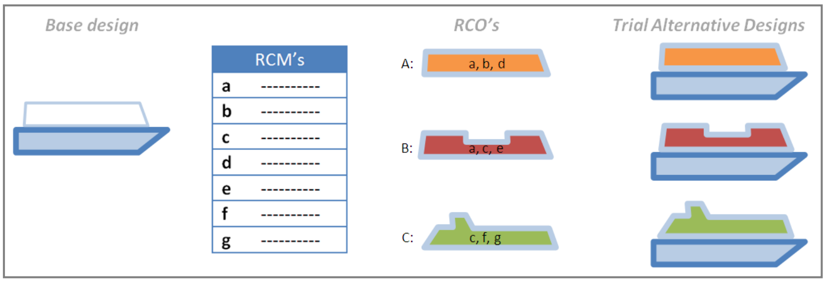


Figure A3. Illustration of the base design in relation to trial alternative designs.

General arrangement for the Norwegian Future

General plans for all decks were provided by Meyer Werft and are presented below in figures B1, B2, B3 and B4.

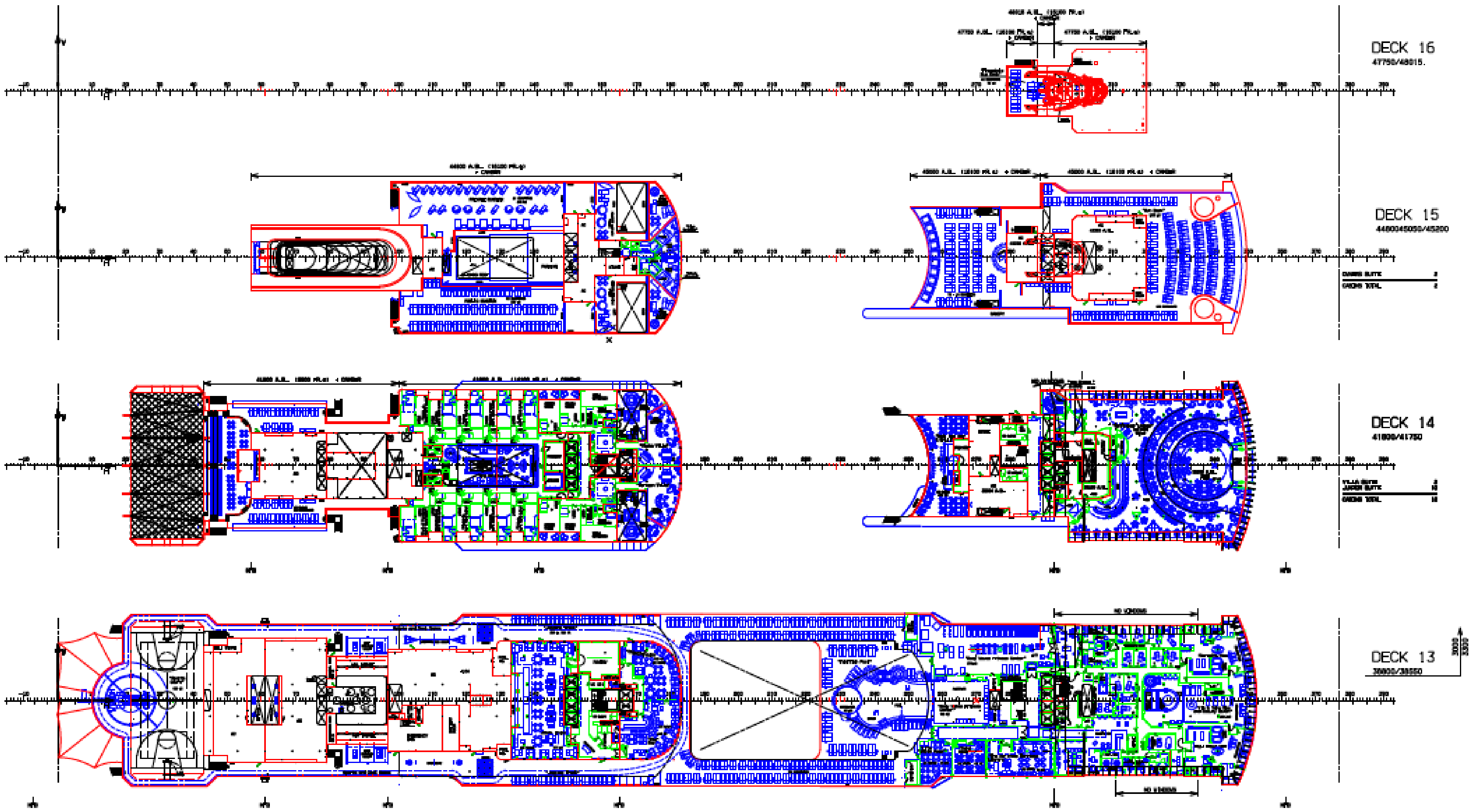


Figure B1. General plans for decks 13-16, containing many sun decks, luxurious cabins, ventilation machinery, spa, gym and other amenities.

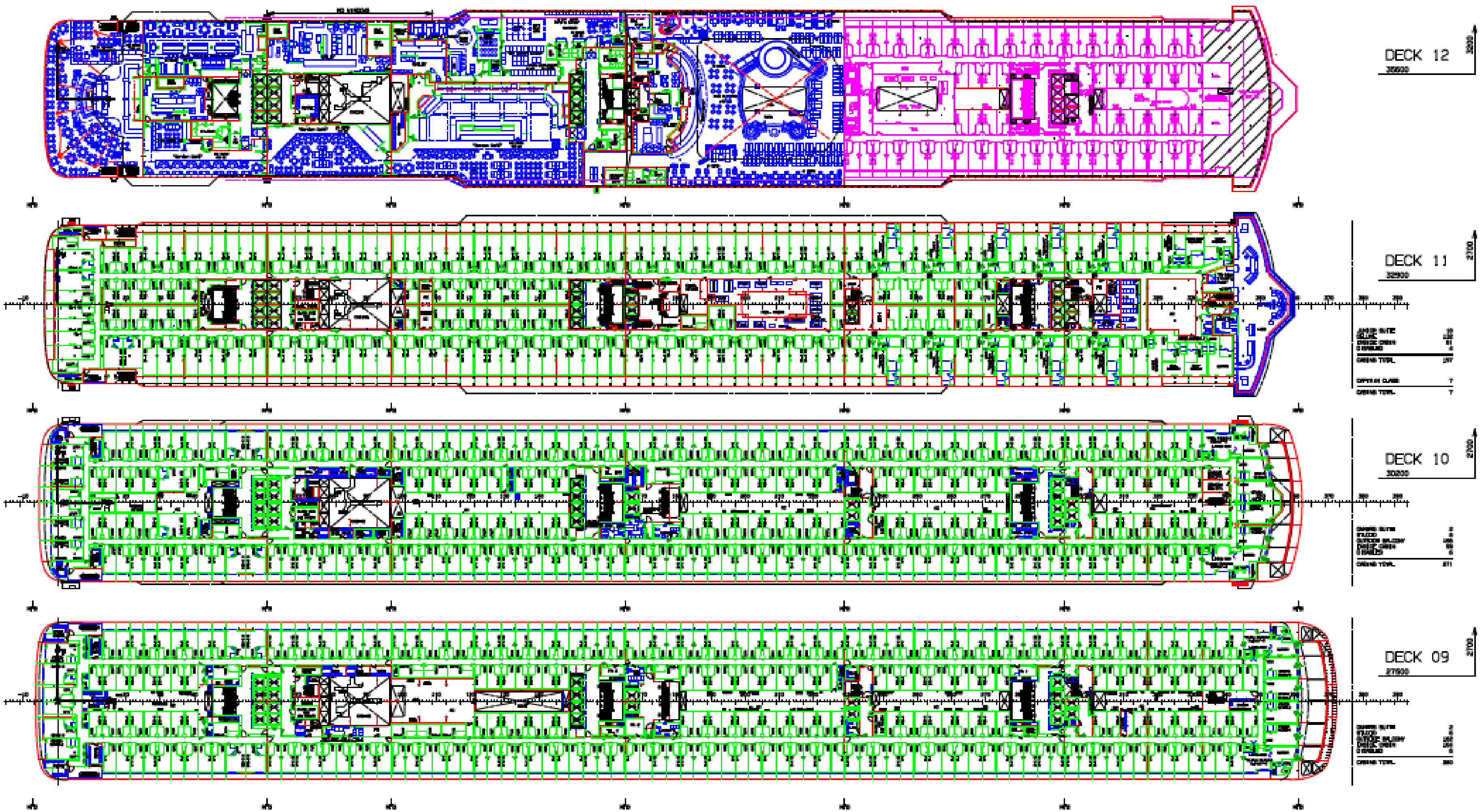


Figure B2. General plans for decks 9-12, where the lower three decks mainly contain cabins and deck 12 also includes restaurants and a pool area.

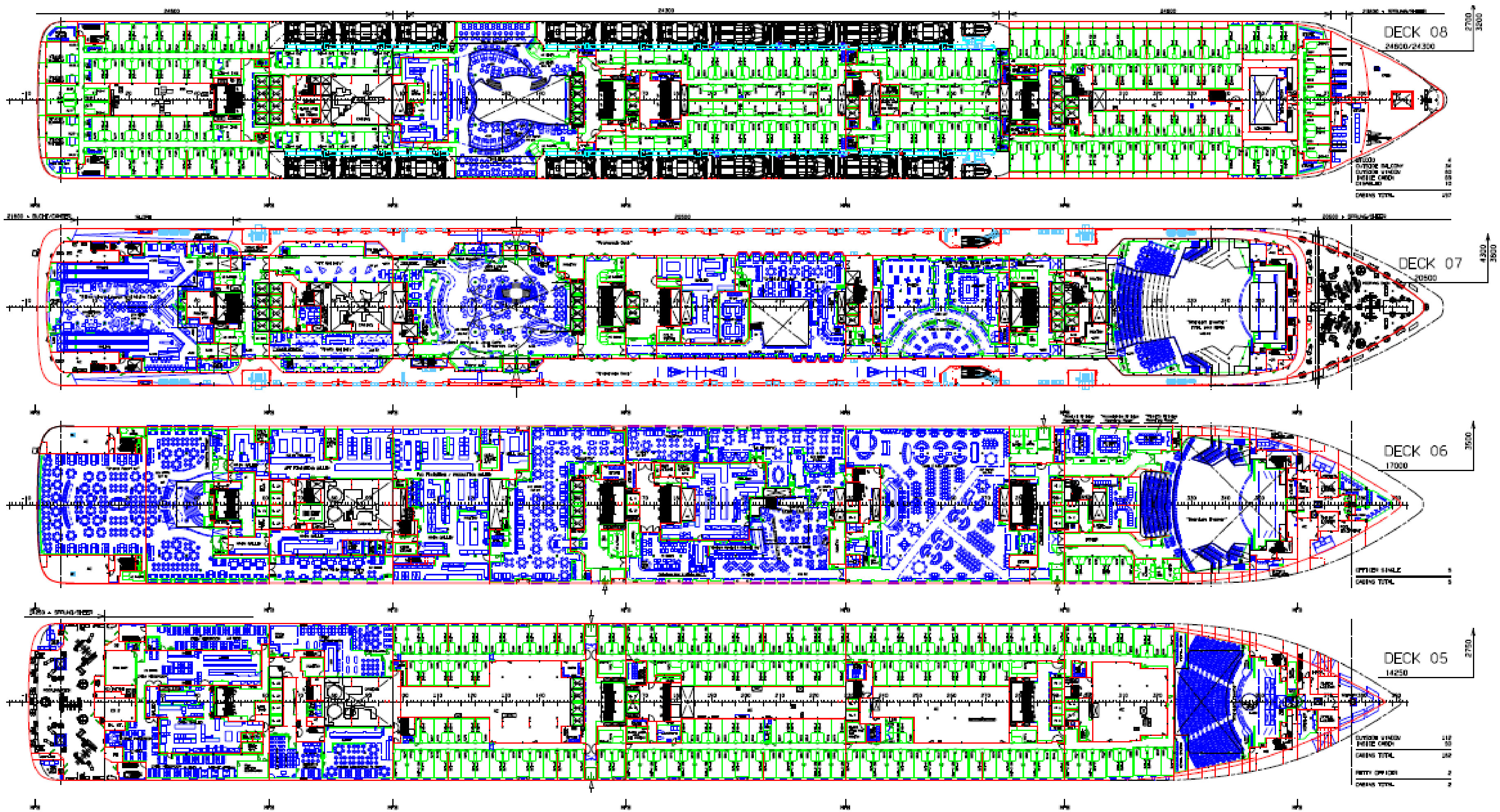


Figure B3. General plans for decks 5-8, with passenger cabins, theatre, reception, galleys, restaurants, bars, crew mess and LSA (life saving appliances).

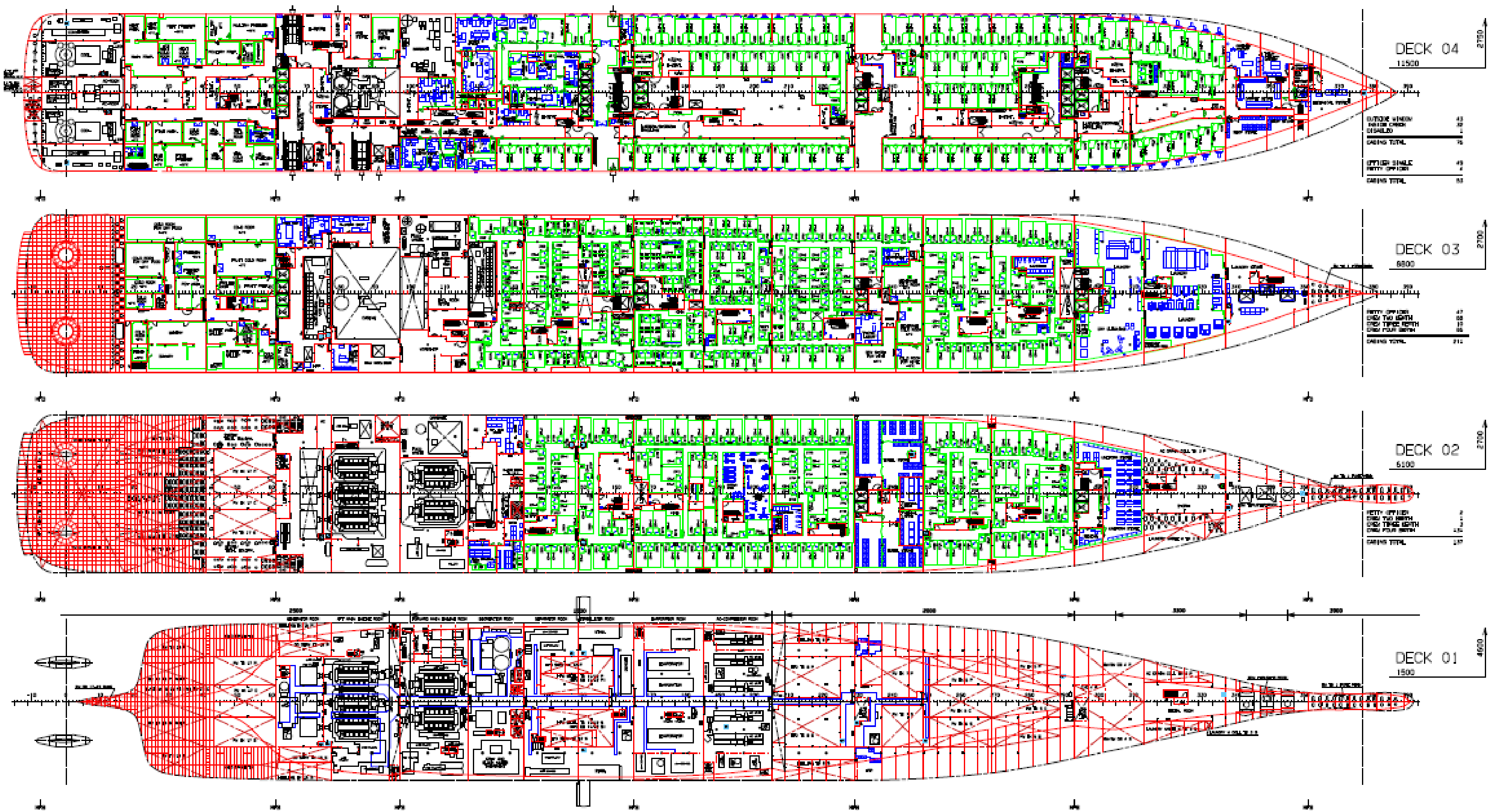


Figure B4. General plans for decks 1-4, containing mainly machinery spaces, cold rooms and crew quarters, but also passenger cabins on deck 4.

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 [7]. 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 [9].

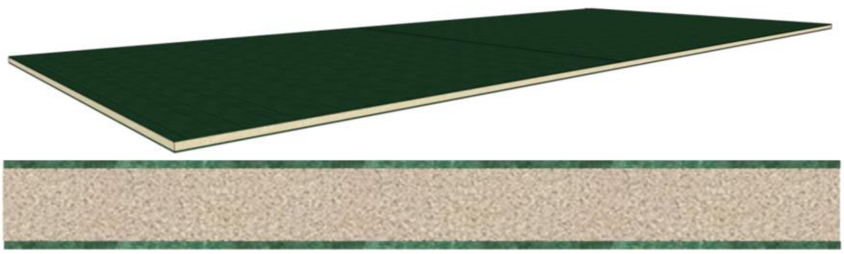


Figure C1. Illustration of an FRP composite panel (top) and a close-up on the lightweight core and the rigid and strong fibre reinforced laminates (bottom).

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 [45, 46].

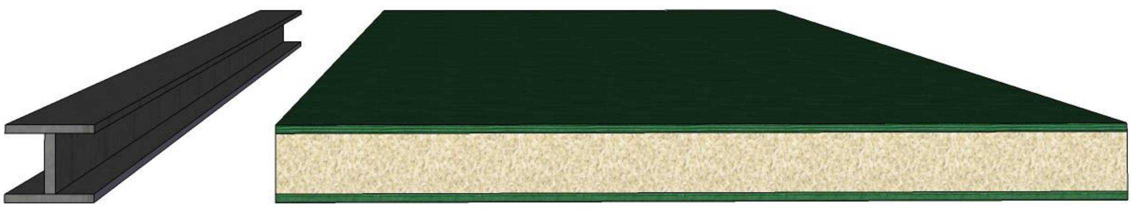


Figure C2. Illustration of how the lightweight core works as a prolate stiffener in order to provide the FRP composite panel with a distribution of loads similar to an “I-beam”.

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 [47].

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 [48].

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 [11], 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 [15]. An FRP composite is a good thermal barrier and has demonstrated ability to contain fire on its own [7, 16, 49, 50]. 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).

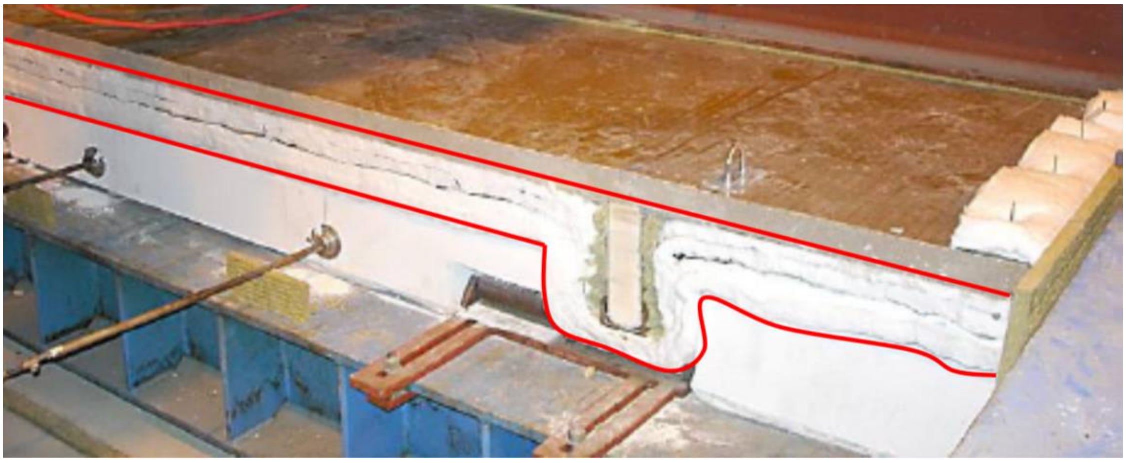


Figure C3. The insulation marked in the picture provides heat integrity to the FRP composite, a composition that makes up a fire resisting division (FRD). An FRD-60 deck construction is here tested on top of a large furnace in accordance with MSC.45(65) [12] in the IMO Fire Test Procedures Code [13].

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 “FRD-60” 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 begins to soften at about 100˚C. When the temperature reaches about 130-140˚C the structural performance can 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 FRD-60 with case specific loading, since its performance in fire tests will not depend on the magnitude of the loading. As explained above, the FRD-60 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 [9].

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 FRD-60 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) [12], as shown in figure C4 [9].

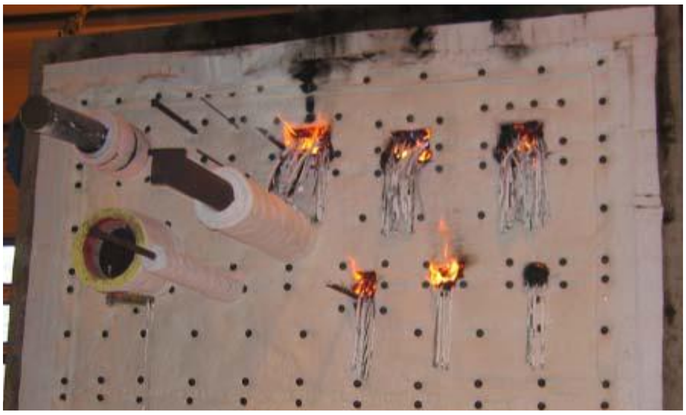


Figure C4. Exposed side of a FRD bulkhead specimen after successful penetration test.

An FRP composite module was tested in full-scale at SP Technical Research in December 2007 [16]. 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 [11]. 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.

Additional regulation and fire safety evaluations

The individual fire safety regulations of SOLAS II-2 were evaluated above in section *3.3. Discussion of affected SOLAS chapter II-2 regulations and their functional requirements*. The fire safety objectives and functional requirements are although not fully embodied in the regulations. Furthermore, in order to achieve a design as safe as prescribed by the fire safety chapter, the change from steel to FRP composite was judged to need further evaluation [4, 5]. Hence, based on 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. The individual regulations were analysed above, but in order to attain also the objectives and functional requirements, not fully embodied in the prescriptive requirements, the change from steel to FRD-60 is evaluated also through Regulation 2 in SOLAS II-2, which is meant to originate the following regulations.

The 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 [3] 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 have been 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 FRD-60 instead of steel in all load-bearing structures will inevitably affect some of the fire safety objectives. Comments concerning each fire safety objective are summarized in table D.1 and discussed below.

Table D.1. A summary of the fire safety objectives in SOLAS II-2/2.1 and comments on how they are affected by the base design

The fire safety objectives in SOLAS II-2/2	*Will the objective be affected?*
.1 prevent the occurrence of fire and explosion;	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 well, 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;	This objective will be affected similar to the above but on a passenger ship the risk to life is the most significant.
.4 contain, control and suppress fire and explosion in the compartment of origin; and	New approved structure and penetrations will imply improved containment of fire and to some extent new equipment and routines for fire-fighting. The effects needs to be verified.
.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 be no differences affecting the first objective. The same goes for the last objective, except that the novel design might improve the conditions in adjacent spaces during an escape (defined as the escape from a fire to the lifeboat and liferaft embarkation deck, 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).

Fire tests for load-bearing structures and penetrations have documented the fire integrity of the novel technology. The fourth objective insists on containing, controlling and suppressing a fire in the space of origin. This objective will most likely be achieved at least as well as well as by prescriptive design. The base design could, however, also imply improvements which could be beneficial to verify.

The greatest needs for verification tend to appear in the second and third fire safety objectives (see table D.1). 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 study. The value of several thousand lives will always be much greater than a billion dollar 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 meaning of the second objective is although not only to prevent the construction from collapse during an escape in order to protect passengers and crew. The objective also means to protect 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.

Therefore, even if the base design seems to have a positive effect on the risks to fire-fighting crew, this matter needs to be further analysed.

The above effects on the fire safety objectives from implementing FRD-60 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 D.1, the functional requirements in table D.2 have been embodied in the regulations of SOLAS II-2. The change from steel to FRD-60 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 D.2 and discussed below.

Table D.2. 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*
.1 division of the ship into main vertical and horizontal zones by thermal and structural boundaries;	The differences in behaviour between FRD-60 and steel divisions will need to be established in order to discern the effect on this requirement.
.2 separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries;	The effects from separations in the novel material need to be established as above.
.3 restricted use of combustible materials;	Combustible materials will be added but not without restriction and as a general rule not unprotected. The effects from having insulated FRP composite in structures although needs to be verified.
.4 detection of any fire in the zone of origin;	The novel design will not affect this requirement.
.5 containment and extinction of any fire in the space of origin;	The improved thermal insulation capacity implies the containment and extinction of fires will be affected, probably in a positive way.
.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 novel design will not affect this requirement.
.8 minimization of possibility of ignition of flammable cargo vapour.	The novel design will not affect this requirement.

The review of SOLAS II-2/2.2 enlightened some areas that will be affected by a change from steel to FRD-60. 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 FRD-60 will affect these regulations and are therefore necessary to identify. 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 prescriptive requirements. As a general rule there should not be any unprotected combustible materials added. However, the effects from having external FRP composite surfaces protected by e.g. drencher need to be verified. The same goes for the effects from having insulated FRP composite in the structure. Functional requirements five and six will be affected in similar ways as the first and second. Depending on the properties of the novel 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. These and the above effects on functional requirements indicate some important needs for verification that ought to be targeted when evaluating the novel design.

The fire safety structure

The analysis in this section utilizes a methodology presented by [51], endorsing an investigation of the goals of different fire safety functions in consideration with 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.

This 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 FRD-60 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 [51]?

A synoptic classification of different forms of fire protection was carried out by [52] 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, adjoining ships etc.). Each risk control measure can reach one or more of these functions or will give an effect only in collaboration 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 [51]. 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 are the basis for 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

Every fire starts small and if it is detected at an early stage, not given the fuel to develop, or contained in the space of origin there is a great probability it will stay that way. To get early control over a fire and limit its potential to grow are crucial factors to limit the possible consequences of a fire. It is also mainly during this time 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 reason to the focus in SOLAS chapter II-2 on the first stages of a fire. The division is, however, not carried out without objections and omits the last four regulations (consisting in Regulation 17 and special requirements).

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 D.1).

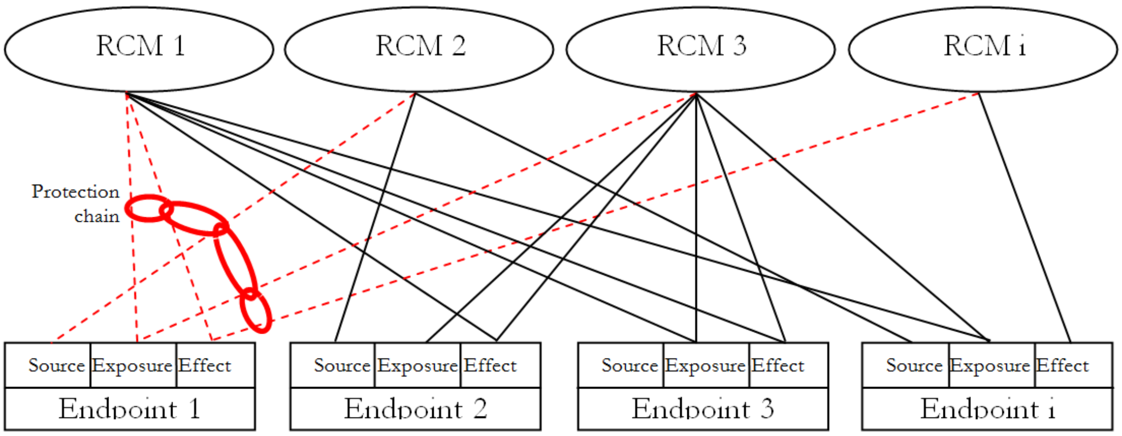


Figure D.1. A simplified illustration of how risk control measures (RCM) make up protection chains for a certain endpoint.

The ellipse shaped objects in figure D.1 represent risk control measures (e.g. sprinkler system, fire detector or structural division) and the lower boxes 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 RCM's connecting with the protection categories of a certain endpoint make up a protection chain. RCM's 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 D.1). If it was to be exchanged with RCM i it would mean 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 [53]. 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 [51]. 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 right risk control measures [51].

Matrix describing the 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 is created, based on a division of the regulations in SOLAS II-2 depending on the fire protection category (see table D.3). The matrix will help to identify the protection chains affected by a modification; in the present study a change from steel to FRD-60. 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 FRD-60 to maritime superstructures.

Table D.3. Matrix describing the overall effects to the fire protection strategy when implementing novel fire safety arrangements, adapted from [51]. The markings symbolize possibly affected functions in the fire protection strategy when exchanging steel (Fe) with FRD-60 (FRD)

	Regulation in SOLAS II-2		Change						
			Fe → FRD	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 [51].

Marking changes in the matrix

In this study the change from steel to FRD-60 is to be evaluated in terms of fire safety. It is not the same thing as exchanging risk control measures but the matrix can reveal some interesting information. For the purpose of evaluating a design with FRD-60 in relation to a steel design, an additional column has been added to the matrix, table D.3. Markings in this column show how functions (regulations) in the fire protection strategy may be affected by a change from steel (Fe) to FRD-60 (FRD). Below follows explanations to the markings in the added column.

Section 5.1 Fire safety regulations 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 with certain positive effects. The increased thermal insulating capacity implies less heat will be conducted through FRD-60 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. 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 novel design but the insulating capacity will improve conditions in adjacent spaces. Whether the total effect will be better or worse does not need to be distinguished in order to establish that there will be certain differences in the fire protection strategy.

Regulation 5 is also marked with a capital “X” in table D.3. 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 is reason to believe a fire development would be more limited in an design with boundaries made of FRD-60, which implies a positive change. This function is, however, represented in Regulation 9. There are no reasons to believe smoke spread would behave differently and the smoke production would not be different except in the exceptional case of a delayed evacuation. Then, however, there could be a minor difference, hence the lower-case “x” by Regulation 6, representing functions with possibly minor effects due to a change to FRD-60. Functions in the fire protection strategy without any relevant effects are marked 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 combustible 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 FRD-60 boundaries. The effect from sound insulating properties 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, such as cabins, whilst regular routines are more practicable in larger spaces. Moreover, if a fire proceeds for more than an hour in a compartment, fire fighters need to further consider the risk of local collapse.

Using the matrix to analyse a change to FRD-60

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 FRD-60, 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 raises the needs for verification in order to establish the effects for fire safety. When the effects have been recognized and estimated the matrix can help find suitable supplementary actions.

A evaluation of the preceding analysis is that the structure will be affected in the sense that the novel FRD-60 construction will imply a greater probability of avoiding exposure whilst the effect from the fire might be supported. Boundaries in FRD-60 will to a larger extent contain the fire in its origin if openings are closed. However, it will also imply that the heat to a larger extent will stay in the compartment, which may increase the fire, and the FRP composite will also add to the fuel if the fire progresses. Hence there is a need to target RCM’s to minimize the effects from a fire.

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.

The 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 [54]. 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 [51]. 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 FRD-60 in order to establish the needs for verification. It will be done by investigating characteristic properties of a system for fire safety, suggested by [51], and how these will be affected. The effects when changing from steel (Fe) to FRD-60 are marked in table D.4 and explained subsequently.

Table D.4. Matrix used to get an overview of the effects from a change in a 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 → FRD	S1	S2	S3	Fe → FRD
Human intervention	X				0
Complexity in fire protection strategy	X				+
Fire protection complexity	x				0
Flexibility	x				0
Sensitivity	x				x
Reliability	X				x
Vulnerability	X				x

The markings in the matrix above have the same meanings as in table D.3, except minus and plus signs have also been included to describe if an effect can be discerned positive or negative. The “S” followed by a number represent possible supplementary measures which can be evaluated through the matrix. Below follow further discussions on how each of the fire safety properties can be affected by a change from steel to FRD-60 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 [51].

A change from steel to FRD-60 will imply new routines in order to assure there will not be any unprotected combustible surfaces. 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 FRD-60 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, will be 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 FRD-60 and possibly different routines for different parts of the ship might although have a negative influence on human intervention. As a general conclusion, the changes in human intervention are although 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 (see 5.3.2 Multi-purpose complexities). 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 (CCF). When several risk control measures are replaced by one measure, or by many dependant measures, it will cause some protection barriers to fall. 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 [51].

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. Improved thermal insulation in the novel structure would make all spaces separated by FRD-60 into structural fire zones in case no other than fire resistance requirements were of interest. No main divisions with extreme capacity will exist but all divisions will be adapted into the higher standard, which will reduce complexity. A reduction in complexity will also be the result when heat can no longer be conducted far through the structure and bring about fires where there are weaknesses in integrity. A change from steel to FRD-60 could also imply an increase in complexity since some mitigating efforts need to be implemented in order to protect external surfaces. The combustible surfaces represent an additional target for risk control measures which inevitably will add to the already complex fire protection strategy. The total effect on complexity in the fire protection system is estimated positive 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 increase the needs for verification [51].

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 FRD-60 is on this level and will not imply any great increases in complexity. However, the exterior surfaces require an additional passive or active measure which will somewhat increase the complexity of the whole fire protection system. A drencher system would although not require any drainage and the risk of list would not be significantly increased. 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 effects on safety.

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 D.1). If the 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 [51].

Building a superstructure with FRD-60 on a ship will imply differences in the approach for fire-fighting crew. The novel material will allow for fire-fighting without entering the fire enclosure, which is an additional measure for fire protection. The flexibility can also be affected if a fire is not under control within 60 minutes. If the probability for collapse is greater in the novel construction it can hinder fire-fighting crew from accomplishing their task which will reduce flexibility. The overall effect on flexibility 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 [51].

When evaluating fire safety in the novel design there are some functions of great importance for the design to perform satisfactory. The sprinkler system is one of the most important systems onboard and will determine the consequences of a fire. This will, however, be the same in both designs with steel and with FRD-60. A difference if the sprinkler system fails to control the fire is that the fire safety in the novel design and arrangements is based on the improved insulation of decks and bulkheads. The sensitivity to defects in fire protection of the structure should therefore be evaluated. Most likely, a fire contained in the space of origin in the novel structure will be more isolated and less dependent on circumstances, such as the performance of fire-fighting and sprinkler system. The load-bearing capacity of the structure is not particularly sensitive to the magnitude of loading, but rather to the time it is exposed to fire. Before the temperature in the interface between the exposed laminate and the core reaches a certain temperature the strength will not be affected. Since the structure will persist 60 minutes of fully developed fire it can be said to be independent of the fire development within this period. The capacity after that will, however, depend on the previous development and the effect of mitigating efforts. 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 FRD-60 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 [51].

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 superstructure with FRD-60. The improved thermal insulation for interior divisions will increase reliability when it comes to containing the fire in the compartment of origin. The question is how the consequences will be affected if a fire is not under control after 60 minutes in the novel design. The reliability will definitely be affected by a change to FRD-60 but in order to establish the effects on safety the consequences need to be analysed in association with the changes in reliability. These effects need to be further analysed in a risk analysis.

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 [51].

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 designs. Except what is mentioned in section *D.3.6 Reliability* there may be differences in vulnerability when it comes to maintenance and sabotage. Since the structure is based on improved insulation qualities to protect the combustible FRP composite, the insulation may also becomes a source of vulnerability. The sensitivity against defects in the fire protection was also identified as a prospect for further investigation in 5.4.5 Sensitivity. 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.

The fact that the novel design in this case implies a change from steel to FRD-60 in the whole superstructure will reduce the vulnerability of the fire protection. It will be less vulnerable to hazardous circumstances and activity changes since the whole design already meets the highest requirements for structural integrity. The vulnerability of the system in case a fire lasts for more than 60 minutes needs to be further investigated.

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 may be positive. This, however, needs to be further investigated through in the forthcoming quantitative analysis.

The fire development

In the previous analyses, characteristics of the base design have been investigated in order to ascertain the impact of the novel FRD-60 structure on fire safety. Below the above revealed differences are discussed with regards to fire dynamics and draws on conclusions from diverse tests carried out at SP Technical Research Institute of Sweden [9, 16]. 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, fire load, ventilation openings, fire control installations, etc. which are all assumed to be identical in the two designs. At this stage the fire will be detected, 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 which reveals no major differences between the prescriptive design and the alternative design and arrangements at this stage. There might, however, be extended possibilities for fire-fighting crew to extinguish a fire from adjacent spaces. If a fire, for whatever reason, is given the possibility to develop, dissimilarities will eventually appear as the fire proceeds [16].

The above implies, if a fire breaks out in an FRD-60 construction, the conditions will not 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. The big question is however what will happen after 60 minutes of fire that the prescriptive fire tests embrace.

Structural divisions within the first 60 minutes

Can FRD-60 be considered equivalent to steel? It deteriorates at 130-140˚C (if PVC foam is used in the core) which is equal to about one minute of fire exposure to the FRP composite. However, if only a part of the material would be exposed to heat, just that limited area would be subject to deformation since the construction, unlike steel, does not conduct heat very well. Steel starts to deteriorate at a much higher temperature (400-500˚C) but the improved thermal insulation of an FRD-60 construction implies adjacent spaces will be at normal temperature while a steel design allows 140 (180)˚C on the other side of a division [9].

All divisions will have at least 60 minutes of thermal insulation which will be a great increase in some places (compared with e.g. A-0 divisions). In terms of fire safety requirements it implies all spaces become fire zones. It will also reduce complexity, sensitivity and vulnerability when all divisions are the same and adapted to the highest standard. When assessing fire safety it is therefore noteworthy how many decks and bulkheads are intended for the improved insulation. Complexity will also be reduced for fire fighters who will not need to focus on boundary cooling and will be able to extinguish a fire without actually entering the fire enclosure.

The prerequisite of not allowing any interior composite surfaces without at least 60 minutes of fire protective insulation results in less heat 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 FRD-60 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. The sensitivity to defects in fire protection should also be evaluated to ensure robustness of the novel design. Since the properties of an FRD-60 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 although be damaged, e.g. from maintenance, penetrations or sabotage, may, however, still need to be investigated.

The heat from a fire will to a larger extent stay in the space of origin and not easily be transmitted to adjacent spaces, which could be beneficial from a fire safety point of view. 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 the FRD-60 since 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 in simulations or tests. If the hypothesis is proved, the increased insulation will only lead to improved conditions for fire safety within the first 60 minutes.

Structural divisions after propagation or deterioration (> 60 min)

If a fire is not under control after 60 minutes the FRP composite will be considered to take part in the propagating fire. Provided with enough energy to reach the composite in spite of the used insulation it would in fact worsen the already hazardous conditions. Not only by adding more fuel to the fire but also by increasing the smoke production. Down to the improved thermal insulation capacity this stage of a fire is less likely to occur, and if it happens it is likely to be delayed in an design with FRD-60.

This stage would only be reached after 60 minutes of uncontrolled fire and a ship should already have been evacuated by then. Even if the consequences, when it comes to evaluating hazards to life in the new design, seem to be of minor importance it should still be brought to attention in an analysis. More combustible materials will exist on board, even if unavailable for a fire within the first 60 minutes. When contributing with combustible materials it will increase the fire load and the production of smoke and toxic products to the uncontrolled fire. At this stage conditions must already have become uninhabitable in many more ways, especially in the space of origin. Even if no one is present in the already uninhabitable spaces after 60 minutes it could be hazardous to persons on the embarkation deck in case of an unfortunate wind.

The questions are if a fire is more likely to be under control in a design with FRD-60 and what the consequences will be? How will the consequences be affected by the use of FRD-60 after 60 minutes of fire? In the exceptional case of a time-consuming fire, collapse will be more likely to occur in the FRD-60 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 FRD-60 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 [16].

A fire might be more likely to be controlled in the novel design and thanks to the improved conditions within the first 60 minutes the expected outcome might be acceptable. However, the consequences in case of failure still need to be considered. The result after more than 60 minutes may be catastrophic because of the increased amount of combustible materials.

Any magnitude of consequences will not be acceptable if e.g. the sprinkler system fails and an evacuation is protracted, which is not unusual [30]. Even if not directly affected by the fire, an increased smoke production could e.g. imply an additional risk to people embarking life safety appliances. Differences in ability to resist collapse could also affect the initiation of an evacuation itself. The evacuation process could be hazardous and affected by the novel design which invokes to also account for risks in the evacuation process.

Exterior surfaces

A direct change from steel to FRP would not imply increased risks when it comes to ignition sources but unprotected external surfaces would 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 balcony door is left open. Except including external surfaces in the fire it could imply fire spread between decks and 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. 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, making the drencher a vulnerable measure. New routines could, however, also include fire-fighting crew to prevent and limit 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 an analysis [16].

As a general conclusion one could regard the novel design to be advantageous in comparison with a prescriptive design within the first 60 minutes, which is the time the performance of decks and bulkheads are tested and the time frame in which an evacuation should be carried out. Depending on the proceeding scenario, differences between the designs might come in to play which could affect the fire safety of a ship in a negative way.

Data from the first hazard identification

Fire room	Fire type	Severity of fire	Likelihood	Possible consequence	Severity of consequence (1,2,3)
Fire in spinnaker lounge	“Fancy” drink sets seat on fire	Seat only	3	none	1
		Spread to other seats	2	limited	1
		Flashed over spinnaker lounge	1	Windows break, fire spread on outside	2 or 3
				Collapse of deck 14	3
	Fireworks on stage	Several seats and decorations involved	2-3	Smoke spread	2
		Flashed over spinnaker lounge	1-2	Windows break, fire spread on outside	3
				Collapse of deck 14	3
				Radar not so important after a fire, would go back on low speed.	
Fire in deck store on deck 14	Fire in sun chairs and cushions and paint	Confined to storage	1-2		
		Fire spread outside of storage	1-2	Spread to AC room and lift	2
Fire in AC room	Electrical failure	Confined to room	2-3	Smoke spread in AC	1 provided that the AC can be turned off
		Spread to lift machinery room	1	Fire or smoke spread throughout the vessel	3
Fire in sunbed	Cigarette, deliberate fire	Limited to a few beds	1-2	limited	1
Fire in radar transceiver	Electrical failure	confined to room	2	limited	
		Spread to other room	1	Spread to lift	
Spinnaker lounge	Fire starting nearby	limited	3		

	stage due to hot lamp, electrical failure	Spread to curtains and seats	2	limited	1
		Whole area involved in fire	1	Collapse of deck 14, windows break and get fire on outside Fire or smoke spread into staircase	3
	Fire starting in pantry or bar due to electrical failure	confined			
		Spreading			
Fire in Storage on deck 13	Fire due to cigarette	limited	1	limited	1
		spreading	1	Spread to AC, staircase	3
Fire in WC	Fire due to lamp, cigarette, deliberate	limited	2		
		growing	2	Spread through direct access to staircase	
				Emergency generator very important	
Fire in emergency room or battery room	Electrical or gas/diesel fire			Loss of emergency power, Must be stopped immediately whether it is a steel or other vessel	
Fire in casing	Due to fire in machinery room	confined			
		spreading		Spreading to AC and emergency room	3

Fire in AC room	Electrical failure	confined			
		spreading		Spreading to emergency room	
Fire in switchboard room	Electrical failure			Loss of electricity in case emergency	

Fire room	Fire type	Severity of fire	Likelihood	Possible consequence	Severity of consequence (1,2,3)
Deck 15, public sundeck	Arson, bottle of gasoline, paper*			Fire spreads to exterior of funnel or rest of superstructure***	
				Fire spreads and deck 15 collapses, light weight structure catches fire and spreads downwards****	
				Combustion of structure causes smoke and toxic	

				gases*****	
	Accidental fire, cigarette, faulty electrical appliance**			***	
				****	
				*****	
	Lightning			***	
				****	
				*****	
Deck 15, private sundeck	*			***	
				****	
				*****	
	**			***	
				****	
				*****	
	Lightning			***	
				****	
				*****	
Deck 15, private villa, external	*			***	
				****	
				*****	
	**			***	
				****	
				*****	
	Lightning			***	
				****	
				*****	
Deck 15, private villa, internal	*			***	
				****	
				*****	
	**			***	

				****	
				*****	
Deck 15, Store (what type of store is it?)	*			***	
				****	
				*****	
				explosion	
	**			***	
				****	
				*****	
				explosion	
Deck 15, Elevator shaft	*				
	**				
Deck 15, Corridor (in front of elevators)	*				
	**				
Dec 14 public sundeck	*				
	**				

	Lightning				
Deck 14, sauna	Arson				
	Faulty electricity				
	Faulty heater				
Deck 14 pantry (alcohol, oil,…)	Faulty electricity				
	Arson				
	Secret smoker				
Deck 14 cabins	*				
	**				
Deck 14 buffet area	*				
	**				
Deck 14 service elevator shaft (linen, alcohol, …)	*				
	**				
Deck 14 public elevator shaft (people, bags)	*				
	**				
Deck 13, battery room					
Deck 13, emergency generator room with oil and diesel (is diesel tank in room?)					

Deck 13 switchboard room					
Deck 13 lift machinery room					
Deck 13 pool equipment room					
Deck 13 grill	Duct fire			Quick spread through ductwork	
	Grill catch fire			Spread locally in steak house	
Deck 13, steak house, few doors and lot of people!	*				
	**				
Deck 13, sports ground					

Deck 13, front grill (outdoors)	Duct fire				
	Grill catch fire				
Deck 13, front dance floor				Severe immediate consequences due to high density of people.	

Fire room	Fire type	Severity of fire	Likelihood	Possible consequence	Severity of consequence (1,2,3)
Fire in passenger cabin on deck 11	Initiated from casing due to engine room fire Arson fire			Fire spread to the Crew section	
				Structural collapse of deck 12	
				Fire spread to deck 12	
				Fire spread through stairways	
				Fire spread to the balconies through large doors	
Fire in crew cabin on deck 11	Arson			Fire spread to the Bridge	
				Structural collapse of deck 12	
				Fire spread to deck 12	

				Fire spread through stairways	
				Fire spread to the balconies through large doors	
Beauty and relaxation areas at deck 12 front				Window breaking leading to an intense fire	
				Fire spread to outside	
				Fire spread to bridge beneath	
Dance floor on deck 13				Window breaking leading to an intense fire	
				Fire spread to outside	
				Fire spread to bridge beneath	
Deck 10 front fire in the studio suites, directly underneath the bridge area				Fire spread through windows and balcony to the outside and the bridge on deck 11	
Life style room at deck 12				Window breaking leading to an intense fire	
				Fire spread to outside	
Balcony fires				Fire spread to deck 12 composite structure	
Pool area	Barbecue, deep fryers			Fire spread to surrounding areas	

General fire types:

- Arson (deliberate)
- Spread from other area

Assume crew does not smoke, passengers may smoke.

<table>
<tr><th>Fire room</th><th>Fire type</th><th>Severity of fire</th><th>Likelihood</th><th>Possible consequence</th><th>Severity of consequence (1,2,3)</th></tr>
<tr><td rowspan="7">Fire in spinnaker lounge</td><td rowspan="4">“Fancy” drink sets seat on fire</td><td>Seat only</td><td>3</td><td>none</td><td>1</td></tr>
<tr><td>Spread to other seats</td><td>2</td><td>limited</td><td>1</td></tr>
<tr><td rowspan="2">Flashed over spinnaker lounge</td><td rowspan="2">1</td><td>Windows break, fire spread on outside</td><td>2 or 3</td></tr>
<tr><td>Collapse of deck 14</td><td>3</td></tr>
<tr><td rowspan="3">Fireworks on stage</td><td>Several seats and decorations involved</td><td>2-3</td><td>Smoke spread</td><td>2</td></tr>
<tr><td rowspan="2">Flashed over spinnaker lounge</td><td rowspan="2">1-2</td><td>Windows break, fire spread on outside</td><td>3</td></tr>
<tr><td>Collapse of deck 14</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fire in passenger cabin</td><td>Cigarette</td><td>x</td><td></td><td></td><td></td></tr>
</table>

(inside, no window)	Electric fault Candle	x			
		x			
		x			
		x			
Fire in passenger cabin (outside, window, balcony)	Cigarette Electric fault Candle	x			
		x			
		x			
		x x			
	x	x			
		x			
Fire in Linen store	Electric fault	Lots of burnable material			
		x			
		x			
	x	x			
		x			
Fire in Corridor	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Passenger staircase	Electric fault	x			
		x			

		x			
	x	x			
		x			
Fire in Crew staircase	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Passenger elevator	Electric fault Mechanical friction e.g. bearings	x			
		x			
		x			
	x	x			
		x			
Fire in Crew elevator	Electric fault Mechanical friction e.g. bearings	x			
		x			
		x			
	x	x			
		x			
Fire in Glass wash and ice pantry	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in AC trunk	NA	x			
		x			

		x			
	x	x			
		x			
Fire in Casing (funnel)	Electric fault Fire in engine room	x			
		x			
		x			
	x	x			
		x			
Fire in store (apart from linen)	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in AC room	Electric fault Mechanical friction e.g. bearings	x			
		x			
		x			
	x	x			
		x			
Fire in Hotel comp ??	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Chemical store	Electric fault Chemical reaction	x			
		x			

		x			
	x	x			
		x			
Fire in Pool equipment	Electric fault Mechanical friction e.g. bearings	x			
		x			
		x			
	x	x			
		x			
Fire in Passenger balcony	Cigarette Electric fault Candle	x		Horizontal spread	
		x		Vertical spread	
		x			
		x			
		x			
Fire in Lift machinery	Electric fault Mechanical friction e.g. bearings	x			
		x			
		x			
	x	x			
		x			
Fire in Electric locker	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Pantry	Electric fault	x			
		x			

		x			
	x	x			
		x			
Fire in Penthouse (passenger luxury cabin)	Cigarette Electric fault Candle	x			
		x			
		x			
	x	x			
		x			
Fire in Bridge (Wheel house)	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Bridge viewing room	Electric fault Cigarette	x			
		x			
		x			
	x	x			
		x			
Fire in Fire equipment room	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Radio equipment room	Electric fault	x			
		x			

		x			
	x	x			
		x			
Fire in Communication officer room	Electric fault	x			
		x			
		x			
	x	x			
		x			
Fire in Communication centre	Electric fault	x			
		x			
		x			
	x	x			
		x			

Deck 12 aft to amidships, to frame 165

Fire in Great outdoors (bar)	x	x			
		x			
		x			
	x	x			
		x			
Fire in La Cuicina Italian restaurant	x	x			
		x			
		x			

	x	x			
		x			
Fire in Cold store (refrigerator)	x	x			
		x			
		x			
	x	x			
		x			
Fire in Garden café (aft)	x	x			
		x			
		x			
	x	x			
		x			
Fire in WC (ladies, gents, disabled)	x	x			
		x			
		x			
	x	x			
		x			
Fire in Galley	x	x			
		x			
		x			
	x	x			
		x			

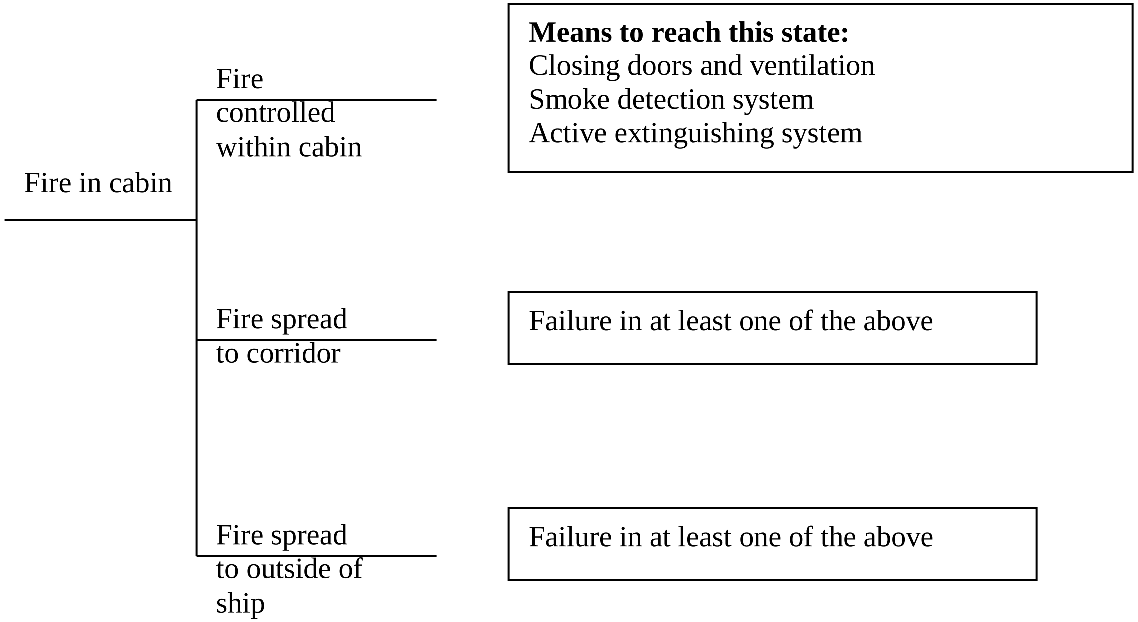
Fire in Passenger staircase	x	x			
		x			
		x			
	x	x			
		x			
Fire in Crew staircase	x	x			
		x			
		x			
	x	x			
		x			
Fire in Passenger elevator	x	x			
		x			
		x			
	x	x			
		x			
Fire in Crew elevator	x	x			
		x			
		x			
	x	x			
		x			
Fire in AC room	x	x			

<table>
<tr><td rowspan="5"></td><td rowspan="3"></td><td>x</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Fire in Casing (Funnel)</td><td rowspan="4">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Fire in CCTV (internal TV)</td><td rowspan="4">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Fire in AC trunk</td><td rowspan="4">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td rowspan="2"></td><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td rowspan="2">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Fire in Garden café (middle)</td><td rowspan="3">x</td><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
<tr><td>x</td><td></td><td></td><td></td></tr>
</table>

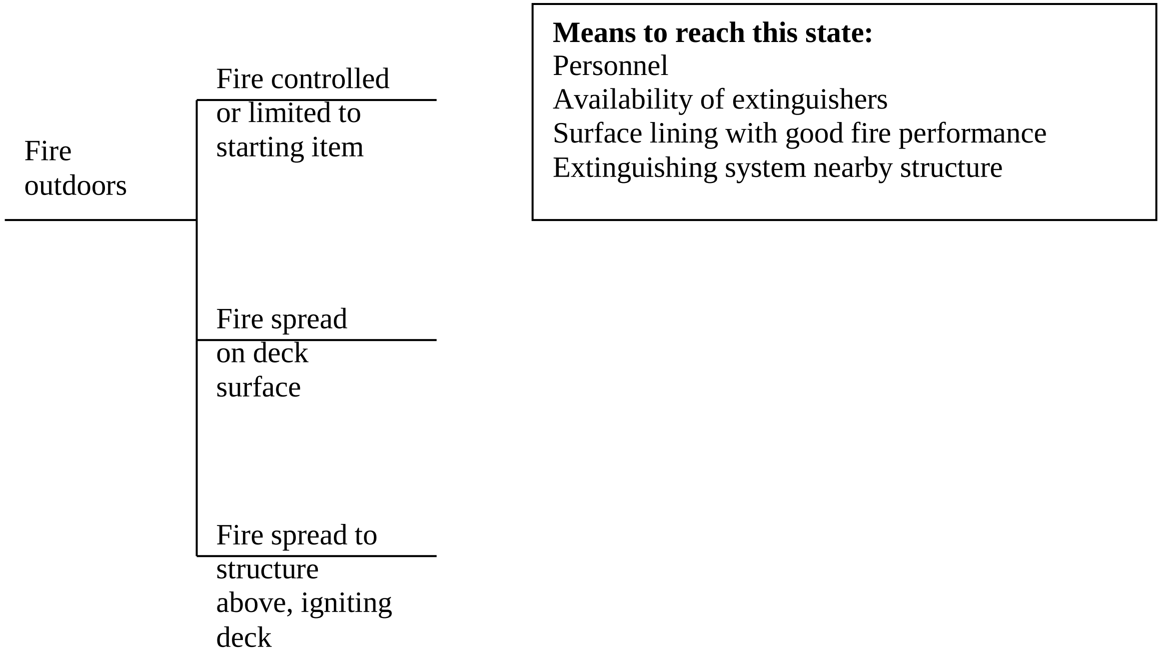
	x	x			
		x			
Fire in Garden café (fore)	x	x			
		x			
		x			
	x	x			
		x			
Fire in Video game room	x	x			
		x			
		x			
	x	x			
		x			
Fire in Change video technical (for cinema)	x	x			
		x			
		x			
	x	x			
		x			
Fire in Treetops kids club	x	x			
		x			
		x			
	x	x			

		x			
Fire in	x	x			
		x			
		x			
	x	x			
		x			

Summary of the first hazard identification



Suggest to focus on cabins on deck 11 as fire spreads more easily upwards and fires on cabins on top desks are somewhat similar to fires on deck.


Fire outdoors
Fire controlled or limited to starting item
Fire spread on deck surface
Fire spread to structure above, igniting deck
Means to reach this state:
Personnel
Availability of extinguishers
Surface lining with good fire performance
Extinguishing system nearby structure

Fire in pantry or galley

Fire controlled

Means to reach this state:
Detection
Extinguishing system
Control in ducts

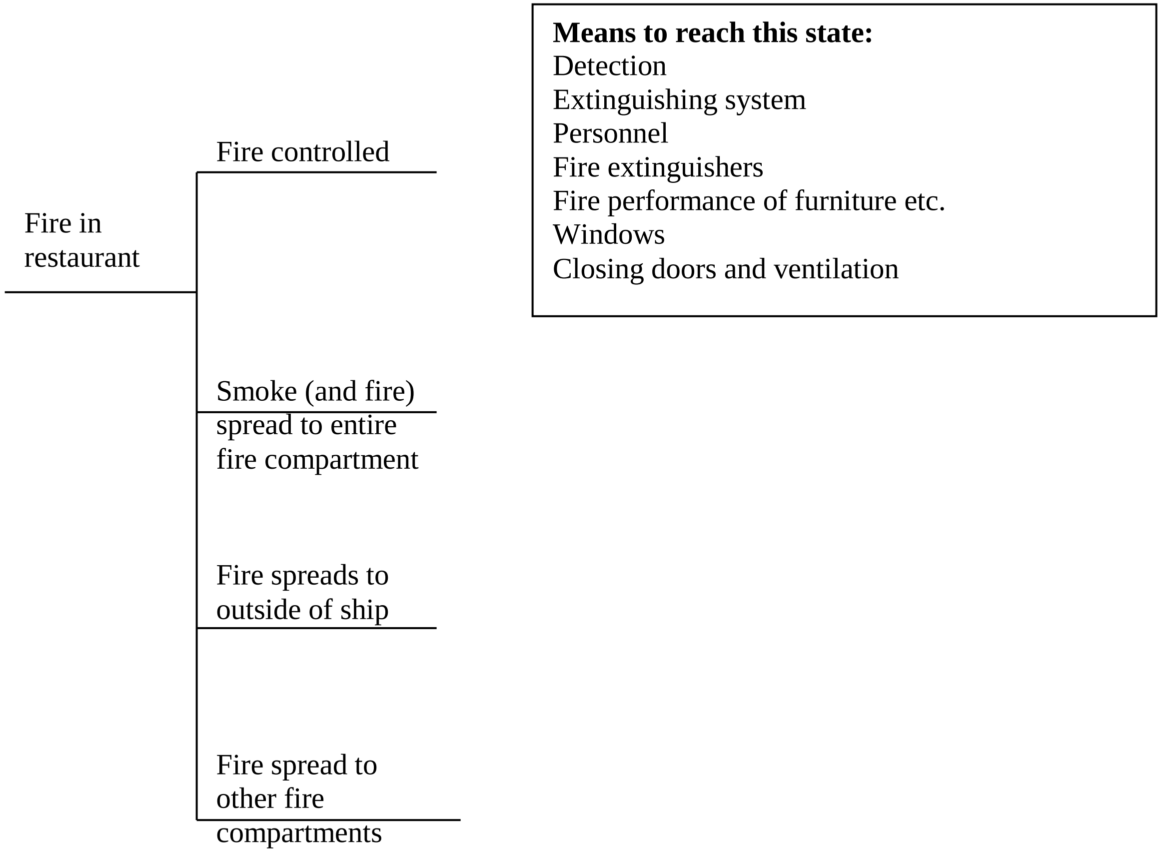
Fire spread through duct

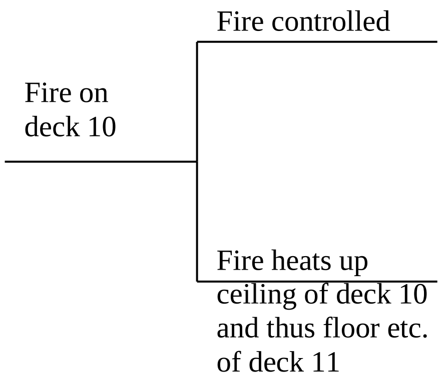
Question: Will ducts also be made of FRP?

Fire spread to adjacent*

Fire spread to outside of ship

*room, corridor or whatever is next
Suggest focus on Galley on deck 12.


Means to reach this state:
Detection
Extinguishing system
Personnel
Fire extinguishers
Fire performance of furniture etc.
Windows
Closing doors and ventilation
Fire in restaurant
Fire controlled
Smoke (and fire) spread to entire fire compartment
Fire spreads to outside of ship
Fire spread to other fire compartments



Question: How will joints between steel and FRP be made?

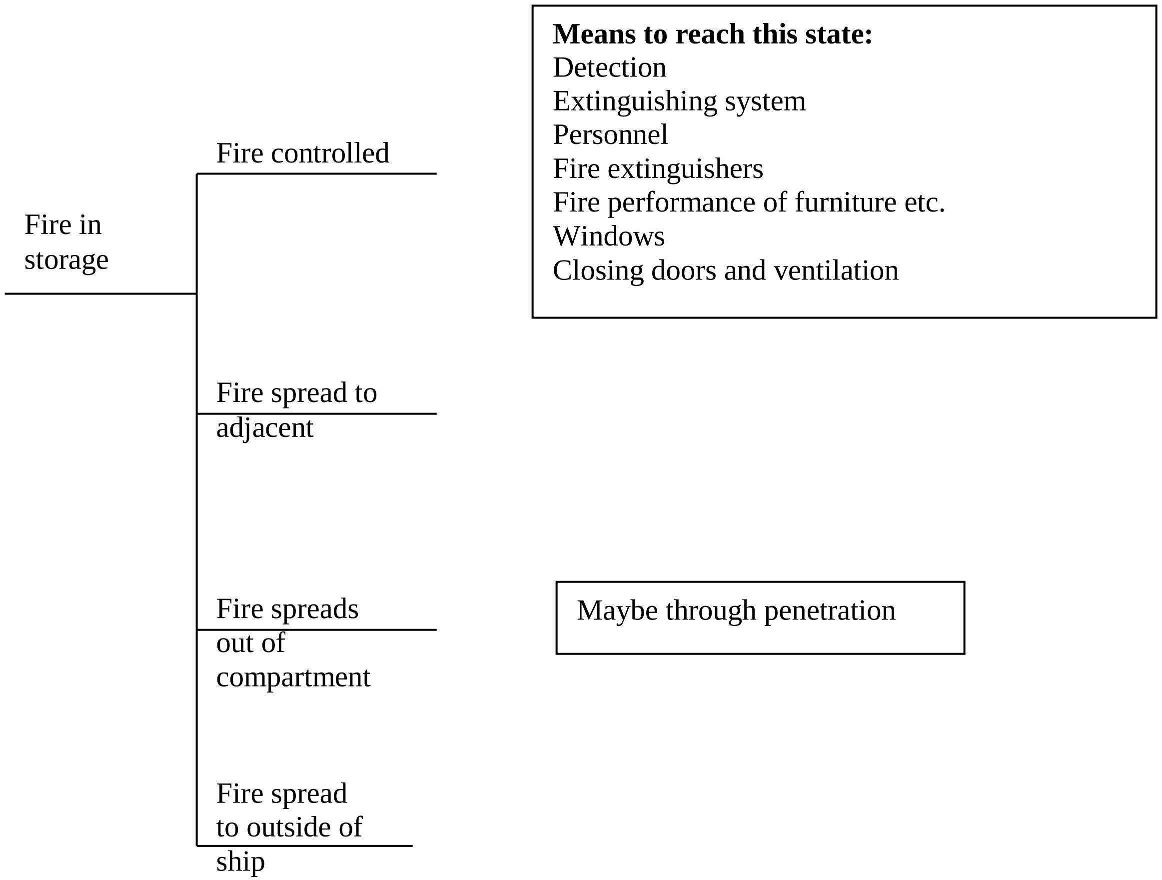
Fire in funnel/ casing

Fire controlled

Means to reach this state:
Machine maintenance and control
Extinguishing system ?

Question: Will funnel/casing also be made of FRP?

Fire Spread



Select storage with highest fire load.

Data from the second hazard identification

Below follows the tabulated fire hazards for the concerned spaces divided in decks.

Deck 11

space	ignition source	initial fuel	secondary fuels	extension potentials	target locations	critical factors	stat/freq	fire hazard characterizat and risk rating
Void space	electrical failure in junction boxes	cable insulation material, dust	combustible insulation material on pipes	**Propagation to adjacent space (including deck above)**	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**1:** Little probability of ignition access for fire-fighting difficu prescriptive design (as oppos to in a design with FRD-60, where cutting extinguishers c be used). Fire load is small a much smaller than for cabin, while passive fire protection i rated for min 60 min fully developed fire - and ventilatio very limited provided that dra stops are mounted.
	fire spread from adjacent space or deck below	FRP composite, cables, dust	dust		Detection system	Detection (not only the system)		
	electrical cable failure	cable insulation material, dust	cables		Penetrations	Insulation integrity, improved insulation		
			electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting	Integrity of pipes and other penetrations		

Cabin	cigarette, lighter	combustible disposal materials, newspaper, clothes, blankets, duvet/bed linens, etc.	**Furniture:** Bed frame, wardrobe, desk, bedside table	**Exterior propagation:** Through balcony/window to exterior surfaces	External composite surfaces	Reaction to fire properties for exterior surfaces		**3:** Much upholstered furniture and electronics and ignition sources can only be limited t some extent since people bri just about anything onboard. Discovery and fire-fighting m be delayed if the room is unattended.
	arson	combustible disposal materials, newspaper, clothes, blankets, duvet, furniture, flammable liquids etc.	**Linings:** Carpet, wall linings, ceiling material, plastic floor levelling material	**Propagation to adjacent spaces:** Cabins, corridor, void space, storage, stair case	Fuels in cabin (carpet and wall and ceiling coverings)	Reaction to fire properties for materials in cabin		
	spread from other areas	FRP, flooring, wall linings, bedding, wardrobe etc.	**Plastics and electrical equipment:** Lights, computer, luggage, cell phone, TV, hair straightener, water boiler, etc.	**Propagation through open door to corridor/balcony**	AC	Smoke spread		
	carelessness, e.g hairdryer or lamp covered by fabric or brought candles	clothes, blankets, duvet, bedding, paper	**Upholstered materials:** Cushions, mattress, duvet	**Propagation to deck above**	Detector	Detection and extinguishment in cabin		
	electrical equipment	Electrical insulation material, dust, batteries, cables	**Textiles:** Clothes, bed linens, towels, blanket		Open cabin door or balcony door/broken window	Ventilation		

					Sprinkler/active fire-fighting system	Function of sprinkler system (reliability and probability to control fire)		
					FRP divisions	Insulation integrity		
						Easy and fast fire-fighting		
Bridge	cigarette, lighter, carelessness	combustible disposal materials, books/papers, dust	Equipment	**Exterior propagation:** Through window to exterior surfaces	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Bridge is always attended educated personnel, i.e. low probability for a fire to sustai Many electrical instruments b fire would not go on unnotice Combustible materials are limited. A fire in the chart roo could, however, lead to a rap fire development and an inte fire.
	arson	combustible disposal materials, cables, books/papers	Carpet	**Propagation to adjacent spaces:** Staff cabins, staircase, void space, void space below bridge floor, corridor	Detection system	Detection (not only the system)		
	lightning	electrical insulation material, plastic material, books/papers, batteries	FRP		Penetrations	Insulation integrity, improved insulation		
	spread from other areas	FRP, flooring, wall linings, furniture etc.	Surface linings, floor levelling material		Ventilation/draft stopper	Open or closed door		
	electrical failure	electrical insulation material, plastics, dust, batteries	Furniture, books		Access for fire-fighting	Integrity of pipes and other penetrations		
			Plastic material		Windows	Reaction to fire for materials		

			Monitors			Ventilation		
AC	Arson	Cables, electrical equipment, plastics, waste, towels, newspapers	linings	**Propagation to adjacent spaces:** Store, corridors, cabins, communication officer, radio equipment, FE	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Small probability of ignitior small fire load, AC control de important to avoid smoke spr closing doors are important. Limited ventilation.
	Human error	electrical insulation material, dust, waste, rags	cables		Doors	Supply of air		
	Electrical failure	Cable insulation material, electrical equipment, plastics, dust	hvac components		Detection system	Detection (not only the system)		
	spread from other areas	FRP composite, cables, dust, electrical equipment	Electrical machinery equipment		Penetrations	Integrity of pipes and other penetrations		
	overheating of fan motors, bearings	Cable insulation material, electrical equipment, plastics, dust, oil, cooling media	FRP deck and walls		Fire dampers, AC design to prevent smoke spread	Spread of smoke		
			combustible insulation material on pipes		Electrical equipment and other fuels in space	Access for fire-fighting, easy and fast operation		
						Reaction to Fire for electrical Equipment		
						Insulation integrity, improved insulation		

Lifts and shaft	Arson	electrical insulation material	Lining material	corridors	Doors to staircases	Smoke spread		**1:** Small probability of ignitio and limited amount of initial fuel. Cables and other combustible materials could however ignite due to electric failure. Smoke spread could dangerous if spreading to staircases and evacuating people. Lift control and detection is therefore importa Extinguishing system reduce the probability of an uncontrolled fire.
	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	staircases	Draft stoppers	Lift control		
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	cabins	Detection system	Detection		
	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	communication officers	Extinguishing system	Control of fire by extinguishing system		
			FRP walls		Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
					Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
						Ventilation (supply of air)		

Store	Arson	Cleaning products, linen, towels, plastics (depends on type of storage)	Towels, linen, etc.	Cabins	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**2:** Space is not open for publ ignition sources are limited b not insignificant. Fire load is great, especially in relation to the space. The consequence from a fire will be quite dependable to the supply of a i.e. if the doors are closed. Functional door closers are important. Arson could be catastrophic.
	Machinery failure	Batteries, plastic covers, cleaning products, linen, towels, dust (depends on type of storage)	FRP ceiling, walls and floor	AC	Detection system	Insulation integrity, improved insulation		
	Electrical failure	Batteries, cleaning products, linen, towels, plastics, dust (depends on type of storage)	Linings	Pantry	Penetrations	Open or closed door		
	Cigarette or carelessness	Paper materials, cleaning products, linen, towels, plastics (depends on type of storage)	Stored equipment	Staircases	Ventilation system	Fire integrity of pipes and other penetrations		
	Spread from other areas	FRP, wall linings, cables, dust	Deck chairs					

Pool trunk including chemical store and pool equipment	Arson	Flammable liquids, chemicals, paper materials, grease, waste material, rags	Cleaning equipment	Cabins	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**2:** Space contains a few initia fuels that could result in a rap first stage of a fire (flammabl liquids, chemicals). The spac is, however, small and close from the public.

	Overheating due to carelessness e.g. mixing wrong chemicals	Flammable liquids, chemicals, paper materials, grease, dust, waste material, rags	Surface linings	Corridor	Detection system	Fire insulation integrity (improved insulation)		
	spread from other areas	Flammable liquids, chemicals, paper materials, grease, dust, waste material, rags	Pressurized bottles	AC	Penetrations	Open or closed door		
	Machinery problems	Flammable liquids, grease, dust, waste material, rags	FRP ceiling	Staff staircase	Ventilation system	Fire integrity of pipes and other penetrations		
	Electrical failure	Paper materials, grease, dust, waste material	Plastic materials		Door	Open or closed door		
Staircases	Arson	Arson flammables (limited amounts), paper, carpet	Temporary furniture (table, chair, poster)	To the next level	Detection system	Detection		**2.** Potentially crowded. Huma error could lead to a fire whic would have a good supply of air. Smoke spread could be a problem. Detection is crucial. The amount of combustible materials should be very limited.
	cigarette, lighter	Paper, carpet	Surface linings (carpet, wall lining)	Lifts	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	Paper materials, surface linings, dust	Decorations	Hotel store	Closing doors	Smoke spread through staircase		

	Electrical failure (lamps, cabinets, elevator motor..), short circuit	cable insulation material, plastic covers, dust	Passenger belongings	AC	Surface linings	Reaction to fire by surface linings		
	Human error (smoking etc.)	Carpet, paper	Trash can	Corridor				
				Cabins				
Communication Centre, Radio Equipment, Comm officer	electrical failure	Combustible disposal materials, newspaper, dust, electrical insulation material, plastic covers, cables	Carpet, FRP ceiling	(Staff) cabins	Deck and bulkhead: non-combustible insulation	Insulation integrity, improved insulation		**1:** Much combustible materia Personnel available/close by Not a public space. Detectior important. Confined space.
	cigarette, lighter	Insulation material, carpet, combustible disposal material, newspaper, plastic material, books		Pool equipment	Detection system	Detection (not only the system)		
	spread from other areas	Cables, FRP composite, surface linings, furnishings, books		Lifts/staircase	Penetrations	Extinguishment		
	arson	arson liquids	Carpet, FRP ceiling	Corridor	Access for fire-fighting	Ventilation		

				FE AC	Windows	Reaction to fire for materials Integrity of pipes and other penetrations Open or closed door		
Lift Machinery	Arson	electrical insulation material	Lining material	Cabins	Doors to staircases	Smoke spread		**2:** Overheated bearing could result in cable fire. Probability of ignition still regarded small and amount of initial fuel limited. Cables and other combustible materials could however ignite due to electric failure. Smoke spread could dangerous if spreading to staircases and evacuating people. Lift control and detection is therefore importa Extinguishing system reduce the probability of an uncontrolled fire.
	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	Corridor	Draft stoppers	Lift control		
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	Hotel Store	Detection system	Detection		
	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	Pool trunk	Extinguishing system	Control of fire by extinguishing system		
			FRP walls and ceiling		Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
					Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
					FRP ceiling	Ventilation (supply of air)		

Pantry	Electrial failure	Cables, smaller equipment, plastic covers, grease, flour, dust, food boxes	Furniture	Corridor	Door	Insulation integrity, improved insulation		**3:** Small controlled flames ar common when cooking. Gett in contact with initial fuels cou lead to a potential fire, especially if igniting nearby products that could burn rapi (boxes, bags of dry foods/chips). Cooking failure with grease could be potentia dangerous. Grease in duct could spread the fire verticall Spread to exteriors is commo since pantries are often in connection with open deck.
	Arson	Arson flammables and material, books/newspapers, towels, clothes, food boxes	Surface linings	Cabins	Extinguishing system	Extinguishment		
	Cigarette, lighter	paper towels, towels, clothes, grease, dust, food boxes	FRP walls and ceiling	AC	Detection system	Detection		
	Spread from other areas	Surface linings, books, FRP composite, food boxes	White goods	Hotel store	Draft stoppers	Neat order		
	Cooking failure	Cables, smaller equipment, grease, flour, dust, grease, flour, towels, clothes, food boxes	Plastic materials		Deck and bulkhead construction	Ventilation (supply of air)		
			Try foods (spice bags, bags of chips, bread, boxes of foods)		Penetrations	Integrity of pipes and other penetrations		
						Spread of smoke		

Casing	Engine room fire	Soot, grease, dust, dirt, rags, electrical equipment, cables	FRP	All decks	Adjacent deck and bulkhead constructions	Insulation integrity, improved insulation		**3:** Ignition sources are available but combustible materials are limited/restricte Detection is difficult in casing Arson could lead to involvement of entire funnel and outside structure.
	Smoke exhaust leakage	Soot, grease, dust, dirt, rags, electrical equipment, cables		Outside structure	Extinguishing system	Extinguishment of engine fires, engine control		
	Arson	Flammable liquids or material			Detectors	Detection		
	Electrical failure	Soot, grease, dust, dirt, rags, electrical equipment, cables			Openings	Smoke spread		
						Integrity of openings		
Balcony	Arson	Arson flammables (limited amounts), waste material, linen, towels, paper	Furniture	Other balconies	FRP composite	Drencher reliability		**3:** Ignition sources such as smoking and candles may nc be possible to restrict on balconies. Limited amounts c fuels but unprotected FRP composite surfaces are also present which could fuel and spread a fire.
	Fire spread from cabin	FRP composite, waste material, linen, towels, paper	Carpet	Exterior surface	Materials in cabin	Reaction to fire properties for materials		
	Human error (candles, smoking etc.)	Waste material, paper, towel clothes, books/magazine	Blankets/towels	Cabin	Sprinkler system	Function of sprinkler system		

	Electrical equipment	Waste material, paper, towel, clothes, linen, dust	Floor levelling material	Vertical fire spread to next deck	Balcony door	Opening to cabin		
			Upholstered cushions		Fire-fighting	Easy and fast operation		
			Bag of clothes					
Void space below bridge floor	electrical failure in junction boxes	cable insulation material, dust	combustible insulation material on pipes	**Propagation to adjacent space:** Bridge	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Little probability of ignition but access for fire-fighting difficult in prescriptive design (as opposed to in a design w FRD-60, where cutting extinguishers can be used). Fire load is small and much smaller than for cabin, while passive fire protection is rate for min 60 min fully develope fire - and ventilation is very limited provided that draft sto are mounted.
	fire spread from adjacent space or deck below	FRP composite, cables, dust	dust		Detection system	Detection (not only the system)		
	electrical cable failure	cable insulation material, dust	cables		Penetrations	Insulation integrity, improved insulation		
			electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting	Integrity of pipes and other penetrations		
Corridors	Arson	Arson flammables (limited amounts), waste material, linens, cleaning products, plastic covers/bottles, electrical cleaning equipment and machines	Surface linings	Surrounding cabins	External composite surfaces	Reaction to fire properties for surface linings/divisions		**2:** A fire in the corridor could block the evacuation path for many passengers in cabins. cleaning wagon would be ea for an arsonist/human error/electrical failure to ignit A fire in a cleaning wagon could imply a rapid fire scena and would imply inhabitable conditions will be reached fa

	Human error	Waste material, linens, cleaning products, plastic covers/bottles	Passenger belongings/luggage	Stairways	Doors	Open ways for the fire to spread		Personnel should, however, l very close and should, if not out the fire, be able to Other than that fuels should be very restricted.
	Spread from other areas	FRP composite, wall and deck linings/carpet, lights	Electrical cleaning equipment/machines	Store	Detector	Detection		
	Electrical failure	Waste material, linens, cleaning products, plastic covers/bottles	Decorations	AC	Sprinkler/active fire-fighting system	Smoke spread		
			Cleaning wagon	…		Extinguishment Easy and fast fire-fighting Function of sprinkler system (reliability and probability to control fire)		

Deck 12

space	ignition source	initial fuel	secondary fuels	extension potentials	target locations	critical factors	stat/freq	fire hazard characterization and risk rating
Void space	electrical failure in junction boxes	cable insulation material, dust	combustible insulation material on pipes	**Propagation to adjacent space (including deck above)**	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**1:** Little probability of ignition, but access for fire-fighting difficult in prescriptive design (as opposed t in a design with FRD-60, where cutting extinguishers can be used). Fire load is small and muc smaller than for cabin, while passive fire protection is rated for min 60 min fully developed fire - and ventilation is very limited provided that draft stops are mounted.
	electrical cable failure	cable insulation material, dust	dust		Detection system	Fire reaction for insulation		
	fire spread from space below or adjacent space	FRP composite, cables, dust	cables		Penetrations	Insulation integrity, improved insulation		
			electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting, access for inspection	Integrity of pipes and other penetrations		

Sundeck mid	cigarette, lighter	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and bulkheads	**Small materials:** towels, waste, pillows	**Propagation to adjacent space:** life style room, fitness centre, deck store, dive in, elevator area, grill/bar	External composite surfaces	Detection		**3:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent smoke problems. Detection could be a problem. Furthermore, the sundeck contains unprotected corners with ceiling where a larger fire could develop faster. Fire origin in corner or under balcony could be a worst case scenario.
	arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and bulkheads	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather), music instruments and speakers	**Exterior propagation:** up to deck 13 (exterior combustible surfaces and materials on sun deck)	Reaction to fire by deck coverings	Extinguishment		
	lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and bulkheads	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		

	spread from other areas	FRP divisions, furniture	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		
	barbeque	combustible disposal materials, newspaper, towel, fat, dust				(reliability of drencher if installed)		
	electrical equipment	Electrical components, insulation material, dust						
Sundeck stern	cigarette, lighter	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and bulkheads	**Small materials:** towels, waste, cushions	**Propagation to adjacent space:** AC, restaurant, galley, food court seating area	External composite surfaces	Detection		**3:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent smoke problems. Detection could be a problem. Furthermore, the sundeck contains unprotected corners with ceiling where a larger fire could develop faster. Fire origin in corner or under balcony could be a worst case scenario.
	arson	Flammable liquids/materials combustible disposal materials, newspaper, towel, sunbeds, FRP deck and bulkheads	**Large materials:** Chairs, tables, bar, buffet furniture	**Exterior propagation:** up to deck 14 (exterior combustible surfaces and materials on sun deck)	Reaction to fire by deck coverings	Extinguishment		

	lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and bulkheads	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
	spread from other areas	depends on from where fire propagates (FRP composite?)	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		
	electrical equipment	Electrical components, insulation material, dust				(reliability of drencher if installed)		
AC	Arson	Cables, electrical equipment, plastics, waste, towels, newspapers	linings	**Propagation to adjacent spaces:** Casing, storage, galley, food court, spa, lift machinery	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Small probability of ignition, small fire load, AC control design important to avoid smoke spread, closing doors are important. Limited ventilation.

Human error	electrical insulation material, dust, waste, rags	cables		Doors	Supply of air		
Electrical failure	Cable insulation material, electrical equipment, plastics, dust	hvac components		Detection system	Detection (not only the system)		
spread from other areas	FRP composite, cables, dust, electrical equipment	Electrical machinery equipment		Penetrations	Integrity of pipes and other penetrations		
overheating of fan motors/bearings	Cable insulation material, electrical equipment, plastics, dust, oil, cooling media	FRP deck and walls		Fire dampers, AC design to prevent smoke spread	Spread of smoke		
		combustible insulation material on pipes		Electrical equipment and other fuels in space	Access for fire-fighting, easy and fast operation		
					Reaction to Fire for electrical Equipment		
					Insulation integrity, improved insulation		

Lifts and shaft	Arson	electrical insulation material, electrical cabinets	Lining material	Shaft	Doors to staircases	Smoke spread		**1:** Small probability of ignition and limited amount of initial fuel. Cables and other combustible materials could however ignite due to electrical failure. Smoke spread could be dangerous if spreading to staircases and evacuating people. Lift control and detection is therefore important. Extinguishing system reduces the probability of an uncontrolled fire.
	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	Staircases	Draft stoppers	Lift control		
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	AC	Detection system	Detection		
	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	Area in front of lifts	Extinguishing system	Control of fire by extinguishing system		
			FRP walls	Food court	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
			Electrical cabinets		Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
						Ventilation (supply of air)		
Store	Arson	Cleaning products, linen, towels, plastics (depends on type of storage)	Towels, linen, etc.	Pantry	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**2:** Space is not open for public, ignition sources are limited but not insignificant. Fire load is great, especially in relation to the space. The consequences

	Machinery failure	Batteries, plastic covers, cleaning products, linen, towels, (depends on type of storage)	FRP ceiling, walls and floor	WC	Detection system	Insulation integrity, improved insulation		from a fire will be quite dependable to the supply of air, i.e. if the doors are closed. Functional door closers are important. Arson could be catastrophic.
	Electrical failure	Batteries, cleaning products, linen, towels, plastics (depends on type of storage)	Linings		Penetrations	Open or closed door		
	Cigarette or carelessness	Paper materials, cleaning products, linen, towels, plastics (depends on type of storage)	Stored equipment		Ventilation system	Fire integrity of pipes and other penetrations		
	Spread from other areas	FRP, wall linings, cables, dust	Deck chairs					
Staircases	Arson	Arson flammables (limited amounts), paper, carpet	Temporary furniture (table, chair, poster)	To the next level	Detection system	Detection		**2:** Potentially crowded. Human error could lead to fire which would have a good supply of air. Smoke spread could be a problem. Detection is crucial. The amount of combustible materials should be very limited.
	cigarette, lighter	Paper, carpet	Surface linings (carpet, wall lining)	Lifts	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	Decorations, surface linings, dust	Decorations	Hotel store	Closing doors	Smoke spread through staircase		

	Electrical failure (lamps, cabinets, elevator motor..), short circuit	cable insulation material, plastic covers, dust	Passenger belongings	AC	Surface linings	Reaction to fire by surface linings		
	Human error (smoking etc.)	Carpet, paper	Trash can	Corridor				
				Cabins				
WC etc	electrical failure, overheating	cables, plastic covers	Furniture	Adjacent deck	Detection system	Detection		**2:** A typical location for arson. WC is typically located next to staircase which could be hazardous in case door opens and smoke spreads rapidly in the escape route/staircase. Fuels are however normally limited.
	cigarette, lighter	paper towels, waste, towels, clothes	Linings	AC	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	paper towels, waste	Trashcan	Courtyard	Closing doors	Smoke spread through staircase		
	arson	paper towels, waste, towels, clothes, linen, boxes, flammable liquids	Upholstered cushions	Staircase	Surface linings	Reaction to fire by surface linings		
			Plastic material/decorations			Ventilation		

Spa area	electrical failure, overheating	cable insulation, cables, dust, waste material, paper towels, plastic covering, magazines, books	Furniture	Fitness centre	FRP divisions	Insulation integrity		**2:** Hot surfaces (sauna, etc.) and lots of electrical equipment and treatment products (chemicals). Fire load similar to cabin (many small separate spaces) but fuels may be more limited and easy to restrict. Detection important to make sure evacuation is initiated as well as smoke management in order to prevent lost lives.
	cigarette, lighter	towels, clothes, waste material, paper towels, magazines, books, chemicals	Carpet	Lifts	AC	Smoke spread		
	spread from other areas	FRP, wall linings, cables, dust	Linings	Staircase	Sprinkler system	Detection		
	arson	flammable liquids, waste material, paper towels, plastic materials, magazines, books, chemicals		Exterior structure/FRP composite surface	Fire-fighting	Extinguishment		
	carelessness (fabric over lamp etc.)	towels, clothes, waste material, paper towels, magazines, books, chemicals		Library	Doors	Ventilation		

				AC		Function of sprinkler system (reliability and probability to control fire)		
						Easy and fast fire-fighting		
Gym area	electrical failure, overheating	Cable insulation, cables, dust, waste material, paper towels, plastic covering, magazines	Furniture	Spa	FRP divisions	Insulation integrity		**1:** Many machines and electrical equipment. Fire load is however limited and. Detection important as well as spread management in order to prevent lost lives and to make sure evacuation is initiated.
	cigarette, lighter	towels, clothes, waste material, paper towels, magazines, chemicals	Exercise machines	Lifts	Sprinkler system	Smoke spread		
	spread from other areas	FRP, wall linings, cables, dust	Linings	Staircase	Fire-fighting	Detection		
	arson	flammable liquids, waste material, paper towels, plastic materials, magazines, chemicals, bag, box	Plants	Exterior structure/FRP composite surface	Doors	Extinguishment		
	carelessness (fabric over lamp etc.)	towels, clothes, waste material, paper towels, magazines, books, chemicals		Deck store		Ventilation		
				Sundeck		Function of sprinkler system (reliability and probability to control fire)		
						Easy and fast fire-fighting		

Library and Card Room	electrical failure	Combustible disposal materials, newspaper, dust, electrical insulation material, plastic covers, cables	Furniture	**Propagation to adjacent space:** Fitness Centre, Lifts and Staircases, Spa area, open deck on deck 12	Deck and bulkhead: non-combustible insulation	Insulation integrity, improved insulation		**2:** Ignition sources limited. Much combustible materials. Personnel available/close by. Detection is important.
	cigarette, lighter	Carpet, combustible disposal material, newspaper, plastic material, books, cushions	Upholstered cushions	**Exterior propagation:** up to deck 13 (exterior combustible surfaces and materials on sun deck)	Detection system	Detection (not only the system)		
	spread from other areas	Cables, FRP composite, surface linings, furnishings, books	Carpet		Penetrations	Extinguishment		
	arson	Arson liquids and combustible materials/books	FRP composite		Access for fire-fighting	Ventilation		
	carelessness (fabric over lamp etc.)	Carpet, combustible disposal material, newspaper, plastic material, books, cushions	Surface linings		Windows	Reaction to fire for materials		
						Integrity of pipes and other penetrations Open or closed door		

Children's area	Arson	Arson flammables (limited amounts), waste material, towels, paper, toys, upholstered furniture/pillows, TV, electrical equipment	Furniture	Lifts	FRP composite	Drencher reliability		**2:** Human error may be more likely than in other spaces. Large amounts of upholstered pillows/furniture and electrical equipment. Available personnel could provide fast detection.
	Fire spread from other areas	FRP composite, waste material, upholstered furniture,	Carpet	Café area	Materials in the area	Reaction to fire properties for materials		
	Human error (candles, water on electronics etc.)	Waste material, towels, paper, toys, upholstered furniture/pillows, TV, electrical equipment, clothes, books/magazine	Bag of clothes	Sundeck	Sprinkler system	Function of sprinkler system		
	Electrical equipment	Waste material, towels, paper, toys, upholstered furniture/pillows, TV, electrical equipment, clothes, dust	Floor levelling material	Vertical fire spread to next deck/exterior surfaces	Doors	Supply of air to the space and possibility for smoke spread		
			Upholstered cushions		Fire-fighting	Easy and fast operation		

Pantry	Electrical failure	Cables, smaller equipment, plastic covers, grease, flour, dust, food boxes	Furniture	Garden Café	Door	Insulation integrity, improved insulation		**3:** Small controlled fires are common when cooking. Getting in contact with initial fuels could lead to a potential fire, especially if igniting nearby products that could burn rapidly (boxes, bags of dry foods/chips). Cooking failure with grease could be potentially dangerous. Grease in duct could spread the fire vertically. Spread to exteriors is common since pantries are often in connection with open deck.
	Arson	Arson flammables and material, books/newspapers, towels, clothes, food boxes	Surface linings	WC	Extinguishing system	Extinguishment		
	Cigarette, lighter	paper towels, towels, clothes, grease, dust, food boxes	FRP walls and ceiling	Restaurant	Detection system	Detection		
	Spread from other areas	Surface linings, books, FRP composite, food boxes	White goods	Grill	Draft stoppers	Neat order		
	Cooking failure	Cables, smaller equipment, grease, flour, dust, grease, flour, towels, clothes, food boxes	Plastic materials	Staircase	Deck and bulkhead construction	Ventilation (supply of air)		
			Try foods (spice bags, bags of chips, bread, boxes of foods)		Penetrations	Integrity of pipes and other penetrations		
						Spread of smoke		

Deck 13

space	ignition source	initial fuel	secondary fuels	extension potentials	target locations	critical factors	stat/freq	fire hazard characterization
Void space	electrical failure in junction boxes	cable insulation material, dust	combustible insulation material on pipes	**Propagation to adjacent space (including deck above)**	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**1:** Little probability of ignition, but access for fire-fighting difficult in prescriptive design (as opposed to in an FRD design where cutting extinguishers can be used). Fire load is small and much smaller than for cabin, while passive fire protection is rated for min 60 min fully developed fire - and ventilation is very limited provided that draft stops are mounted.
	electrical cable failure	cable insulation material, dust	dust		Detection system	Fire reaction for insulation		
	fire spread from space below or adjacent space	FRP composite, cables, dust	cables		Penetrations	Insulation integrity, improved insulation		
			electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting, access for inspection	Integrity of pipes and other penetrations		
Sundeck	cigarette, lighter	combustible disposal materials, newspaper, towel	**Small materials:** towels, waste, pillows	**Propagation to adjacent space:** restaurant, bar, AC, storage room…	External composite surfaces	Detection		**3:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent smoke problems. Detection could

arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	Large materials: sunbeds, racks of sunbeds (particularly in case the sundeck is not crowded, e.g. night time or in case of cloudy weather), music instruments and speakers	**Exterior propagation:** up to deck 14 (exterior combustible surfaces and materials on sun deck)	Reaction to fire by deck coverings	Extinguishment		be a problem. Furthermore, the sundeck contains unprotected corners with ceiling where a larger fire could develop faster. Fire origin in corner or under balcony could be a worst case scenario.
lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
spread from other areas	FRP divisions, furniture	Structural surfaces: FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		
barbeque	combustible disposal materials, newspaper, towel, fat, dust				(reliability of drencher if installed)		
electrical equipment	Electrical components, insulation material, dust				Available personnel		

Steakhouse including grill, Pantry, WC, store and reception	cigarette/lighter	combustible disposal materials, newspaper, furniture, cushions, curtains, carpet, table cloth	Furniture	AC	Deck and bulkhead: non-combustible insulation	Insulation integrity, improved insulation		**3:** Ignition sources are hard to restrict in public areas. The fuels in the area cannot be said to be limited since people can bring just about anything to the spaces. Many of the fuels will however be of similar sort (much furniture, upholstered cushions, table cloths etc.). A fire in this area could be hazardous since it could contain a lot of people. Successful evacuation is crucial. A fire could also spread to include exterior FRP composite surfaces and the sundeck.
	arson	combustible disposal materials, newspaper, furniture, cushions, curtains, carpet, boxes, flammable liquids and materials	Carpets	Pool equipment room	Detection system	Reaction to fire for materials		
	lightning	combustible disposal materials, newspaper, furniture, cushions, curtains, carpet	Upholstered cushions	Lift shaft	Windows	Easy and fast evacuation, personnel organization		
	Cooking failure	grease, flour etc.	Linings	Sundeck	Doors	Ventilation (supply of air)		
	spread from other areas	FRP composite, cables, dust, electrical equipment	Packing material	Staircase	Extinguishing system	Control of fire by extinguishing system		
	electrical equipment	Electrical insulation material, white goods, dust, table cloth	Clothes	Corridor	Detection system	Smoke and fire spread through openings		
			FRP surfaces	Exterior FRP surfaces		Detection (not only the system)		

AC	Arson	Cables, electrical equipment, plastics, waste, towels, newspapers	linings	**Propagation to adjacent spaces:** Lift machinery, switchboard room, emergency room, battery room, store, wc, pantry, casing	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Small probability of ignition, AC control design important to avoid smoke spread, closing doors are important. Limited ventilation.
	Human error	electrical insulation material, dust, waste, rags	cables	**Exterior propagation:** Sundeck	Doors	Supply of air		
	Electrical failure	Cable insulation material, electrical equipment, plastics, dust	hvac components		Detection system	Detection (not only the system)		
	spread from other areas	FRP composite, cables, dust, electrical equipment	Electrical machinery equipment		Penetrations	Integrity of pipes and other penetrations		
	overheating of fan motors/bearings	Cable insulation material, electrical equipment, plastics, dust, oil, cooling media	FRP deck and walls		Fire dampers, AC design to prevent smoke spread	Spread of smoke		
			combustible insulation material on pipes		Electrical equipment and other fuels in space	Access for fire-fighting, easy and fast operation		
						Reaction to Fire for electrical Equipment		
						Insulation integrity, improved insulation		

Lift Machinery	Arson	electrical insulation material	Lining material	Restaurant	Doors to staircases	Smoke spread		**1:** Small probability of ignition and limited amount of initial fuel. Cables and other combustible materials could however ignite due to electrical failure. Smoke spread could be dangerous if spreading to staircases and evacuating people. Lift control and detection is therefore important. Extinguishing system reduces the probability of an uncontrolled fire.
	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	staircases	Draft stoppers	Lift control		
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	cabins	Detection system	Detection		
	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	Area in front of lifts	Extinguishing system	Control of fire by extinguishing system		
			FRP walls		Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
					Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
						Ventilation (supply of air)		

Store	Arson	Cleaning products, linen, towels, plastics (depends on type of storage)	Towels, linen, etc.	Sundeck	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**2:** Space is not open for public, ignition sources are limited but not insignificant. Fire load is great, especially in relation to the space. The consequences from a fire will be quite dependable to the supply of air, i.e. if the doors are closed. Functional door closers are important. Arson could be catastrophic.
	Machinery failure	Batteries, plastic covers, cleaning products, linen, towels, (depends on type of storage)	FRP ceiling, walls and floor	Pantry	Detection system	Insulation integrity, improved insulation		
	Electrical failure	Batteries, cleaning products, linen, towels, plastics (depends on type of storage)	Linings	WC	Penetrations	Open or closed door		
	Cigarette or carelessness	Paper materials, cleaning products, linen, towels, plastics (depends on type of storage)	Stored equipment	AC	Ventilation system	Fire integrity of pipes and other penetrations		
	Spread from other areas	FRP, wall linings, cables, dust	Deck chairs					
Pantry	Electrical failure	Cables, smaller equipment, plastic covers, grease, flour, dust, food boxes	Furniture	restaurants	Door	Insulation integrity, improved insulation		**3:** Small controlled fires are common when cooking. Getting in contact with initial fuels could lead to a potential fire, especially if igniting nearby products that could burn rapidly (boxes, bags of dry foods/chips). Cooking failure with grease could be potentially dangerous. Grease in duct could spread the fire vertically. Spread to exteriors is common since
	Arson	Arson flammables and material, books/newspapers, towels, clothes, food boxes	Surface linings	Staircase	Extinguishing system	Extinguishment		

	Cigarette, lighter	paper towels, towels, clothes, grease, dust, food boxes	FRP walls and ceiling	Reception	Detection system	Detection		pantries are often in connection with open deck.
	Spread from other areas	Surface linings, books, FRP composite, food boxes	White goods	AC	Draft stoppers	Neatliness		
	Cooking failure	Cables, smaller equipment, grease, flour, dust, grease, flour, towels, clothes, food boxes	Plastic materials	Store	Deck and bulkhead construction	Ventilation (supply of air)		
			Try foods (spice bags, bags of chips, bread, boxes of foods)	Sundeck	Penetrations	Integrity of pipes and other penetrations		
						Spread of smoke		
Staircases	Arson	Arson flammables (limited amounts), paper, carpet	Temporary furniture (table, chair, poster)	To the next level	Detection system	Detection		**2:** Potentially crowded. Human error could lead to fire which would have a good supply of air. Smoke spread could be a problem. Detection is crucial. The amount of combustible materials should be very limited.
	cigarette, lighter	Paper, carpet	Surface linings (carpet, wall lining)	Lifts	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	Paper materials, surface linings, dust	Decorations	Hotel store	Closing doors	Smoke spread through staircase		
	Electrical failure (lamps, cabinets, elevator motor..), short	cable insulation material, plastic covers, dust	Passenger belongings	AC	Surface linings	Reaction to fire by surface linings		

	circuit							
	Human error (smoking etc.)	Carpet, paper	Trash can	Corridor				
				Cabins				
WC	electrical failure, overheating	cables, plastic covers	Furniture	Adjacent deck	Detection system	Detection		**2:** A typical location for arson. WC is typically located next to staircase which could be hazardous in case door opens and smoke spreads rapidly in the escape route/staircase. Fuels are however normally limited.
	cigarette, lighter	paper towels, waste, towels, clothes	Linings	AC	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	paper towels, waste	Trashcan	Courtyard	Closing doors	Smoke spread through staircase		
	arson	paper towels, waste, towels, clothes, linen, boxes, flammable liquids	Upholstered cushions	Staircase	Surface linings	Reaction to fire by surface linings		
			Plastic material/decorations			Ventilation		
Lifts and shaft	Arson	electrical insulation material	Lining material	corridors	Doors to staircases	Smoke spread		**1:** Small probability of ignition and limited amount of initial fuel. Cables and other combustible materials could however ignite due to electrical failure. Smoke spread could be dangerous if spreading to staircases and evacuating people. Lift control and detection is therefore
	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	staircases	Draft stoppers	Lift control		
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	Restaurant	Detection system	Detection		

	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	staircases	Extinguishing system	Control of fire by extinguishing system		important. Extinguishing system reduces the probability of an uncontrolled fire.
			FRP walls and ceiling	cabins	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
				Area in front of lifts	Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
					FRP ceiling	Ventilation (supply of air)		
Spinnaker Lounge	cigarette/lighter	combustible disposal materials, newspaper, furniture, cushions, curtains, carpet	Furniture	AC	Deck and bulkhead: non-combustible insulation	Insulation integrity, improved insulation		**3:** Ignition sources are hard to restrict in public areas. The fuels in the area cannot be said to be limited since people can bring just about anything to the spaces. Many of the fuels will however be of similar sort (much furniture, upholstered cushions, table cloths etc.). A fire in this area could be hazardous since it could be crowded. Successful evacuation is crucial. A fire could also spread to include exterior FRP composite surfaces and the sundeck.
	arson	combustible disposal materials, newspaper, furniture, cushions, curtains, carpet, boxes, flammable liquids and materials	Carpets	Pool equipment room	Detection system	Reaction to fire for materials		
	lightning	combustible disposal materials, newspaper, furniture, cushions, curtains, carpet	Upholstered cushions	Lift shaft	Windows	Easy and fast evacuation, personnel organization		

	Cooking failure	grease, flour etc.	Linings	Sundeck	Doors	Ventilation (supply of air)		
	spread from other areas	FRP composite, cables, dust, electrical equipment	Packing material	Staircase	Extinguishing system	Control of fire by extinguishing system		
	electrical equipment	Electrical insulation material, white goods, dust	Clothes	Corridor	Detection system	Smoke and fire spread through openings		
	Fire works on stage/hot lights	Electrical insulation material, white goods, dust	FRP surfaces	Exterior FRP surfaces		Detection (not only the system)		
			Stage					
			Floor levelling material					
Emergency generator	Arson	electrical insulation material, dust, plastic material, cables, diesel, rags	Lining material	Casing	Doors	Detection		**2:** Emergency generator is not run very often and personnel is available. Cables and other combustible materials could however ignite due to electrical failure or hot surfaces. Smoke spread to open deck not so dangerous. Extinguishing system reduces the probability of an uncontrolled fire.
	spread from other areas	FRP, wall linings, cables, dust, rags	Combustible material on pipes	Battery room	Draft stoppers	Control of fire by extinguishing system/fire-fighting		
	Electrical failure	electrical insulation material, dust, plastic material, cables, diesel	Cables	AC	Detection system	Reaction to fire for insulation		
	Mechanical failure, hot surfaces (bearings etc.)	electrical insulation material, dust, plastic material, cables, diesel leakage, rags	Electrical equipment	Sundeck	Extinguishing system	Integrity of pipes and other penetrations		

			FRP surfaces		Deck and bulkhead: non-combustible insulation	Insulation integrity, improved insulation		
					Penetrations	Ventilation (supply of air)		
					Access for fire-fighting			
Battery room	electrical failure in junction boxes	cable insulation material, dust, battery acid, plastic covers	combustible insulation material on pipes	Emergency Generator	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Dangerous acids. Many secondary fuels but not so much initial fuels. Ignition is not unlikely with lots of electrical equipment. Not a public space. Detection is important.
	fire spread from adjacent space or deck below	FRP composite, cables, dust, battery acid, rags, boxes	dust	AC	Detection system	Detection (not only the system)		
	electrical cable failure	cable insulation material, dust, battery acid, rags	cables	Sundeck	Penetrations	Insulation integrity, improved insulation		
	Arson	cable insulation material, dust, battery acid, rags, boxes, flammable liquids	electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting	Integrity of pipes and other penetrations		

Sports Court	Arson	Arson flammables (limited amounts), waste material, linen, towels, paper, bags of combustibles	Furniture	AC	FRP composite surfaces	Reaction to fire properties for materials		**2:** Ignition sources such as smoking and candles may not be possible to restrict. Limited amounts of fuels but unprotected FRP composite surfaces are also present which could fuel and spread a fire. Fire on sundeck more severe since more fuels, but less people here so maybe more prone to arson
	Fire spread from cabin	FRP composite, waste material, linen, towels, paper	Carpet	Lift machinery spaces	Fire-fighting system	Easy and fast operation		
	Human error (candles, smoking etc.)	Waste material, paper, towel clothes, books, magazines	Blankets/towels	Climbing wall				
	Electrical equipment	Waste material, paper, towel, clothes, linen, dust	Floor levelling material	Exterior composite surfaces				
			Bag of clothes					
Switchboard Room	electrical failure in junction boxes	cable insulation material, dust	combustible insulation material on pipes	AC	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Much secondary fuels but not so much initial fuels. Ignition is not unlikely with lots of electrical equipment. Not a public space. Detection is important.
	fire spread from adjacent space or deck below	FRP composite, cables, dust	dust	Casing	Detection system	Detection (not only the system)		
	electrical cable failure	cable insulation material, dust	cables	Sundeck	Penetrations	Insulation integrity, improved insulation		
			electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting	Integrity of pipes and other penetrations		

Deck 14

space	ignition source	initial fuel	secondary fuels	extension potentials	target locations	critical factors	stat/freq	fire hazard characterization and risk rating
Void space	electrical failure in junction boxes	cable insulation material, dust	combustible insulation material on pipes	**Propagation to adjacent space (including deck above)**	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**1:** Little probability of ignition, but access for fire-fighting difficult in prescriptive design (as opposed to in a design with FRD-60, where cutting extinguishers can be used). Fire load is small and much smaller than for cabin, while passive fire protection is rated for min 60 min fully developed fire - and ventilation is very limited provided that draft stops are mounted.
	electrical cable failure	cable insulation material, dust	dust		Detection system	Fire reaction for insulation		
	fire spread from space below or adjacent space	FRP composite, cables, dust	cables		Penetrations	Insulation integrity, improved insulation		
			electrical equipment		Ventilation/draft stopper	Open or closed door		
			plastic material		Access for fire-fighting, access for inspection	Integrity of pipes and other penetrations		

Sundeck	cigarette, lighter	combustible disposal materials, newspaper, towel	**Small materials:** towels, waste, pillows	**Propagation to adjacent space**	External composite surfaces	Detection		**3:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent smoke problems. Detection could be a problem. Furthermore, the sundeck contains unprotected corners with ceiling where a larger fire could develop faster. Fire origin in corner or under balcony could be a worst case scenario.
	arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather)	**Exterior propagation:** up to deck 15 (exterior combustible surfaces and materials on sun deck)	Reaction to fire by deck coverings	Extinguishment		
	lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
	spread from other areas	FRP divisions, furniture	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		

	Hot particles from funnel	combustible disposal materials, newspaper, towel, fat, dust				(reliability of drencher if installed)		
	electrical equipment	Electrical components, insulation material, dust				Available personnel		
Villas/suites	cigarette, lighter	combustible disposal materials, newspaper, clothes, blankets, duvet/bed linens, etc.	**Furniture:** Bed frame, wardrobe, desk, bedside table	**Exterior propagation:** Through private sundeck/window to exterior surfaces	External composite surfaces	Reaction to fire properties for exterior surfaces		**3:** Available personnel. Lots of upholstered furniture and electronics. Available personnel. Discovery and fire-fighting may be delayed if the room is unattended.
	arson	combustible disposal materials, newspaper, clothes, blanket, duvet/bed linens, furniture, flammable liquids etc.	**Linings:** Carpet, wall linings, ceiling material, plastic floor levelling material	**Propagation to adjacent spaces:** Cabins, corridor, void space, storage, stair case	Fuels in cabin (carpet and wall and ceiling coverings)	Reaction to fire properties for materials in cabin		
	spread from other areas	FRP, flooring, wall linings, bedding, wardrobe etc.	**Plastics and electrical equipment:** Lights, computer, luggage, cell phone, TV, hair straightener, water boiler, etc.	**Propagation through open door to corridor/balcony**	AC	Smoke spread		
	carelessness, e.g hairdryer or lamp covered by fabric or brought candles	clothes, blankets, duvet, bedding, paper	**Upholstered materials:** Cushions, mattress, duvet	**Propagation to deck above**	Detector	Detection and extinguishment in cabin		

	electrical equipment	Electrical insulation material, dust, batteries, cables	**Textiles:** Clothes, bed linens, towels, blanket		Open cabin door or balcony door/broken window	Ventilation		
					Sprinkler/active fire-fighting system	Function of sprinkler system (reliability and probability to control fire)		
					FRP divisions	Insulation integrity Easy and fast fire-fighting		
AC	Arson	Cables, electrical equipment, plastics, waste, towels, newspapers	linings	**Propagation to adjacent spaces:** Lift machinery, store	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Small probability of ignition, AC control design important to avoid smoke spread, closing doors are important. Limited ventilation.
	Human error	electrical insulation material, dust, waste, rags	cables	**Exterior propagation:** Public and private sundeck, funnel, villa private sundeck	Doors	Supply of air		
	Electrical failure	Cable insulation material, electrical equipment, plastics, dust	hvac components		Detection system	Detection (not only the system)		

	spread from other areas	FRP composite, cables, dust, electrical equipment	Electrical machinery equipment		Penetrations	Integrity of pipes and other penetrations		
	overheating of fan motors/bearings	Cable insulation material, electrical equipment, plastics, dust, oil, cooling media	FRP deck and walls		Fire dampers, AC design to prevent smoke spread	Spread of smoke		
			combustible insulation material on pipes		Electrical equipment and other fuels in space	Access for fire-fighting, easy and fast operation		
						Reaction to Fire for electrical Equipment		
						Insulation integrity, improved insulation		
Lift Machinery	Arson	electrical insulation material	Lining material	Lift shaft	Doors to staircases	Smoke spread		**2:** Overheated bearing could result in cable fire. Probability of ignition still regarded small and amount of initial fuel limited. Cables and other combustible materials could however ignite due to electrical failure. Smoke spread could be dangerous if spreading to staircases and evacuating people. Lift control and detection is
	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	Staircase	Draft stoppers	Lift control		
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	Store	Detection system	Detection		

	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	Pantry	Extinguishing system	Control of fire by extinguishing system		therefore important. Extinguishing system reduces the probability of an uncontrolled fire.
			FRP walls and ceiling	Corridor	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
				Radar transmitter	Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
					FRP ceiling	Ventilation (supply of air)		
Store	Arson	Cleaning products, linen, towels, plastics (depends on type of storage)	Towels, linen, etc.	Villa private sundeck	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**2:** Space is not open for public, ignition sources are limited but not insignificant. Fire load is great, especially in relation to the space. The consequences from a fire will be quite dependable to the supply of air, i.e. if the doors are closed. Functional door closers are important. Arson could be catastrophic.
	Machinery failure	Batteries, plastic covers, cleaning products, linen, towels, (depends on type of storage)	FRP ceiling, walls and floor	AC	Detection system	Insulation integrity, improved insulation		

	Electrical failure	Batteries, cleaning products, linen, towels, plastics (depends on type of storage)	Linings		Penetrations	Open or closed door		
	Cigarette or carelessness	Paper materials, cleaning products, linen, towels, plastics (depends on type of storage)	Stored equipment		Ventilation system	Fire integrity of pipes and other penetrations		
	Spread from other areas	FRP, wall linings, cables, dust	Deck chairs					
Pantry	Electrical failure	Cables, smaller equipment, plastic covers, grease, flour, dust, food boxes	Furniture	corridor	Door	Insulation integrity, improved insulation		**3:** Small controlled fires are common when cooking. Getting in contact with initial fuels could lead to a potential fire, especially if igniting nearby products that could burn rapidly (boxes, bags of dry foods/chips). Cooking failure with grease could be potentially dangerous. Grease in duct could spread the fire vertically. Spread to exteriors is common since pantries are often in connection with open deck.
	Arson	Arson flammables and material, books/newspapers, towels, clothes, food boxes	Surface linings	Store	Extinguishing system	Extinguishment		
	Cigarette, lighter	paper towels, towels, clothes, grease, dust, food boxes	FRP walls and ceiling	Lift shaft	Detection system	Detection		
	Spread from other areas	Surface linings, books, FRP composite, food boxes	White goods	Deck 15	Draft stoppers	Neat order		

	Cooking failure	Cables, smaller equipment, grease, flour, dust, grease, flour, towels, clothes, food boxes	Plastic materials		Deck and bulkhead construction	Ventilation (supply of air)		
			Try foods (spice bags, bags of chips, bread, boxes of foods)		Penetrations	Integrity of pipes and other penetrations		
						Spread of smoke		
Staircases	Arson	Arson flammables (limited amounts), paper, carpet	Temporary furniture (table, chair, poster)	To the next level	Detection system	Detection		**2:** Potentially crowded. Human error could lead to fire which would have a good supply of air. Smoke spread could be a problem. Detection is crucial. The amount of combustible materials should be very limited.
	cigarette, lighter	Paper, carpet	Surface linings (carpet, wall lining)	Lifts	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	Paper materials, surface linings, dust	Decorations	Hotel store	Closing doors	Smoke spread through staircase		
	Electrical failure (lamps, cabinets, elevator motor..), short circuit	cable insulation material, plastic covers, dust	Passenger belongings	AC	Surface linings	Reaction to fire by surface linings		
	Human error (smoking etc.)	Carpet, paper	Trash can	Corridor				
				Cabins				

WC etc	electrical failure, overheating	cables, plastic covers	Furniture	Adjacent deck	Detection system	Detection		**2:** A typical location for arson. WC is typically located next to staircase which could be hazardous in case door opens and smoke spreads rapidly in the escape route/staircase. Fuels are however normally limited.
	cigarette, lighter	paper towels, waste, towels, clothes	Linings	AC	Extinguishing system	Staircases is kept clean from passenger belongings etc		
	spread from other areas	paper towels, waste	Trashcan	Courtyard	Closing doors	Smoke spread through staircase		
	arson	paper towels, waste, towels, clothes, linen, boxes, flammable liquids	Upholstered cushions	Staircase	Surface linings	Reaction to fire by surface linings		
			Plastic material/decorations			Ventilation		
The courtyard	cigarette, lighter	combustible disposal materials, newspaper, towel, clothes	**Small materials:** towels, waste, pillows	**Propagation to adjacent space:** into cabins, pantry, store, WC area, sundeck above	External composite surfaces	Detection		**3:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces and corners of FRP composite.

arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls, clothes	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather), speakers, large upholstered furniture	**Exterior propagation:** Exterior surfaces, adjacent spaces, sundeck above	Reaction to fire by deck coverings	Extinguishment		Upholstered furniture available. ignition sources can only be limited to some extent. Good ventilation/visibility - no apparent smoke problems. Detection could be a problem.
lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering, carpets, walls		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
spread from other areas	FRP divisions, furniture			Detection system	Possibility to spread on external combustible surfaces (reliability of drencher if installed)		
Hot particles from funnel	combustible disposal materials, clothes, newspaper, towel, fat, dust, clothes						

	electrical equipment	Electrical components, insulation material, dust				Available personnel, manual extinguishment		
Radar transceiver	electrical failure	insulation material, cables	Electrical equipment	Lift machinery	Detection system	Detection		**1.** Small closed space and low probability of ignition.
	arson	arson flammables		Sundeck	Extinguishment system/fire-fighting	Extinguishment		

Deck 15

space	ignition source	initial fuel	secondary fuels	extension potentials	target locations	critical factors	stat/freq	fire hazard characterization and risk rating
Public Sundecks	cigarette, lighter	combustible disposal materials, newspaper, towel	**Small materials:** towels, waste, pillows	**Propagation to adjacent space:** into AC, lift machinery, funnel, deck below	External composite surfaces	Detection		**2:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent smoke problems. Detection could be a problem, e.g. at night. No fire spread to decks above and easy access for fire-fighting and evacuation.
	arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather)	**Exterior propagation:** Exterior surfaces, radar mast, adjacent spaces	Reaction to fire by deck coverings	Extinguishment		

	lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
	spread from other areas	FRP divisions, furniture	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		
	Hot particles from funnel	combustible disposal materials, newspaper, towel, fat, dust				(reliability of drencher if installed)		
	electrical equipment	Electrical components, insulation material, dust				Available personnel, manual extinguishment		
Private Sundeck	cigarette, lighter	combustible disposal materials, newspaper, towel	**Small materials:** towels, waste, pillows	**Propagation to adjacent space:** into AC, lift machinery, funnel, deck below	External composite surfaces	Detection		**2:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent

arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather), speakers, large upholstered furniture	**Exterior propagation:** Exterior surfaces, adjacent spaces	Reaction to fire by deck coverings	Extinguishment		smoke problems. Detection could be a problem, e.g. at night. No fire spread to decks above and easy access for fire-fighting and evacuation.
lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
spread from other areas	FRP divisions, furniture	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		
Hot particles from funnel	combustible disposal materials, newspaper, towel, fat, dust				(reliability of drencher if installed)		
electrical equipment	Electrical components, insulation material, dust				Available personnel, manual extinguishment		

Private Villa Sundeck	cigarette, lighter	combustible disposal materials, newspaper, towel	**Small materials:** towels, waste, pillows	**Propagation to adjacent space:** into AC, Blue or Black Diamond, store, deck below	External composite surfaces	Detection		**3:** Initial fire load is small and access for fire-fighting is good. is surrounded by external surfaces which could be included in a fire. Good ventilation/visibility - no apparent smoke problems. Furthermore, the sundeck contains unprotected corners where a larger fire could develop faster. Fire origin in corner could be a worst case scenario. No fire spread to decks above. Limited number of people, detection could be a problem if unoccupied.
	arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather), speakers, large upholstered furniture	**Exterior propagation:** Exterior surfaces, adjacent spaces	Reaction to fire by deck coverings	Extinguishment		
	lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Tensioned fabrics:** sun sails, parasols/umbrellas		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
	spread from other areas	FRP divisions, furniture	**Structural surfaces:** FRP decks (particularly consider non-insulated ceilings) and bulkheads, paint, deck covering		Detection system	Possibility to spread on external combustible surfaces		

	Hot particles from funnel	combustible disposal materials, newspaper, towel, fat, dust				(reliability of drencher if installed)		
	electrical equipment	Electrical components, insulation material, dust				Available personnel, manual extinguishment		
Blue/Black Diamond or Golden/Black Pearl	cigarette, lighter	combustible disposal materials, newspaper, clothes, blankets, duvet/bed linens, etc.	**Furniture:** Bed frame, wardrobe, desk, bedside table	**Exterior propagation:** Through private sundeck/window to exterior surfaces	External composite surfaces	Reaction to fire properties for exterior surfaces		**3:** Much upholstered furniture and electronics and ignition sources can only be limited to some extent since people bring just about anything onboard. Discovery and fire-fighting may be delayed if the room is unattended.
	arson	combustible disposal materials, newspaper, clothes, blanket, duvet/bed linens, furniture, flammable liquids etc.	**Linings:** Carpet, wall linings, ceiling material, plastic floor levelling material	**Propagation to adjacent spaces:** Cabins, corridor, void space, storage, stair case	Fuels in cabin (carpet and wall and ceiling coverings)	Reaction to fire properties for materials in cabin		

	spread from other areas	FRP, flooring, wall linings, bedding, wardrobe etc.	**Plastics and electrical equipment:** Lights, computer, luggage, cell phone, TV, hair straightener, water boiler, etc.	**Propagation through open door to corridor/balcony**	AC	Smoke spread		
	carelessness, e.g hairdryer or lamp covered by fabric or brought candles	clothes, blankets, duvet, bedding, paper	**Upholstered materials:** Cushions, mattress, duvet	**Propagation to deck above**	Detector	Detection and extinguishment in cabin		
	electrical equipment	Electrical insulation material, dust, batteries, cables	**Textiles:** Clothes, bed linens, towels, blanket		Open cabin door or balcony door/broken window	Ventilation		
					Sprinkler/active fire-fighting system	Function of sprinkler system (reliability and probability to control fire)		
					FRP divisions	Insulation integrity Easy and fast fire-fighting		
Freestyle Sundeck	cigarette, lighter	combustible disposal materials, newspaper, towel	**Small materials:** towels, waste	**Propagation to adjacent space:** into AC, lift machinery, funnel, deck below	External composite surfaces	Detection		**2:** Initial fire load is small and access for fire-fighting is good. Fire could include external surfaces. Good ventilation/visibility - no apparent

	arson	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Large materials:** sunbeds, racks of sunbeds (particularly in case the sundeck is uncrowded, e.g. night time or in case of cloudy weather)	**Exterior propagation:** Exterior surfaces, adjacent spaces, radar mast	Reaction to fire by deck coverings	Extinguishment		smoke problems. Not so much that could burn and limited areas for the fire to spread vertically.
	lightning	combustible disposal materials, newspaper, towel, sunbeds, FRP deck and walls	**Structural surfaces:** FRP deck and bulkheads, paint, deck covering		Reaction to fire for materials on sundeck (such as sunbeds, pillows and chairs)	Easy and fast fire-fighting operation		
	spread from other areas	FRP divisions, furniture			Detection system	Possibility to spread on external combustible surfaces (reliability of drencher if installed) Available personnel, manual extinguishment		
AC	Arson	Cables, electrical equipment, plastics, waste, towels, newspapers	linings	**Exterior propagation:** Public and private sundeck, funnel, villa private sundeck	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		**2:** Small probability of ignition, small fire load, AC control design important to avoid smoke spread, closing doors are important. Limited openings to space but ventilation system

	Human error	electrical insulation material, dust, waste, rags	cables		Doors	Supply of air		could provide air and spread smoke.
	Electrical failure	Cable insulation material, electrical equipment, plastics, dust	hvac components		Detection system	Detection (not only the system)		
	spread from other areas	FRP composite, cables, dust, electrical equipment	Electrical machinery equipment		Penetrations	Integrity of pipes and other penetrations		
	overheating of fan motors/bearings	Cable insulation material, electrical equipment, plastics, dust, oil, cooling media	FRP deck and walls		Fire dampers, AC design to prevent smoke spread	Spread of smoke		
			combustible insulation material on pipes		Electrical equipment and other fuels in space	Access for fire-fighting, easy and fast operation		
						Reaction to Fire for electrical Equipment		
						Insulation integrity, improved insulation		
Lift Machinery	Arson	electrical insulation material	Lining material	Private and public sundeck	Doors to staircases	Smoke spread		**2:** Overheated bearing could result in cable fire. Probability of ignition still regarded small and

	spread from other areas	FRP, wall linings, cables, dust	Combustible material on pipes	AC	Draft stoppers	Lift control		amount of initial fuel limited. Cables and other combustible materials could however ignite due to electrical failure. Smoke spread could be dangerous if spreading to staircases and evacuating people. Lift control and detection is therefore important. Extinguishing system reduces the probability of an uncontrolled fire.
	Electrical failure	electrical insulation material, dust, plastic material, cables etc.	Cables	Lift shaft	Detection system	Detection		
	Mechanical failure (bearings etc.)	electrical insulation material, dust, plastic material, cables etc.	electrical equipment	Staircase	Extinguishing system	Control of fire by extinguishing system		
			FRP walls and ceiling	Corridor	Deck and bulkhead: non-combustible insulation	Reaction to fire for insulation		
					Penetrations	Integrity of pipes and other penetrations		
					Access for fire-fighting	Insulation integrity, improved insulation		
					FRP ceiling	Ventilation (supply of air)		
Store	Arson	Cleaning products, linen, towels, plastics (depends on type of storage)	Towels, linen, etc.	Villa private sundeck	Deck and bulkhead: non-combustible insulation	Detection (not only the system)		**2:** Space is not open for public, ignition sources are limited but not insignificant. Fire load is great, especially in relation to the space. The consequences

	Machinery failure	Batteries, plastic covers, cleaning products, linen, towels, (depends on type of storage)	FRP ceiling, walls and floor	AC	Detection system	Insulation integrity, improved insulation		from a fire will be quite dependable to the supply of air, i.e. if the doors are closed. Door closers are important.
	Electrical failure	Batteries, cleaning products, linen, towels, plastics (depends on type of storage)	Linings		Penetrations	Open or closed door		
	Cigarette or carelessness	Paper materials, cleaning products, linen, towels, plastics (depends on type of storage)	Stored equipment		Ventilation system	Fire integrity of pipes and other penetrations		
	Spread from other areas	FRP, wall linings, cables, dust	Deck chairs					
Funnel	Engine room fire	Soot, grease, dust, dirt, rags, electrical equipment, cables	FRP	All decks	Adjacent deck and bulkhead constructions	Insulation integrity, improved insulation		**2:** Ignition sources are available but combustible materials are limited/restricted. Detection is difficult in casing. Arson could lead to involvement of entire funnel and outside structure.

	Smoke exhaust leakage	Soot, grease, dust, dirt, rags, electrical equipment, cables		Outside structure	Extinguishing system	Extinguishment of engine fires, engine control		
	Arson	Flammable liquids or material			Detectors	Detection		
	Electrical failure	Soot, grease, dust, dirt, rags, electrical equipment, cables			Openings	Smoke spread		
						Integrity of openings		

Whole ship

area	ignition source	initial fuel	secondary fuels	extension potentials	target locations	critical factors	stat/freq	fire hazard characterization
Vertical exterior fire spread	Fire spread from internal spaces	Fire in internal space	External FRP surfaces	Ships external surface, upwards downwind (e.g. on the great outdoors or to embarkation deck)	Windows Drencher system (if added RCM) Bridge/manoeuvre station FRP composite surfaces	Flame spread characteristics Possibility to manoeuvre the ship to assure fire is spread in the most preferred direction Windows integrity Drencher efficiency (if added) Drencher reliability (if added)		**5.** Fire is spread through broken window, from balcony or sundeck etc and ignites the external FRP surfaces. Fire can propagate alon the ships external surfaces and vi broken windows, balconies etc spread the fire to adjacent fire zones. Relatively small continuing FRP surfaces along the sides of t reference ship.
Increased smoke production	Any fire continuing until insulation failure	Any internal fire	FRP bulkheads and decks External FRP surfaces	Smoke spread down wind -	Embarkation deck stations FRD-60 construction Bridge/manoeuvre station	Passenger safety on embarkation stations Passenger safety while abandoning ship Toxicity Possibility to manoeuvre the ship to assure that embarkation deck is kept up wind from fire		**4.** If a fire is allowed to continue until insulation failure, additional fuel from the FRP bulkheads and decks will contribute to the fire an add smoke production. At the time of insulation failure, passengers tl were in the affected space are already evacuated or dead. The additional smoke mentioned abov may cause a threat to passengers on embarking stations, passenger evacuating other spaces on the sl and passengers abandoning ship

Increased amount of combustible materials	Any fire continuing until insulation failure	Any internal fire	FRP bulkheads and decks External FRP surfaces	Adjacent fire zone	Embarkation deck stations FRD-60 construction Bridge/manoeuvre station	Passenger safety on embarkation stations Passenger safety while abandoning ship Maintained insulation on FRP surfaces adjacent to the fire 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		**4:** Fire is spread throughout bulkheads and decks as structura integrity is lost and deformation exposes more FRP material. If a f is allowed to continue until insulation failure additional fuel fro the FRP bulkheads and decks wil contribute to the fire. At this point the fire intensity might accelerate when more and more structures collapses. At the time of insulatio failure passengers that were in th affected space are already evacuated or dead. The additiona intensity of the fire mentioned above may cause a threat to passengers on embarking station passengers evacuating other spaces on the ship and passenge abandoning ship.
Loss of structural integrity	Any fire continuing until insulation failure	Any internal fire	FRP bulkheads and decks External FRP surfaces	Entire ship	Embarkation deck stations FRD-60 construction	Passenger safety on embarkation stations Passenger safety while abandoning ship/on embarkation deck No major structural collapses before passengers has abandoned the ship		**5:** Fire is spread throughout bulkheads and decks as structura integrity is lost and deformation exposes more FRP material. If a f is allowed to continue until insulation failure additional fuel fro the FRP bulkheads and decks wil contribute to the fire. At this point the fire intensity might accelerate when more and more structures collapses. Due to structural collapses important systems such as sprinkler piping, control cabling etc might be damaged. A collapse

							of a larger section of the ship mig expose large quantities of fuel in well ventilated conditions causing very intensive fire which might make conditions on embarkation deck inhabitable.

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.

Pros and cons with the base design from a fire safety perspective	Rating	
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 hazard should be possible to manage independently.
The use of combustible materials is not restricted on external surfaces.	-4	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.
Increased smoke production when FRP composite structures take part in a fire after 60 minutes, i.e. could not affect evacuation but maybe embarkation?	-1	Given that crew and passengers will be on the embarkation deck (deck 7) after 60 minutes, the potentially increased smoke production is estimated not to have a significant negative effect. Risks associated with increased smoke production after 60 minutes are hence ignored.
Increased amount of fuel when FRP composite structures take part in a fire after 60 minutes, i.e. could fuel an already uncontrolled fire.	-2	An uncontrolled fire after 60 minutes will be given more fuel which could develop and particularly prolong the fire.
Smoke production will be increased in case external surfaces take part in a fire on deck (even if less significant when not in an enclosure).	-2	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.
Fire rated penetrations (insulated against 60 minutes of fire) are used also when penetrating A-0, A-15 and A-30 divisions	2	The fire integrity of penetrations will of the same quality as the division as a whole. This advantage is therefore managed below.
FRD-60 will be used also where A-0, A-15 and A-30 is required	3	In the prescriptive design of the ship there are considerably less A-60 divisions than there are FRD60 divisions in the base design. According to prescriptive regulations it is in general only the main vertical zones and divisions around the bridge, galleys and escape routes which will be surrounded by A-60 divisions. All decks and a considerable number of bulkheads in each main vertical zone in the trial alternative designs are made in FRD60. In general, cabins, corridors and lounges (and void spaces) are subdivided by B-15 divisions, even if there are FRD60 decks around the spaces and at least one FRD60 bulkhead. Horizontal fire spread it therefore considered unaffected whilst vertical fire spread is not considered within

		60 minutes for these spaces. All other spaces are normally completely surrounded by FRD60 divisions. An enclosed fire is therefore more likely to be contained.
Thermal insulation will be improved ubiquitously in order to keep the exposed interface between the laminate and the core below 100 degrees	2	Depends on the particular FRP composite used. Both the A-60 and the FRD60 constructions pass the same furnace test and that is what matters. This benefit falls within the safety margin of that test and will not be taken into account.
Insulation will be used on both sides of divisions	1	This benefit will be ignored.
Within the first 60 minutes, steel structures suffer from deterioration problems if heated enough. Down to thermal insulation, the FRD-60 structure will not be deformed even if a fire is uncontrolled and reaches flash-over. The effect is greatest when a non-insulated side of a steel division is exposed to fire.	1	Windows etc. could last longer in a construction which does not deform but this will not be taken into account.
A fire for more than 60 minutes 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 if using balsa wood). Fire-fighting will however be very difficult at this stage, both in a design with FRD-60 and a prescriptive design.	-2	An uncontrolled fire for more than 60 minutes 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.
A fire will be more likely to be contained/isolated in a space (fire zone) on account to the improved thermal insulation.	2	This was taken into account above when considering FRD60 divisions replacing A-0 divisions in particular.
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)	2	This was taken into account above when considering FRD60 divisions replacing A-0 divisions in particular.
Heat from a fire will be more isolated/contained, which could imply an increased heat release rate, which on the other hand would not affect the FRD-60 construction within the first 60 minutes since it is designed to pass 60 minutes of fully developed fire.	-1	Both the A-60 and the FRD60 constructions pass the same furnace test and that is what matters. A more severe fire falls within the safety margin of that test and will not be taken into account with regards to the structure. Furthermore, as discussed in [22], the effect is only relevant if the fire is not too small in relation to the space, i.e. mainly in small spaces. Since most small spaces in the trial alternative designs are subdivided by the same divisions as in the prescriptive design (B-15) this effect is only necessary to consider in store-rooms, technical spaces and machinery spaces in the present case.
A long-lasting fire could bring about a major collapse which could affect great parts of the ship.	-4	A fire which is uncontrolled (well) beyond 60 minutes anywhere in the superstructure of the ship could lead to structures collapsing. People should by then although be on the

		embarkation deck and be able to move if so that they are not directly below the fire if necessary. Nevertheless this is a risk to consider.
Fire-fighting will be affected in a way that the access to fire will be easier (from new tools useful for FRP composites).	2	This benefit should be accounted for when evaluating the probability of successful fire-fighting.
More fire-fighting resources could be allocated to help in the escape process since boundary cooling will not be necessary.	1	This is an effect that should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting.
Relieving boundary cooling will reduce complexity in the fire protection strategy.	1	This is an effect that should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting.
The fire-fighting routines and maintenance will need to be changed, which implies new routines and inexperience.	-2	This is an effect that should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting.
The fire-fighting routines and maintenance will need to be changed, which implies different routines for different areas of the ship.	-2	This is an effect that should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting.
Complexity in fire safety will be reduced down to the uniform use of FRD-60 divisions.	1	This mainly affects fire-fighting and should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting.
In steel structures heat can be conducted far through the structure and bring about fires where there are weaknesses in integrity. In an FRD-60 structure heat will not be easily conducted to other places which will reduce the complexity in the fire protection strategy.	2	This should be taken into account when considering FRD60 divisions replacing A-0 divisions in particular.
The complexity in the fire protection system will be increased as a result of additional risk control measures.	-1	This is an effect that should be taken into account when considering the effects on the effectiveness and efficiency of fire-fighting.
The ability to accomplish the expected function in different ways (flexibility) will be affected.	0	This is not taken into consideration due to its minor effects on safety.
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 [55]. 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.
The construction will be independent of the fire development in a compartment within the first 60 minutes of fire.	2	This will implicitly be taken into account when considering compartments where FRD60 divisions replace A-0 divisions in particular. However, in general in the furnace tests cover most fires and that is what matters.
Unprotected external surfaces need to be targeted somehow. However, the fire safety will then be sensitive to the function of the provided RCM/RCM's and the reliability of the fire safety will then be reduced regardless of the added measures.	-2	This deficiency is accounted for in the risk assessment of fire scenarios.

The change from variously insulated steel structures to FRD-60 implies that the new structures and compartments will be less vulnerable to hazardous circumstances (e.g. arson) and changes of activity in the affected spaces.	2	Arson is accounted for as a fire source. Changes of activity may need to be considered if refurbishing the ship but will not be considered further currently.
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.	3	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.
Conditions will be improved within the first 60 minutes of fire, which is the time frame for escape and evacuation.	3	This benefit was taken into account when considering the improved conditions for escape and evacuation above.
An evacuation process could be hazardous on its own and if the novel design will affect the probability of initiating an evacuation process it invokes to also account for risks in the evacuation process.	-2	This will be taken into account in the risk assessment.
Exchanging the external steel surfaces with combustible FRP composite will make an uncontrolled fire more probable to propagate vertically if a window breaks or if a balcony door is left open. Except including external surfaces in the fire it could imply fire spread between decks and fire zones.	-4	Considering the Star Princess fire [25], vertical fire spread is obviously possible also on a prescriptive ship, even if the probability may be greater with combustible FRP composite surfaces. This was although taken into account when considering use of combustible exterior surfaces above.

Appendix I. Risk Control Measures

	Possible additional Risk Control Measures	Goals			
a1	**Drencher system covering all external composite surfaces**	External drencher prevents ignition of FRP if activated as a precautionary measure	Control fire on FRP composite surfaces	Preventing spread of fire on exposed FRP surfaces	Increased probability of maintaining structural st
a2	**Drencher system covering all vertical external composite surfaces**	External drencher prevents ignition of vertical FRP surfaces, on which fire is more prone to spread, if activated as a precautionary measure	Control fire on vertical FRP composite surfaces	Preventing spread of fire on exposed vertical FRP surfaces, on which fire is more prone to spread	Increased probability of maintaining structural st
a3	**Drencher system covering all large external composite surfaces (e.g. over 1 m high or covering more than 50% of a surface more than 1 m^2) on open deck**	External drencher prevents ignition of large FRP surfaces, where a fire could be significant, if activated as a precautionary measure	Control fire on large FRP composite surfaces	Preventing spread of fire on exposed large FRP surfaces where a fire could grow to be significant	Increased probability of maintaining structural st
a4	**Sprinkler system covering all horizontal external composite surfaces**	External sprinkler prevents ignition of horizontal FRP surfaces if activated as a precautionary measure	Control fire on horizontal FRP composite surfaces	Preventing spread of fire on horizontal FRP surfaces	Increased probability of maintaining structural st
a5	**Sprinkler system in balconies**	External sprinkler prevents ignition of FRP surfaces in balcony and on the side of the ship if activated as a precautionary measure	Control fire on balcony	Preventing spread of fire to the FRP surfaces on the side of the ship	Increased probability of maintaining structural st
a6	**Drencher system over openings (windows, doors, etc.) facing exteriors on outboard sides of the ship superstructures.**	External drencher prevents ignition of large FRP surfaces, where a fire could be significant, if activated as a precautionary measure	Control fire on large FRP composite surfaces	Preventing spread of fire on exposed large FRP surfaces where a fire could grow to be significant	Increased probability of maintaining structural st

b1	**Fire rated windows (A0) in cabins**	Reduce the probability of fire spreading to exterior surfaces	Control fire on FRP composite surfaces	Preventing spread of fire on horizontal FRP surfaces	Increased probability of maintaining structural st
b2	**A0 windows on bridge**	Reduce the probability of a fire spreading to bridge	Reduce the probability of a fire spreading from bridge to adjacent spaces or external FRP surfaces		
b3	**A0 windows in large spaces or spaces with many windows, e.g. steakhouse (including grill, pantry, WC, store and reception on deck 13)**	Reduce the probability of fire spread to/from large external surfaces	Reduce the probability of a well-ventilated fire in a large space		
c1	**Extinguishing system in void spaces**	Controlling fire in void spaces	Reduce the probability of fire spreading from void spaces		
c2	**Sprinkler system redundancy in high fire risk spaces**	Increased probability of controlling a fire	Preventing spread of fire to adjacent spaces	Increased probability of maintaining structural strength	
d1	**Fire dampers and smart control in cabins**	Reduce the probability of fire spread to adjacent spaces	Preventing spread of fire to adjacent spaces		
d2	**More fire dampers in AC spaces**	Reduce the probability of fire spreading from/to AC spaces			
e1	**Redundant smoke detectors in cabins**	Increased reliability of early detection of fire in cabins			
e2	**Redundant detectors in certain spaces**	Higher probability of detection			
e3	**Redundant or multi-detecting detectors in communication centre etc.**	Fast detection in communication centre etc.	Higher probability of detection		
f	**Door closing mechanism on balcony doors**	Reduce probability of fire spreading to balcony and exterior FRP surfaces			
g1	**Redundant bridge**	Increase the redundancy of manoeuvrability in case of fire on bridge	Flexibility to manoeuvre ship into fortunate wind in case increased smoke production		

g2	**Redundancy of communication centre, radio equipment, comm officer…**	Increase the redundancy of communication in case of fire in communication centre etc.		
h	**Restrict the main materials used on sundeck**	Control the reaction to fire for materials on sundeck (such as sunbeds and chairs)		
i1	**Substitution of core material in places where extra fire resistance is needed to protect from collapse, e.g. ceiling in Emergency generator room, lift machinery spaces and battery room.**	Increased probability of maintaining structural strength in spaces containing important functions.	Provide warning to people on decks close to collapse and slow down the collapse process	Increased time until collapse
i2	**Substitution of core material in places where FRP surfaces are probable to be exposed (exteriors)**	Increased probability of maintaining structural strength	Provide warning to people on decks close to collapse and slow down the collapse process	Increased time until collapse
j1	**Substitution of a resin with better reaction to fire properties (e.g. phenol) for low flame spread characteristics on external decks**	Reduced probability of ignition	Reduced probability of fire propagation	Reduced probability of local collapse
j2	**Use of fire-rated deck coverings**	Reduced probability of fire propagation	Reduced probability of ignition	Reduced probability of local collapse
j3	**Use of low flame-spread surface finish on external surfaces**	Reduced probability of ignition	Reduced probability of fire propagation	Reduced probability of local collapse
j3	**Structural redundancy**	Reduced probability of major collapse	Increased probability of fire-fighting	Reduced probability of local collapse
k1	**New fire-fighting routines/resources to manage fires on open deck**	Increased probability of controlling fire on deck		
k2	**Change cleaning routines**	Reduce the probability of an open door to cabins		
l1	**Provide 60 minutes thermal insulation under exterior ceilings (and balconies)**	Reduce the probability of including combustible composite surfaces in an		

		external fire
l2	**Provide improved thermal insulation under high risk exterior ceilings (90 minutes)**	Reduce the probability of including combustible composite surfaces in an external fire after 60 minutes
l3	**Provide 90 minutes insulation under ceilings of large enclosures**	Reduce the probability of fire spread to the space above after 60 minutes
m	**Fresh air stations on embarkation deck**	Ensure fresh air for embarking and abandoning passengers

FEM simulation of the joint in the fire test for BESST II.2

The main identified hazard associated with steel-composite joints is the possibility of conduction of fire induced heat in the steel structure to the actual adhesive joint. If the adhesive reaches a critical temperature the joint might fail. This hazard can easily be avoided if requirements of insulation of the steel deck is added. However, this is not a preferred solution since the insulation will add weight and the design of the ship will be more complex since the spaces below cannot be designed only according to prescriptive requirements. The problem was firstly addressed in FEM-simulations, performed by CMT, to evaluate the temperature rise in the steel joint in case of a fire in a compartment below the joint with worst case insulation setup. A direct copy (except from references) of the report by CMT follows subsequently.

Geometry

A joint in a SP fire test (cf. Figure J1) was analyzed with Ansys Workbench version 13. According to the dimension in Figure 1, the geometry for the joint was built, which is shown in Figure J2. Note the thickness of the laminates was 0.9 mm; the lengths of the steel decks were 2 m on both sides.

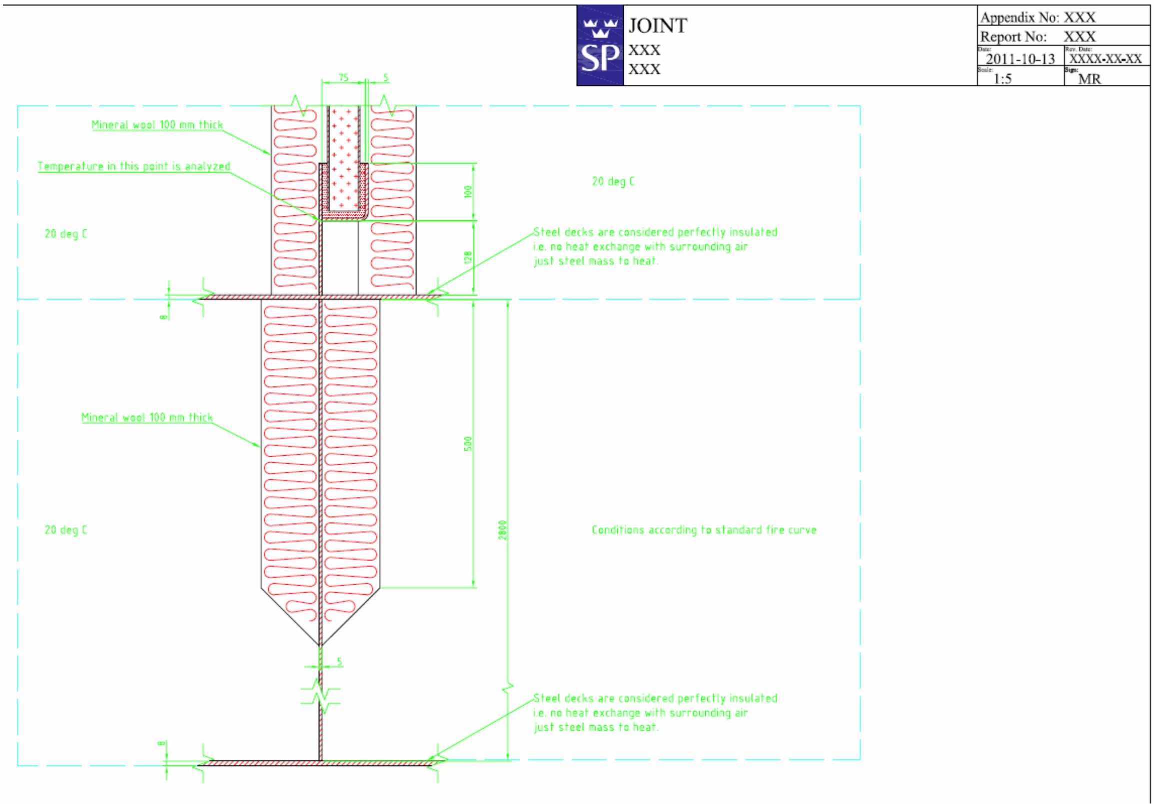


Figure J1. Joint in SP fire test.

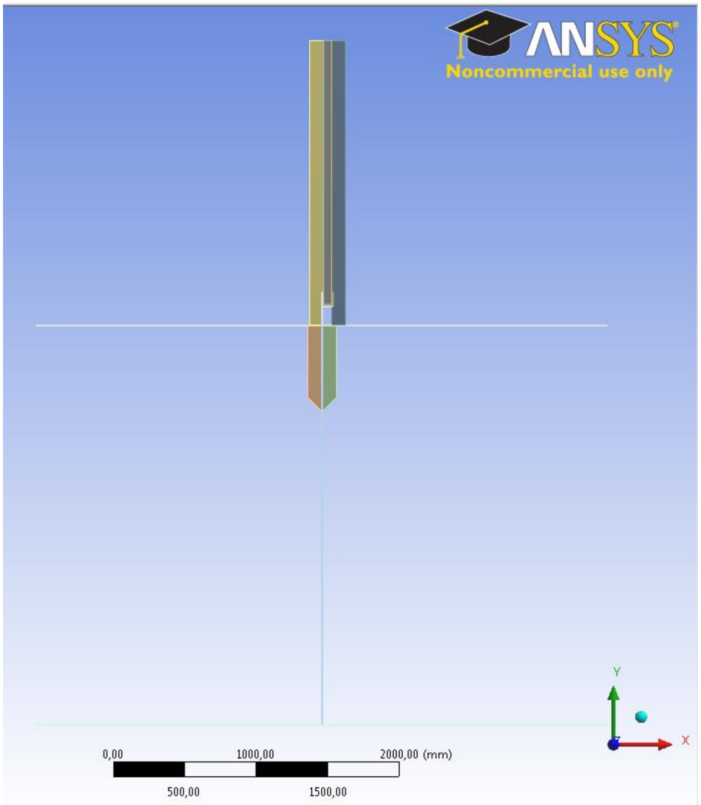


Figure J2. Geometry of the joint in SP fire test.

Material properties

Stainless steel and structural steel from the Ansys Workbench “Engineering Material Sources” were assigned to the joint and the steel decks (cf. Figure J1.), respectively. The properties of other materials are listed in Table J1 and J2. Note the specific heat of the mineral wool is from the producer [Rockwool Technical Insulation. Rockwool Str. 37-41, 45966 Gladbeck]. All other data were provided by project partners [SP Technical Research Institute of Sweden, Fire Technology. Box 857, SE-501 15 Borås, Sweden & ThyssenKrupp Marine Systems. Kockums. SE-371 82 Karlskrona, Sweden].

Table J1. Material properties

Materials	*Density [kg/m-3]*	*Isotropic thermal conductivity [W/(m·°C)]*	*Specific heat [J/(kg·°C)]*
Core	80	0.031	1050
Laminate in	1830	0.64	1510
Laminate out	1830	0.31	1510
Mineral wool	100	cf. Table 2	840
Adhesive	1.4	0.3	840

Table J2. Isotropic thermal conductivity of mineral wool

Temperature [°C]	*10*	*50*	*100*	*150*	*200*	*300*	*400*
Isotropic thermal conductivity [W/(m·°C)]	0.032	0.038	0.045	0.053	0.063	0.088	0.119

Meshing

This was a 2-D simulation. The 2-D free/mapped mesh was used. In order to investigate the influences of the meshing on the results, several simulations with different numbers of elements were done (cf. Table J3).

Table J3. Meshing parameters

No.	*Element type*	*Minimum edge length [mm]*	*Element number*	*Node number*
1	Triangle + Quad	0.9	1531	1846
2	Triangle + Quad	0.9	5179	5574
3	Triangle + Quad	0.9	9663	10106

Boundary conditions

The boundary conditions applied to the model are shown in Figure J3. A temperature condition, which was according to standard fire curve, was applied to the right down corner (cf. Figure J3 A).

$$T = 20 + 345\lg(8t + 1) \qquad (1)$$

where T - temperature, °C; t - time, min.

Convention and radiation were set for other parts of the model (cf. Figure J3 B-G) and Table J4.

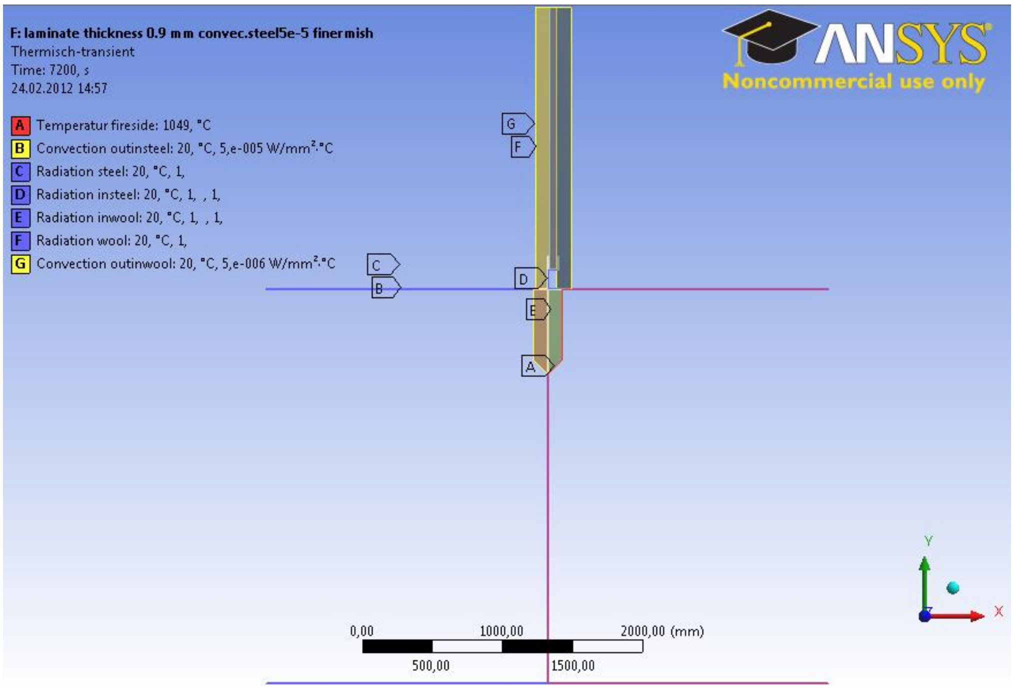


Figure J3. Boundary conditions.

Table J4. Boundary conditions

No. (cf. Figure J3)	*Name*	*Coefficient [W/mm2·°C]*	*Ambient temperature [°C]*
B	Convection outinsteel	5e-5	20
C	Radiation steel	---	20
D	Radiation insteel	---	20
E	Radiation inwool	---	20
F	Radiation wool	---	20
G	Convection outinwool	5e-6	20

Solution

“Auto Time Stepping” with initial time step as 0.01 s, minimum time step 0.001 s, maximum time step 5 s, is used to calculate 7200 s testing time.

Results

The temperature of the whole model and the analyzed point (cf. Figure J1) of the model with the No. 3 meshing in Table J3 are shown in Figure J4 and J5, respectively. From Table J5 one can observe that within the simulated 7200 s the temperature of the analyzed point in the three models with different meshing all raised around 140 °C. The influence of the numbers of elements was not dramatic (< 2 %).

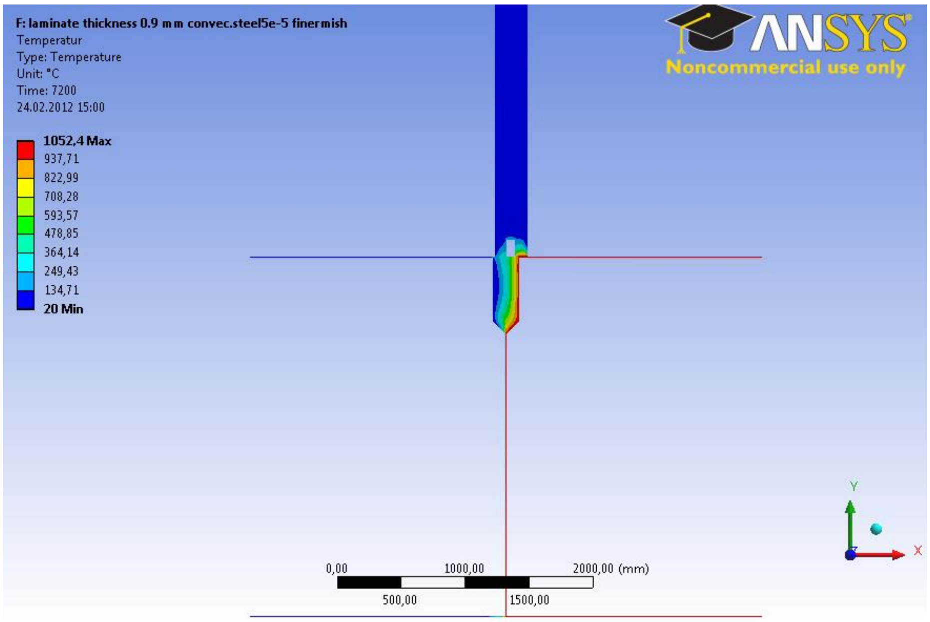


Figure J4. Temperature distribution in the whole model (Table 1, No. 3).

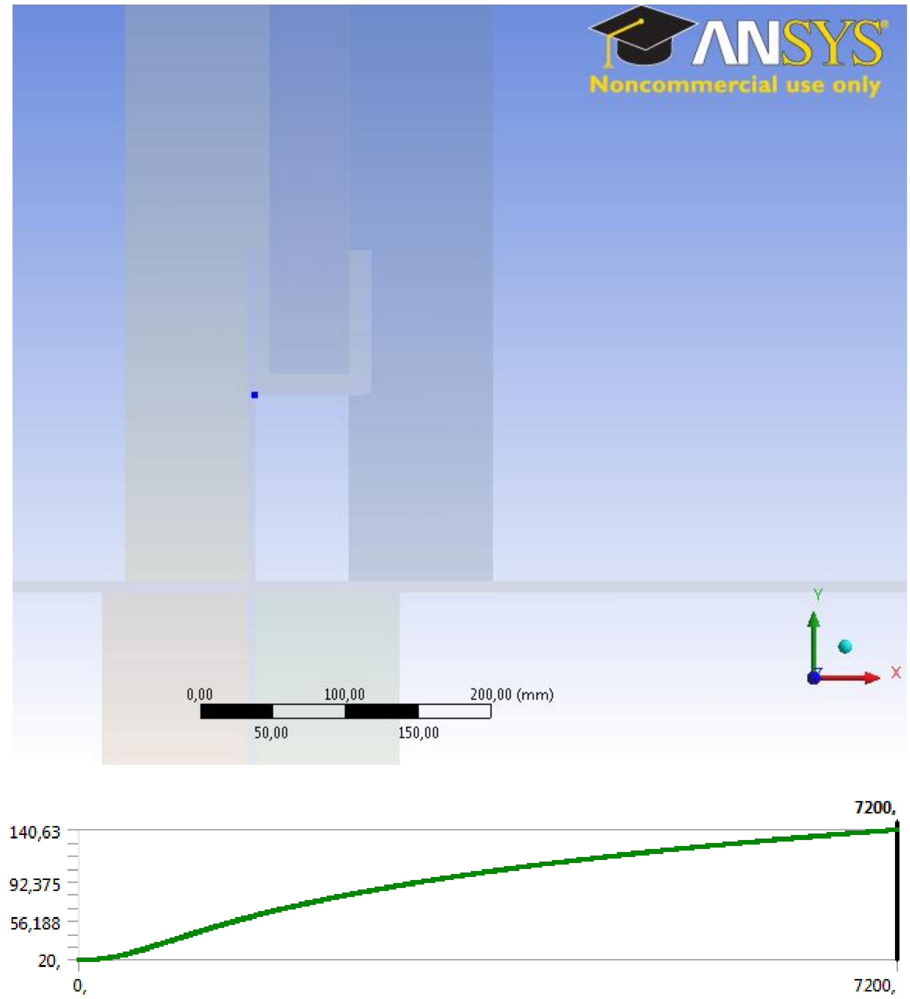


Figure J5. Position of the analyzed point (upper) and temperature of the analyzed point (lower, Table 1, No. 3).

Table J5. Temperature rise of the analyzed point

No.	*Type of elements*	*Elements*	*Nodes*	*Temperature rise [°C]*
1	Triangle + Quad	1531	1846	143.4
2	Triangle + Quad	5179	5574	140.5
3	Triangle + Quad	9663	10106	140.6

Influence of the lengths of the upper steel decks

Table J6 shows the temperature result of the model with 4 m long upper steel decks. It can be seen that the temperature rise after 7200 s of the analyzed point (132.5 °C) was smaller compared to the model with shorter steel decks (i.e. 2 m) (140.6 °C).

Table J6. Temperature result of the model with 4 m long upper steel decks

Element type	*Minimum edge length [mm]*	*Element number*	*Node number*	*Temperature rise [°C]*
Triangle + Quad	0.9	5339	5864	132.5

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 LEO, the fourth for the base design with structural redundancy and the fifth for the base design with both LEO and structural redundancy. Note that differences are signified by bold numbers.

Probabilities	PD	BD	TAD H	TAD O	TAD R
Relative area on open deck in category 1. Unfurnished and bare	40,0%	40,0%	40,00%	40,00%	40,00%
Relative area on open deck in category 2. Sparsely furnished and few fuels	**30,0%**	30,0%	30,00%	30,00%	30,00%
Relative area on open deck in category 3. Upholstered furniture and many combustibles	**30,0%**	30,0%	30,00%	30,00%	30,00%
Probability of no one present in cabin	**22,8%**	22,8%	22,80%	22,80%	22,80%
Probability of awake person present in cabin	**48,6%**	48,6%	48,60%	48,60%	48,60%
Probability of sleeping person present in cabin	28,6%	28,6%	28,60%	28,60%	28,60%
Probability of person present in corridor	**54,5%**	54,5%	54,50%	54,50%	54,50%
Probability of person present in stairway	**80,8%**	80,8%	80,80%	80,80%	80,80%
Probability of person present in galley	**95,2%**	95,2%	95,20%	95,20%	95,20%
Probability of person present in lounge	**55,3%**	55,3%	55,30%	55,30%	55,30%
Probability of person present in restaurant	**54,5%**	54,5%	54,50%	54,50%	54,50%
Probability of person present in store-room	**38,9%**	38,9%	38,90%	38,90%	38,90%
Probability of person present in technical space	**66,7%**	66,7%	66,67%	66,67%	66,67%
Probability of person present in machinery space	**27,5%**	27,5%	27,50%	27,50%	27,50%
Probability of failure of manual extinguishment in case no one present in cabin	**70,0%**	70,0%	70,00%	70,00%	70,00%
Probability of failure of manual extinguishment in case awake person present in cabin	**52,5%**	52,5%	52,50%	52,50%	52,50%
Probability of failure of manual extinguishment in case sleeping person present in cabin	**63,0%**	63,0%	63,00%	63,00%	63,00%
Probability of failure of manual extinguishment in case no one present in corridor	**60,0%**	60,0%	60,00%	60,00%	60,00%
Probability of failure of manual extinguishment in case person present in corridor	**39,0%**	39,0%	39,00%	39,00%	39,00%
Probability of failure of manual extinguishment in case no one present in stairway	**50,0%**	50,0%	50,00%	50,00%	50,00%
Probability of failure of manual extinguishment in case person present in stairway	**37,5%**	37,5%	37,50%	37,50%	37,50%
Probability of failure to hinder fire establishment on open deck area of category 1	**5,0%**	5,0%	5,00%	5,00%	5,00%
Probability of failure to hinder fire establishment on open deck area of category 2	**10,0%**	10,0%	10,00%	10,00%	10,00%
Probability of failure to hinder fire establishment on open deck area of category 3	**85,0%**	85,0%	85,00%	85,00%	85,00%
Probability of failure of manual extinguishment in case no one present in galley	**70,0%**	70,0%	70,00%	70,00%	70,00%
Probability of failure of manual extinguishment in case person present in galley	**20,0%**	20,0%	20,00%	20,00%	20,00%
Probability of failure of manual extinguishment in case no one present in lounge	**65,0%**	65,0%	65,00%	65,00%	65,00%
Probability of failure of manual extinguishment in case person present in lounge	**42,3%**	42,3%	42,25%	42,25%	42,25%
Probability of failure of manual extinguishment in case no one present in restaurant	**80,0%**	80,0%	80,00%	80,00%	80,00%
Probability of failure of manual extinguishment in case person present in restaurant	**35,0%**	35,0%	35,00%	35,00%	35,00%
Probability of failure of manual extinguishment in case no one present in store-room	**70,0%**	70,0%	70,00%	70,00%	70,00%

Probability of failure of manual extinguishment in case person present in store-room	**24,5%**	24,5%	24,50%	24,50%	24,50%
Probability of failure of manual extinguishment in case no one present in technical space	**70,0%**	70,0%	70,00%	70,00%	70,00%
Probability of failure of manual extinguishment in case person present in technical space	**10,0%**	10,0%	10,00%	10,00%	10,00%
Probability of failure of manual extinguishment in case no one present in machinery space	**85,0%**	85,0%	85,00%	85,00%	85,00%
Probability of failure of manual extinguishment in case person present in machinery space	**55,3%**	55,3%	55,25%	55,25%	55,25%
Probability of failure of manual extinguishment in engine room	**50,0%**	50,0%	50,00%	50,00%	50,00%
Probability of failure of door in case none present in cabin	**8,0%**	8,0%	8,00%	8,00%	8,00%
Probability of failure of door in case awake person present in cabin	**6,0%**	6,0%	6,00%	6,00%	6,00%
Probability of failure of door in case sleeping person present in cabin	**1,0%**	1,0%	1,00%	1,00%	1,00%
Probability of failure of door in case no one present in corridor	**3,0%**	3,0%	3,00%	3,00%	3,00%
Probability of failure of door in case person present in corridor	**6,0%**	6,0%	6,00%	6,00%	6,00%
Probability of failure of door in case no one present in stairway	**5,0%**	5,0%	5,00%	5,00%	5,00%
Probability of failure of door in case person present in stairway	**9,0%**	9,0%	9,00%	9,00%	9,00%
Probability of failure of door in case no one present in galley	**10,0%**	10,0%	10,00%	10,00%	10,00%
Probability of failure of door in case person present in galley	**15,0%**	15,0%	15,00%	15,00%	15,00%
Probability of failure of door in case no one present in lounge	**4,0%**	4,0%	4,00%	4,00%	4,00%
Probability of failure of door in case person present in lounge	**8,0%**	8,0%	8,00%	8,00%	8,00%
Probability of failure of door in case no one present in store-room	**2,0%**	2,0%	2,00%	2,00%	2,00%
Probability of failure of door in case person present in store-room	**3,0%**	3,0%	3,00%	3,00%	3,00%
Probability of failure of door in case no one present in technical space	**2,0%**	2,0%	2,00%	2,00%	2,00%
Probability of failure of door in case person present in technical space	**3,0%**	3,0%	3,00%	3,00%	3,00%
Probability of failure of door in case no one present in machinery space	**2,0%**	2,0%	2,00%	2,00%	2,00%
Probability of failure of door in case person present in machinery space	**3,0%**	3,0%	3,00%	3,00%	3,00%
Probability of failure of ventilation control in engine room	**50,0%**	50,0%	50,00%	50,00%	50,00%
Probability of failure of sprinkler system	**9,0%**	9,0%	9,00%	9,00%	9,00%
Probability of failure of fully redundant interior sprinkler system	**9,0%**	0,81%	0,81%	0,81%	0,81%
Probability of failure of semi-redundant sprinkler system	**2,0%**	2,0%	2,00%	2,00%	2,00%
Probability of failure of redundant balcony sprinkler system	**-**	**10,0%**	10,00%	10,00%	10,00%
Probability of failure of drencher system	**-**	**20,0%**	20,00%	20,00%	20,00%
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin	**60,0%**	60,0%	60,00%	60,00%	60,00%
Probability of failure of pre-flashover fire-fighting in case door is open in cabin	**90,0%**	90,0%	90,00%	90,00%	90,00%
Probability of failure of pre-flashover fire-fighting in case doors are closed in corridor	**10,0%**	10,0%	10,00%	10,00%	10,00%
Probability of failure of pre-flashover fire-fighting in case door is open in corridor	**65,0%**	65,0%	65,00%	65,00%	65,00%
Probability of failure of pre-flashover fire-fighting in case doors are closed in stairway	**50,0%**	50,0%	50,00%	50,00%	50,00%
Probability of failure of pre-flashover fire-fighting in case door is open in stairway	**60,0%**	60,0%	60,00%	60,00%	60,00%
Probability of failure to hinder fire development on open deck area of category 1	**1,0%**	**25,0%**	25,00%	25,00%	25,00%
Probability of failure to hinder fire development on open deck area of category 2	**5,0%**	**30,0%**	30,00%	30,00%	30,00%
Probability of failure to hinder fire development on open deck area of category 3	**40,0%**	**50,0%**	50,00%	50,00%	50,00%
Probability of failure of pre-flashover fire-fighting in case doors are closed in galley	**17,5%**	17,5%	17,50%	17,50%	17,50%
Probability of failure of pre-flashover fire-fighting in case door is open in galley	**80,0%**	80,0%	80,00%	80,00%	80,00%

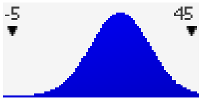
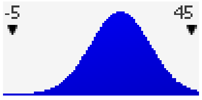
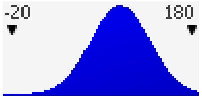
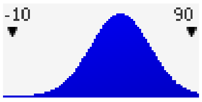
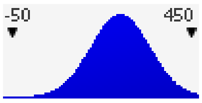
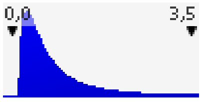
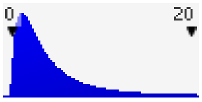
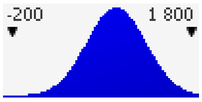
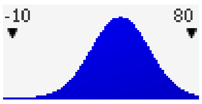
Probability of failure of pre-flashover fire-fighting in case doors are closed in lounge	**55,0%**	55,0%	55,00%	55,00%	55,00%
Probability of failure of pre-flashover fire-fighting in case door is open in lounge	**70,0%**	70,0%	70,00%	70,00%	70,00%
Probability of failure of pre-flashover fire-fighting in restaurant	**80,0%**	80,0%	80,00%	80,00%	80,00%
Probability of failure of pre-flashover fire-fighting in store-room	**70,0%**	70,0%	70,00%	70,00%	70,00%
Probability of failure of pre-flashover fire-fighting in in case doors are closed in technical space	**25,0%**	25,0%	25,00%	25,00%	25,00%
Probability of failure of pre-flashover fire-fighting in in case door is open in technical space	**70,0%**	70,0%	70,00%	70,00%	70,00%
Probability of failure of pre-flashover fire-fighting in in case doors are closed in machinery space	**20,0%**	20,0%	20,00%	20,00%	20,00%
Probability of failure of pre-flashover fire-fighting in in case door is open in machinery space	**80,0%**	83,2%	83,18%	83,18%	83,18%
Probability of failure of early fire-fighting in engine room	**60,0%**	60,0%	60,00%	60,00%	60,00%
Probability of failure of limited fire spread in cabin or corridor	**67,5%**	**0,0%**	0,00%	0,00%	0,00%
Probability of failure of limited fire spread in lounge	**4,0%**	**0,0%**	0,00%	0,00%	0,00%
Probability of failure of limited fire spread in restaurant	**9,0%**	**0,0%**	0,00%	0,00%	0,00%
Probability of failure of limited fire spread in store-room	**95,0%**	**0,0%**	0,00%	0,00%	0,00%
Probability of failure of limited fire spread in technical space	**20,0%**	**0,0%**	0,00%	0,00%	0,00%
Probability of failure of limited fire spread in machinery space	**95,0%**	**0,0%**	0,00%	0,00%	0,00%
Probability of failure of limited fire in engine room within 60 minutes	**10,0%**	10,0%	10,00%	10,00%	10,00%
Probability of failure of fire-fighting in case of limited fire spread in cabin, corridor, lounge, restaurant or technical space	**45,0%**	45,0%	45,00%	45,00%	45,00%
Probability of failure of fire-fighting in case of failure of limited fire spread in cabin, corridor, lounge, restaurant or technical space	**68,0%**	-	-	-	-
Probability of failure of fire-fighting in case of limited fire spread in store-room	**25,0%**	25,0%	25,00%	25,00%	25,00%
Probability of failure of fire-fighting in case of failure of limited fire spread in store-room	**52,0%**	-	-	-	-
Probability of failure of fire-fighting in case of limited fire spread in machinery space	**25,0%**	25,0%	25,00%	25,00%	25,00%
Probability of failure of fire-fighting in case of failure of limited fire spread in machinery space	**68,0%**	-	-	-	-
Probability of failure of fire-fighting within 60 minutes in engine room	**30,0%**	30,0%	30,00%	30,00%	30,00%
Probability of failure to prevent outboard fire spread from cabin	**29,0%**	**55,0%**	29,00%	55,00%	55,00%
Probability of failure to prevent outboard fire spread from lounge	**33,0%**	**66,0%**	33,00%	66,00%	66,00%
Probability of failure to prevent outboard fire spread from restaurant	**43,0%**	**79,0%**	43,00%	79,00%	79,00%
Probability of failure to prevent outboard fire spread from technical space	**35,0%**	**64,0%**	35,00%	64,00%	64,00%
Probability of failure to prevent outboard fire spread from machinery space	**4,0%**	**8,0%**	4,00%	8,00%	8,00%
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides	**50,0%**	**95,0%**	77,00%	86,00%	52,25%
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides	**-**	**-**	**40,00%**	**20,00%**	**95,00%**
Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides	**60,0%**	**90,0%**	78,00%	84,00%	66,00%
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides	**-**	**-**	**40,00%**	**20,00%**	**80,00%**
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1	**40,0%**	**85,0%**	**49,00%**	67,00%	28,75%
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2	**20,0%**	**70,0%**	**30,00%**	50,00%	7,50%
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3	**40,0%**	**75,0%**	**47,00%**	61,00%	31,25%
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck	**-**	**-**	**80,00%**	**40,00%**	**125,00%**
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck	**40,0%**	**80,0%**	**60,00%**	70,00%	44,00%
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck	**-**	**-**	**50,00%**	**25,00%**	**90,00%**
Probability of abandonment in case of internal fire and fire-fighting success	**27,0%**	**38,0%**	38,00%	**32,50%**	**29,75%**
Probability of abandonment in case of internal fire and fire-fighting failure	**82,0%**	**90,0%**	90,00%	**86,00%**	**84,00%**

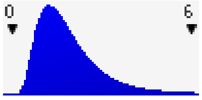
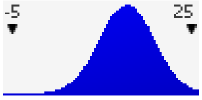
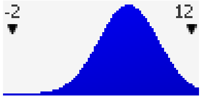
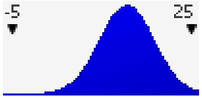
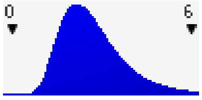
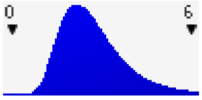
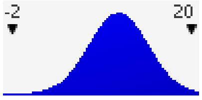
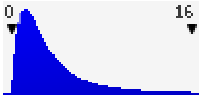
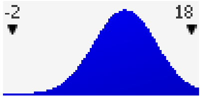
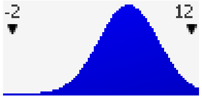
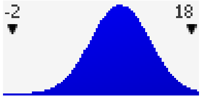
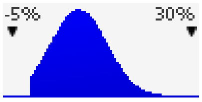
Probability of abandonment in case of extreme engine room fire and fire-fighting success	**63,5%**	63,5%	63,50%	63,50%	63,50%
Probability of abandonment in case of extreme engine room fire and fire-fighting failure	**91,0%**	91,0%	91,00%	91,00%	91,00%
Probability of abandonment in case of outboard fire and fire-fighting success	27,0%	27,0%	27,00%	27,00%	27,00%
Probability of abandonment in case of outboard fire and fire-fighting failure	82,0%	**95,0%**	95,00%	**88,50%**	**85,25%**
Probability of ship being at sea when abandoning in case fire is not escalating	**56,0%**	56,0%	56,00%	56,00%	56,00%
Probability of ship being at sea when abandoning in case fire is escalating	**43,0%**	43,0%	43,00%	43,00%	43,00%
Probability of bad weather	**20,0%**	20,0%	20,00%	20,00%	20,00%
Probability of casualties when abandoning ship at shore	**5,0%**	5,0%	5,00%	5,00%	5,00%
Probability of casualties when abandoning ship at sea in good weather and fire is not escalating	**5,0%**	5,0%	5,00%	5,00%	5,00%
Probability of casualties when abandoning ship at sea in bad weather and fire is not escalating	**60,0%**	60,0%	60,00%	60,00%	60,00%
Probability of casualties when abandoning ship at sea in good weather and fire is escalating	**36,0%**	36,0%	36,00%	36,00%	36,00%
Probability of casualties when abandoning ship at sea in bad weather and fire is escalating	**95,0%**	95,0%	95,00%	95,00%	95,00%
Consequences					
Fatalities from long-lasting internal fire	**11**	11	11	11	11
Fatalities from long-lasting engine room fire affecting the casing	**2,75**	**4**	4	**2,75**	**2,75**
Fatalities due to internal collapse in case of evacuation	**0**	**25**	25	**6**	6
Fatalities from local collapse due to collapse on outboard sides	**2**	**14**	6	2	2
Fatalities from local collapse due to smoke on outboard sides	**7**	**14**	9	14	9
Fatalities (total) from local collapse on outboard sides	9	28	15	16	11
Fatalities from collapse in case of local collapse on open deck	**1**	**5**	2	1	1
Fatalities from smoke in case of local collapse on open deck	**4**	**10,5**	7	11	7
Fatalities (total) from local collapse on open deck	5	16	9	11,5	8
Fatalities in superstructure due to major collapse on outboard sides	**10**	**70**	46	58	34
Fatalities in superstructure due to major collapse on open deck	10	**35**	20	28	13
Fatalities due to major collapse on outboard sides in case of evacuation	**50**	**250**	140	200	90
Fatalities due to major collapse on open deck in case of evacuation	**25**	**100**	44	66	25
Fatalities in rare occasions due to evacuation at shore	**7**	7	7	7	7
Fatalities from evacuation at sea in case of unsuccessful in good weather	**44**	44	44	44	44
Fatalities from evacuation at sea in case of unsuccessful in bad weather	**958**	958	958	958	958
Reduced increased fatalities from local collapse (due to collapse) on outboard sides	**-**	**-**	**70%**	**100%**	**100%**
Reduced increased fatalities from local collapse (due to smoke) on outboard sides	**-**	**-**	**70%**	**0%**	**70%**
Reduced increased fatalities from local collapse (due to collapse) on open deck	**-**	**-**	**75%**	**100%**	**100%**
Reduced increased fatalities from local collapse (due to smoke) on open deck	**-**	**-**	**50%**	**0%**	**50%**
Reduced increased fatalities from major collapse on outboard sides	**-**	**-**	**40%**	**20%**	**60%**
Reduced increased fatalities from major collapse on open deck	**-**	**-**	**60%**	**30%**	**90%**
Reduced increased fatalities due to major collapse on outboard sides in case of evacuation	**-**	**-**	**55%**	**25%**	**80%**
Reduced increased fatalities due to major collapse on open deck in case of evacuation	**-**	**-**	**75%**	**45%**	**100%**

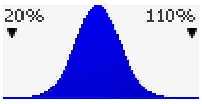
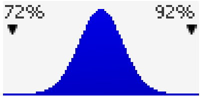
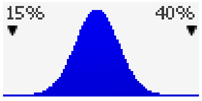
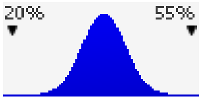
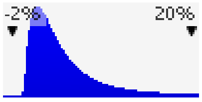
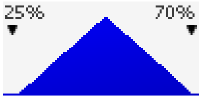
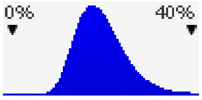
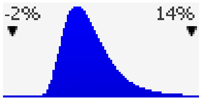
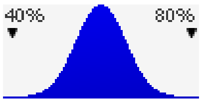
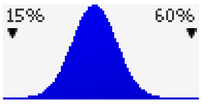
Uncertainty and sensitivity analysis

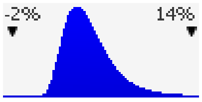
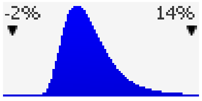
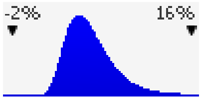
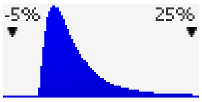
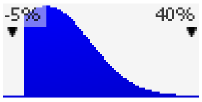
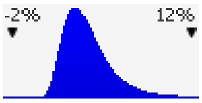
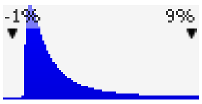
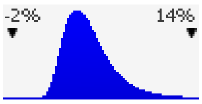
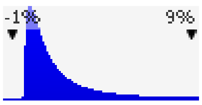
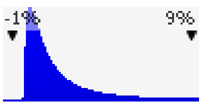
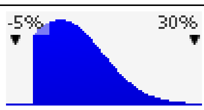
All estimated probabilities and consequences summarized in *Appendix K. Summarized input data* were, based on the discussions in the quantification above, assigned probability distributions. Thereby the uncertainties of the estimations and assumptions made in the quantification processes were managed. 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.

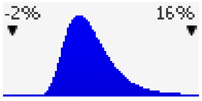
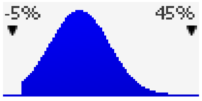
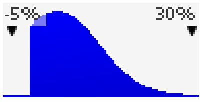
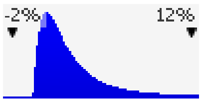
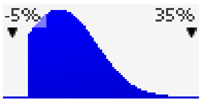
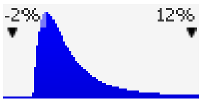
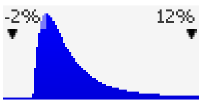
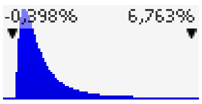
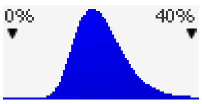
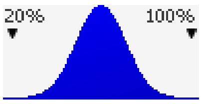
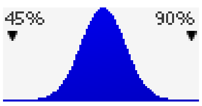
Input distributions

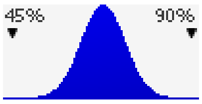
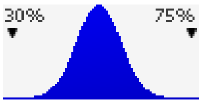
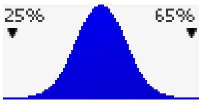
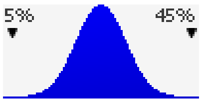
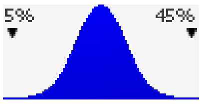
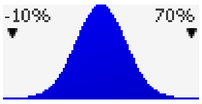
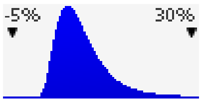
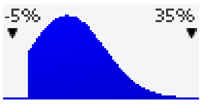
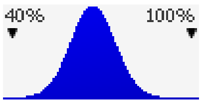
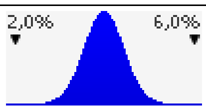
	Name	Graph	Function	Mean
Category: Fatalities due to internal collapse in case of evacuation				
	Fatalities due to internal collapse in case of evacuation / BD		RiskNormal(25;7,5;RiskTruncate(0;);RiskStatic(25))	25,01
Category: Fatalities due to major collapse on open deck in case of evacuation				
	Fatalities due to major collapse on open deck in case of evacuation / PD		RiskNormal(25;7,5;RiskTruncate(0;);RiskStatic(25);RiskName(A161&" / "&B24);RiskCorrmat(majcol2;3))	25,01
	Fatalities due to major collapse on open deck in case of evacuation / BD		RiskNormal(100;30;RiskTruncate(0;);RiskStatic(100);RiskName(A161&" / "&C24);RiskCorrmat(majcol2;4))	100,05
Category: Fatalities due to major collapse on outboard sides in case of evacuation				
	Fatalities due to major collapse on outboard sides in case of evacuation / PD		RiskNormal(50;15;RiskTruncate(0;);RiskStatic(50);RiskName(A160&" / "&B24);RiskCorrmat(majcol2;1))	50,02
	Fatalities due to major collapse on outboard sides in case of evacuation / BD		RiskNormal(250;75;RiskTruncate(0;);RiskStatic(250);RiskName(A160&" / "&C24);RiskCorrmat(majcol2;2))	250,12
Category: Fatalities from collapse in case of local collapse on open deck				
	Fatalities from collapse in case of local collapse on open deck / PD		RiskLognorm(0,75;1;RiskShift(0,25);RiskStatic(1);RiskName(A155&" / "&B24);RiskCorrmat(Loccol2;1))	1,00
	Fatalities from collapse in case of local collapse on open deck / BD		RiskLognorm(4,5;5;RiskShift(0,5);RiskStatic(5);RiskName(A155&" / "&C24);RiskCorrmat(Loccol2;2))	5,00
Category: Fatalities from evacuation at sea in case of unsuccessful in bad weather				
	Fatalities from evacuation at sea in case of unsuccessful in bad weather / PD		RiskNormal(957,26;300;RiskTruncate(0;);RiskStatic(958);RiskName(A164&" / "&B24))	958,00
Category: Fatalities from evacuation at sea in case of unsuccessful in good weather				
	Fatalities from evacuation at sea in case of unsuccessful in good weather / PD		RiskNormal(44;13,2;RiskTruncate(0;);RiskStatic(44);RiskName(A163&" / "&B24))	44,02

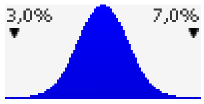
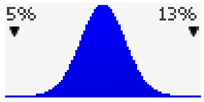
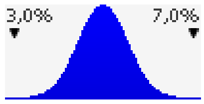
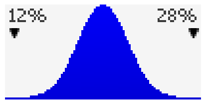
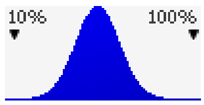
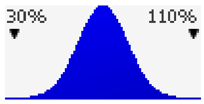
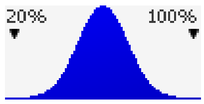
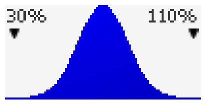
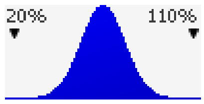
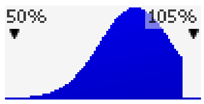
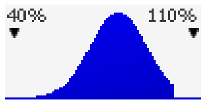
Category: Fatalities from local collapse due to collapse on outboard sides			
Fatalities from local collapse due to collapse on outboard sides / PD		RiskLognorm(1,75;1;RiskShift(0,25);RiskStatic(2);RiskName(A152&" / "&B24);RiskCorrmat(FatLoccol;1))	2,00
Fatalities from local collapse due to collapse on outboard sides / BD		RiskNormal(14;4,2;RiskTruncate(0;);RiskStatic(14);RiskName(A152&" / "&C24);RiskCorrmat(FatLoccol;2))	14,01
Category: Fatalities from local collapse due to smoke on outboard sides			
Fatalities from local collapse due to smoke on outboard sides / PD		RiskNormal(7;2,1;RiskTruncate(0;);RiskStatic(7);RiskName(A153&" / "&B24);RiskCorrmat(FatLoccol;3))	7,00
Fatalities from local collapse due to smoke on outboard sides / BD		RiskNormal(14;4,2;RiskTruncate(0;);RiskStatic(14);RiskName(A153&" / "&C24);RiskCorrmat(FatLoccol;4))	14,01
Category: Fatalities from long-lasting engine room fire affecting the casing			
Fatalities from long-lasting engine room fire affecting the casing / PD		RiskLognorm(2,5;1;RiskShift(0,25);RiskStatic(2,75);RiskName(A150&" / "&B24))	2,75
Fatalities from long-lasting engine room fire affecting the casing / TAD O		RiskLognorm(2,5;1;RiskShift(0,25);RiskStatic(2,75);RiskName(A150&" / "&R24))	2,75
Category: Fatalities from long-lasting internal fire			
Fatalities from long-lasting internal fire / PD		RiskNormal(11;3,3;RiskTruncate(0;);RiskStatic(11))	11,01
Category: Fatalities from smoke in case of local collapse on open deck			
Fatalities from smoke in case of local collapse on open deck / PD		RiskLognorm(3,5;3,5;RiskShift(0,5);RiskStatic(4);RiskCorrmat(Loccol2;3))	4,00
Fatalities from smoke in case of local collapse on open deck / BD		RiskNormal(10,5;3,15;RiskTruncate(0;);RiskStatic(10,5);RiskCorrmat(Loccol2;4))	10,50
Category: Fatalities in rare occations due to evacuation at shore			
Fatalities in rare occations due to evacuation at shore / PD		RiskNormal(7;2,1;RiskTruncate(0;);RiskStatic(7))	7,00
Category: Fatalities in superstructure due to major collapse on outboard sides			
Fatalities in superstructure due to major collapse on outboard sides / PD		RiskNormal(10;3;RiskTruncate(0;);RiskStatic(10);RiskName(A158&" / "&B24);RiskCorrmat(majcol1;1))	10,00
Category: Probability of abandonment in case of extreme engine room fire and fire-fighting failure			
Probability of abandonment in case of extreme engine room fire and fire-fighting failure / PD		RiskNormal(0,0851;0,05;RiskTruncate(0;1);RiskStatic(0,09);RiskName(A137&" / "&B24))	9,0%

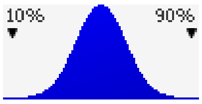
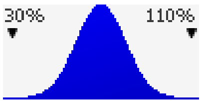
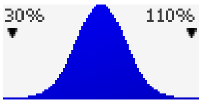
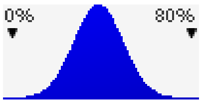
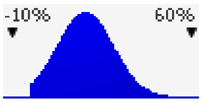
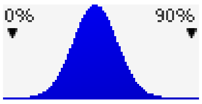
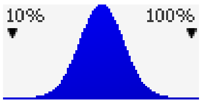
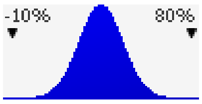
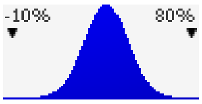
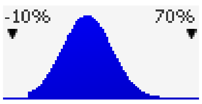
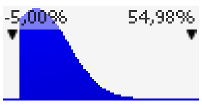
Category: Probability of abandonment in case of extreme engine room fire and fire-fighting success			
Probability of abandonment in case of extreme engine room fire and fire-fighting success / PD		RiskNormal(0,635;0,1;RiskTruncate(0;1);RiskStatic(0,635);RiskName(A136&" / "&B24))	63,5 %
Category: Probability of abandonment in case of internal fire and fire-fighting failure			
Probability of abandonment in case of internal fire and fire-fighting failure / PD		RiskNormal(0,82;0,022;RiskTruncate(0;1);RiskStatic(0,82);RiskName(A135&" / "&B24);RiskCorrmat(IntAbandon;3))	82,0 %
Probability of abandonment in case of internal fire and fire-fighting failure / BD	X	RiskNormal(0,9;0,01;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A135&" / "&C24);RiskCorrmat(IntAbandon;4))	90,0 %
Category: Probability of abandonment in case of internal fire and fire-fighting success			
Probability of abandonment in case of internal fire and fire-fighting success / PD		RiskNormal(0,27;0,027;RiskTruncate(0;1);RiskStatic(0,27);RiskName(A134&" / "&B24);RiskCorrmat(IntAbandon;1))	27,0 %
Probability of abandonment in case of internal fire and fire-fighting success / BD		RiskNormal(0,38;0,038;RiskTruncate(0;1);RiskStatic(0,38);RiskName(A134&" / "&C24);RiskCorrmat(IntAbandon;2))	38,0 %
Category: Probability of abandonment in case of outboard fire and fire-fighting failure			
Probability of abandonment in case of outboard fire and fire-fighting failure / BD		RiskLognorm(0,05;0,05;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A139&" / "&C24))	5,0%
Category: Probability of awake person present in cabin			
Probability of awake person present in cabin / PD		RiskTriang(0,286;0,486;0,686;RiskStatic(0,486);RiskCorrmat(Persincabin;2))	48,6 %
Category: Probability of bad weather			
Probability of bad weather / PD		RiskLognorm(0,2;0,05;RiskTruncate(0;1);RiskStatic(0,2))	20,0 %
Category: Probability of casualties when abandoning ship at sea in bad weather and fire is escalating			
Probability of casualties when abandoning ship at sea in bad weather and fire is escalating / PD		RiskLognorm(0,05;0,02;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A147&" / "&B24))	5,0%
Category: Probability of casualties when abandoning ship at sea in bad weather and fire is not escalating			
Probability of casualties when abandoning ship at sea in bad weather and fire is not escalating / PD		RiskNormal(0,6;0,05;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A145&" / "&B24))	60,0 %
Category: Probability of casualties when abandoning ship at sea in good weather and fire is escalating			
Probability of casualties when abandoning ship at sea in good weather and fire is escalating / PD		RiskNormal(0,36;0,05;RiskTruncate(0;1);RiskStatic(0,36);RiskName(A146&" / "&B24))	36,0 %

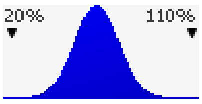
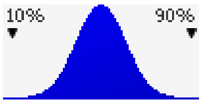
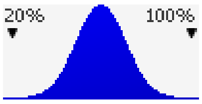
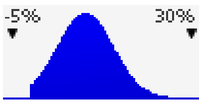
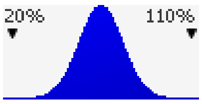
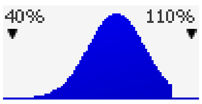
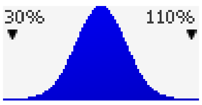
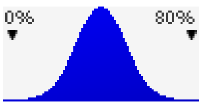
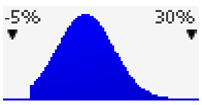
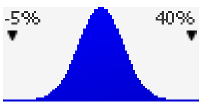
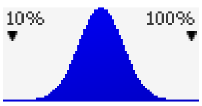
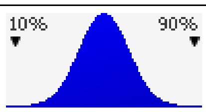
Category: Probability of casualties when abandoning ship at sea in good weather and fire is not escalating			
Probability of casualties when abandoning ship at sea in good weather and fire is not escalating / PD		RiskLognorm(0,05;0,02;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A144&" / "&B24))	5,0%
Category: Probability of casualties when abandoning ship at shore			
Probability of casualties when abandoning ship at shore / PD		RiskLognorm(0,05;0,02;RiskTruncate(0;1);RiskStatic(0,05))	5,0%
Category: Probability of failure of door in case awake person present in cabin			
Probability of failure of door in case awake person present in cabin / PD		RiskLognorm(0,06;0,022;RiskTruncate(0;1);RiskStatic(0,06);RiskName(A63&" / "&B24))	6,0%
Category: Probability of failure of door in case no one present in corridor			
Probability of failure of door in case no one present in corridor / PD		RiskLognorm(0,06;0,05;RiskTruncate(0;1);RiskStatic(0,03);RiskName(A65&" / "&B24))	6,0%
Category: Probability of failure of door in case no one present in galley			
Probability of failure of door in case no one present in galley / PD		RiskNormal(0,048;0,1;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A69&" / "&B24))	10,0 %
Category: Probability of failure of door in case no one present in lounge			
Probability of failure of door in case no one present in lounge / PD		RiskLognorm(0,04;0,017;RiskTruncate(0;1);RiskStatic(0,04);RiskName(A71&" / "&B24))	4,0%
Category: Probability of failure of door in case no one present in machinery space			
Probability of failure of door in case no one present in machinery space / 0.3		RiskLognorm(0,02;0,03;RiskTruncate(0;1);RiskStatic(0,02);RiskName(A77&" / "&B26))	2,0%
Category: Probability of failure of door in case no one present in stairway			
Probability of failure of door in case no one present in stairway / PD		RiskLognorm(0,05;0,02;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A67&" / "&B24))	5,0%
Category: Probability of failure of door in case no one present in store-room			
Probability of failure of door in case no one present in store-room / PD		RiskLognorm(0,02;0,03;RiskTruncate(0;1);RiskStatic(0,02);RiskName(A73&" / "&B24))	2,0%
Category: Probability of failure of door in case no one present in technical space			
Probability of failure of door in case no one present in technical space / PD		RiskLognorm(0,02;0,03;RiskTruncate(0;1);RiskStatic(0,02);RiskName(A75&" / "&B24))	2,0%
Category: Probability of failure of door in case none present in cabin			
Probability of failure of door in case none present in cabin / PD		RiskNormal(0,046;0,075;RiskTruncate(0;1);RiskStatic(0,08))	8,0%

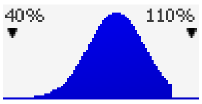
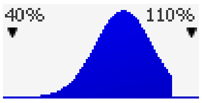
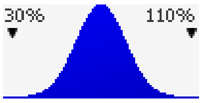
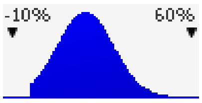
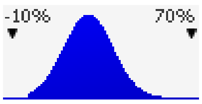
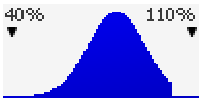
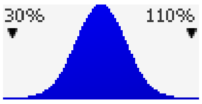
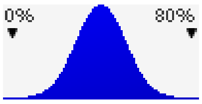
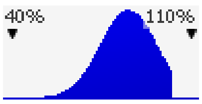
Category: Probability of failure of door in case person present in corridor				
	Probability of failure of door in case person present in corridor / PD		RiskLognorm(0,06;0,022;RiskTruncate(0;1); RiskStatic(0,06);RiskName(A66&" / "&B24))	6,0%
Category: Probability of failure of door in case person present in galley				
	Probability of failure of door in case person present in galley / PD		RiskNormal(0,145;0,075;RiskTruncate(0;1); RiskStatic(0,15);RiskName(A70&" / "&B24))	15,0 %
Category: Probability of failure of door in case person present in lounge				
	Probability of failure of door in case person present in lounge / PD		RiskNormal(0,046;0,075;RiskTruncate(0;1); RiskStatic(0,08);RiskName(A72&" / "&B24))	8,0%
Category: Probability of failure of door in case person present in machinery space				
	Probability of failure of door in case person present in machinery space / PD		RiskLognorm(0,03;0,03;RiskTruncate(0;1);RiskStatic(0,03);RiskName(A78&" / "&B24))	3,0%
Category: Probability of failure of door in case person present in stairway				
	Probability of failure of door in case person present in stairway / PD		RiskNormal(0,0642;0,075;RiskTruncate(0;1);RiskStatic(0,09);RiskName(A68&" / "&B24))	9,0%
Category: Probability of failure of door in case person present in store-room				
	Probability of failure of door in case person present in store-room / PD		RiskLognorm(0,03;0,03;RiskTruncate(0;1);RiskStatic(0,03);RiskName(A74&" / "&B24))	3,0%
Category: Probability of failure of door in case person present in technical space				
	Probability of failure of door in case person present in technical space / PD		RiskLognorm(0,03;0,03;RiskTruncate(0;1);RiskStatic(0,03);RiskName(A76&" / "&B24))	3,0%
Category: Probability of failure of door in case sleeping person present in cabin				
	Probability of failure of door in case sleeping person present in cabin / PD		RiskLognorm(0,01;0,01;RiskTruncate(0;1);RiskStatic(0,01);RiskName(A64&" / "&B24))	1,0%
Category: Probability of failure of drencher system				
	Probability of failure of drencher system / TAD C		RiskLognorm(0,2;0,05;RiskTruncate(0;1);RiskStatic(0,2);RiskCorrmat(Extsystems;4))	20,0 %
Category: Probability of failure of early fire-fighting in engine room				
	Probability of failure of early fire-fighting in engine room / PD		RiskNormal(0,6;0,1;RiskTruncate(0;1);RiskStatic(0,6))	60,0 %
Category: Probability of failure of fire-fighting in case of failure of limited fire spread in cabin, corridor, lounge, restaurant or technical space				
	Probability of failure of fire-fighting in case of failure of limited fire spread in cabin, corridor, lounge, restaurant or technical space / PD		RiskNormal(0,68;0,05;RiskTruncate(0;1);RiskStatic(0,68);RiskName(A113&" / "&B24))	68,0 %

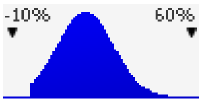
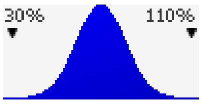
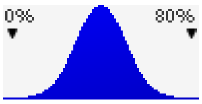
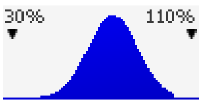
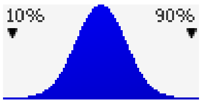
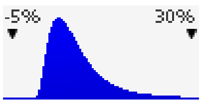
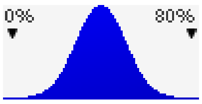
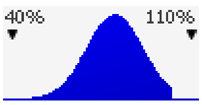
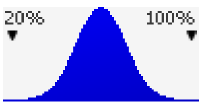
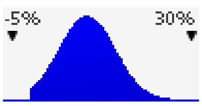
Category: Probability of failure of fire-fighting in case of failure of limited fire spread in machinery space				
	Probability of failure of fire-fighting in case of failure of limited fire spread in machinery space / PD		RiskNormal(0,68;0,05;RiskTruncate(0;1);RiskStatic(0,68);RiskName(A117&" / "&B24))	68,0 %
Category: Probability of failure of fire-fighting in case of failure of limited fire spread in store-room				
	Probability of failure of fire-fighting in case of failure of limited fire spread in store-room / PD		RiskNormal(0,52;0,05;RiskTruncate(0;1);RiskStatic(0,52);RiskName(A115&" / "&B24))	52,0 %
Category: Probability of failure of fire-fighting in case of limited fire spread in cabin, corridor, lounge, restaurant or technical space				
	Probability of failure of fire-fighting in case of limited fire spread in cabin, corridor, lounge, restaurant or technical space / PD		RiskNormal(0,45;0,05;RiskTruncate(0;1);RiskStatic(0,45);RiskName(A112&" / "&B24))	45,0 %
Category: Probability of failure of fire-fighting in case of limited fire spread in machinery space				
	Probability of failure of fire-fighting in case of limited fire spread in machinery space / PD		RiskNormal(0,25;0,05;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A116&" / "&B24))	25,0 %
Category: Probability of failure of fire-fighting in case of limited fire spread in store-room				
	Probability of failure of fire-fighting in case of limited fire spread in store-room / PD		RiskNormal(0,25;0,05;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A114&" / "&B24))	25,0 %
Category: Probability of failure of fire-fighting within 60 minutes in engine room				
	Probability of failure of fire-fighting within 60 minutes in engine room / PD		RiskNormal(0,3;0,1;RiskTruncate(0;1);RiskStatic(0,3);RiskName(A118&" / "&B24))	30,0 %
Category: Probability of failure of fully redundant interior sprinkler system				
	Probability of failure of fully redundant interior sprinkler system / PD		RiskLognorm(0,09;0,045;RiskTruncate(0;1);RiskStatic(0,09);RiskName(A81&" / "&B24);RiskCorrmat(Extsystems;2))	9,0%
Category: Probability of failure of limited fire in engine room within 60 minutes				
	Probability of failure of limited fire in engine room within 60 minutes / PD		RiskNormal(0,081;0,075;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A111&" / "&B24))	10,0 %
Category: Probability of failure of limited fire spread in cabin or corridor				
	Probability of failure of limited fire spread in cabin or corridor / PD		RiskNormal(0,675;0,0675;RiskTruncate(0;1);RiskStatic(0,675);RiskName(A105&" / "&B24))	67,5 %
Category: Probability of failure of limited fire spread in lounge				
	Probability of failure of limited fire spread in lounge / PD		RiskNormal(0,04;0,004;RiskTruncate(0;1);RiskStatic(0,04))	4,0%

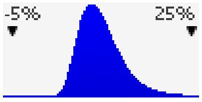
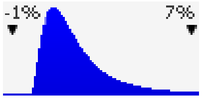
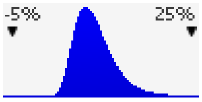
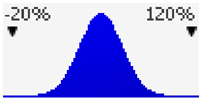
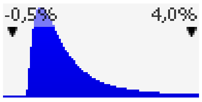
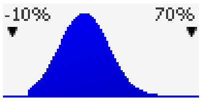
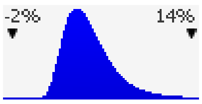
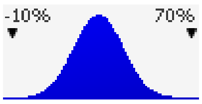
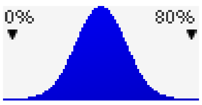
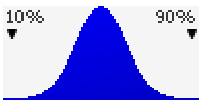
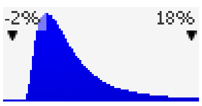
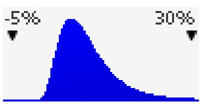
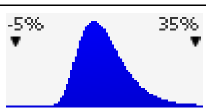
Category: Probability of failure of limited fire spread in machinery space			
Probability of failure of limited fire spread in machinery space / PD		RiskNormal(0,05;0,005;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A110&" / "&B24))	5,0%
Category: Probability of failure of limited fire spread in restaurant			
Probability of failure of limited fire spread in restaurant / PD		RiskNormal(0,09;0,009;RiskTruncate(0;1);RiskStatic(0,09))	9,0%
Category: Probability of failure of limited fire spread in store-room			
Probability of failure of limited fire spread in store-room / PD		RiskNormal(0,05;0,005;RiskTruncate(0;1);RiskStatic(0,05))	5,0%
Category: Probability of failure of limited fire spread in technical space			
Probability of failure of limited fire spread in technical space / PD		RiskNormal(0,2;0,02;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A109&" / "&B24))	20,0 %
Category: Probability of failure of manual extinguishment in case awake person present in cabin			
Probability of failure of manual extinguishment in case awake person present in cabin / PD		RiskNormal(0,525;0,1;RiskTruncate(0;1);RiskStatic(0,525);RiskName(A40&" / "&B24))	52,5 %
Category: Probability of failure of manual extinguishment in case no one present in cabin			
Probability of failure of manual extinguishment in case no one present in cabin / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A39&" / "&B24))	70,0 %
Category: Probability of failure of manual extinguishment in case no one present in corridor			
Probability of failure of manual extinguishment in case no one present in corridor / PD		RiskNormal(0,6;0,1;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A42&" / "&B24))	60,0 %
Category: Probability of failure of manual extinguishment in case no one present in galley			
Probability of failure of manual extinguishment in case no one present in galley / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A49&" / "&B24))	70,0 %
Category: Probability of failure of manual extinguishment in case no one present in lounge			
Probability of failure of manual extinguishment in case no one present in lounge / PD		RiskNormal(0,65;0,1;RiskTruncate(0;1);RiskStatic(0,65);RiskName(A51&" / "&B24))	65,0 %
Category: Probability of failure of manual extinguishment in case no one present in machinery space			
Probability of failure of manual extinguishment in case no one present in machinery space / PD		RiskNormal(0,868;0,1;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A59&" / "&B24))	85,0 %
Category: Probability of failure of manual extinguishment in case no one present in restaurant			
Probability of failure of manual extinguishment in case no one present in restaurant / PD		RiskNormal(0,806;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A53&" / "&B24))	80,0 %

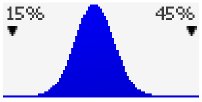
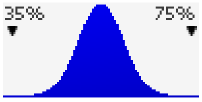
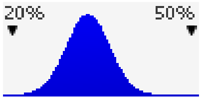
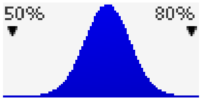
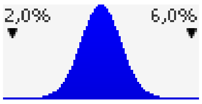
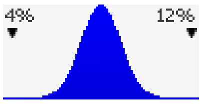
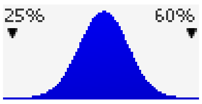
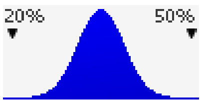
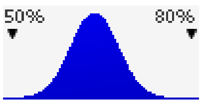
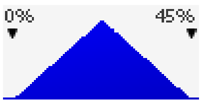
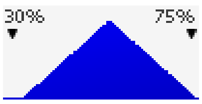
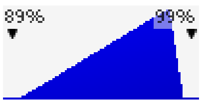
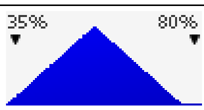
Category: Probability of failure of manual extinguishment in case no one present in stairway				
	Probability of failure of manual extinguishment in case no one present in stairway / PD		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A44&" / "&B24))	50,0 %
Category: Probability of failure of manual extinguishment in case no one present in store-room				
	Probability of failure of manual extinguishment in case no one present in store-room / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A55&" / "&B24))	70,0 %
Category: Probability of failure of manual extinguishment in case no one present in technical space				
	Probability of failure of manual extinguishment in case no one present in technical space / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A57&" / "&B24))	70,0 %
Category: Probability of failure of manual extinguishment in case person present in corridor				
	Probability of failure of manual extinguishment in case person present in corridor / PD		RiskNormal(0,39;0,1;RiskTruncate(0;1);RiskStatic(0,39);RiskName(A43&" / "&B24))	39,0 %
Category: Probability of failure of manual extinguishment in case person present in galley				
	Probability of failure of manual extinguishment in case person present in galley / PD		RiskNormal(0,194;0,1;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A50&" / "&B24))	20,0 %
Category: Probability of failure of manual extinguishment in case person present in lounge				
	Probability of failure of manual extinguishment in case person present in lounge / PD		RiskNormal(0,423;0,1;RiskTruncate(0;1);RiskStatic(0,423);RiskName(A52&" / "&B24))	42,3 %
Category: Probability of failure of manual extinguishment in case person present in machinery space				
	Probability of failure of manual extinguishment in case person present in machinery space / PD		RiskNormal(0,553;0,1;RiskTruncate(0;1);RiskStatic(0,553);RiskName(A60&" / "&B24))	55,3 %
Category: Probability of failure of manual extinguishment in case person present in restaurant				
	Probability of failure of manual extinguishment in case person present in restaurant / PD		RiskNormal(0,35;0,1;RiskTruncate(0;1);RiskStatic(0,35);RiskName(A54&" / "&B24))	35,0 %
Category: Probability of failure of manual extinguishment in case person present in stairway				
	Probability of failure of manual extinguishment in case person present in stairway / PD		RiskNormal(0,375;0,1;RiskTruncate(0;1);RiskStatic(0,375);RiskName(A45&" / "&B24))	37,5 %
Category: Probability of failure of manual extinguishment in case person present in store-room				
	Probability of failure of manual extinguishment in case person present in store-room / PD		RiskNormal(0,243;0,1;RiskTruncate(0;1);RiskStatic(0,245);RiskName(A56&" / "&B24))	24,5 %
Category: Probability of failure of manual extinguishment in case person present in technical space				
	Probability of failure of manual extinguishment in case person present in technical space / PD		RiskNormal(0,048;0,1;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A58&" / "&B24))	10,0 %

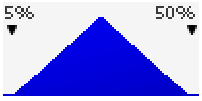
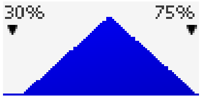
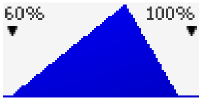
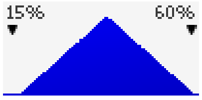
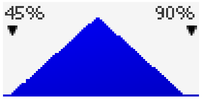
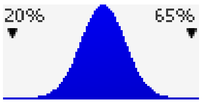
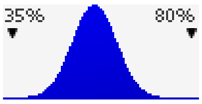
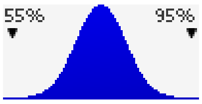
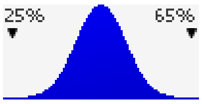
Category: Probability of failure of manual extinguishment in case sleeping person present in cabin				
	Probability of failure of manual extinguishment in case sleeping person present in cabin / PD		RiskNormal(0,63;0,1;RiskTruncate(0;1);RiskStatic(0,63);RiskName(A41&" / "&B24))	63,0 %
Category: Probability of failure of manual extinguishment in engine room				
	Probability of failure of manual extinguishment in engine room / PD		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A61&" / "&B24))	50,0 %
Category: Probability of failure of pre-flashover fire-fighting in case door is closed in cabin				
	Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD		RiskNormal(0,6;0,1;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A85&" / "&B24))	60,0 %
Category: Probability of failure of pre-flashover fire-fighting in case door is open in cabin				
	Probability of failure of pre-flashover fire-fighting in case door is open in cabin / PD		RiskNormal(0,097;0,05;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A86&" / "&B24))	10,0 %
Category: Probability of failure of pre-flashover fire-fighting in case door is open in corridor				
	Probability of failure of pre-flashover fire-fighting in case door is open in corridor / PD		RiskNormal(0,65;0,1;RiskTruncate(0;1);RiskStatic(0,65);RiskName(A88&" / "&B24))	65,0 %
Category: Probability of failure of pre-flashover fire-fighting in case door is open in galley				
	Probability of failure of pre-flashover fire-fighting in case door is open in galley / PD		RiskNormal(0,806;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A95&" / "&B24))	80,0 %
Category: Probability of failure of pre-flashover fire-fighting in case door is open in lounge				
	Probability of failure of pre-flashover fire-fighting in case door is open in lounge / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A97&" / "&B24))	70,0 %
Category: Probability of failure of pre-flashover fire-fighting in case door is open in stairway				
	Probability of failure of pre-flashover fire-fighting in case door is open in stairway / PD		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A90&" / "&B24))	40,0 %
Category: Probability of failure of pre-flashover fire-fighting in case doors are closed in corridor				
	Probability of failure of pre-flashover fire-fighting in case doors are closed in corridor / PD		RiskNormal(0,097;0,05;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A87&" / "&B24))	10,0 %
Category: Probability of failure of pre-flashover fire-fighting in case doors are closed in galley				
	Probability of failure of pre-flashover fire-fighting in case doors are closed in galley / PD		RiskNormal(0,175;0,05;RiskTruncate(0;1);RiskStatic(0,175);RiskName(A94&" / "&B24))	17,5 %
Category: Probability of failure of pre-flashover fire-fighting in case doors are closed in lounge				
	Probability of failure of pre-flashover fire-fighting in case doors are closed in lounge / PD		RiskNormal(0,55;0,1;RiskTruncate(0;1);RiskStatic(0,55);RiskName(A96&" / "&B24))	55,0 %
Category: Probability of failure of pre-flashover fire-fighting in case doors are closed in stairway				
	Probability of failure of pre-flashover fire-fighting in case doors are closed in stairway / PD		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A89&" / "&B24))	50,0 %
Category: Probability of failure of pre-flashover fire-fighting in in case door is open in machinery space				

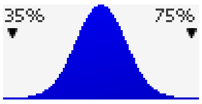
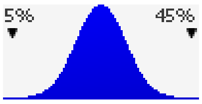
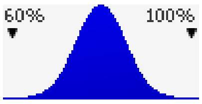
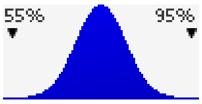
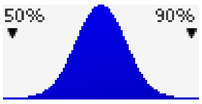
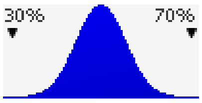
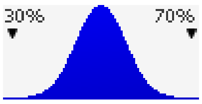
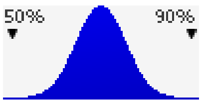
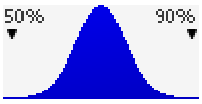
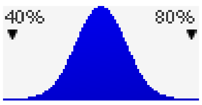
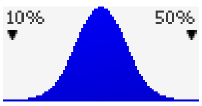
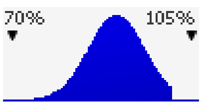
	Probability of failure of pre-flashover fire-fighting in in case door is open in machinery space / PD		RiskNormal(0,806;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A103&" / "&B24))	80,0 %
	Probability of failure of pre-flashover fire-fighting in in case door is open in machinery space / BD		RiskNormal(0,8318;0,1;RiskTruncate(0;1);RiskStatic(0,8318);RiskName(A103&" / "&C24))	82,2 %
Category: Probability of failure of pre-flashover fire-fighting in in case door is open in technical space				
	Probability of failure of pre-flashover fire-fighting in in case door is open in technical space / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A101&" / "&B24))	70,0 %
Category: Probability of failure of pre-flashover fire-fighting in in case doors are closed in machinery space				
	Probability of failure of pre-flashover fire-fighting in in case doors are closed in machinery space / PD		RiskNormal(0,194;0,1;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A102&" / "&B24))	20,0 %
Category: Probability of failure of pre-flashover fire-fighting in in case doors are closed in technical space				
	Probability of failure of pre-flashover fire-fighting in in case doors are closed in technical space / PD		RiskNormal(0,248;0,1;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A100&" / "&B24))	25,0 %
Category: Probability of failure of pre-flashover fire-fighting in restaurant				
	Probability of failure of pre-flashover fire-fighting in restaurant / PD		RiskNormal(0,806;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A98&" / "&B24))	80,0 %
Category: Probability of failure of pre-flashover fire-fighting in store-room				
	Probability of failure of pre-flashover fire-fighting in store-room / PD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A99&" / "&B24))	70,0 %
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1				
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / PD		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A128&" / "&B24);RiskCorrmat(Precol3;1))	40,0 %
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / BD		RiskNormal(0,85;0,1;RiskTruncate(0;1);RiskStatic(0,85);RiskName(A128&" / "&C24);RiskCorrmat(Precol3;2))	83,6 %

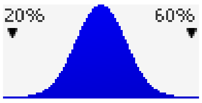
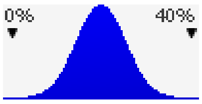
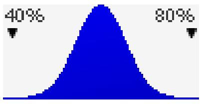
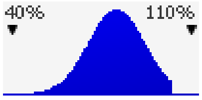
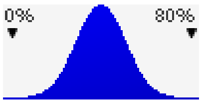
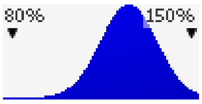
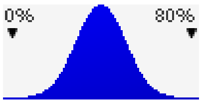
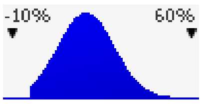
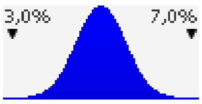
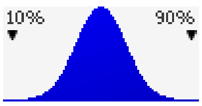
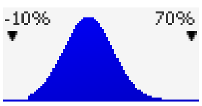
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2				
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2 / PD		RiskNormal(0,194;0,1;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A129&" / "&B24);RiskCorrmat(Precol3;3))	20,0 %
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 2 / BD		RiskNormal(0,7;0,1;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A129&" / "&C24);RiskCorrmat(Precol3;4))	70,0 %
Category: Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3				
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3 / PD		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A130&" / "&B24);RiskCorrmat(Precol3;5))	40,0 %
	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 3 / BD		RiskNormal(0,75;0,1;RiskTruncate(0;1);RiskStatic(0,75);RiskName(A130&" / "&C24);RiskCorrmat(Precol3;6))	74,8 %
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		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A124&" / "&B24);RiskCorrmat(Precol1;1))	50,0 %
	Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides / BD		RiskLognorm(0,08;0,05;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A124&" / "&C24);RiskCorrmat(Precol1;2))	8,0%
Category: Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck				
	Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / PD		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A132&" / "&B24);RiskCorrmat(Premajcol1;1))	40,0 %
	Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / BD		RiskNormal(0,8;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A132&" / "&C24);RiskCorrmat(Premajcol1;2))	79,4 %
Category: Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides				
	Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / PD		RiskNormal(0,6;0,1;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A126&" / "&B24);RiskCorrmat(Precol2;1))	60,0 %
	Probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / BD		RiskNormal(0,1;0,05;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A126&" / "&C24);RiskCorrmat(Precol2;2))	10,3 %
Category: Probability of failure of redundant balcony sprinkler system				

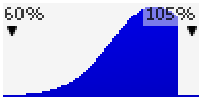
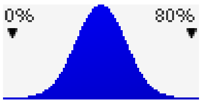
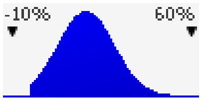
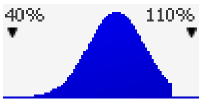
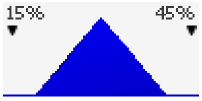
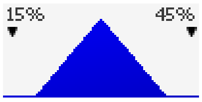
	Probability of failure of redundant balcony sprinkler system / TAD B		RiskLognorm(0,1;0,033;RiskTruncate(0;1);RiskStatic(0,1);RiskCorrmat(Extsystems;3))	10,0 %
Category: Probability of failure of semi-redundant sprinkler system				
	Probability of failure of semi-redundant sprinkler system / PD		RiskLognorm(0,02;0,015;RiskTruncate(0;1); RiskStatic(0,02))	2,0%
Category: Probability of failure of sprinkler system				
	Probability of failure of sprinkler system / PD		RiskLognorm(0,09;0,03;RiskTruncate(0;1);RiskStatic(0,09);RiskCorrmat(Extsystems;1))	9,0%
Category: Probability of failure of ventilation control in engine room				
	Probability of failure of ventilation control in engine room / PD		RiskNormal(0,5;0,15;RiskTruncate(0;1);RiskStatic(0,5))	50,0 %
Category: Probability of failure to hinder fire development on open deck area of category 1				
	Probability of failure to hinder fire development on open deck area of category 1 / PD		RiskLognorm(0,01;0,01;RiskTruncate(0;1);RiskStatic(0,01);RiskName(A91&" / "&B24);RiskCorrmat(_Cat1;1))	1,0%
	Probability of failure to hinder fire development on open deck area of category 1 / BD		RiskNormal(0,23;0,1;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A91&" / "&C24);RiskCorrmat(_Cat1;2))	23,3 %
Category: Probability of failure to hinder fire development on open deck area of category 2				
	Probability of failure to hinder fire development on open deck area of category 2 / PD		RiskLognorm(0,05;0,02;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A92&" / "&B24);RiskCorrmat(_Cat2;1))	5,0%
	Probability of failure to hinder fire development on open deck area of category 2 / BD		RiskNormal(0,29;0,1;RiskTruncate(0;1);RiskStatic(0,3);RiskName(A92&" / "&C24);RiskCorrmat(_Cat2;2))	29,1 %
Category: Probability of failure to hinder fire development on open deck area of category 3				
	Probability of failure to hinder fire development on open deck area of category 3 / PD		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A93&" / "&B24);RiskCorrmat(_Cat3;1))	40,0 %
	Probability of failure to hinder fire development on open deck area of category 3 / BD		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A93&" / "&C24);RiskCorrmat(_Cat3;2))	50,0 %
Category: Probability of failure to hinder fire establishment on open deck area of category 1				
	Probability of failure to hinder fire establishment on open deck area of category 1 / PD		RiskLognorm(0,05;0,04;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A46&" / "&B24))	5,0%
Category: Probability of failure to hinder fire establishment on open deck area of category 2				
	Probability of failure to hinder fire establishment on open deck area of category 2 / PD		RiskLognorm(0,1;0,05;RiskTruncate(0;1);RiskStatic(0,1);RiskName(A47&" / "&B24))	10,0 %
Category: Probability of failure to hinder fire establishment on open deck area of category 3				
	Probability of failure to hinder fire establishment on open deck area of category 3 / PD		RiskLognorm(0,15;0,05;RiskTruncate(0;1);RiskStatic(0,15);RiskName(A48&" / "&B24))	15,0 %
Category: Probability of failure to prevent outboard fire spread from cabin				

	Probability of failure to prevent outboard fire spread from cabin / PD		RiskNormal(0,29;0,029;RiskTruncate(0;1);RiskStatic(0,29);RiskName(A119&" / "&B24);RiskCorrmat(PreventOutbFS;1))	29,0 %
	Probability of failure to prevent outboard fire spread from cabin / BD		RiskNormal(0,55;0,045;RiskTruncate(0;1);RiskStatic(0,55);RiskName(A119&" / "&C24);RiskCorrmat(PreventOutbFS;2))	55,0 %
Category: Probability of failure to prevent outboard fire spread from lounge				
	Probability of failure to prevent outboard fire spread from lounge / PD		RiskNormal(0,33;0,033;RiskTruncate(0;1);RiskStatic(0,33);RiskName(A120&" / "&B24);RiskCorrmat(PreventOutbFS;3))	33,0 %
	Probability of failure to prevent outboard fire spread from lounge / BD		RiskNormal(0,66;0,034;RiskTruncate(0;1);RiskStatic(0,66);RiskName(A120&" / "&C24);RiskCorrmat(PreventOutbFS;4))	66,0 %
Category: Probability of failure to prevent outboard fire spread from machinery space				
	Probability of failure to prevent outboard fire spread from machinery space / PD		RiskNormal(0,04;0,004;RiskTruncate(0;1);RiskStatic(0,04);RiskName(A123&" / "&B24);RiskCorrmat(PreventOutbFS;9))	4,0%
	Probability of failure to prevent outboard fire spread from machinery space / BD		RiskNormal(0,08;0,008;RiskTruncate(0;1);RiskStatic(0,08);RiskName(A123&" / "&C24);RiskCorrmat(PreventOutbFS;10))	8,0%
Category: Probability of failure to prevent outboard fire spread from restaurant				
	Probability of failure to prevent outboard fire spread from restaurant / PD		RiskNormal(0,43;0,043;RiskTruncate(0;1);RiskStatic(0,43);RiskName(A121&" / "&B24);RiskCorrmat(PreventOutbFS;5))	43,0 %
	Probability of failure to prevent outboard fire spread from restaurant / BD	X	RiskNormal(0,79;0,021;RiskTruncate(0;1);RiskStatic(0,79);RiskName(A121&" / "&C24);RiskCorrmat(PreventOutbFS;6))	79,0 %
Category: Probability of failure to prevent outboard fire spread from technical space				
	Probability of failure to prevent outboard fire spread from technical space / PD		RiskNormal(0,35;0,035;RiskTruncate(0;1);RiskStatic(0,35);RiskName(A122&" / "&B24);RiskCorrmat(PreventOutbFS;7))	35,0 %
	Probability of failure to prevent outboard fire spread from technical space / BD		RiskNormal(0,64;0,036;RiskTruncate(0;1);RiskStatic(0,64);RiskName(A122&" / "&C24);RiskCorrmat(PreventOutbFS;8))	64,0 %
Category: Probability of no one present in cabin				
	Probability of no one present in cabin / PD		RiskTriang(0,028;0,228;0,428;RiskStatic(0,228);RiskCorrmat(Persincabin;1))	22,8 %
Category: Probability of person present in corridor				
	Probability of person present in corridor / PD		RiskTriang(0,345;0,545;0,745;RiskStatic(0,545))	54,5 %
Category: Probability of person present in galley				
	Probability of person present in galley / PD		RiskTriang(0,899;0,975;0,982;RiskStatic(0,952))	95,2 %
Category: Probability of person present in lounge				
	Probability of person present in lounge / PD		RiskTriang(0,353;0,553;0,753;RiskStatic(0,553))	55,3 %
Category: Probability of person present in				

machinery space			
Probability of person present in machinery space / PD		RiskTriang(0,075;0,275;0,475;RiskStatic(0,275))	27,5 %
Category: Probability of person present in restaurant			
Probability of person present in restaurant / PD		RiskTriang(0,345;0,545;0,745;RiskStatic(0,545))	54,5 %
Category: Probability of person present in stairway			
Probability of person present in stairway / PD		RiskTriang(0,616;0,85;0,958;RiskStatic(0,808))	80,8 %
Category: Probability of person present in store-room			
Probability of person present in store-room / PD		RiskTriang(0,189;0,389;0,589;RiskStatic(0,389))	38,9 %
Category: Probability of person present in technical space			
Probability of person present in technical space / PD		RiskTriang(0,4667;0,6667;0,8667;RiskStatic(0,6667))	66,7 %
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		RiskNormal(0,43;0,05;RiskTruncate(0;1);RiskStatic(0,43);RiskName(A141&" / "&B24))	43,0 %
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		RiskNormal(0,56;0,05;RiskTruncate(0;1);RiskStatic(0,56);RiskName(A140&" / "&B24))	56,0 %
Category: Reduced increased fatalities due to major collapse on open deck in case of evacuation			
Reduced increased fatalities due to major collapse on open deck in case of evacuation / TAD H		RiskNormal(0,75;0,05;RiskTruncate(0;1);RiskStatic(0,75);RiskName(A172&" / "&K24))	75,0 %
Reduced increased fatalities due to major collapse on open deck in case of evacuation / TAD O		RiskNormal(0,45;0,05;RiskTruncate(0;1);RiskStatic(0,45);RiskName(A172&" / "&R24))	45,0 %

Category: Reduced increased fatalities due to major collapse on outboard sides in case of evacuation				
	Reduced increased fatalities due to major collapse on outboard sides in case of evacuation / TAD H		RiskNormal(0,55;0,05;RiskTruncate(0;1);RiskStatic(0,55);RiskName(A171&" / "&K24))	55,0 %
	Reduced increased fatalities due to major collapse on outboard sides in case of evacuation / TAD O		RiskNormal(0,25;0,05;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A171&" / "&R24))	25,0 %
	Reduced increased fatalities due to major collapse on outboard sides in case of evacuation / TAD R		RiskNormal(0,8;0,05;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A171&" / "&U24))	80,0 %
Category: Reduced increased fatalities from local collapse (due to collapse) on open deck				
	Reduced increased fatalities from local collapse (due to collapse) on open deck / TAD H		RiskNormal(0,75;0,05;RiskTruncate(0;1);RiskStatic(0,75);RiskName(A167&" / "&K24))	75,0 %
Category: Reduced increased fatalities from local collapse (due to collapse) on outboard sides				
	Reduced increased fatalities from local collapse (due to collapse) on outboard sides / TAD H		RiskNormal(0,7;0,05;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A165&" / "&K24))	70,0 %
Category: Reduced increased fatalities from local collapse (due to smoke) on open deck				
	Reduced increased fatalities from local collapse (due to smoke) on open deck / TAD H		RiskNormal(0,5;0,05;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A168&" / "&K24))	50,0 %
	Reduced increased fatalities from local collapse (due to smoke) on open deck / TAD R		RiskNormal(0,5;0,05;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A168&" / "&U24))	50,0 %
Category: Reduced increased fatalities from local collapse (due to smoke) on outboard sides				
	Reduced increased fatalities from local collapse (due to smoke) on outboard sides / TAD H		RiskNormal(0,7;0,05;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A166&" / "&K24))	70,0 %
	Reduced increased fatalities from local collapse (due to smoke) on outboard sides / TAD R		RiskNormal(0,7;0,05;RiskTruncate(0;1);RiskStatic(0,7);RiskName(A166&" / "&U24))	70,0 %
Category: Reduced increased fatalities from major collapse on open deck				
	Reduced increased fatalities from major collapse on open deck / TAD H		RiskNormal(0,6;0,05;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A170&" / "&K24))	60,0 %
	Reduced increased fatalities from major collapse on open deck / TAD O		RiskNormal(0,3;0,05;RiskTruncate(0;1);RiskStatic(0,3);RiskName(A170&" / "&R24))	30,0 %
	Reduced increased fatalities from major collapse on open deck / TAD R		RiskNormal(0,903;0,05;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A170&" / "&U24))	90,0 %
Category: Reduced increased fatalities from major collapse on outboard sides				

Reduced increased fatalities from major collapse on outboard sides / TAD H		RiskNormal(0,4;0,05;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A169&" / "&K24))	40,0 %
Reduced increased fatalities from major collapse on outboard sides / TAD O		RiskNormal(0,2;0,05;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A169&" / "&R24))	20,0 %
Reduced increased fatalities from major collapse on outboard sides / TAD R		RiskNormal(0,6;0,05;RiskTruncate(0;1);RiskStatic(0,6);RiskName(A169&" / "&U24))	60,0 %
Category: Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck			
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck / TAD H		RiskNormal(0,806;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A131&" / "&K24))	80,0 %
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck / TAD O		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A131&" / "&R24))	40,0 %
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on open deck / TAD R		RiskNormal(1,25;0,1;RiskTruncate(0;);RiskStatic(1,25);RiskName(A131&" / "&U24))	125,0 %
Category: Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides if using LEO			
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides if using LEO / TAD H		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A125&" / "&K24))	40,0 %
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides if using LEO / TAD O		RiskNormal(0,196;0,1;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A125&" / "&R24))	20,2 %
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sides if using LEO / TAD R		RiskNormal(0,05;0,005;RiskTruncate(0;1);RiskStatic(0,05);RiskName(A125&" / "&U24))	5,0%
Category: Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck			
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / TAD H		RiskNormal(0,5;0,1;RiskTruncate(0;1);RiskStatic(0,5);RiskName(A133&" / "&K24))	50,0 %
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire		RiskNormal(0,248;0,1;RiskTruncate(0;1);RiskStatic(0,25);RiskName(A133&" / "&R24))	25,0 %

	development on open deck / TAD O			
	Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on open deck / TAD R		RiskNormal(0,951;0,1;RiskTruncate(0;1);RiskStatic(0,9);RiskName(A133&" / "&U24))	90,0 %
Category: Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides				
	Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / TAD H		RiskNormal(0,4;0,1;RiskTruncate(0;1);RiskStatic(0,4);RiskName(A127&" / "&K24))	40,0 %
	Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / TAD O		RiskNormal(0,196;0,1;RiskTruncate(0;1);RiskStatic(0,2);RiskName(A127&" / "&R24))	20,2 %
	Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire development on outboard sides / TAD R		RiskNormal(0,806;0,1;RiskTruncate(0;1);RiskStatic(0,8);RiskName(A127&" / "&U24))	80,0 %
Category: Relative area on open deck in category 2. Sparsely furnished and few fuels				
	Relative area on open deck in category 2. Sparsely furnished and few fuels / PD		RiskTriang(0,2;0,3;0,4;RiskStatic(0,3);RiskName(A26&" / "&B24);RiskCorrmat(NewMatrix1;1))	30,0 %
Category: Relative area on open deck in category 3. Upholstered furniture and many combustibles				
	Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD		RiskTriang(0,2;0,3;0,4;RiskStatic(0,3);RiskName(A27&" / "&B24);RiskCorrmat(NewMatrix1;2))	30,0 %

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 sprinkler system / TAD B in E83	0,7	0,7	1	
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 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	Probability of failure of pre-major collapse fire-fighting in case of fire

	development on outboard sides / PD in B126	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-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 internal fire and fire-fighting success / BD in C134	0,7	1		
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 in superstructure due to major collapse on outboard sides / PD in B158	
Fatalities in superstructure due to major collapse on outboard sides / PD in B158	1	
	0,5	1

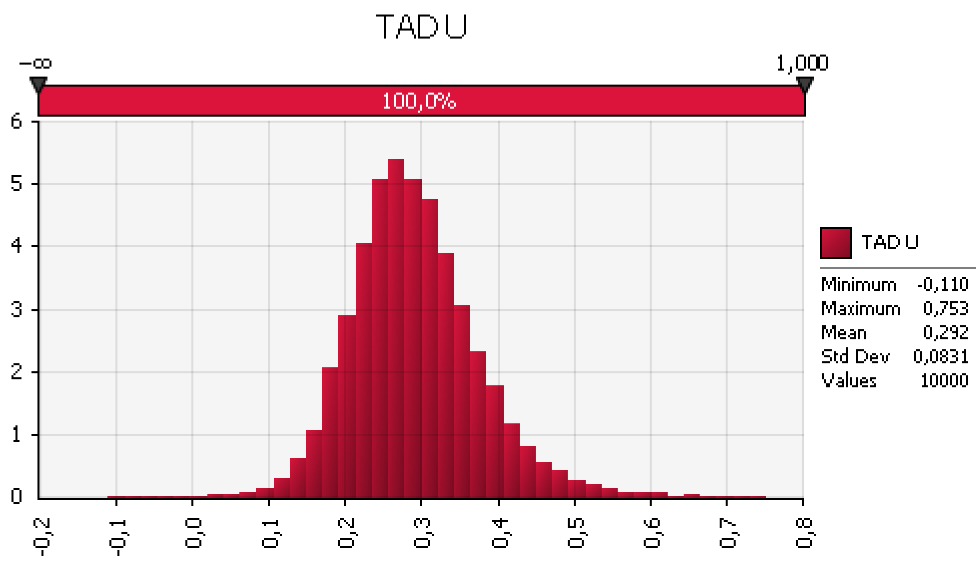
@RISK Correlations	Fatalities due to major collapse on outboard sides in case of evacuation / PD in B160	Fatalities due to major collapse on outboard sides in case of evacuation / BD in C160	Fatalities due to major collapse on open deck in case of evacuation / PD in B161	Fatalities due to major collapse 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

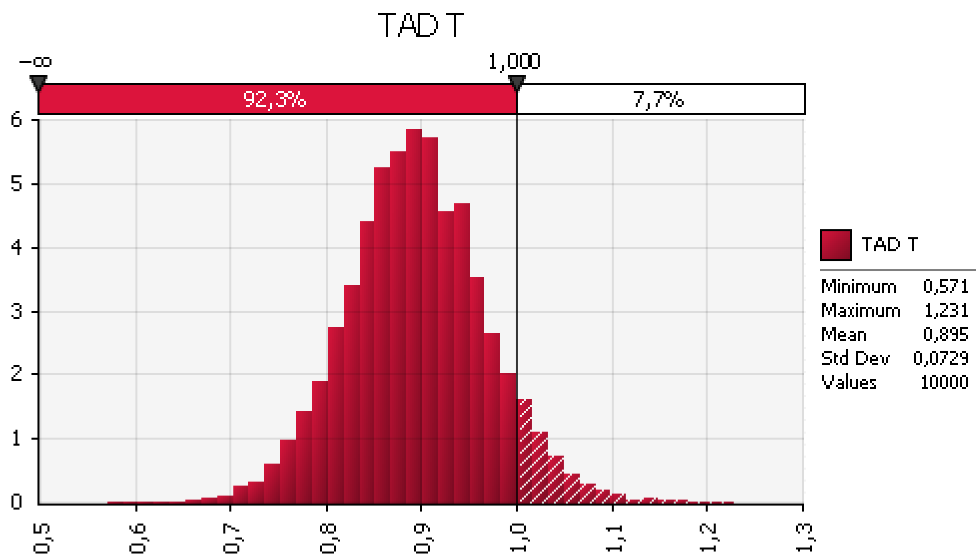
@RISK Correlations	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / PD in B128	Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck area of category 1 / BD in C128	Probability of failure 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 case of fire development on open deck area of category 2 / PD in B129	0	0	1			
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

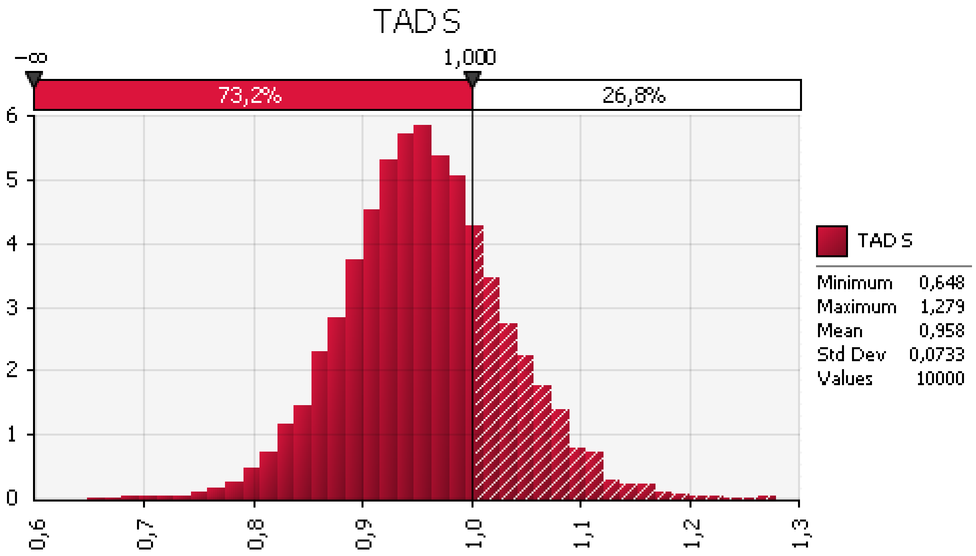
@RISK Correlations	B119	C119	B120	C120	B121	C121	B122	C122	B123	C123
Probability of failure to prevent outboard fire spread from cabin / PD in B119	1									
Probability of failure to prevent outboard fire spread from cabin / BD in C119	0,5	1								
Probability of failure to prevent outboard fire spread from lounge / PD in B120	0	0	1							
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				

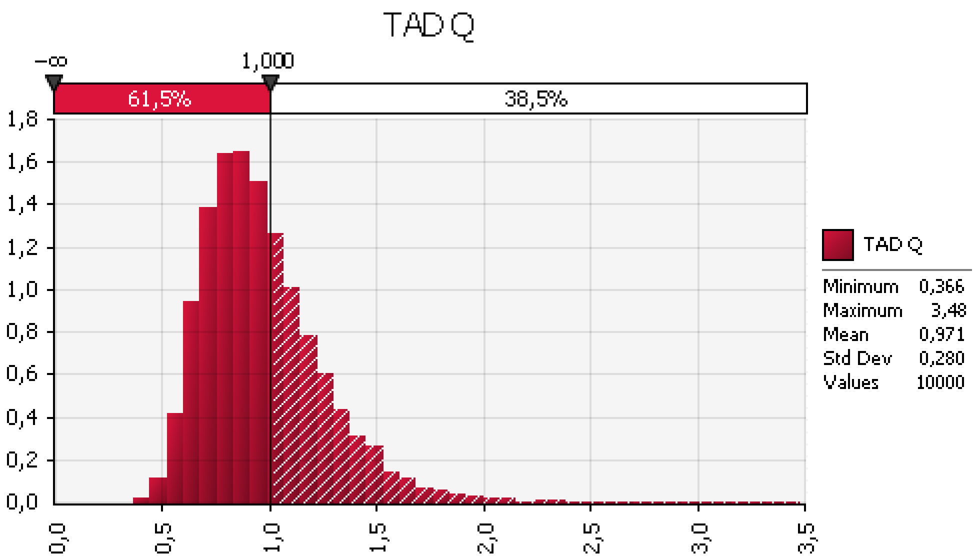
Probability of failure to prevent outboard fire spread from technical space / PD in B122	0	0	0	0	0	0	1			
Probability of failure to prevent outboard fire spread from technical space / BD in C122	0	0	0	0	0	0	0,5	1		
Probability of failure to prevent outboard fire spread from machinery space / PD in B123	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

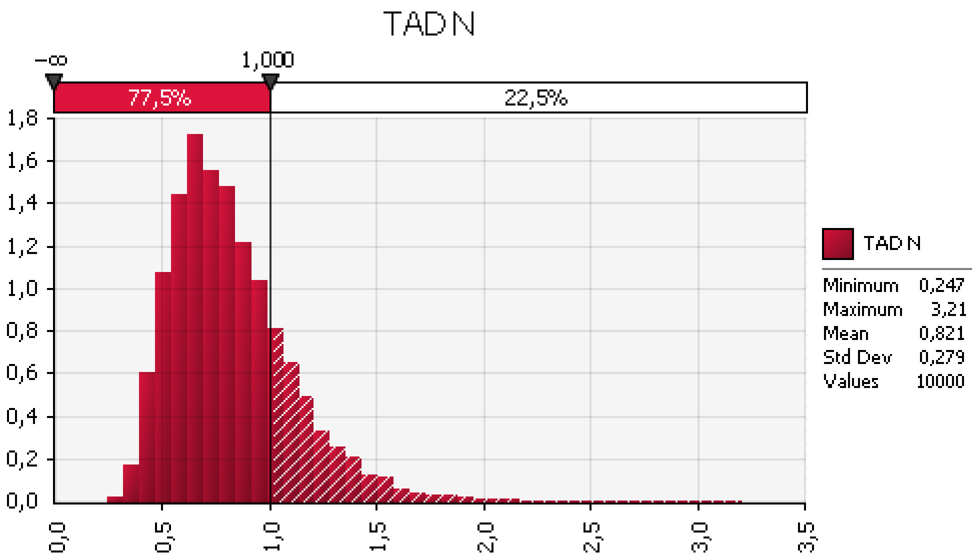
Confidence of relative risk estimations

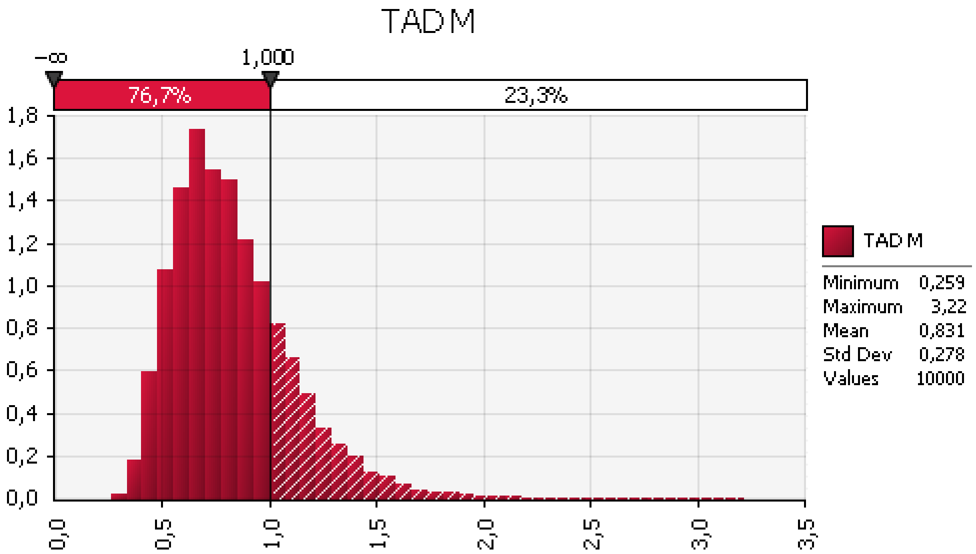


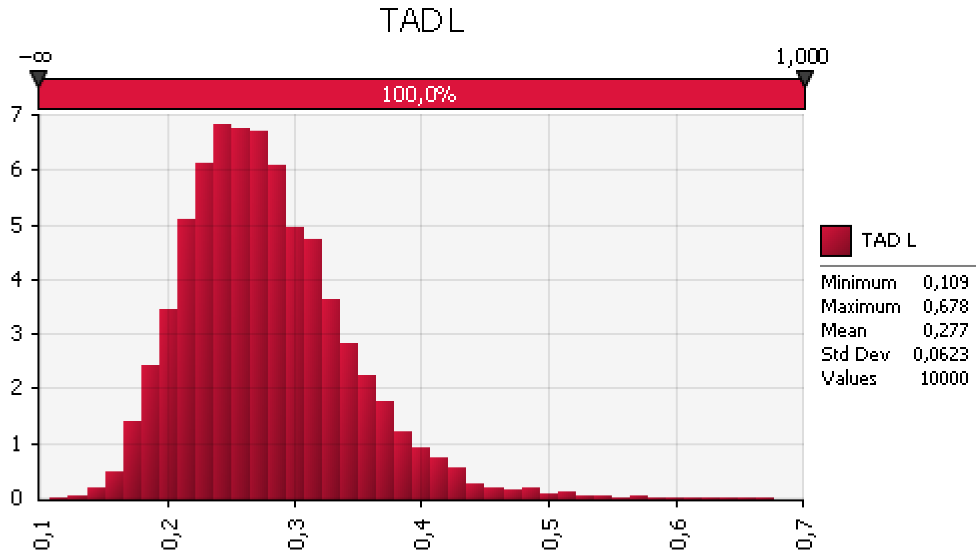


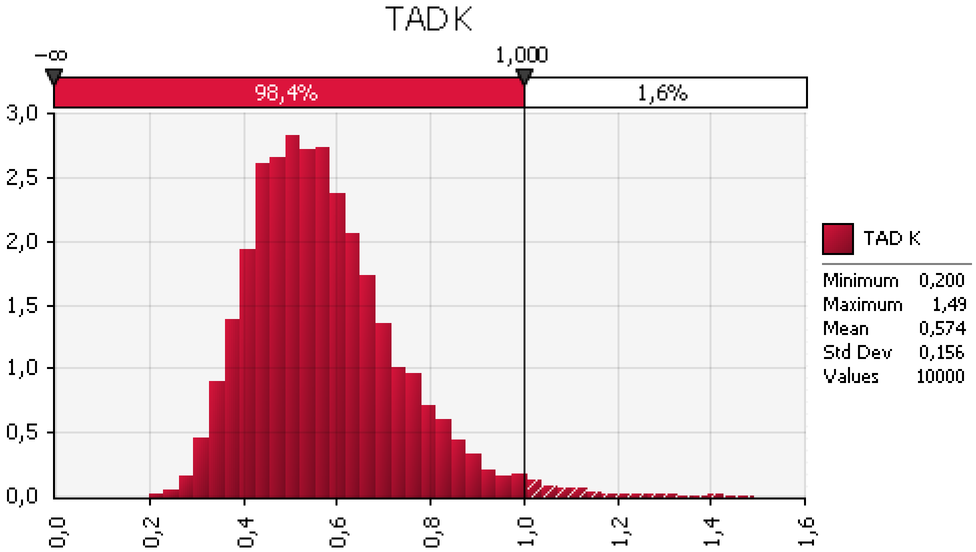

TAD S
−∞
1,000
73,2%
26,8%
TAD S
Minimum 0,648
Maximum 1,279
Mean 0,958
Std Dev 0,0733
Values 10000

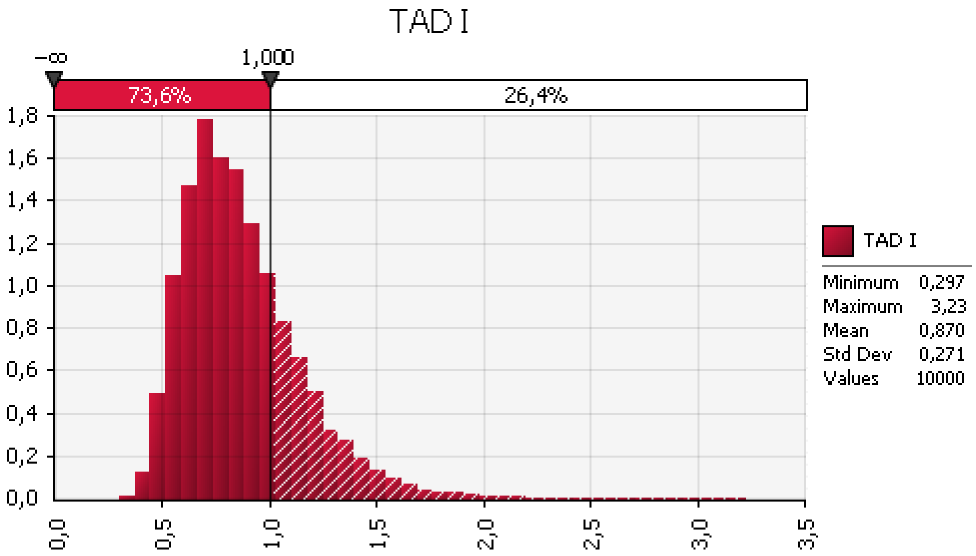

TAD Q
−∞
1,000
61,5%
38,5%
TAD Q
Minimum 0,366
Maximum 3,48
Mean 0,971
Std Dev 0,280
Values 10000

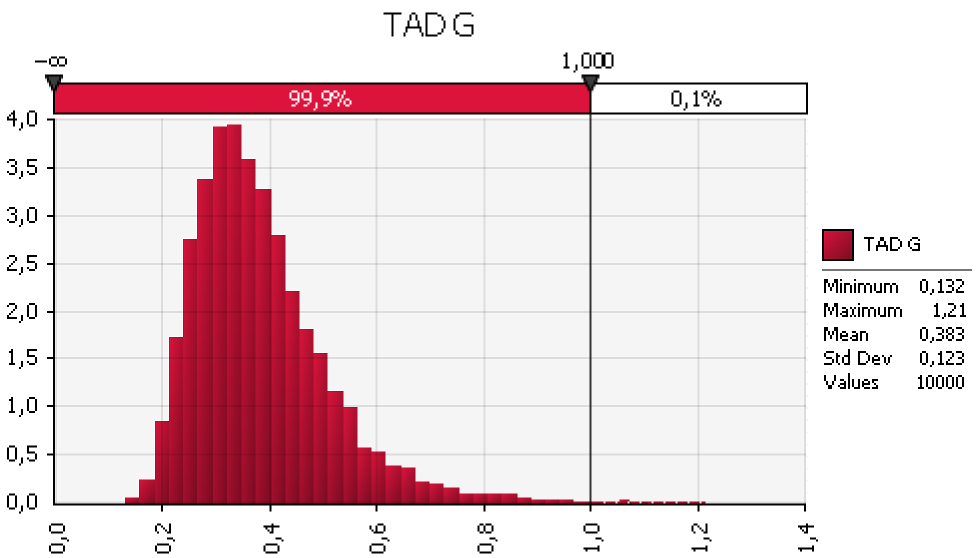

TAD N
−∞
1,000
77,5%
22,5%
TAD N
Minimum 0,247
Maximum 3,21
Mean 0,821
Std Dev 0,279
Values 10000

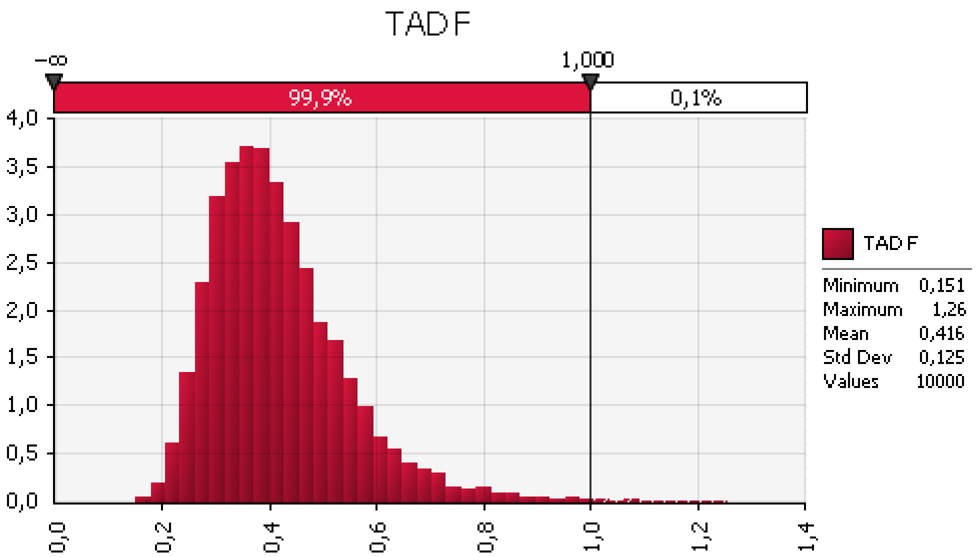

TAD M
−∞
1,000
76,7%
23,3%
TAD M
Minimum 0,259
Maximum 3,22
Mean 0,831
Std Dev 0,278
Values 10000

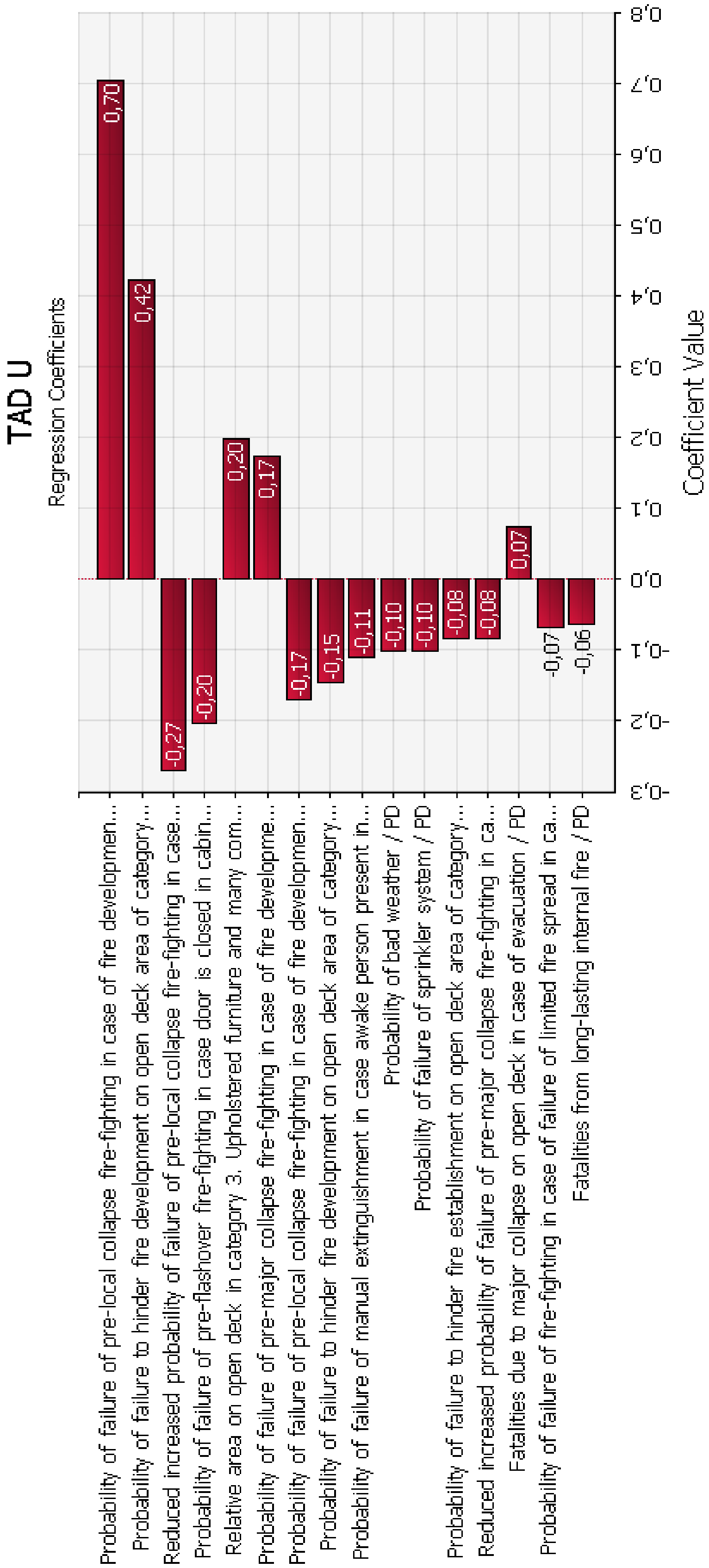

TAD L
−∞
1,000
100,0%
TAD L
Minimum 0,109
Maximum 0,678
Mean 0,277
Std Dev 0,0623
Values 10000


TAD K
−∞
1,000
98,4%
1,6%
TAD K
Minimum 0,200
Maximum 1,49
Mean 0,574
Std Dev 0,156
Values 10000

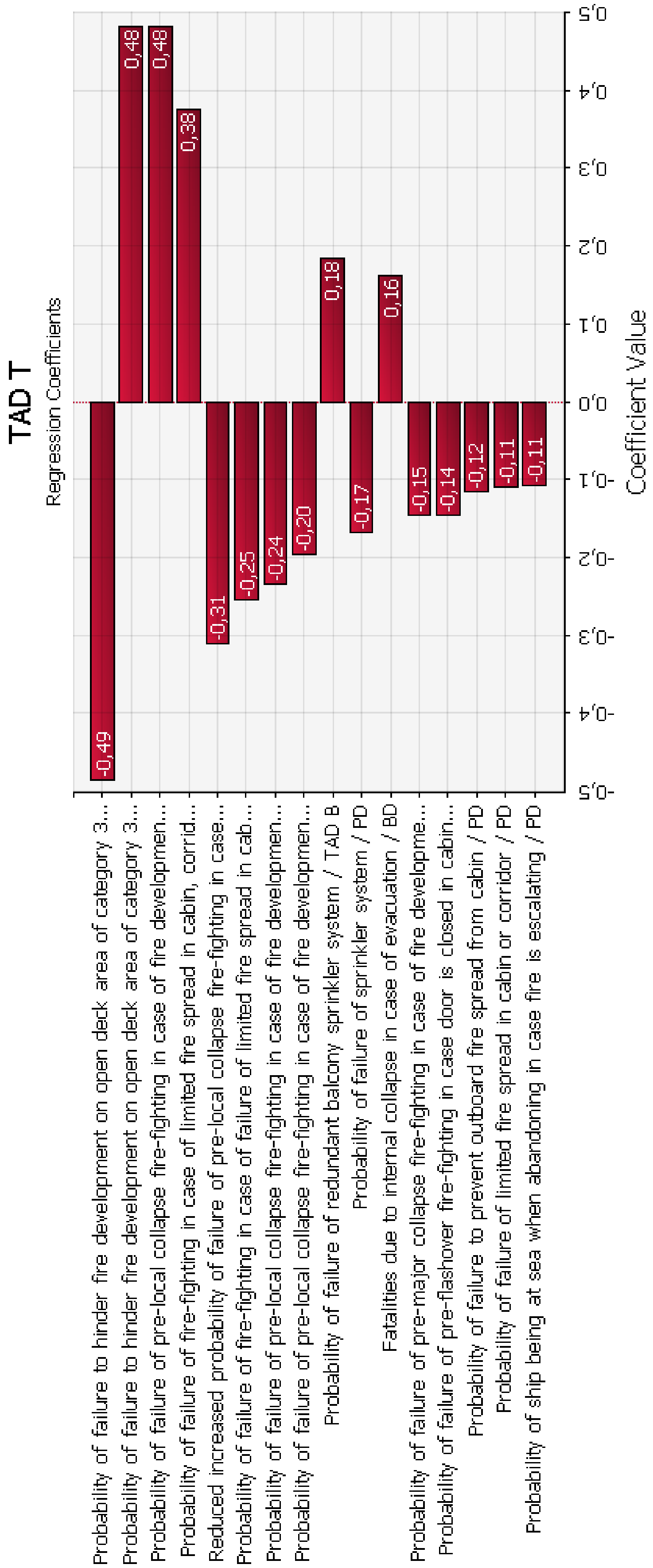

TAD I
−∞
1,000
73,6%
26,4%
TAD I
Minimum 0,297
Maximum 3,23
Mean 0,870
Std Dev 0,271
Values 10000

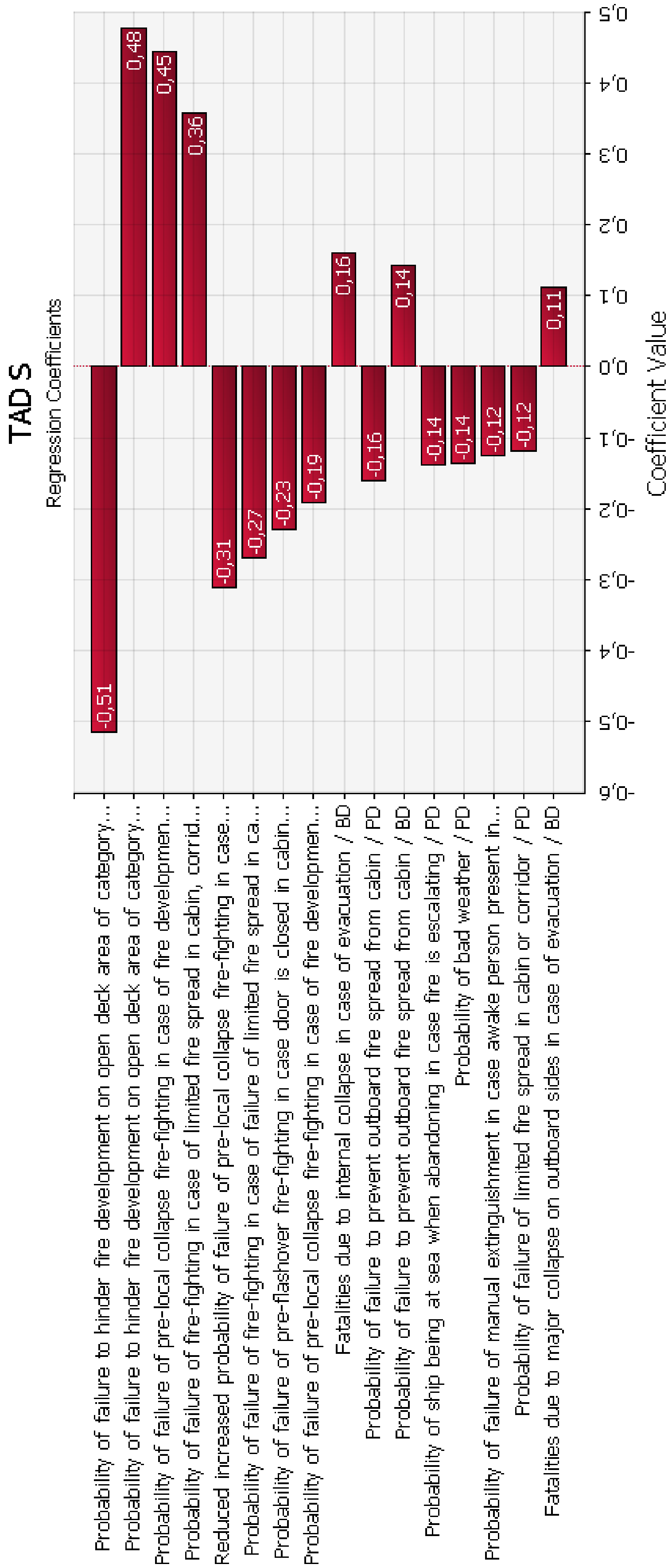

TAD G
−∞
1,000
99,9%
0,1%
TAD G
Minimum 0,132
Maximum 1,21
Mean 0,383
Std Dev 0,123
Values 10000

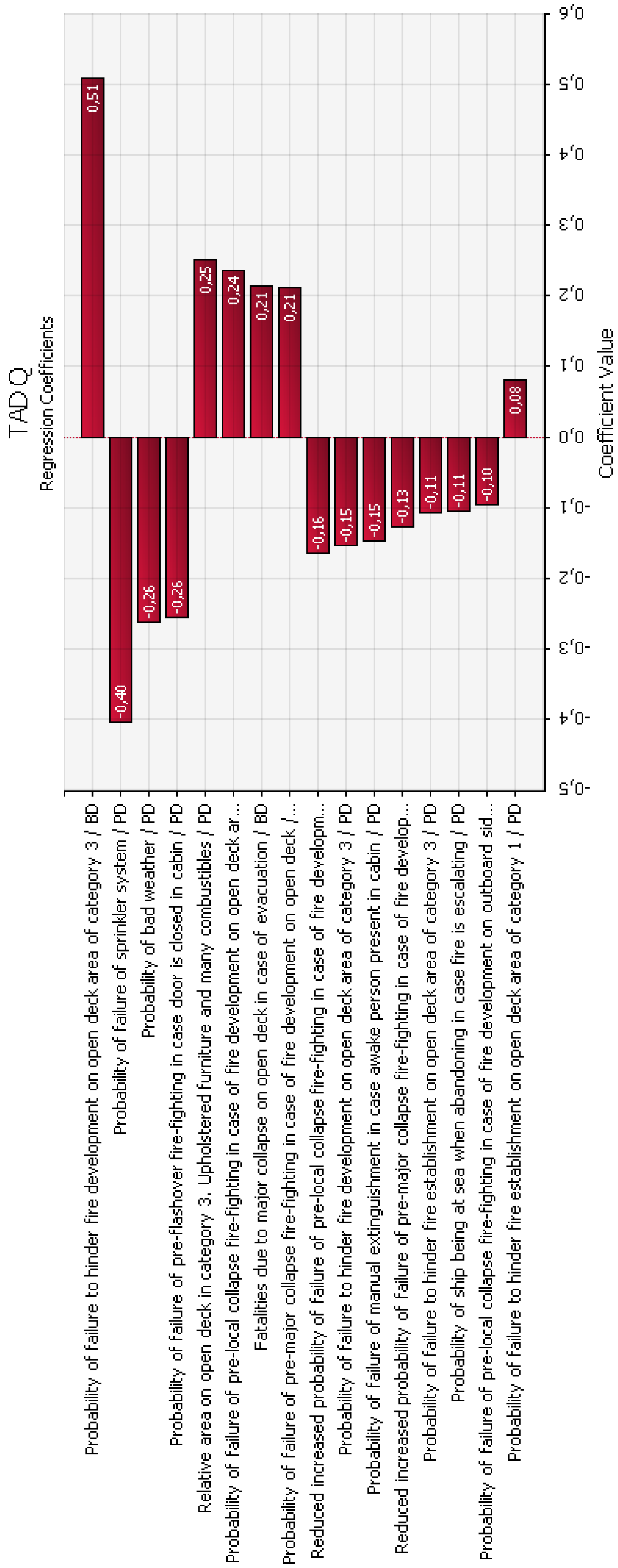

TAD F
−∞
1,000
99,9%
0,1%
TAD F
Minimum 0,151
Maximum 1,26
Mean 0,416
Std Dev 0,125
Values 10000

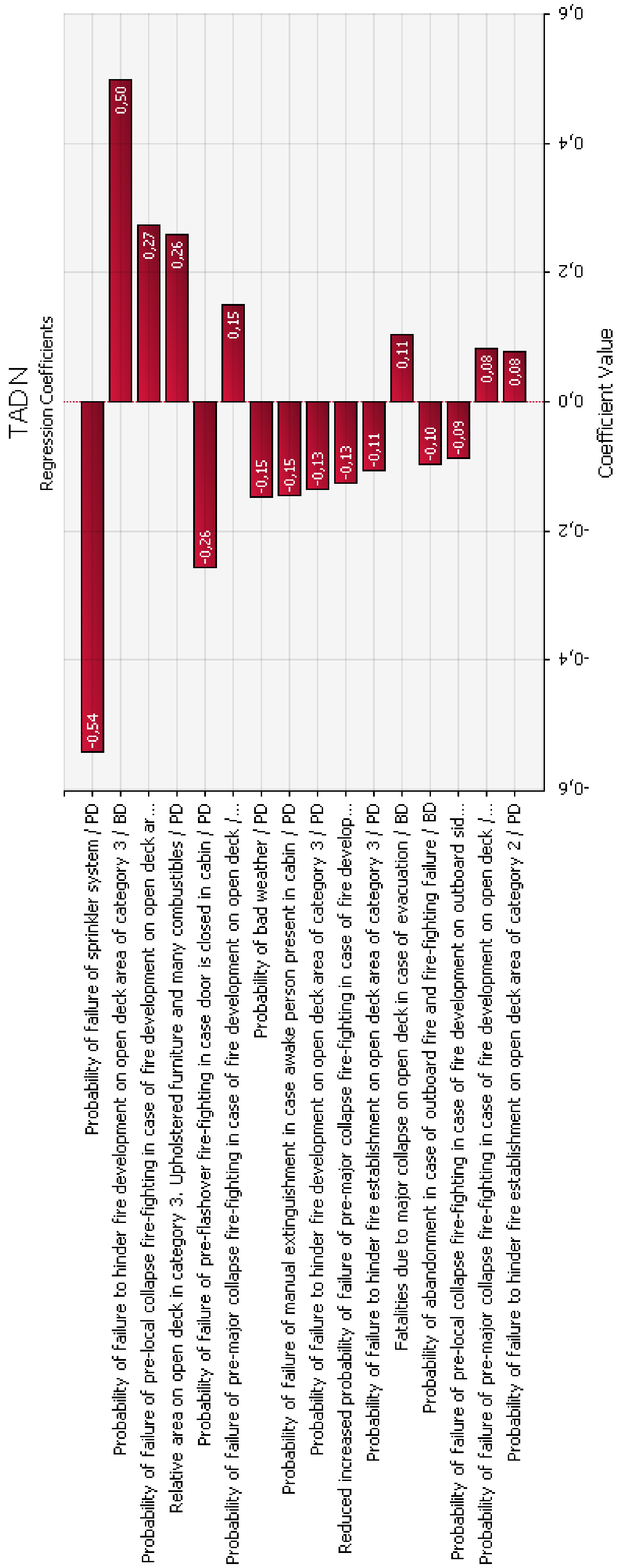


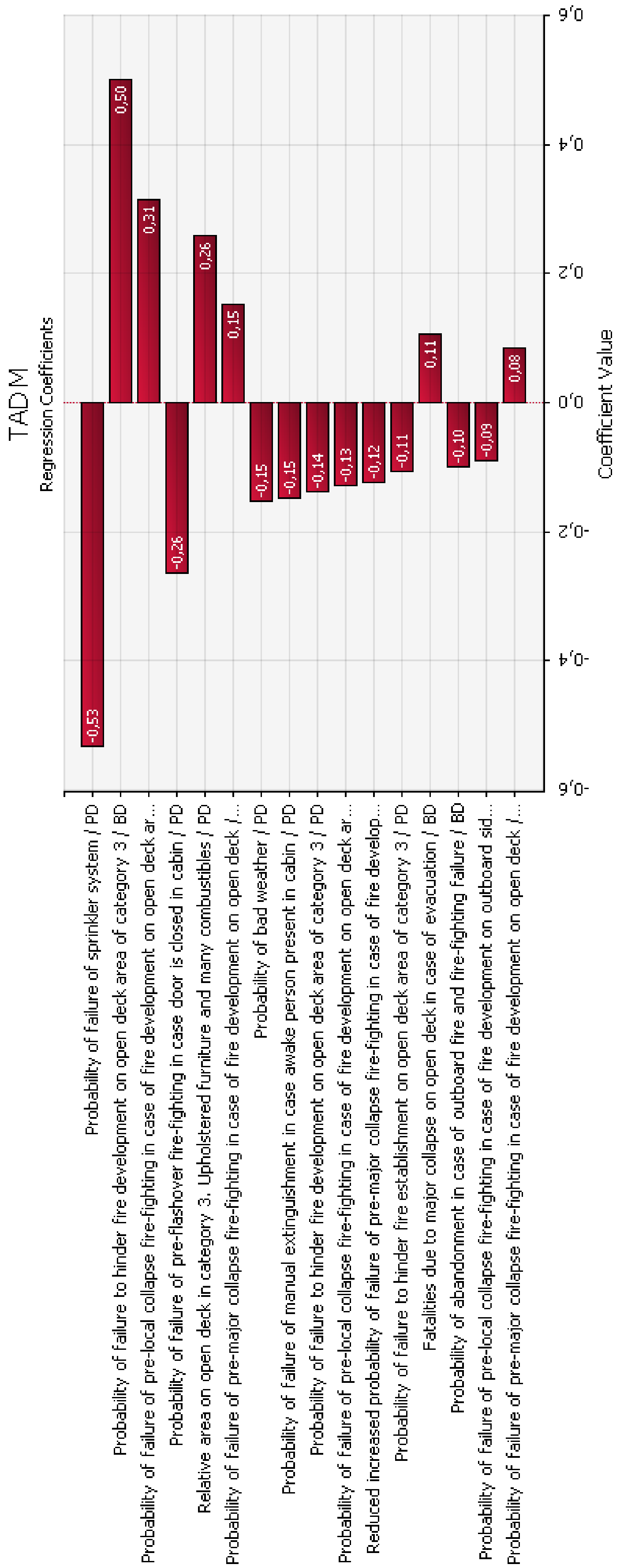
TAD U
Regression Coefficients
Coefficient Value
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Probability of failure to hinder fire development on open deck area of category...
Reduced increased probability of failure of pre-local collapse fire-fighting in case...
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin...
Relative area on open deck in category 3. Upholstered furniture and many com...
Probability of failure of pre-major collapse fire-fighting in case of fire developme...
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Probability of failure to hinder fire development on open deck area of category...
Probability of failure of manual extinguishment in case awake person present in...
Probability of bad weather / PD
Probability of failure of sprinkler system / PD
Probability of failure to hinder fire establishment on open deck area of category...
Reduced increased probability of failure of pre-major collapse fire-fighting in ca...
Fatalities due to major collapse on open deck in case of evacuation / PD
Probability of failure of fire-fighting in case of failure of limited fire spread in ca...
Fatalities from long-lasting internal fire / PD
0,70
0,42
-0,27
-0,20
0,20
0,17
-0,17
-0,15
-0,11
-0,10
-0,10
-0,08
-0,08
0,07
-0,07
-0,06
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
0,8

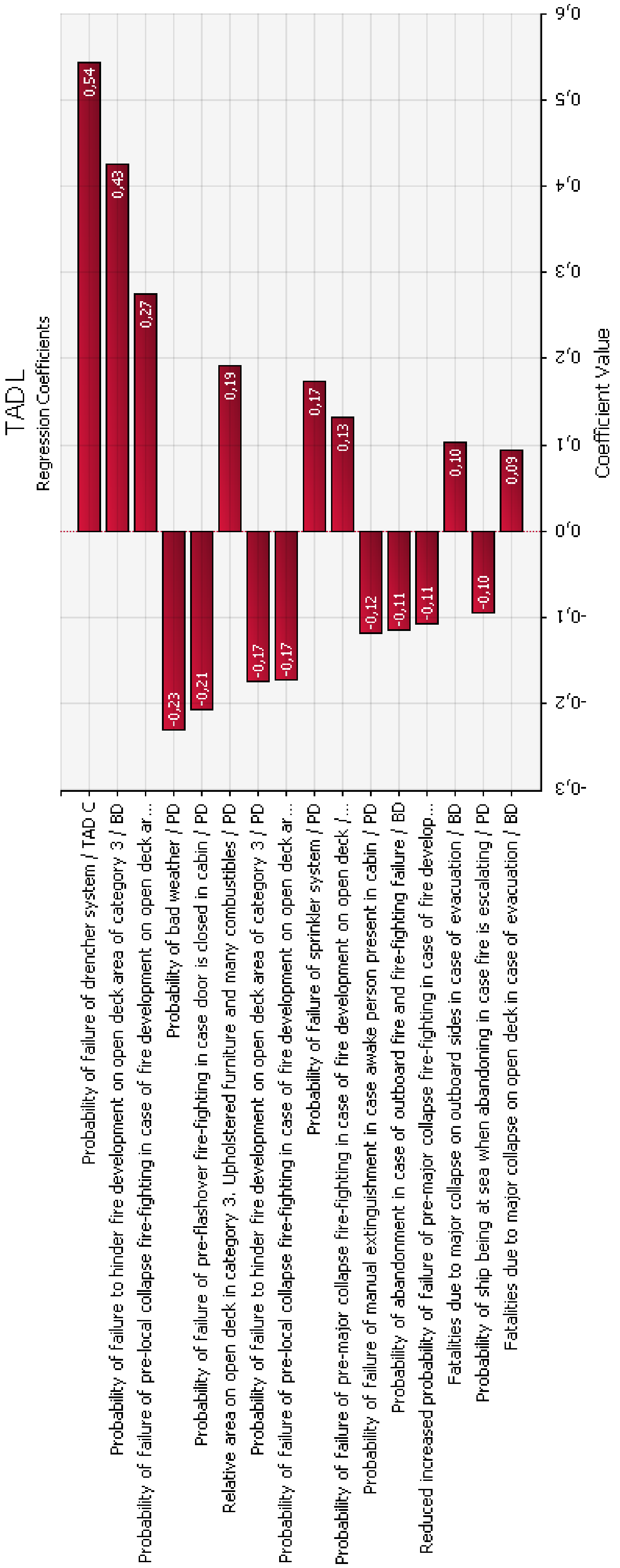

TAD T
Regression Coefficients
Probability of failure to hinder fire development on open deck area of category 3...
Probability of failure to hinder fire development on open deck area of category 3...
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Probability of failure of fire-fighting in case of limited fire spread in cabin, corrid...
Reduced increased probability of failure of pre-local collapse fire-fighting in case...
Probability of failure of fire-fighting in case of failure of limited fire spread in cab...
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Probability of failure of redundant balcony sprinkler system / TAD B
Probability of failure of sprinkler system / PD
Fatalities due to internal collapse in case of evacuation / BD
Probability of failure of pre-major collapse fire-fighting in case of fire developme...
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin...
Probability of failure to prevent outboard fire spread from cabin / PD
Probability of failure of limited fire spread in cabin or corridor / PD
Probability of ship being at sea when abandoning in case fire is escalating / PD
-0,49
0,48
0,48
0,38
-0,31
-0,25
-0,24
-0,20
0,18
-0,17
0,16
-0,15
-0,14
-0,12
-0,11
-0,11
-0,5
-0,4
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
Coefficient Value

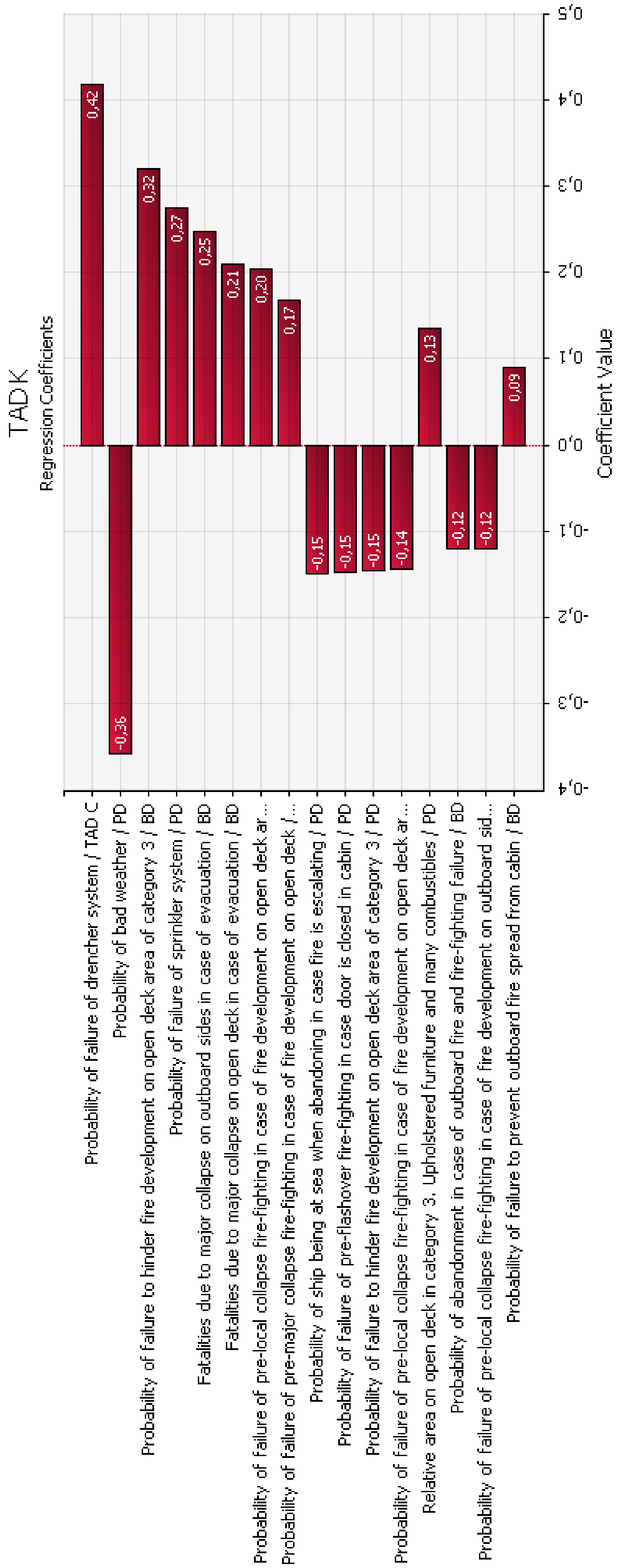

TAD S
Regression Coefficients
Probability of failure to hinder fire development on open deck area of category...
Probability of failure to hinder fire development on open deck area of category...
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Probability of failure of fire-fighting in case of limited fire spread in cabin, corrid...
Reduced increased probability of failure of pre-local collapse fire-fighting in case...
Probability of failure of fire-fighting in case of failure of limited fire spread in ca...
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin...
Probability of failure of pre-local collapse fire-fighting in case of fire developmen...
Fatalities due to internal collapse in case of evacuation / BD
Probability of failure to prevent outboard fire spread from cabin / PD
Probability of failure to prevent outboard fire spread from cabin / BD
Probability of ship being at sea when abandoning in case fire is escalating / PD
Probability of bad weather / PD
Probability of failure of manual extinguishment in case awake person present in...
Probability of failure of limited fire spread in cabin or corridor / PD
Fatalities due to major collapse on outboard sides in case of evacuation / BD
-0,51
0,48
0,45
0,36
-0,31
-0,27
-0,23
-0,19
0,16
-0,16
0,14
-0,14
-0,14
-0,12
-0,12
0,11
-0,6
-0,5
-0,4
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
Coefficient Value

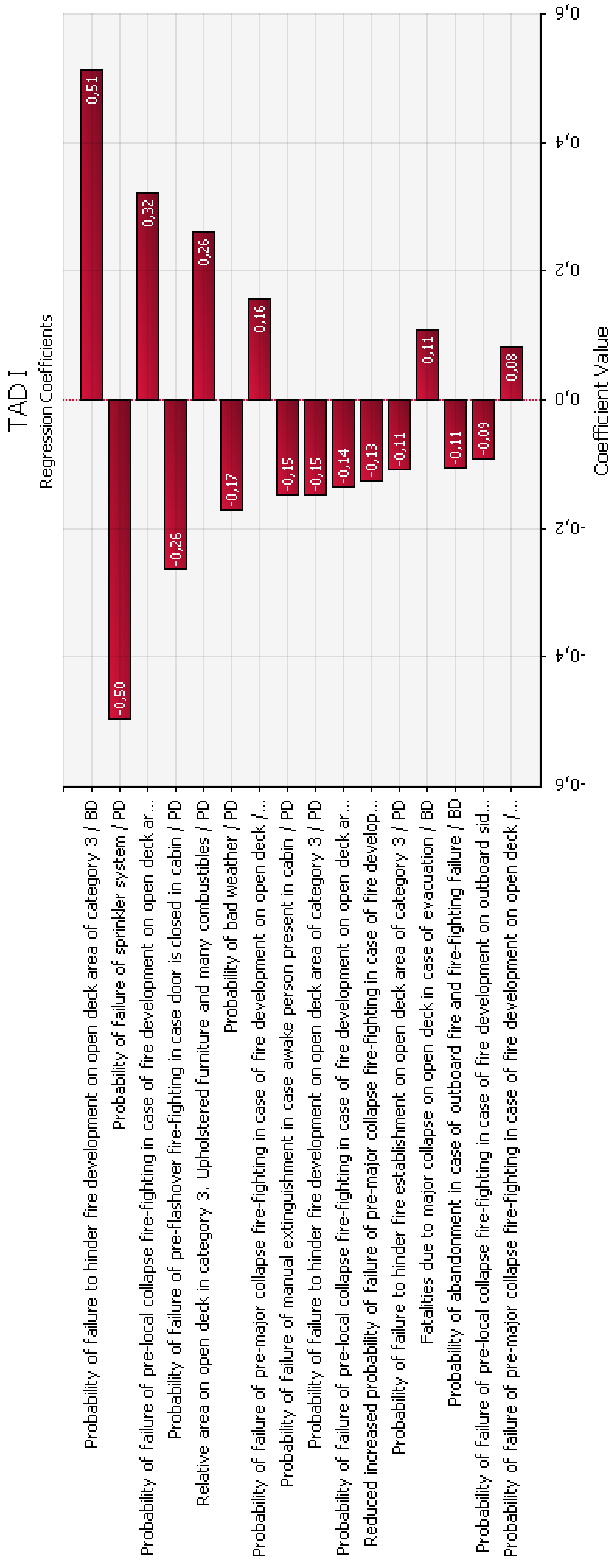

TAD Q
Regression Coefficients
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of sprinkler system / PD
Probability of bad weather / PD
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Reduced increased probability of failure of pre-local collapse fire-fighting in case of fire developm...
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire develop...
Probability of failure to hinder fire establishment on open deck area of category 3 / PD
Probability of ship being at sea when abandoning in case fire is escalating / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sid...
Probability of failure to hinder fire establishment on open deck area of category 1 / PD
0,51
-0,40
-0,26
-0,26
0,25
0,24
0,21
0,21
-0,16
-0,15
-0,15
-0,13
-0,11
-0,11
-0,10
0,08
-0,5
-0,4
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Coefficient Value

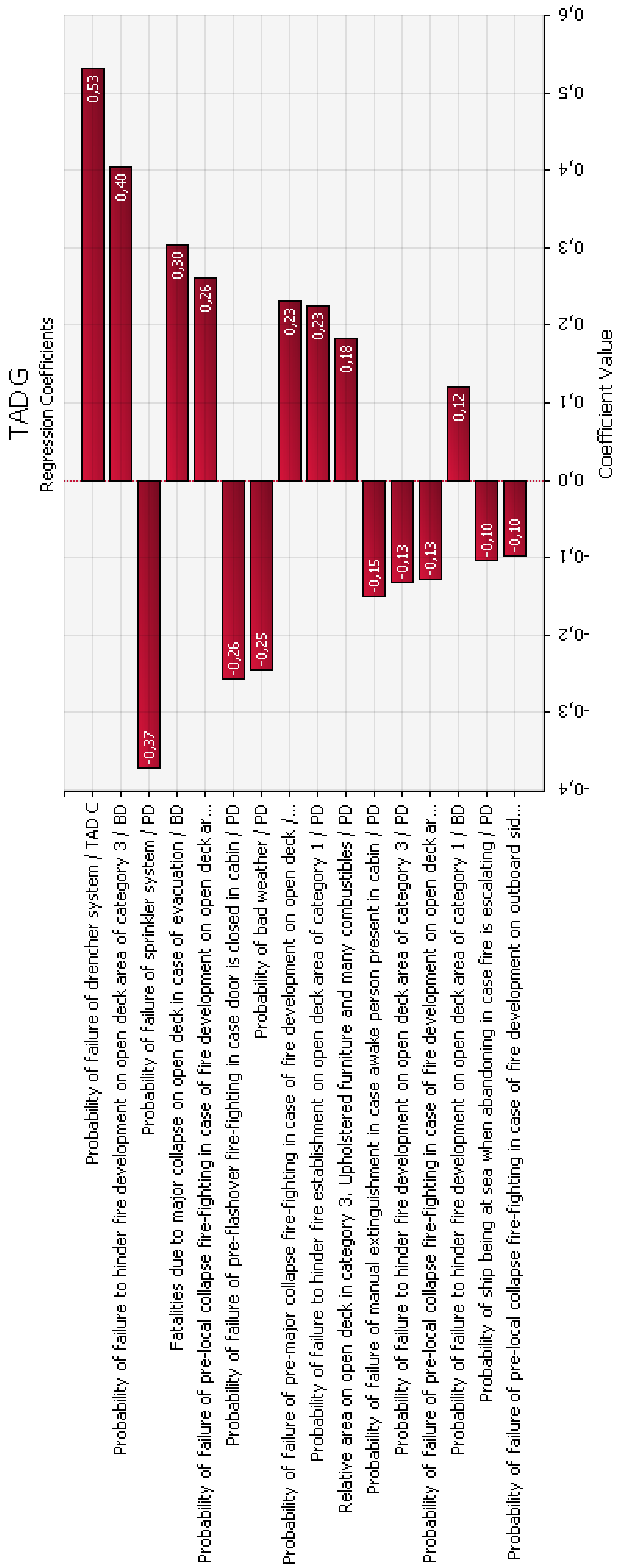

TADN
Regression Coefficients
Probability of failure of sprinkler system / PD
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of bad weather / PD
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Probability of failure to hinder fire development on open deck area of category 3 / PD
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire develop...
Probability of failure to hinder fire establishment on open deck area of category 3 / PD
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of abandonment in case of outboard fire and fire-fighting failure / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sid...
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of failure to hinder fire establishment on open deck area of category 2 / PD
-0,54
0,50
0,27
0,26
-0,26
0,15
-0,15
-0,15
-0,13
-0,13
-0,11
0,11
-0,10
-0,09
0,08
0,08
-0,6
-0,4
-0,2
0,0
0,2
0,4
0,6
Coefficient Value


TADM
Regression Coefficients
Coefficient Value
-0,6
-0,4
-0,2
0,0
0,2
0,4
0,6
-0,53
0,50
0,31
-0,26
0,26
0,15
-0,15
-0,15
-0,14
-0,13
-0,12
-0,11
0,11
-0,10
-0,09
0,08
Probability of failure of sprinkler system / PD
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of bad weather / PD
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire develop...
Probability of failure to hinder fire establishment on open deck area of category 3 / PD
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of abandonment in case of outboard fire and fire-fighting failure / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sid...
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...


TAD L
Regression Coefficients
Coefficient Value
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,54
0,43
0,27
-0,23
-0,21
0,19
-0,17
-0,17
0,17
0,13
-0,12
-0,11
-0,11
0,10
-0,10
0,09
Probability of failure of drencher system / TAD C
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of bad weather / PD
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure of sprinkler system / PD
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Probability of abandonment in case of outboard fire and fire-fighting failure / BD
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire develop...
Fatalities due to major collapse on outboard sides in case of evacuation / BD
Probability of ship being at sea when abandoning in case fire is escalating / PD
Fatalities due to major collapse on open deck in case of evacuation / BD


TADK
Regression Coefficients
Coefficient Value
Probability of failure of drencher system / TAD C
Probability of bad weather / PD
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of sprinkler system / PD
Fatalities due to major collapse on outboard sides in case of evacuation / BD
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of ship being at sea when abandoning in case fire is escalating / PD
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of abandonment in case of outboard fire and fire-fighting failure / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sid...
Probability of failure to prevent outboard fire spread from cabin / BD
0,42
-0,36
0,32
0,27
0,25
0,21
0,20
0,17
-0,15
-0,15
-0,15
-0,14
0,13
-0,12
-0,12
0,09
-0,4
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5


TAD I
Regression Coefficients
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of sprinkler system / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of bad weather / PD
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Reduced increased probability of failure of pre-major collapse fire-fighting in case of fire develop...
Probability of failure to hinder fire establishment on open deck area of category 3 / PD
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of abandonment in case of outboard fire and fire-fighting failure / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sid...
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
0,51
-0,50
0,32
-0,26
0,26
-0,17
0,16
-0,15
-0,15
-0,14
-0,13
-0,11
0,11
-0,11
-0,09
0,08
-0,6
-0,4
-0,2
0,0
0,2
0,4
0,6
Coefficient Value


TAD G
Regression Coefficients
Coefficient Value
Probability of failure of drencher system / TAD C
Probability of failure to hinder fire development on open deck area of category 3 / BD
Probability of failure of sprinkler system / PD
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Probability of bad weather / PD
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of failure to hinder fire establishment on open deck area of category 1 / PD
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure to hinder fire development on open deck area of category 1 / BD
Probability of ship being at sea when abandoning in case fire is escalating / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on outboard sid...
0,53
0,40
-0,37
0,30
0,26
-0,26
-0,25
0,23
0,23
0,18
-0,15
-0,13
-0,13
0,12
-0,10
-0,10
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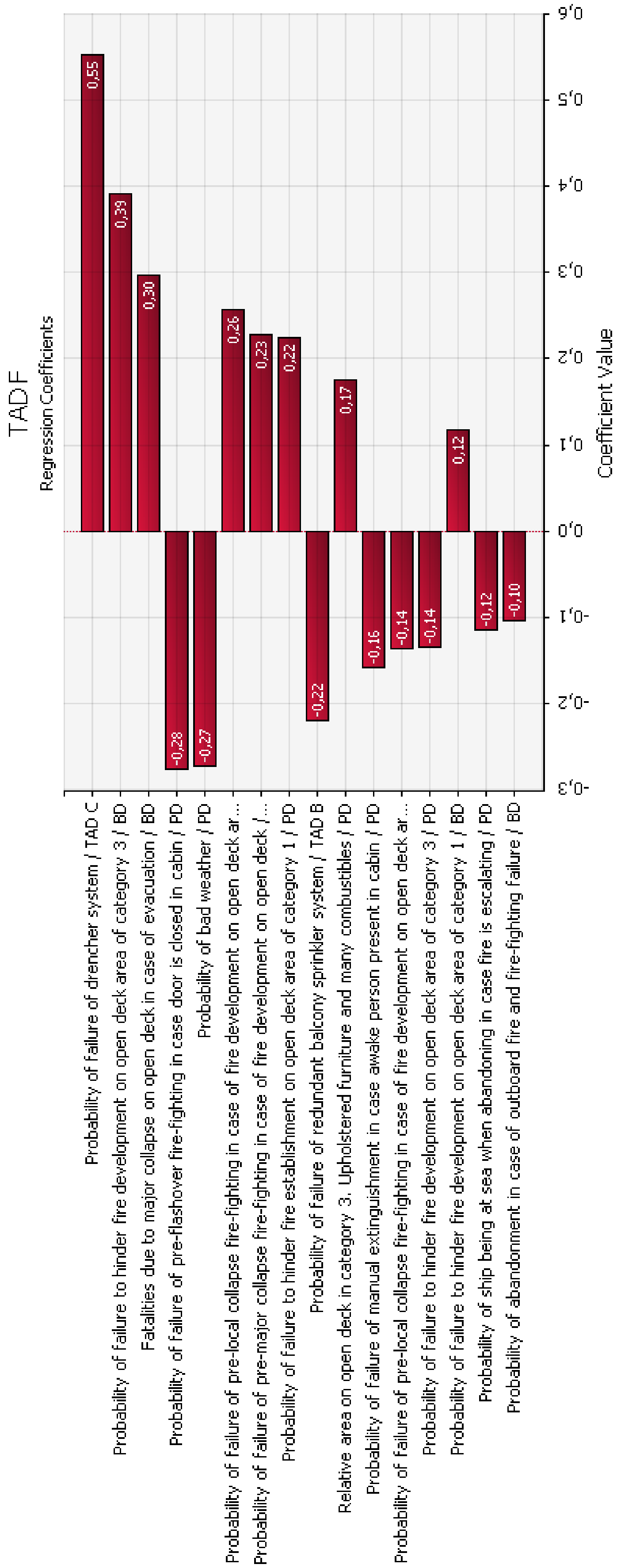
0,2
0,3
0,4
0,5
0,6


TAD F
Regression Coefficients
Probability of failure of drencher system / TAD C
Probability of failure to hinder fire development on open deck area of category 3 / BD
Fatalities due to major collapse on open deck in case of evacuation / BD
Probability of failure of pre-flashover fire-fighting in case door is closed in cabin / PD
Probability of bad weather / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure of pre-major collapse fire-fighting in case of fire development on open deck /...
Probability of failure to hinder fire establishment on open deck area of category 1 / PD
Probability of failure of redundant balcony sprinkler system / TAD B
Relative area on open deck in category 3. Upholstered furniture and many combustibles / PD
Probability of failure of manual extinguishment in case awake person present in cabin / PD
Probability of failure of pre-local collapse fire-fighting in case of fire development on open deck ar...
Probability of failure to hinder fire development on open deck area of category 3 / PD
Probability of failure to hinder fire development on open deck area of category 1 / BD
Probability of ship being at sea when abandoning in case fire is escalating / PD
Probability of abandonment in case of outboard fire and fire-fighting failure / BD
0,55
0,39
0,30
-0,28
-0,27
0,26
0,23
0,22
-0,22
0,17
-0,16
-0,14
-0,14
0,12
-0,12
-0,10
-0,3
-0,2
-0,1
0,0
0,1
0,2
0,3
0,4
0,5
0,6
Coefficient Value

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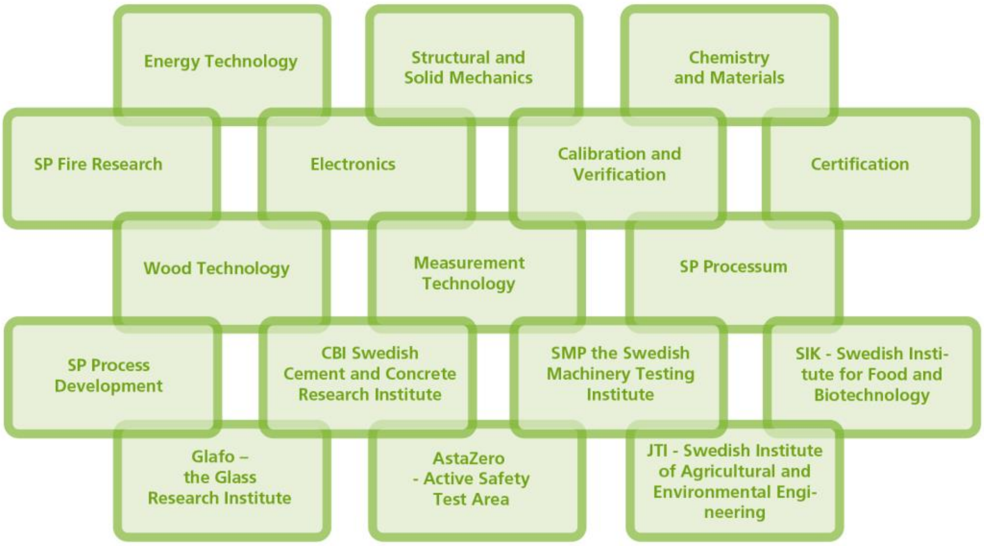

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