SUB-COMMITTEE ON SHIP DESIGN AND CONSTRUCTION
12th session
Agenda item 11

SDC 12/INF.20
14 November 2025
ENGLISH ONLY
Pre-session public release: ☒

REVIEW AND, IF NECESSARY, AMENDMENT OF SOLAS REGULATIONS II-2/13.4.1.1 AND 13.4.2.1 TO CLARIFY THE REQUIREMENTS ON ESCAPE ARRANGEMENTS FROM THE LOWER PART OF MACHINERY SPACES

Engine-room fire simulations

Submitted by IACS

SUMMARY

Executive summary:	This document provides further information in support of the conclusion in document SDC 12/11 that SOLAS regulations need not be revised in relation to requirements for escape from engine-rooms. It contains the report of computational fluid dynamics (CFD) simulations of fire scenarios in the engine-room of a container ship, aimed at assessing the risks associated with elevated access to emergency escape trunks and the potential benefit of lowering the access point. It is demonstrated that there is no measurable impact of an emergency escape trunk with inclined ladder on the crew's ability to evacuate safely and swiftly during a fire.
Strategic direction, if applicable:	7
Output:	7.33
Action to be taken:	Paragraph 5
Related documents:	SDC 11/10/3; MSC 110/11/2, MSC 110/21 and SDC 12/11

Introduction

1 In support of the conclusion presented in paragraph 25 of document SDC 12/11 (Marshall Islands et al.) that "in the absence of clear evidence of safety concerns, SOLAS regulations need not be revised", this document provides the results of the computational fluid dynamics (CFD) simulations of fire scenarios in the engine-room of a 15,600 TEU container ship. The primary objective is to assess the risks associated with the elevated access to an emergency escape trunk and the potential benefits of lowering the access point.

2 In some ship designs, physical constraints prevent the escape trunk from extending to the lowest deck level, resulting in the use of inclined stairs to an elevated access.

Summary of the results of the CFD simulations

3 The CFD simulations model a range of fire scenarios and compare an arrangement where the escape trunk access was located 2.3 metres above the lowest floor level, with another where the escape trunk extends to the lowest floor level.

4 The key findings are:

.1 no notable and relevant advantage was found in relocating the escape trunk access from the elevated position to a lower position, based on visibility and radiation results;

.2 the ventilation system and the arrangement of deck structures were found to direct smoke upwards, limiting the smoke accumulation near the escape trunk access; and

.3 the time available for safe evacuation was not notably affected by the vertical position of the escape trunk access.

Action requested of the Sub-Committee

5 The Sub-Committee is invited to note and take into account the report provided in the annex when considering document SDC 12/11, concluding that SOLAS regulations need not be revised.

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ANNEX

CFD ANALYSIS FOR RULE DEVELOPMENT

Engine room fire simulations

DNV Maritime, Ship Classification, Quality Task Force,
M-SQ-Q

Report no.: 2025-0134, Rev. 01
Document no.: 10040778-01
Date: 2025-04-28

Project name:	CFD analysis for rule development	DNV Maritime Advisory
Report title:	Engine room fire simulations	Hydrodynamics and stability
Customer:	DNV Maritime, Ship Classification, Quality Task Force, M-SQ-Q, Veritasveien 1, 1363, Høvik	Veritasveien 1, 1363 Høvik Tel: +47 6757 0000
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Date of issue:	2025-04-28	
Project no.:	10040778	
Organisation unit:	Maritime Advisory, Hydrodynamics and stability, M-DP-H	
Report no.:	2025-0134, Rev. 01	
Document no.:	10040778-01	

Applicable contract(s) governing the provision of this Report:

Objective:

To check the risk of the current elevated access of emergent escape and the benefit by lowering down the access, through a series of CFD simulations of fire scenarios in the engine room of a container ship.

Prepared by:	Verified by:	Approved by:
Hui Sun Principal Engineer	Asmund Huser Senior Principal Specialist	Olav Rognebakke Head of Section

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Rev. no.	Date	Reason for issue	Prepared by	Verified by	Approved by
01	2025-04-28	First issue for comments	HUSUN	AHU	OROGN

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Table of contents

1 EXECUTIVE SUMMARY

CFD simulations by KFX are performed on fire scenarios within the machinery space of a container vessel. The primary objective is to assess the impact of a raised emergency escape trunk on the crew's ability to evacuate safely and swiftly during a fire. These simulations compare the trunk access door raised 2.3 meters above the lowest floor level with the door at the lowest floor level.

To maximize separation from other escape routes, the emergency escape trunk is typically located in the aft part of the machinery space. However, physical constraints such as hull form, structural elements, or technical installations in the narrow aft section may prevent the trunk from extending to the lowest deck level. In such cases, industry practice involves arranging direct access to the trunk via short, SOLAS II-2/13.4.1.5 compliant inclined stairs leading to the lowermost door, which is generally considered to provide an equivalent level of safety.

The fire simulations incorporate both conservative and realistic fuel leak rates, assuming various locations and directions of fuel spray leaks. The ultimate results of the CFD simulations include visibility plots around the escape trunk access during a fire scenario and the differences in visibility and thus evacuation time available for the crew.

1.1 Conclusions

Based on the visibility results from all simulated cases, there is no significant advantage in relocating the escape trunk access from its current position (2.3 m above the floor deck) to a lower position.

The radiation flux results indicates that there is no dangerous heat flux near the escape trunk access, regardless of whether it is positioned higher or lower.

The primary reasons why the smoke does not impede escape in the aft and lower regions of the engine room are due to the efficient ventilation system, which directs air and smoke upwards and into the funnel in most scenarios. Additionally, the 3rd deck, aft of the main engine and above the escape trunk access, helps to block the dispersion of smoke towards the lower spaces.

1.2 Supporting argumentation

The primary goal is to simulate the smoke hazard at the elevated escape trunk, assuming that no firefighting measures or controls to limit the fire growth are activated (worst case scenario).

To ensure the simulations are conservative, in estimating the impact of fire, but still realistic, the following assumptions are made.

- **Engine room fans:** The 4 engine room fans are running as normal to supply air during the scenarios.
- **Ventilation dampers:** The 6 engine room ventilation dampers in the funnel are kept open during the fire.
- **Main engine operation:** The main engine is running as normal during the fire, consuming air in the engine room.
- **Generator engines:** 4 out of 5 generator engines are running as normal during the fire, consuming air in the engine room.
- **Fuel type:** Heavy fuel is assumed as the fuel for the main engine.
- **Firefighting system**: Automatic, or manual, release of main engine local firefighting system (water mist) is not considered.
- **Quick closing valves**: Quick closing valves, which stop the transport of fuel in the machinery space, are not activated.
- **Engine room tightness:** The engine room is assumed air tight, except the louver vents in the funnel.

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- **Local firefighting**: Local firefighting by fire squads is not considered.

2 INTRODUCTION

The objective of the simulations is to check the consequence of having a raised emergency escape trunk in the machinery space on the crew's ability to safely and swiftly evacuate in case of a fire.

All fire situations in engine rooms are chaotic by nature and the evacuation of engine room personnel, the capability to extinguish the fire, and the sequence of events, will to a large degree depend on the training of the crew and the fire squads, the officers' making the right decisions at the right time as to actions to be taken, and whether all relevant equipment and installations on board is maintained and works as intended. No vessels nor fires are the same and neither are the crews handling of the fire. The primary goal of this study is to simulate the smoke/visibility hazard at the elevated escape trunk, and to be on the conservative side it is assumed that no means of firefighting or controls to limit the fire growth is activated.

DNV Maritime advisory and Energy advisory cooperated to investigate the problem in this project. CFD simulations by DNV software KFX are carried out to simulate the fire scenarios. The software is well suited for such simulations, since fuel sprays, rigorous combustion and a large number of air inlets and outlets can be modelled. Fire simulation is the main and strongest feature of KFX, and the program is used and validated for a large number of industrial fire situations. Experts from KFX development team also provided quality assurance and highly valuable suggestions, support and guidance during the work.

It is decided that the engine room of a 15,600 TEU twin island container vessel will be considered in the study. The engine room geometry is made by using the 3D models sent from the shipyard, with all details of hull structures, bulkheads, engines, equipment, pipes, etc. inside the engine room. The total volume of the engine room is about 25000 m^3, and the engine is a 46360 kW Marine Diesel engine.

The ventilation system in the engine room is modelled by placing the air nozzles at different locations inside the engine room and defining air suctions at engine inlets. The remaining air after consumption in engines will go up through the funnel and go out through the dampers at the top of the funnel.

When a ventilation simulation reaches a steady state inside the engine room, a fuel spray can be started and ignited to start the fire. Burning of the fuel generates soot which affects the visibility in the engine room. The visibility results are checked for different fire scenarios to see whether the current location of the trunk access door above the lowest floor level gives ample time for the crew to evacuate safely and if a location at the lowest floor level can show significant benefits in this respect. The program is also capturing the heat radiation flux from the flames to check if the heat can affect escape. Heat transfer by convection is much lower than by radiation and has been neglected.

MEANS OF ESCAPE - REGULATORY BACKGROUND

The SOLAS conventions set minimum safety standards for international shipping and the purpose of SOLAS II-2/13 is 'to provide means of escape so that persons onboard can safely and swiftly escape to the lifeboat and liferaft embarkation deck'. SOLAS II-2/13.4.2 specify the requirements for means of escape from machinery spaces on cargo ships.

Two acceptable alternative arrangements are specified for machinery spaces of category A. One of them is a common arrangement on cargo ships, where two sets of steel ladders are as widely separated as possible, leading to doors in the upper part of the space similarly separated and from which access is provided to the open deck. One of these ladders shall be located within a fire protected enclosure, from the lower part of the space it serves to a safe position outside the space. This ladder is typically arranged in the aftmost part of the machinery space.

For the escape ladder required to be located within a fire protected enclosure, SOLAS specify that the ladder shall be located 'from the lower part of the space'. The term 'lower part' is not further defined in SOLAS and IACS proposed a unified interpretation that was released by IMO in circular MSC.1/Circ.1511, applicable for ships keel laid on or after 1 Jan. 2016. The circular interprets that 'the lower part of the space' should be regarded as 'the lowest deck level, platform or passageway within the space'. The IACS unified interpretations SC 277 for cargo ships offers the same interpretation, applicable for ships contracted for construction on or after 1 February 2016.

To complete the picture of SOLAS required means of escapes from machinery spaces of category "A", it should be mentioned that for ships constructed on or after 1 January 2016, having a machinery control room and/or main workshop located within the machinery space the following additional requirements apply.

- two means of escape shall be provided from a machinery control room located within a machinery space. At least one of these escape routes shall provide continuous fire shelter to a safe position outside the machinery space.
- two means of escape shall be provided from the main workshop within a machinery space. At least one of these escape routes shall provide continuous fire shelter to a safe position outside the machinery space.

2.1 Abbreviations

Table 2-1: Abbreviations.

Abbreviation	Description
AB	Above Baseline
AP	Aft perpendicular
CFD	Computational Fluid Dynamics
CL	Central line
IMO NO.	Ship identification number introduced by International Maritime Organization (IMO)
KFX	Kameleon FireEx, a gas dispersion and fire simulator, in general used in safety related analysis. A DNV software.
PT	Port
SB	Starboard

3 BASIS FOR WORK

3.1 Vessel information

The basic information of the container vessel is given in the GA drawing [1].

IMO NO.: 9964194, 9964209, 9964211, 9964223, 9964235, 9964247

Hull NO.: 8164 to 8169

SHIP TYPE: 15,600 TEU CLASS CONTAINER CARRIER

Table 3-1: Principal dimensions.

Length O. A. Max. [m]	366
Length B. P. [m]	350
Breadth MLD. [m]	51
Depth MLD. [m]	29.85
Draught design MLD. [m]	14.5
Draught scant. MLD. [m]	16.9

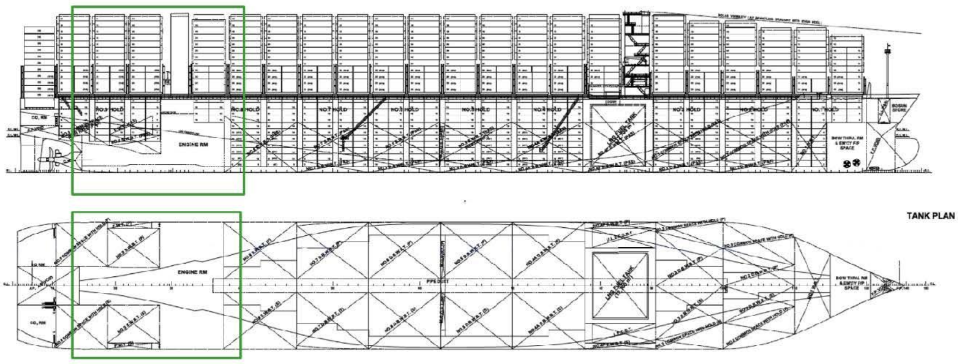

Figure 3-1: Side view and top view of the container vessel. Green boxes indicate the engine room location.

3.2 Engine room

The engine room is located between frame 15 (18.975 m from AP) and frame 38 (77.15 m from AP). Details of machinery arrangement in the engine room are shown in the drawing [2]. The total volume of the engine room is about 25000 m^3.

The engine room geometry is received through 3D CAD model, in a number of rvm files. Each rvm file includes one part of the engine room or one set of inner structures such as exhaust pipe system. The final engine room geometry for CFD is made by combining all the necessary geometries in those rvm files, adding the missing pipes, structures and removing the superfluous parts according to the drawings or photos of the engine room.

An igs file for hull shape is exported from NAPA model and used to define the lower outer boundary of the engine room.

The side view and front view of the engine room and funnel copied from [2] and [3] are shown in Figure 3-2, Figure 3-3 and Figure 3-4. The height of different deck levels is shown in Table 3-2.

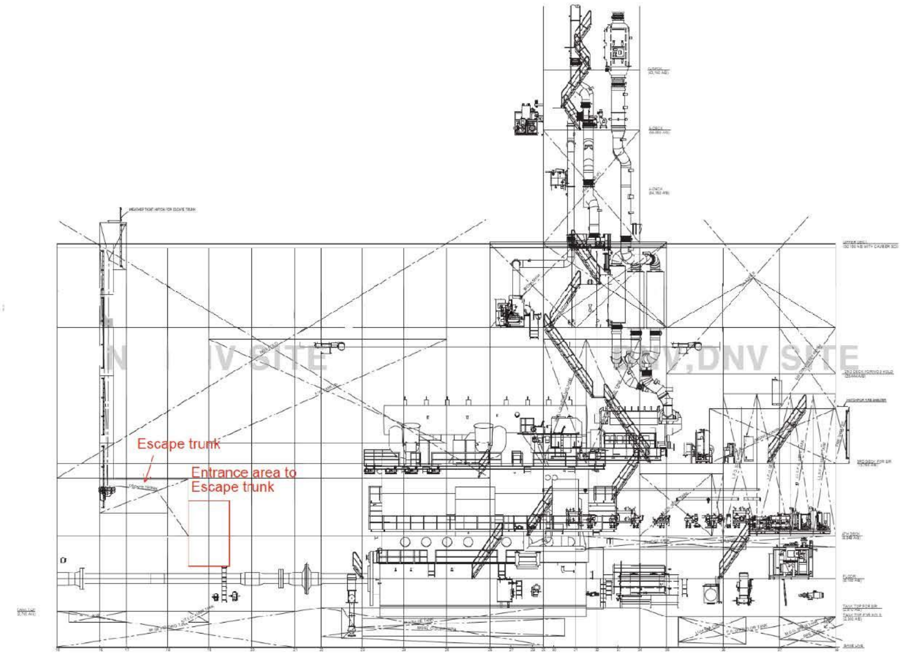

Figure 3-2: Side view (from starboard) of engine room below C-deck. Location of escape trunk and the entrance area to escape trunk are marked.

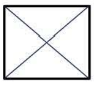

Figure 3-3: Front view of engine room between frame 26 and 38 below C-deck. The drawing is hided due to IP rights.

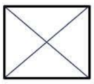

Figure 3-4: Side view and front view of funnel above C-deck. The drawing is hided due to IP rights.

Table 3-2: Height of deck levels in engine room from baseline.

Deck level	Distance from Baseline [m]
Weather shield	63.385
No.5 Stringer	60.1
No.4 Stringer	56.71
No.3 Stringer	52.92
No.2 Stringer	49.93
No.1 Stringer	46.54
C-deck	43.15
B-deck	38.65
A-deck	34.15
Upper deck	30.15
2nd deck for engine room	23.9
2nd deck for No.8 Hold	20.444
3rd deck for engine room	13.78

4th deck	8.348
Floor aft of frame 23	6.10
Floor	5.15
Tank top for engine room	2.97

3.3 Ventilation system in engine room

The ventilation system is defined in drawings for dampers [4], key plan in engine room [5] (with vent duct, ladder & grating) and funnel [3] (for exhaust pipes).

- There are two FAN ROOMs with two fans in each room to provide inflow. Fan No.1&3 are in fan room starboard and fan No. 2&4 are in fan room port. The type, capacity and purpose are listed in the fan list (in [5]) in Figure 3-5. Fan No. 2 and No. 4 are reversable. The fan rooms on upper deck are shown in Figure 3-6.
- Air inflow goes down from fans to engine room through VENT TRUNKs, as marked in [5].
- Air flow pipes extended from vent trunks are distributed on different decks (Floor deck, 4th deck, 3rd deck, 2nd deck, etc.) and send air into engine room through small nozzles or large dampers.
  - An example is shown in Figure 3-7 for the 3rd deck, where the flow rate, diameter (or size) and height over the deck level are marked for each nozzle or damper.
  - The drawings for nozzles on other decks are attached in Appendix A.
  - A table of nozzle parameters is also included in Appendix A. The nozzle number marked in the drawings in Appendix A corresponds to the nozzle number in the table. In total, there are more than 120 nozzles defined in the drawings and 118 nozzles which can be relevant for this investigation are listed in the table.
  - Figure 3-8 shows some nozzles above the 3rd deck and the corresponding photo to help the understanding of the marked parameters for the nozzles.
- Air is sucked into engines through inlets on the main engine and generator engines.
- The exhaust gas from engines runs through exhaust pipes in the FUNNEL to the outside.
- The remaining air after consumption in engines runs through open areas in funnels and finally runs out through the 6 DAMPERs shown in Figure 3-9.

The air flow calculations are given in the document [6]. The air flow rates calculated in [6] are quoted as below.

- Air flow for CASE I:
  - For engine Combustion: 101.61 m^3/s = 6097 m^3/min
  - For evacuation of heat emission from engines and all other equipment 82.3 m^3/s = 4938 m^3/min
  - Total required air flow: 11035 m^3/min
- Air flow for CASE II:
  - Total air flow should not be less than the air flow for combustion plus 50%: 1.5 * 101.61 m^3/s =152.4 m^3/s = 9145.0 m^3/min
- The total air flow to the engine room shall be at least the larger for calculations of CASE I and CASE II. Thus, the total required air flow is based on CASEI, i.e. 11035 m^3/min.

The 4 ventilation fans in the fan rooms to provide inflow:

- Capacity of one vent fan: 3400 m^3/min
- All 4: 3400 * 4 = 13600 m^3/min > 11035 m^3/min

1. FAN LIST

NO.	NAME OF FAN	TYPE	CAPACITY	Q'TY	PURPOSE
1	NO.1 E/R FAN	NON-REVERSIBLE	Q: 3400m^3/min x55 mmAQ	1	AIR SUPPLY
2	NO.2 E/R FAN	REVERSIBLE	Q: 3400m^3/min x55 mmAQ	1	AIR SUPPLY & EXHAUST
3	NO.3 E/R FAN	NON-REVERSIBLE	Q: 3400m^3/min x55 mmAQ	1	AIR SUPPLY
4	NO.4 E/R FAN	REVERSIBLE	Q: 3400m^3/min x55 mmAQ	1	AIR SUPPLY & EXHAUST
5	EXH.FAN FOR PURIFIER ROOM	NON REVERSIBLE	Q: 300m^3/min x30 mmAQ	1	AIR EXHAUST
6	EXH.FAN FOR WELDING SPACE	NON REVERSIBLE	Q: 15m^3/min x10 mmAQ	1	AIR EXHAUST WALL MOUNTING

Figure 3-5: List of fans for engine room.

Figure 3-6: Fan rooms and fans in the room. The drawing is hided due to IP rights.

Figure 3-7: Air nozzles or dampers on 3rd deck, marked by red colour. The flow rate, flow direction and elevation from the deck level are marked for each nozzle or damper. The drawing is hided due to IP rights.

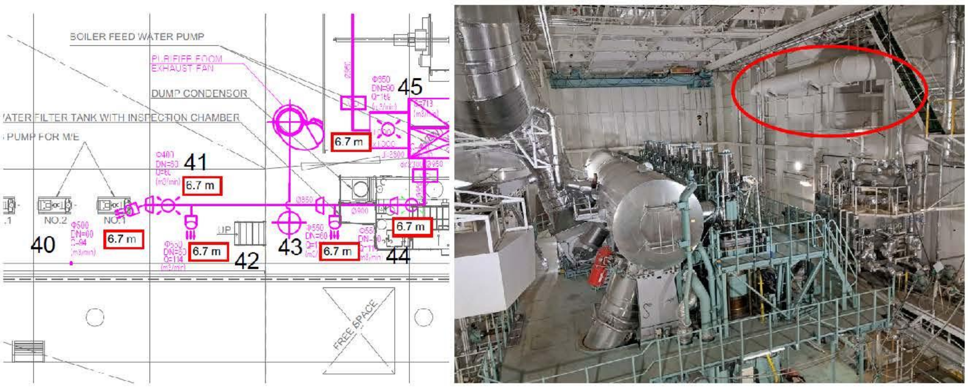

Figure 3-8: Nozzle parameters marked in the drawing and the corresponding photo for the nozzles.

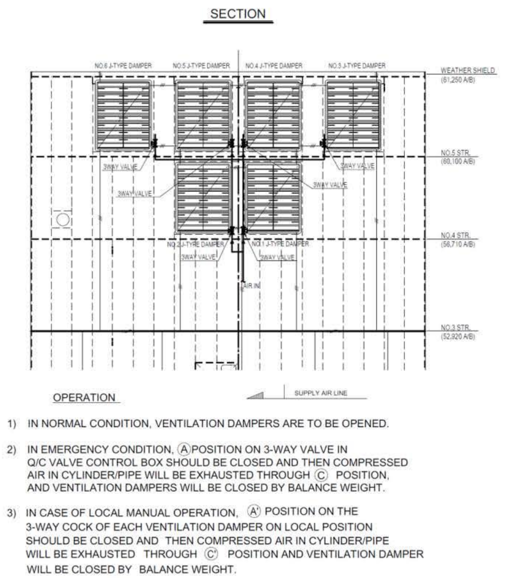

Figure 3-9: Dampers in a view toward the bow.

3.4 Air consumption in engines

As mentioned in the air flow calculation document [6], the air flow is provided for combustion for the main engine, for the generator engines and for the boiler.

- Combustion air consumption by main engine: 71.64 m^3/s through two inlets.
- Combustion air consumption by generator engines: 6.91 m^3/s for each engine, in total 4 out of 5 generators are working at the same time, thus 27.63 m^3/s in total. There is one inlet for one generator.
- Combustion air consumption by boiler: 2.33 m^3/s. (However, this is neglected in the simulations.)

The flow rate for the engines is summarized in Table 3-3.

Table 3-3: Flow rate of air inlet for engines.

Engine name	Flow rate in m^3/s	Flow rate in m^3/min
Main engine	71.64	4298.4
Generator engine No. 1	6.91	414.6
Generator engine No. 2	6.91	414.6
Generator engine No. 4	6.91	414.6
Generator engine No. 5	6.91	414.6
Boiler	2.33	139.8
Total	101.61	6096.6

The inlets for the main engine and for one generator engine are shown in Figure 3-10.

Figure 3-10: Inlets for engines. Left: One inlet for the main engine; Right: the inlet for one generator engine.

3.5 Main engine and main fuel supply pipe

The service standard power of the main engine is 46360 kW [6].

The flow rate in the main fuel supply pipe is 11.6 m^3/h and the pressure in the pipe is 39 N/cm^2 , according to the information provided in "Piping system diagram in E/R" [7]. The flow rate in the main supply pipe is converted as 2.3 kg/s for convenient use in CFD.

3.6 Escape trunk

After the start of the fire, it is interesting to know how long it takes for the smoke to reach the access of the escape trunk. In the current design the door to the escape trunk is located at the top of a staircase, which is about 2.3 m above the floor deck level, as shown in Figure 3-11.

The escape trunk is located in the aft part of engine room, between frame 16 and frame 18.5. The location of the escape trunk and entrance area including the staircase are marked in the drawing in Figure 3-2.

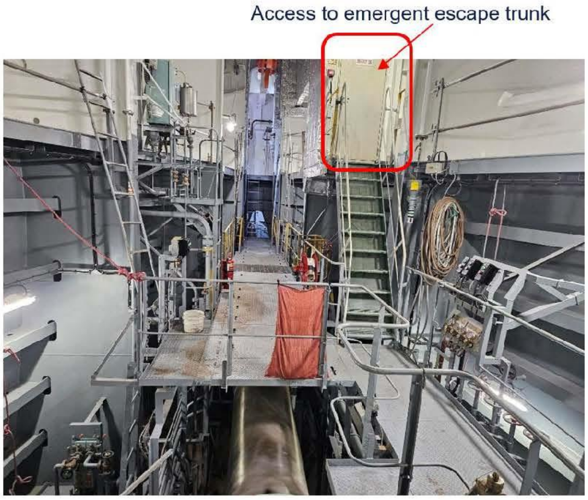

Figure 3-11: Photo of the access to the escape trunk.

3.7 Methodology and assumptions

Fire simulations are carried out by using DNV software KFX version v4.0.10. The KFX is called Kameleon FireEx. It is a gas dispersion and fire simulator by CFD. KFX is in general used in safety and risk related analyses.

Assumptions:

- Before the fire starts, the ventilation system and engines are assumed to run normally. The simulations are first establishing the normal air flow in the engine room (steady state). The fans and engine consumption are assumed to continue as normal also during the fire. This means also that the fuel pumps are running and supplying fuel to the fire.
- After the fire starts, it is assumed that there are no actions regarding the ventilation or the engine fuel supply during the fire. The lack of actions after fire detection is partly due to the manual decision-making process. Previous experience with fire in the engine room justifies this assumption, for instance, in one example engine fire incident, it took more than 18 minutes before the fans were shut [8]. Typically, the fans should only be stopped after the engine has been stopped, and it is confirmed that all personnel are out from the engine room. Further, when sailing it can also be unwanted to stop the engine since the ship will lose her navigational capabilities. Thereafter:
    - The main engine continues normal operation and consumes air;
    - The four generator engines are running normally and consume air;
    - The fuel pumps are running and supplying fuel to the main engine and therefore to the fire;
    - The ventilation fans continue normal operation, i.e. the four fans work normally, providing air to the engine room, and the two reversable fans are not reversed;
    - The 6 dampers in the funnel are always open, before and during a fire.
- There will not be other openings from the engine room to outside air.

   - Escape trunk door is closed
   - The hatch on the upper deck is closed
   - Exhaust fans for purifier room and welding space are neglected, since the exhaust air flow rates are much lower than the major air discharge through funnel and dampers, and these room/space are far away from the main engine, thus will not have significant impact on the overall flow pattern.

- Heavy fuel is selected for fuel leaks from the main engine. The engine may run on Heavy fuel oil, Marine diesel oil or Natural gas. Diesel is considered heavy and will produce a significant amount of soot in a fire. Heavy fuel produces even more soot and thus induces worse visibility. Combustion of gaseous fuel, such as LNG, will produce significantly less soot and smaller particles. Fires involving gaseous release of natural gas , will produce very small amounts of soot as long as sufficient air for combustion are supplied. Therefore, heavy fuel is assumed to account for the worst case.
- Fuel spray rate is assumed constant during the fire, and it will be ignited immediately after the spray starts, except for one scenario (Pool2) for which the lowest pool is ignited after spray running for 5 minutes and generating large pools before ignition (total fuel spill ~ 690 kg).
- The main engine local firefighting water mist system will not be simulated in this study, to represent the worst case. This can be included in a further work. KFX can model the water sprays. Water mist fire suppression may increase visibility but might in some cases produce steam which temporarily may affect the visibility and poses a greater risk to crew (scalding).
- Air consumption by boiler is neglected due to the much smaller amount compared with the air consumption by the main engine and the generator engines (less than 3% of total air consumption). In addition, the boiler is located on the 4th deck and far away from the main engine and the escape trunk.
- Two small rooms on the 2nd deck, “store room” and “transformer space (S)”, are excluded from the simulation because these rooms are often closed and they are towards the side of the ship, thus it is expected that the air flow in these two rooms should have little influence on the flow pattern on this deck and on the overall ventilation.
- The current assumptions with no actions of the engine nor the ventilation system are made to be on the conservative and realistic side [8]. If the ventilation system was shut down and the fuel supply to the engine was stopped, there would be a reduced amount of air in the room causing possibilities of toxic smoke reaching personnel, however it would also give less oxygen and fuel oil to the fire.

3.8 Coordinate system

A Cartesian coordinate system fixed on the ship is used in the geometry model and in the CFD analysis. The x-axis is point to the bow, y-axis to the port and z-axis upwards. The origin is at AP, CL and baseline.

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4 GEOMETRY MODELLING

4.1 Combine geometry

The engine room bottom follows the aft shape of the ship hull. By using the igs file and information in drawings, a geometry model is made to enclose the engine room by solid blocks on all sides of the engine room as shown in Figure 4-1, to ensure the gas tightness in the CFD simulations.

Only the aft bulkhead between No. 4 stringer and Weather shield is kept open, so that the 6 dampers on the bulkhead can be open to the outside.

The engine room walls, internal structures, pipes etc. imported from rvm files are combined, together with the outer geometry in Figure 4-1.

The received rvm files were converted from Navisworks files and the rvm files are further converted into kfx files. During the conversions, some geometries may be changed or distorted. These geometries are removed or modified according to drawings or photos taken in the actual engine room. Sometimes, it is found that some parts are missing in the received models, those geometries are then manually made and added to the correct position to match the drawing and photos.

Finally, the views of the engine room are shown in Figure 4-2 and Figure 4-3.

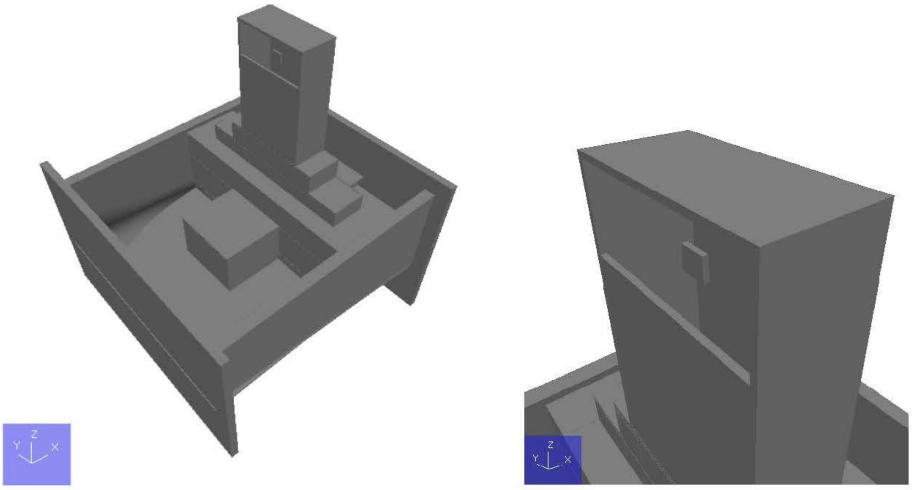


Figure 4-1: Solid blocks to enclose the engine room to ensure gas tight except at the wall where the 6 J-type dampers are located. Right: large figure to show the open side for dampers.

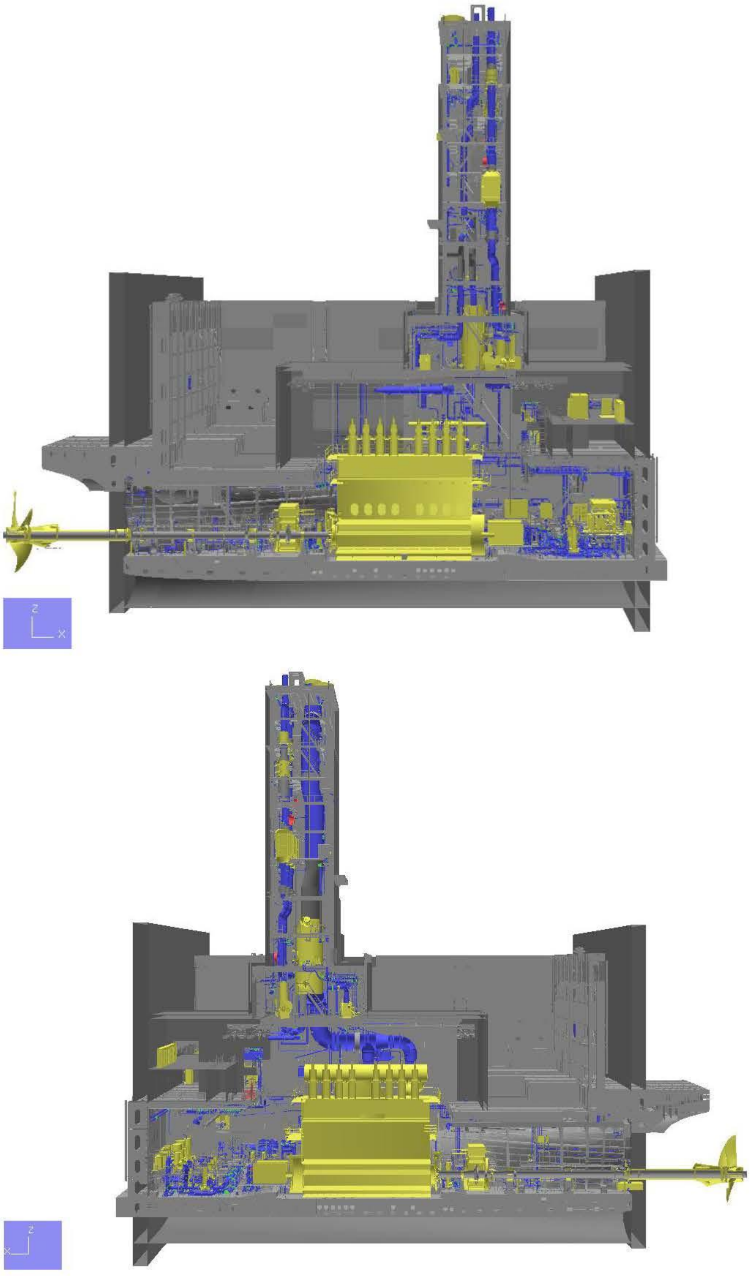
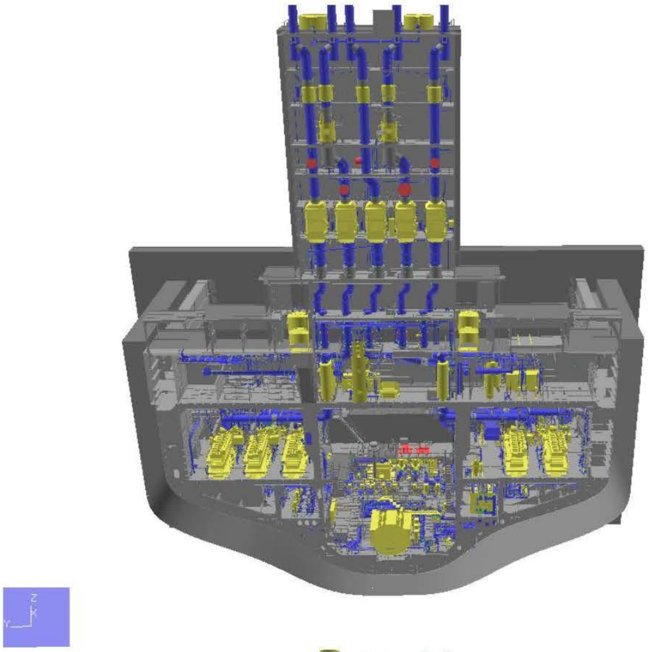


Figure 4-2: Side view of engine room geometry model, cut at y = 0 m. Upper: looking to port; lower: looking to starboard.



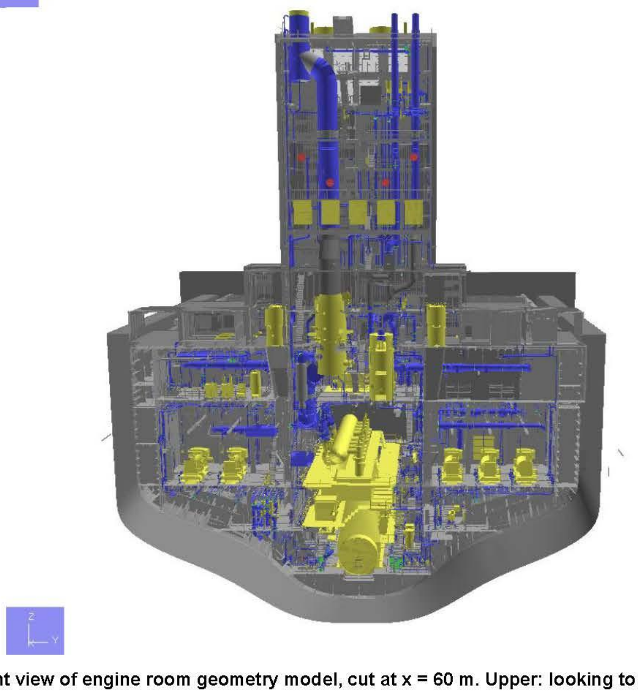


Figure 4-3: Front view of engine room geometry model, cut at x = 60 m. Upper: looking to bow; lower: looking to stern.

4.2 Dampers

The dampers are located on the aft bulkhead of the funnel between No. 4 stringer and weather shield. The geometry model of dampers in CFD is shown in Figure 4-4.

To consider the effect of dampers on the air flow, the damper area is approximated by a porous surface with porosity of 0.7 in the model. Porosity means the ratio of the open area to the total area. Porosity of 1 means completely open. In Figure 4-4, the damper openings look like almost transparent due to visualization in the KFX viewer, but they are actually modelled with 30% closed, i.e. with 0.7 porosity.

The 0.7 porosity for dampers in open position is roughly estimated from the drawing of dampers [4] shown in Figure 4-5 and the photo of dampers shown in Figure 3-9 where they are open.

It is noted that even if the dampers are closed, there are still gaps between the bars. When being put in open positions, the bars are inclined with big openings between every two of them to allow easy air flow but good sheltering of sun light and precipitation.

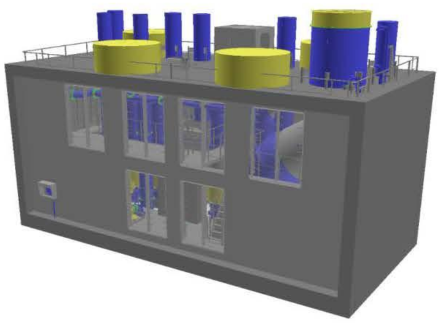


Figure 4-4: 6 J-type dampers defined on the aft bulkhead between No.4 stringer and weather shield.

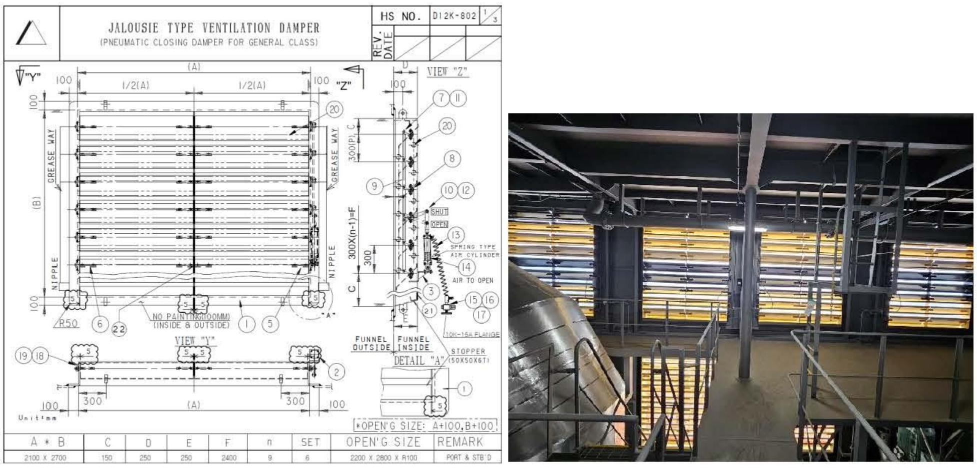
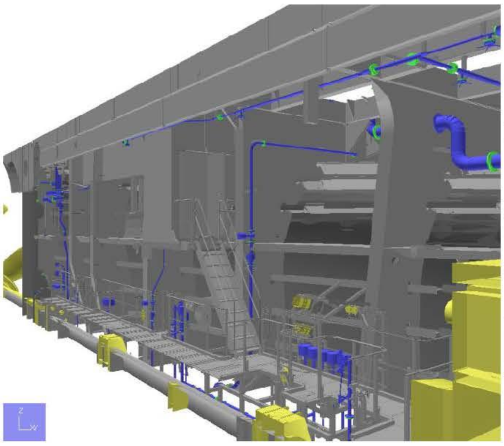


Figure 4-5: Drawing for J-type damper and the photo taken on Stringer No.5 with dampers opened.

4.3 Escape trunk

The geometry model of escape trunk is shown in Figure 4-6. The door to the escape trunk is elevated above the floor deck, at the top of a stair, as shown in Figure 4-6. The entrance region to the escape trunk is then defined by including the stair and the space in front of the door, as indicated in Figure 4-6. This area will be used to decide if the smoke from the fire reaches this entrance area and to decide if harmful heat radiation (since heat radiation is the dominating heat transfer outside flame) can reach this area.

Two different elevations are defined for the evaluation of smoke and heat radiation and to determine the available time to reach these positions as shown in Figure 4-7. The time to reach the current escape trunk elevation (Upper escape) and the time to reach the floor deck elevation (Lower escape) is considered when analysing the results.



Entrance to escape trunk	X [m]	Y [m]	Z [m]
min	28.7	0.8	6.1
max	31.7	1.6	10.4

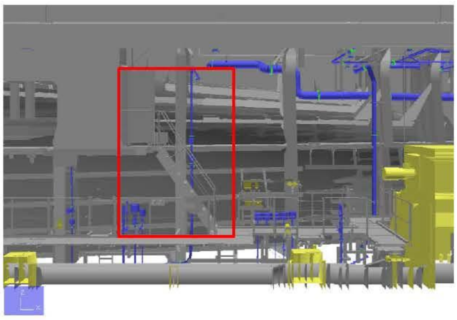


Figure 4-6: Entrance to escape trunk in the geometry model. Red box indicates the entrance region.

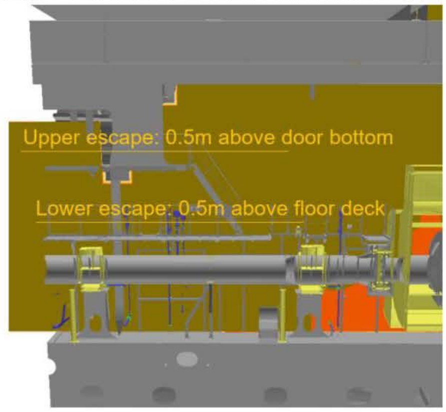


Figure 4-7: Two escape trunk elevations defined for checking the time when the smoke reaches each elevation.

5 VENTILATION MODELLING

5.1 Nozzles and Jalousie dampers

The air inflow from the nozzles including the Jalousie dampers is modelled by air leaks in KFX. The indications of nozzles in the engine room and a complete list of air nozzles are included in appendix A. Due to the limit in KFX for the number of leak types, it is not possible to define more than 100 leak types, each of them characterised by leak rate, leak area and leak flow direction, for more than 100 different nozzles. Thereafter the nozzles with similar flow rate or similar flow direction are categorized as the same leak type, and it has been verified that the total flow rate in simulations is equivalent to the total rate indicated in the drawings. This process resulted in 15 defined leak types that are listed in Table 5-1. The details of the defined nozzles/dampers are listed in the table in Appendix A. After excluding the nozzles in isolated rooms, there are in total 99 nozzles/dampers considered in the simulations to provide inflow into Engine room, with the total air flow rate as 11993 m^3/min. The air volume rates given in the drawing are converted to mass rates as input to KFX.

For some nozzles, more than one leak cells are used to model one nozzle or damper. For example, the 2 Jalousie dampers close to the inlets for the main engine, with 29.4 kg/s flow rate per damper, are modelled by 10 cells for each damper, each leak cell with a flow rate of 2.94 kg/s.

The air flow velocity and direction for the defined nozzles and dampers are checked in a ventilation simulation. Examples of the flow velocities of two nozzles and two dampers are shown in Figure 5-1.

Table 5-1: Leak types defined in KFX.

Air leak type (domain cell type)	Flow rate Q [m^3/min]	Diameter [m]	DN (direction) [deg]	Area [m^2]	U [m/s]	V [m/s]	W [m/s]	Absolute velocity [m/s]	Mass flow rate [kg/s]	Number of cells at each location
1	118	0.56	90	0.246	0.0	0.0	-8.0	8.0	2.4	1
2	173	0.68	60	0.360	0.0	-4.0	-6.9	8.0	3.5	2
3	76	0.45	60	0.159	0	0	-8.0	8.0	1.6	1
4	48	0.36	45	0.100	0.0	-5.7	-5.7	8.0	1.0	1
5	34	0.30	90	0.071	0	0	-8.0	8.0	0.7	1
6	109	0.54	90	0.228	0	0	-8.0	8.0	2.2	1
7	60	0.40	90	0.126	0	0	-8.0	8.0	1.2	1
8	114	0.55	90	0.238	0	0	-8.0	8.0	2.3	1
9	136	0.60	90	0.283	0	0	-8.0	8.0	2.8	1
10	159	0.65	90	0.332	0	0	-8.0	8.0	3.2	2
11	185	0.70	90	0.385	0	0	-8.0	8.0	3.8	2
12	1440	1.75	10	2.400	-9.7	1.7	-1.7	10.0	29.4	10
13	1440	1.75	10	2.400	-4.9	8.5	-1.7	10.0	29.4	10
14	34	0.30	0	0.071	5.7	-5.7	0.0	8.0	0.7	1
15	153	0.64	45	0.318	0.0	-5.7	-5.7	8.0	3.1	2

In which,

u, v, w: velocity component in x, y, z direction of the cartesian coordinate system

Area: cross section area of nozzle

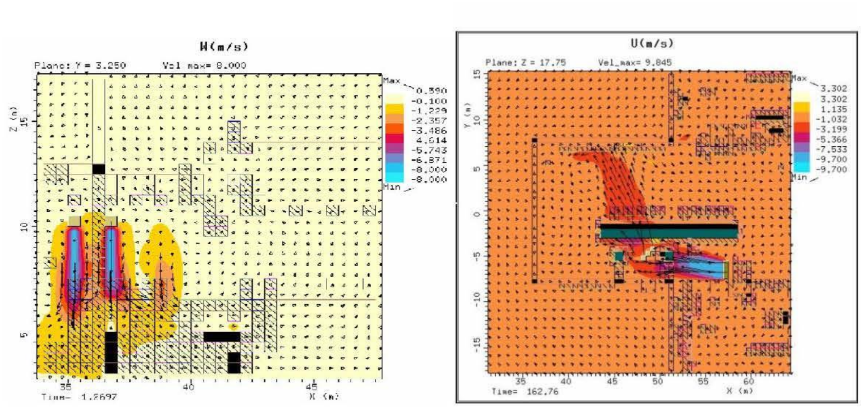


Figure 5-1: Check flow direction and velocity magnitude for defined nozzles and dampers in a ventilation simulation. Left: two nozzles at floor deck; right: two dampers close to the main engine.

5.2 Air consumptions in engines

There are two air inlets for the main engine as shown in Figure 5-2. Each inlet is a cylinder with diameter of about 1.8 m. As indicated by the green arrows in the figure, the air flow is assumed to be sucked into the engine from the cylindrical side of the cylinder, thus 16 cubic cells (each with a size of 0.5 m x 0.5 m x 0.5 m) are used to define the air suction for each inlet, i.e. 4 cells on the top, 4 cells on the bottom, 4 cells on the +y side and 4 cells on the -y side, with cell types defined as No. 16, 17, 18 and 19 in Table 5-2 (with same flow rate but different flow directions). The flow direction on each cell is marked in the right plot in Figure 5-2. The flow rate for each cell is 2.74 kg/s. The flow velocity around the air suction cells is for example checked in Figure 5-3.

It is assumed that 4 out of 5 generator engines, i.e. generator engine No. 1, 2 ,4 and 5, are working at the same time during a fire scenario. The suction air flow directions are indicated in Figure 5-4, which are normal to the circular cross-section of the air inlet modelled by a circular cylinder, one for each generator engine. The diameter of the air inlet for the generator engine is about 0.8 m. Thus, air suctions are defined in 2 x 2 = 4 cells with flow rate of 2.12 kg/s for each cell whose size is 0.5 m x 0.5 m x 0.5 m. The flow direction is in negative y-direction which is normal to the cross-section of the cylinder. The air volume rates are converted to mass rates as input to KFX. The leak type for those cells is No. 20 in Table 5-2. The flow velocity is checked in Figure 5-5.

Table 5-2: Air leak types for air consumption.

Air leak type (domain cell type)	Flow rate Q [m^3/min]	Length [m]	Width [m]	Area [m2]	U [m/s]	V [m/s]	W [m/s]	Absolute velocity [m/s]	Mass flow rate [kg/s]	Number of cells at each location
16	537.3	2.0	0.5	1.00	0	0	-9.0	9.0	11.0	4
17	537.3	2.0	0.5	1.00	0	0	9.0	9.0	11.0	4
18	537.3	2.0	0.5	1.00	0	-9.0	0	9.0	11.0	4
19	537.3	2.0	0.5	1.00	0	9.0	0	9.0	11.0	4
20	414.6	1.0	1.0	1.00	0	-8.6	0.0	8.6	8.5	4

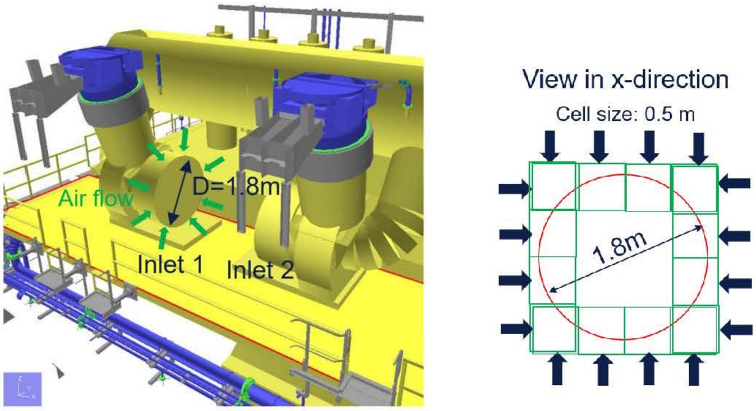


Figure 5-2: Air suction into main engine through two inlets. The green arrows in the left figure indicate the air flow direction for Inlet 1. Inlet 2 is similar. The right figure shows 16 cells which are used to model the air suction for each inlet. The black arrows show the air flow directions. Two cells (located at adjacent x-positions) are used in each corner.

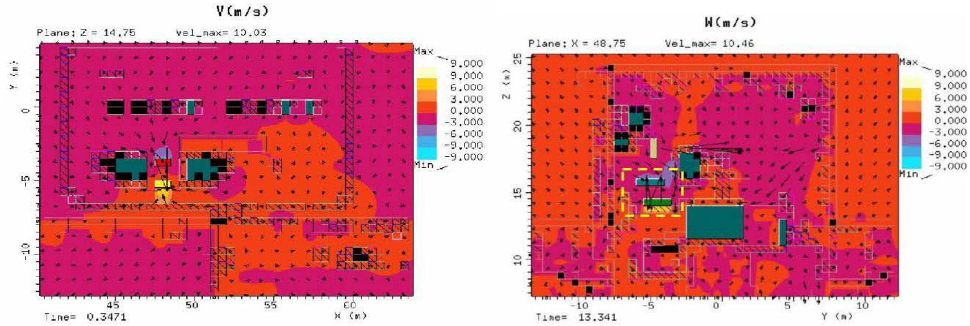


Figure 5-3: Check flow direction and velocity for the defined air suction into main engine. Left: x-y plane cut at z = 14.75 m, with suction cells for the +y side(red) and -y side (yellow); Right: y-z plane cut at x = 48.75 m, with suction cells for the upper side and lower side (as two horizontal green bars inside the yellow square).

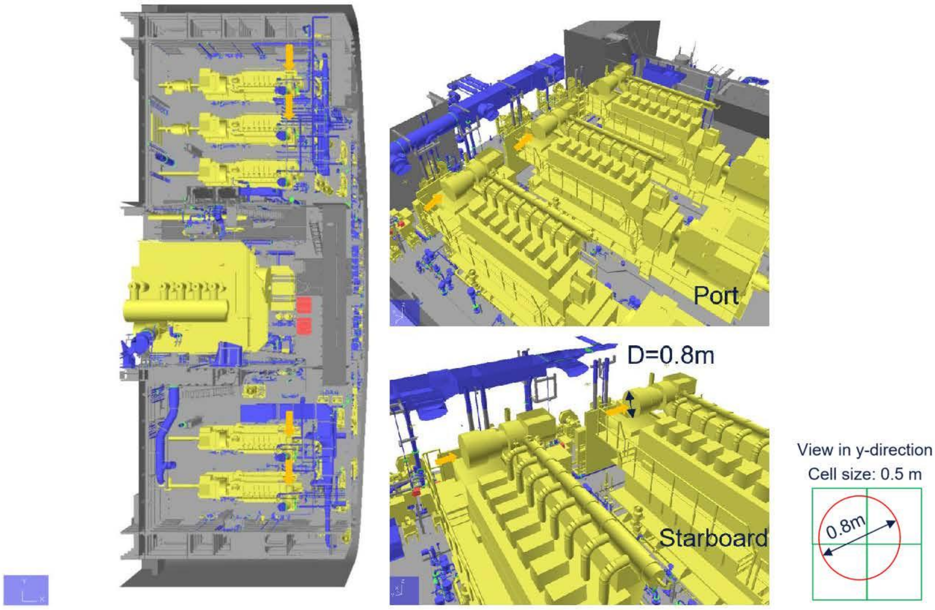


Figure 5-4: Air suction into 4 working generator engines (No. 1, 2, 4, 5). Each suction surface with diameter of 0.8 m is modelled by 4 cells (0.5 m x 0.5 m x 0.5 m). Orange arrows show the flow directions which are normal to the circular cross-section.

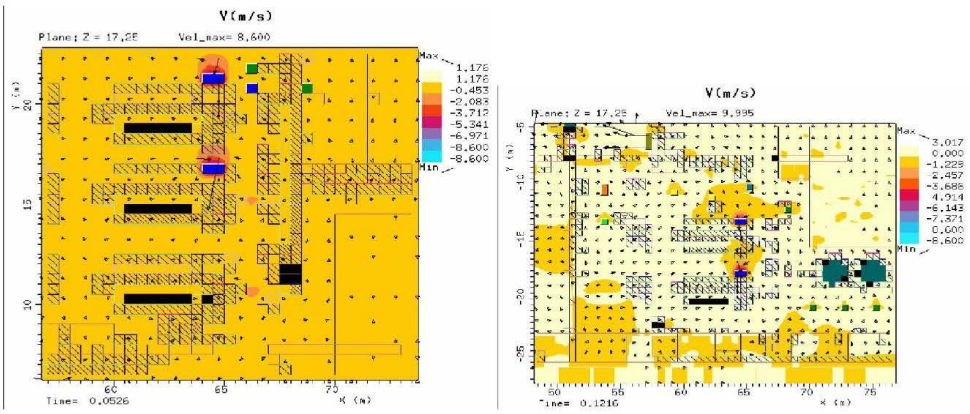


Figure 5-5: Check flow direction and velocity for the defined air suction into generator engines. Left: engine no. 4, 5 on port side; Right: engine no. 1, 2 on starboard side.

5.3 Dampers at the top of the funnel

The 6 dampers are modelled as porous plates as shown in Figure 4-4. The exhaust air flow from the common area in engine room is discharged through the dampers on the funnel. The air flow direction is checked in a ventilation simulation, as shown in Figure 5-6.

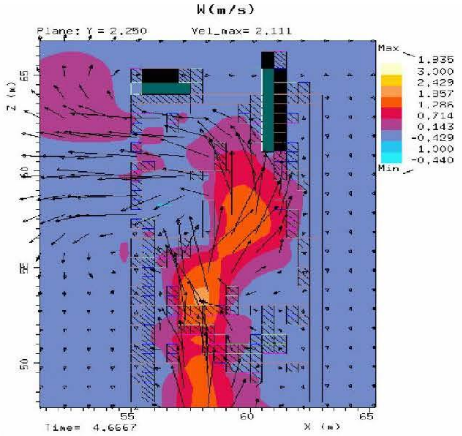


Figure 5-6: Check flow direction and velocity through dampers on funnel.

5.4 Gas tight check of engine room

In order to ensure the gas tightness of the engine room except the opening in dampers in the funnel, the dynamic pressure in the whole engine room is checked. Examples are shown in Figure 5-7. It needs to be ensured that there is no air leakage from the boundaries of engine room due to reasons such as a mismatch of two walls or accidently delete of a boundary cell. Such unwanted air leakage may change the flow pattern inside the engine room and thus result in misleading results. The pressure results show that the engine room is well enclosed without any unwanted leakage in boundaries.

The excess air that is vented up through the funnel is seen to meet the flow resistance at each deck level in the funnel. The pressure is seen to be dropping accordingly at each deck level. Care is taken to model the openings in each deck with the correct flow area so that the representative pressure level can be established.

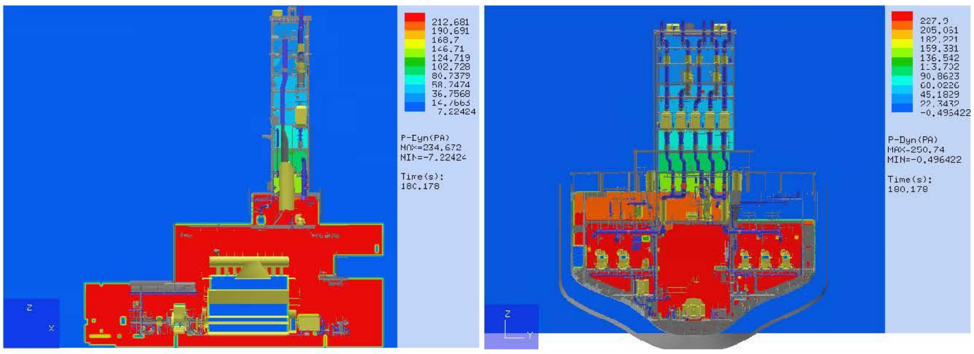


Figure 5-7: Check dynamic pressure to make sure gas tight in the engine room.

6 FIRE SCENARIOS

6.1 Fuel definition and modelling

The fuel for main engine is assumed heavy fuel and represented by **$C_{12}H_{26}$** in the CFD simulations**.**

Different fuel leak rates, leak positions and leak directions are assumed in different fire scenarios.

The fuel leak is modelled in KFX as a liquid spray leak.

The fuel leak rate is assumed to be constant throughout the time in the fire simulation for each scenario.

6.2 Fire scenarios

In all the fire scenario simulations, the ventilation system is initially simulated for approximately 3 minutes with all air sources and consumers activated. This ensures a constant air inflow, allowing a steady state air flow pattern to develop inside the engine room. After a steady state air flow is achieved, a spray leak is started and ignited immediately. The only exception is the scenario 'Pool2' that is ignited 5 minutes after the fuel leak is started.

The fire scenarios are listed in Table 6-1. All scenarios are defined based on the given capacity of the main fuel supply pipe, i.e. 11.6 m^3/hour at pressure of 39 N/cm^2, calculated to 2.3 kg/s.

Table 6-1: Fire scenarios simulated by KFX.

Case No	Leak locaction	Leak direction	Leak rate [kg/s]	Fire energy [MW]	Fuel temperature [°C]	CFD simulation time [min]
Case1	Close to SB engine	Towards Engine +y	2.3	100	300	29.7
Case2	Close to SB engine	Towards aft -x	2.3	100	300	37.6
Case3	Close to SB engine	Downwards -z	2.3	100	300	26.9
Case5	Close to SB engine	Downwards -z	2.3	100	100	28.4
Pool2	Close to SB engine, with 5min pool	Downwards -z	2.3	100	100	24.0
Case7	SB side of engine	Towards SB -y	2.3	100	100	60.3
Case8	SB side of engine	Towards SB -y	0.7	30	100	53.3
Case9	SB side of engine	Towards SB -y	0.23	10	100	65.2
Case10	In front of engine	Downwards -z	2.3	100	100	29.2
Case11	In front of engine	Downwards -z	0.7	30	100	61.7
Case12	In front of engine	Downwards -z	0.23	10	100	51.9
Case13	In front of engine	Upwards +z	0.7	30	100	45.1
Case16	Above main engine	Towads aft -x	0.2875	12	100	45.4
Case17	Above main engine	Towards SB -y	0.2875	12	100	44.5
Case18	Above main engine	Upwards +z	0.2875	12	100	40.0

Fire energy

- **100 MW fire**: This scenario represents a full-bore rupture of the main fuel supply pipe, pumping at 2.3 kg/s. It is the maximum amount of fuel being transported to the main engine and is considered the worst-case leak scenario. This scenario is highly unlikely and it is difficult to imagine what could cause such a pipe rupture. In such an event, the main engine cannot keep running, meaning that the fire simulated with the main engine running will never happen. However, the scenario is included in the report, assuming running engine all the time, to assess the absolute worst-case scenario for safe evacuation.
- **30 MW fire**: This scenario represents a leak rate of 0,7 kg/s. While still very high, it is considered more realistic.
- **10 MW fire**: This scenario represents a leak rate of 0.23 kg/s, which is 10% of the maximum capacity of the supply pipe. It is believed to be realistic in cases of incidents like flanged connection failures, such as blown gaskets.
- **12 MW fire**: This scenario represents a rate of 0.2875 kg/s from the engines high pressure fuel injection system. The leak rate is assumed to be 1/8 (8-cylinder engine) of the maximum main fuel supply pipe flow rate of 2.3 kg/s, which gives 0.2875 kg/s

Fuel temperature Initially, a higher fuel temperature of 300°C is applied to facilitate easier ignition in the simulation, addressing potential ignition difficulties. Subsequently, a more realistic fuel temperature of 100°C is applied later, and the results are found to be similar as those at 300°C.

Leak positions

Four different leak positions are considered, as shown in Figure 6-1 and Figure 6-2 and Figure 6-3. The coordinates for these leak positions are detailed in Table 6-2.

- **Close to SB engine**: This position is near where the main fuel supply pipe enters the engine.
- **SB side of engine:** This position is at a lower level than "Close to SB engine" and just above the floor, which is expected to induce more smoke at the floor level.
- **In front of engine**: This position is closer to the forward bulkhead and further away from the funnel, potentially generating more air flow circulation in the lower engine room space, and directing smoke towards the escape trunk.
- **Above the main engine**: This position represents the most commonly seen leak and ignition position in real fire cases, where the high-pressure spray hits hot surfaces on exhaust pipe or turbocharger area. The leak rate here is assumed as 1/8 of the maximum main fuel supply pipe flow rate of 2.3 kg/s, resulting in 0.2875 kg/s.

For each leak location, different leak directions and leak rates are applied.

Table 6-2: Coordinates of leak positions.

Leak position	X from AP[m]	Y from CL [m]	Z from BL [m]
Close to SB engine	55.60	-3.50	12.50
SB side of engine	51.25	-6.25	6.75
In front of engine	71.25	-1.25	6.25
Above main engine	44.75	-0.75	18.25

Figure 6-1: Spray leak position "Close to SB engine" and 3 leak directions.

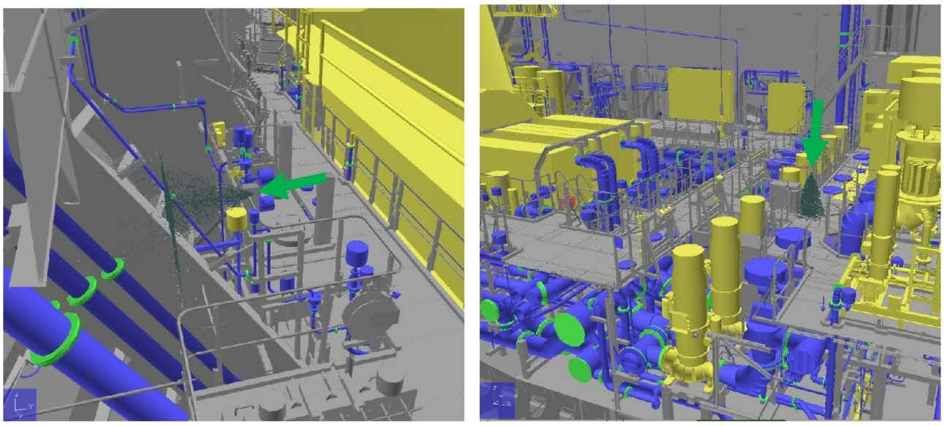


Figure 6-2: Spray leak position "SB side of engine" and position "in front of engine". The liquid spray leak is represented by the green spray in the figure.

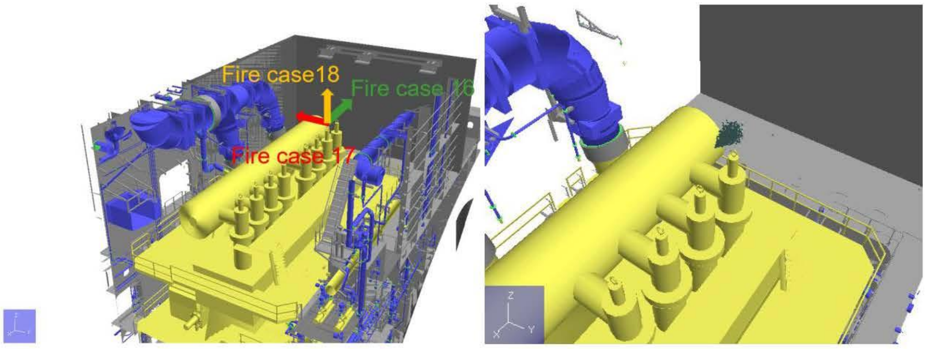


Figure 6-3: Spray leak position "Above main engine" and 3 leak directions. The dark green spray in the right figure only shows the leak direction towards aft, Fire case 16.

7 FIRE SIMULATION RESULTS

7.1 Presentation of results

The results of the fire simulations are presented by visibility in distance, radiation flux and some other physical values such as the oxygen percentage, temperature and soot production rate.

The results are presented in cut planes, by projecting the maximum or minimum of the physical values along the direction normal to the cut plane.

Visibility is given as visible distance in meters, which is calculated in KFX based on soot concentration. Visibility less than 5 m is expected to result in escape route becoming not tenable and thus delaying evacuation. It should be noted that the actual light condition will depend on the arrangement of lightning in the engine room and the light condition may affect the visibility results calculated from soot concentration in CFD results.

Visibility cut plots are provided as the minimum visible distance projected in y-direction within the range of y = 0.8 to 1.6 meters across the width of the escape trunk.

Radiation flux is given in W/m^2. A radiation flux higher than 5 kW/m^2 is expected to give impacts on human. The cut plot of radiation flux is given as the maximum projected in y-direction in the whole y range.

The total simulation time varies for different scenarios. Normally a simulation is stopped manually when it is observed to reach a steady-state, or if the 5 m visibility smoke has reached the escape trunk. The first 165~180 s in CFD simulation is only ventilation. After that a fuel spray leak is started and ignited immediately, except in scenario Pool2 where the fuel spray lasts 5 minutes before ignition. The time shown inside the cut plots in seconds is CFD time, for which the first 165~180 s is without fire. For Pool2, the first 8 minutes is without fire, which includes 3-minute ventilation and 5-minute spray to form the pools. Therefore, the time for fire in minutes, which means the time duration from ignition to the snapshot time, is given in each figure caption. The time for the snapshot is normally close to the end of the CFD simulation when steady state is reached, except for scenarios “Pool2” and “Case10” for which the plots are made when the 5 m visibility smoke reaches the upper escape or the lower escape (which are defined in Figure 4-7).

7.2 Visibility results

The visibility result with focus on the area near escape trunk is presented in Figures 7-1 to 7-12 as plots showing visibility contours in 5-meter bands for visibility larger than 5 m, e.g. the dark-orange-coloured band indicates visibility in the range from 5 to 10 meters. These contours help visualize how smoke affects visibility at different locations, indicating how far one can see at a given location. The bands are the minimum visibility calculated across the width of the escape trunk (y direction).

The results for some scenarios are shown and discussed in this section. For the scenarios not discussed here, the visibility results are shown in Appendix C. In those scenarios, the 5 m or 10 m visibility smoke never reaches the access of the escape trunk no matter if it is elevated or at the floor deck level.

7.2.1 Leak position at SB side of engine

Figure 7-1 to Figure 7-3 show the visibility results for cases 7, 8 and 9, for 100 MW, 30 MW and 10 MW fires respectively, when the leak position is located at the starboard side of the main engine above floor deck. Only the 100 MW fire will reduce the visibility to 5 m or less at the upper escape level and the lower escape level, after 30.8 minutes and 57.3 minutes of fire, respectively.

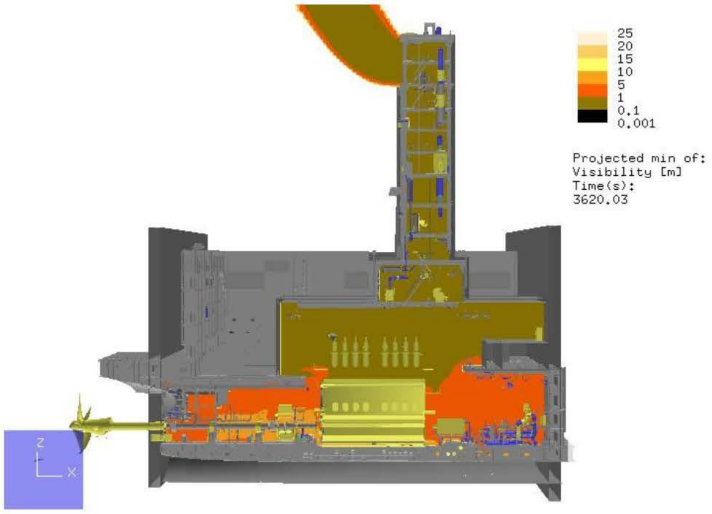


Figure 7-1: Case 7 with leak spray at "SB side of engine", flow rate 2.3 kg/s, towards starboard. The 5 m visibility contour reaches the lower escape. Time for 57.3 minutes fire.

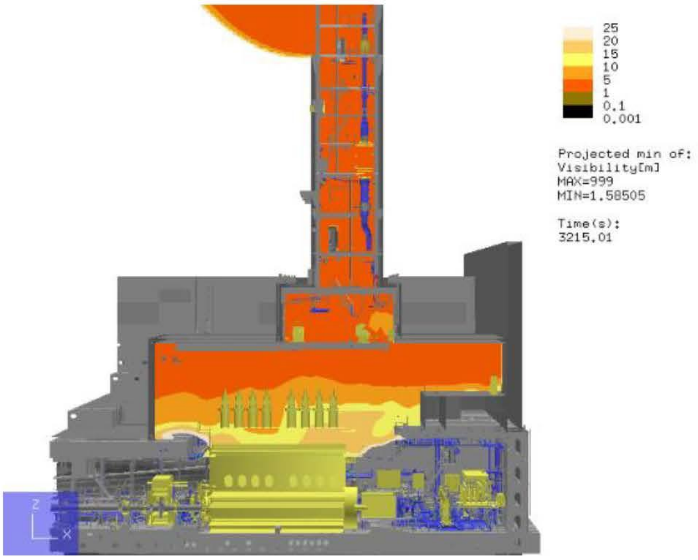


Figure 7-2: Case 8 with leak spray at "SB side of engine", flow rate 0.7 kg/s, towards starboard. No smoke at the escape trunk. Time for 50 minutes fire.

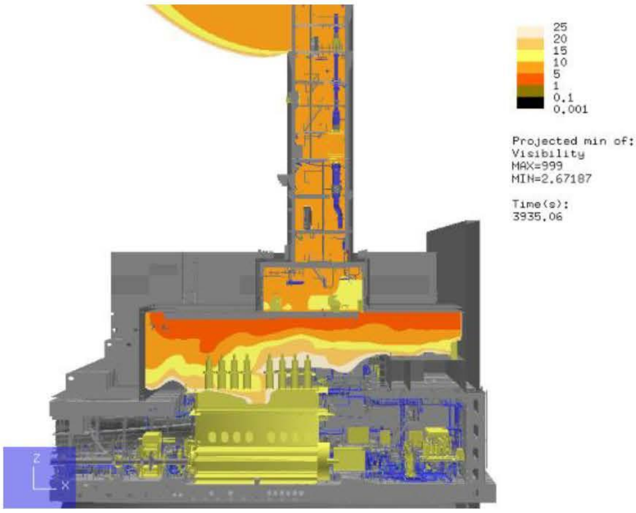


Figure 7-3: Case 9 with leak spray at "SB side of engine", flow rate 0.23 kg/s, towards starboard. No smoke at the escape trunk. Time for 62 minutes fire.

7.2.2 Leak position in front of engine

Figure 7-4 to Figure 7-9 show the visibility results for 100 MW, 30 MW and 10 MW fires, when the leak position is in front of the main engine above the floor deck.

The 100 MW fire will reduce the visibility to 5 m or less at the escape trunk. Actually, the 100 MW fire results in a quick reach of upper escape by the 5 m visibility smoke in 2.5 min of fire (Figure 7-4) and the reach of lower escape in 4.4 min of fire (Figure 7-5). To lower down the access of escape trunk only delay the smoke for about 2 min, and the visibility at the start of the stairs and further forward is less than 5m after about 4 min's fire.

The 30 MW fire in Figure 7-6 for Case 11 with downward leak shows that the fire reduces the visibility to 5 m at upper escape after 49.4 min fire. Case 13 shows also 30 WM fire but with leak spray in upward direction, for which the 5 m visibility contour can reach the upper escape after 23.3 min (Figure 7-7) and reach lower escape after 42 min fire shown in Figure 7-8.

No smoke is observed for Case 12 for 10 MW fire, as shown in Figure 7-9.

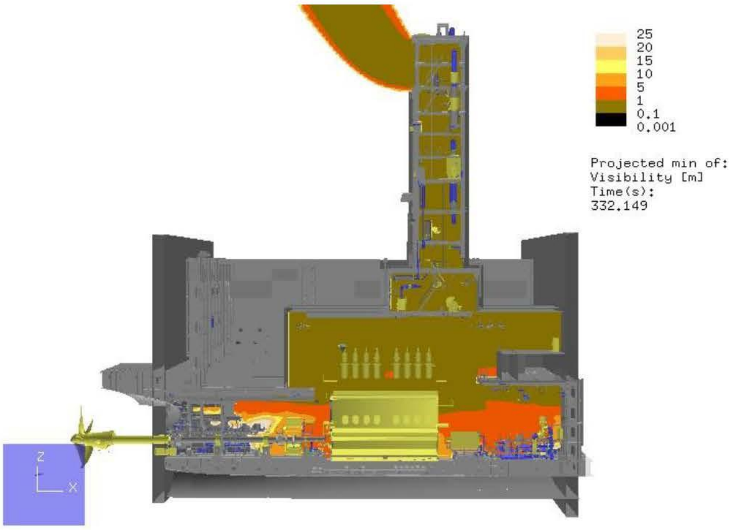


Figure 7-4: Case 10 with leak spray at "In front of engine", flow rate 2.3 kg/s, downwards. The 5 m visibility contour reaches the upper escape. Time for 2.5 minutes fire.

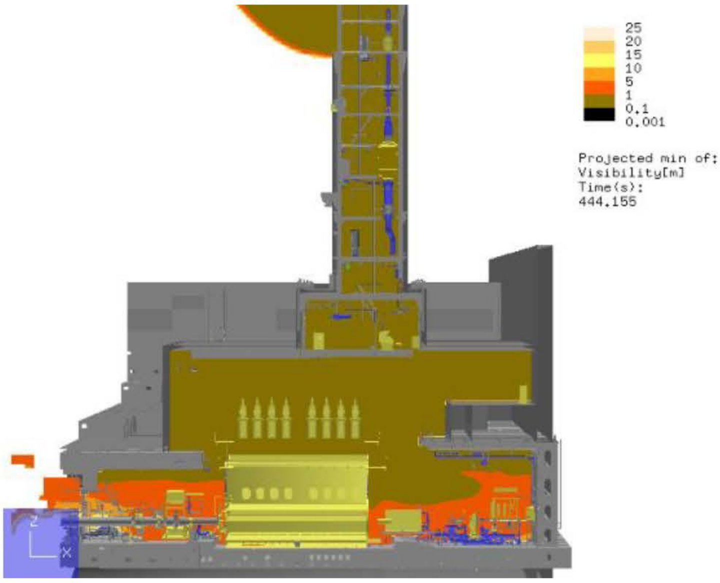


Figure 7-5: Case 10 with leak spray at "In front of engine", flow rate 2.3 kg/s, downwards. The 5 m visibility contour reaches the lower escape. Time for 4.4 minutes fire.

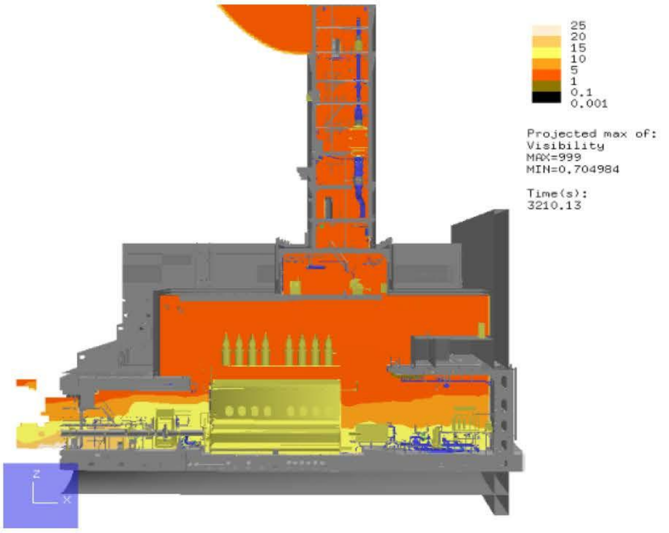


Figure 7-6: Case 11 with leak spray at "In front of engine", flow rate 0.7 kg/s, downwards. The 5 m visibility contour reaches the upper escape. Time for 50 minutes fire.

Figure 7-7: Case 13 with leak spray at "In front of engine", flow rate 0.7 kg/s, upwards. The 5 m visibility contour reaches the upper escape. Time for 23.3 minutes fire.

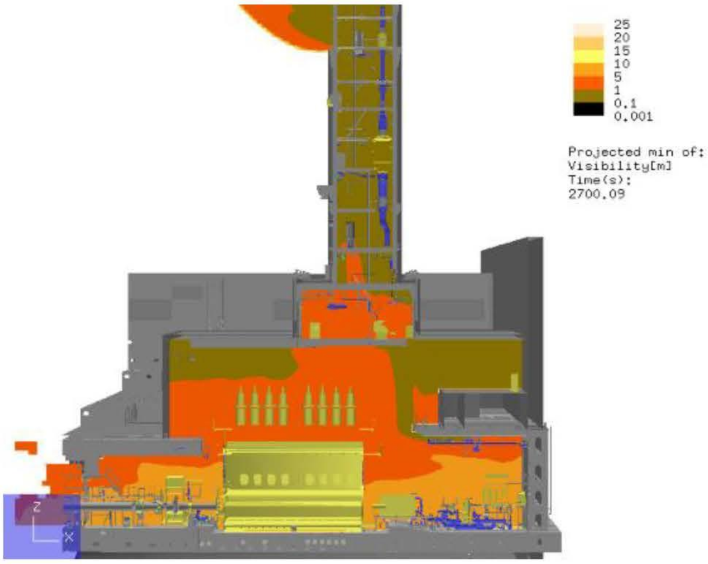


Figure 7-8: Case 13 with leak spray at "In front of engine", flow rate 0.7 kg/s, upwards. The 5 m visibility contour reaches the lower escape. Time for 42 minutes fire.

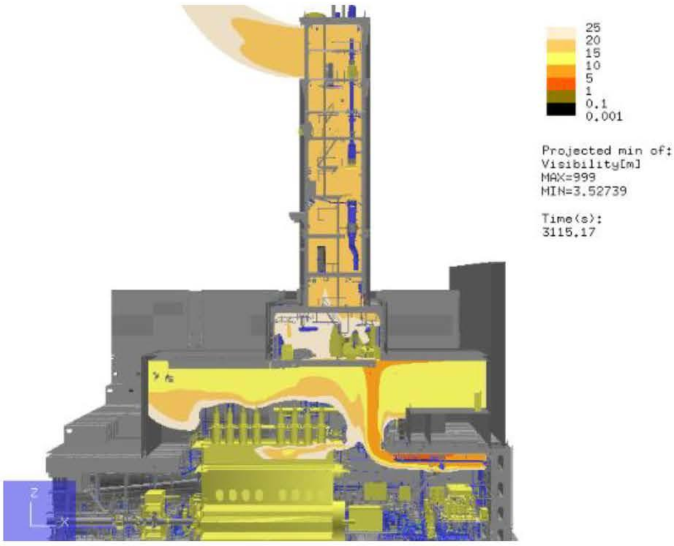


Figure 7-9: Case 12 with leak spray at "In front of engine", flow rate 0.23 kg/s, downwards. No smoke at the escape trunk. Time for 49 minutes fire.

7.2.3 Leak position above main engine

Figure 7-10 to Figure 7-12 show the visibility results for Cases 16, 17 and 18 with 12 MW fire at leak position above the main engine. The leak spray directions are towards aft, starboard or upwards, respectively. The assumed leak position and leak rate for these scenarios are according to the real engine fire scenarios.

The worst case scenario is the leak towards aft. But all 3 scenarios show smoke only in the upper space in the engine room and in the funnel, which is far from the access to escape trunk no matter if it is elevated or on the floor deck.

Figure 7-10: Case 16 with leak spray at "Above main engine", flow rate 0.2875 kg/s, towards aft. No smoke at the escape trunk. Time for 42 minutes fire.

Figure 7-11: Case 17 with leak spray at "Above main engine", flow rate 0.2875 kg/s, towards starboard. No smoke at the escape trunk. Time for 41 minutes fire.

Figure 7-12: Case 18 with leak spray at "Above main engine", flow rate 0.2875 kg/s, upwards. No smoke at the escape trunk. Time for 37 minutes fire.

7.2.4 Pool fire

In the pool fire scenario, the fuel spray at position "Close to SB engine" in 2.3 kg/s rate runs for 5 min without ignition. Pools are formed at different heights as shown in Figure 7-13.

After running fuel spray for 5 minutes, a pool at the lowest level is ignited. The visibility results are shown in Figure 7-14. The 5 m visibility reaches the lower level about 1.9 min after fire ignition. The snapshot shown in the figure is after 2.3 min fire when the thick smoke extends further downwards.

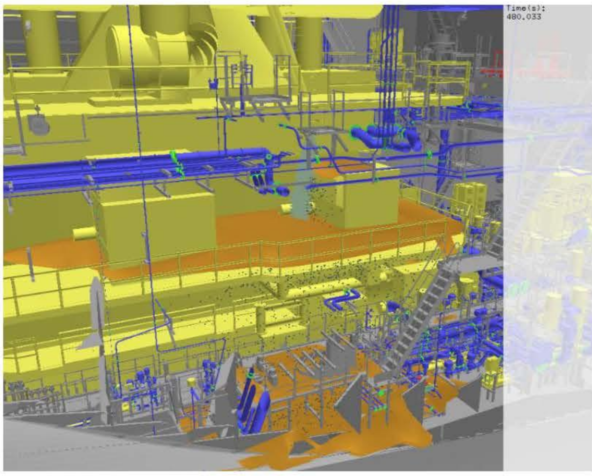


Figure 7-13: Pool2 with leak spray running for 5 min before ignition. Pools (in orange colour) are formed at different heights. Leak rate 2.3 m/s, downwards, at starboard of main engine near the position where fuel supply pipe enters engine.

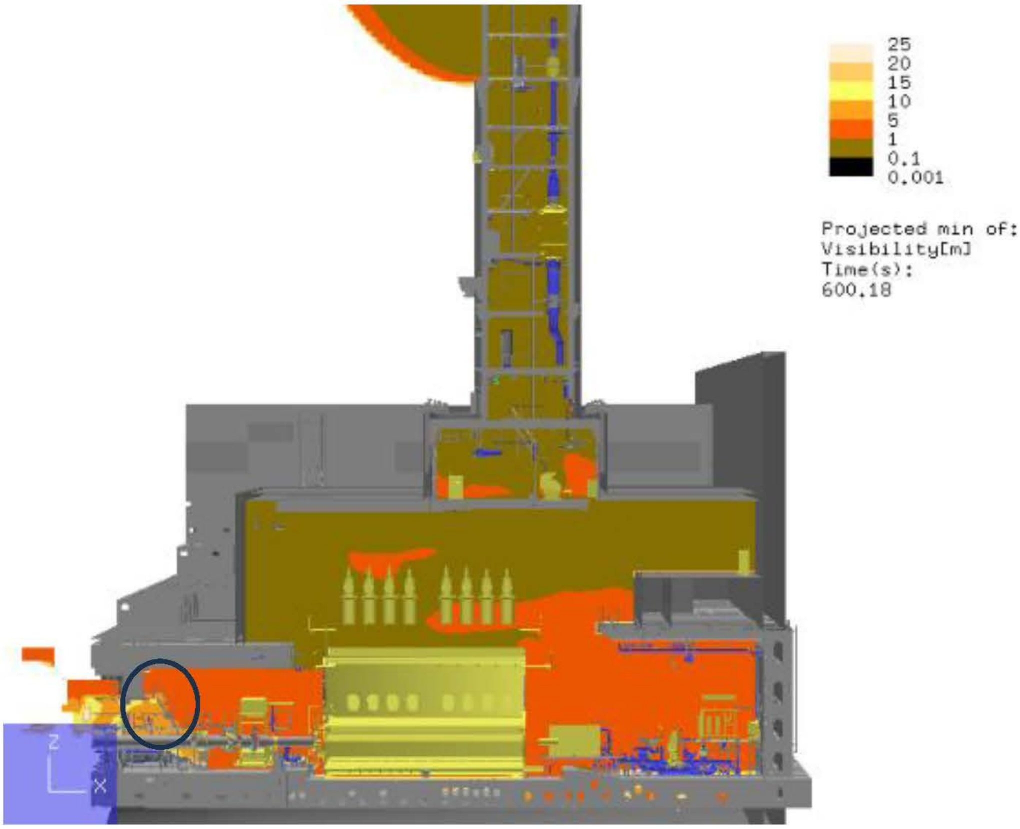


Figure 7-14: Pool2 with leak spray running for 5 min to form pool before ignited at a pool at floor deck. Leak rate 2.3 m/s, downwards. The 5 m visibility contour reached the lower escape. Time for 2.3 min fire. The blue circle indicates the entrance area for the escape trunk.

7.3 Radiation results

In case of fires, the heat radiation may give impacts on humans. The radiation flux results are checked for all the cases. None of the cases show more than 5 kW/m^2 near the access of escape trunk at either higher or lower position. The worst case scenario is shown by Case 2, as shown in Figure 7-15 for 5 minutes of fire and in Figure 7-16 for 35 minutes of fire.

The radiation flux result is also shown in Figure 7-17 for Case 16 scenario defined according to actual fire case. It can be seen that the dangerous radiation is also far from the escape trunk.

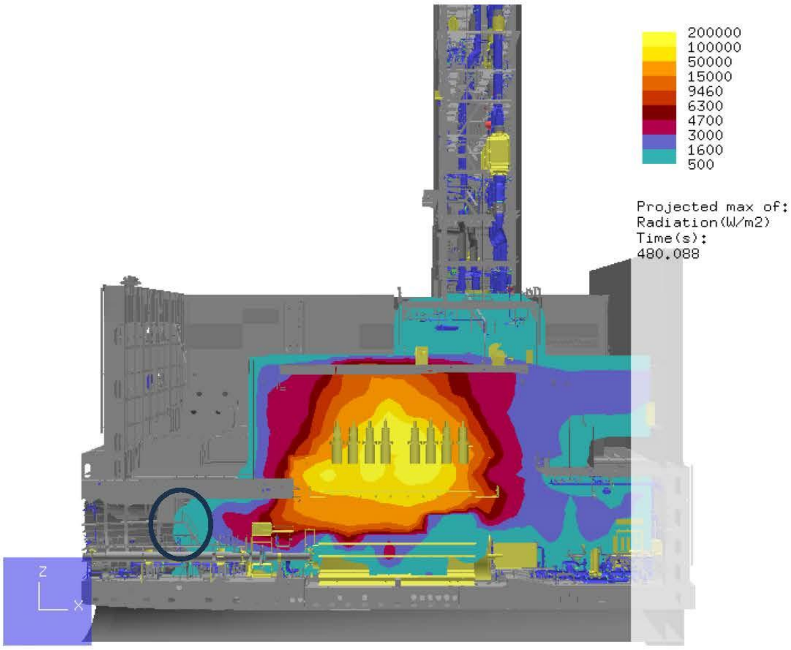


Figure 7-15: The worst radiation results among all cases, in case 2 with leak spray "Close to SB engine" flow rate 2.3 kg/s, towards aft. The blue circle indicates the entrance area for the escape trunk. Time for 5 minutes fire.

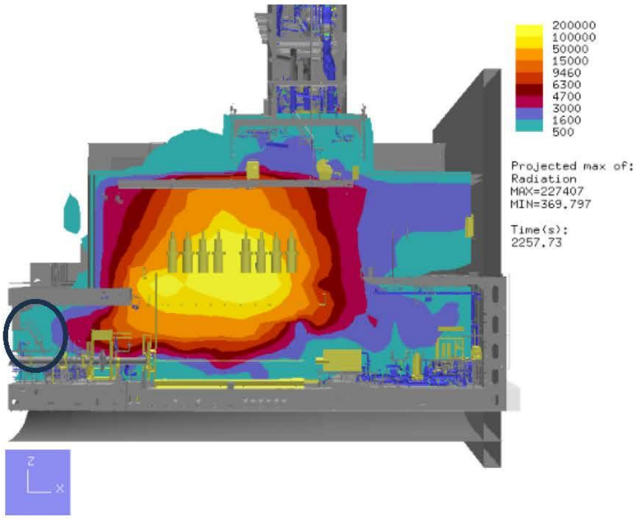


Figure 7-16: The worst radiation results among all cases, in case 2 with leak spray "Close to SB engine" flow rate 2.3 kg/s, towards aft. The blue circle indicates the entrance area for the escape trunk. Time for 35 minutes fire.

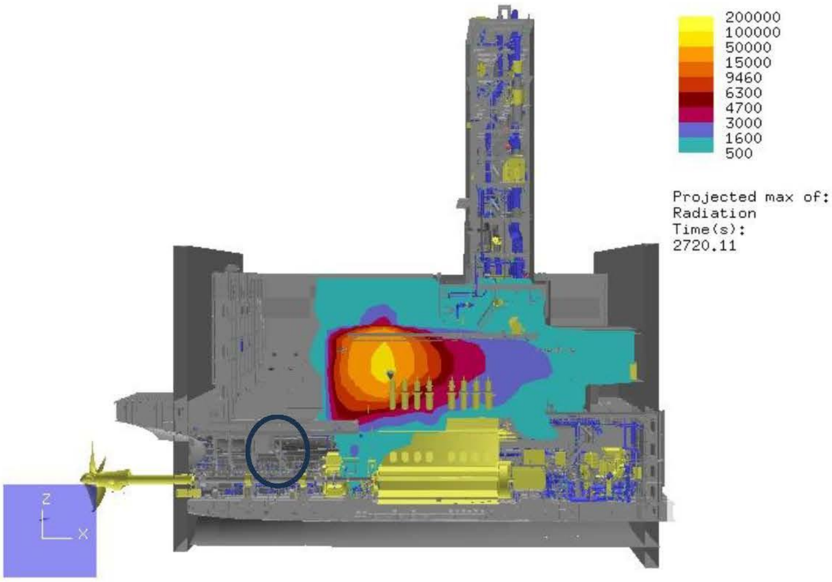


Figure 7-17: The radiation flux for case 16 with leak spray at "Above main engine", flow rate 0.2875 kg/s, towards aft. Time for 42 minutes fire.

7.4 Other physical values

A few other physical values are also exported to check other effects or the soundness of the simulations.

The oxygen volume percentage is checked for case 10 with bad visibility results, as shown in Figure 7-18. Although the fire significantly influences the space above the fire, the oxygen percentage is at a safe level, i.e. around 15%, near the escape trunk.

The temperature is shown for case 10 in Figure 7-19. The big flare can be seen from the plot.

The visibility length in m is based on soot concentration. The soot percentage is for example shown for case 10 in Figure 7-20. It shows consistency with the visibility results.

The soot production in a steady state of fire simulation is used to check if the fire simulation is sound for producing the visibility results. The expected soot ratio of soot production rate (kg/s) over the fuel rate (kg/s) for diesel oil is about 7~15%. Heavy oil may produce even more soot. Most simulated cases have soot results in this range, except for case 11, 16, 17, 18 with 4% and case 12 with 2%. For those cases, soot production may have been underestimated, and the visibility distance should have been shorter than displayed. However, the visibility distances in these cases are very long, with a lot of margin, near the escape trunk, so one can still conclude that the smoke with 10 m or 5 m visibility will not reach the escape trunk.

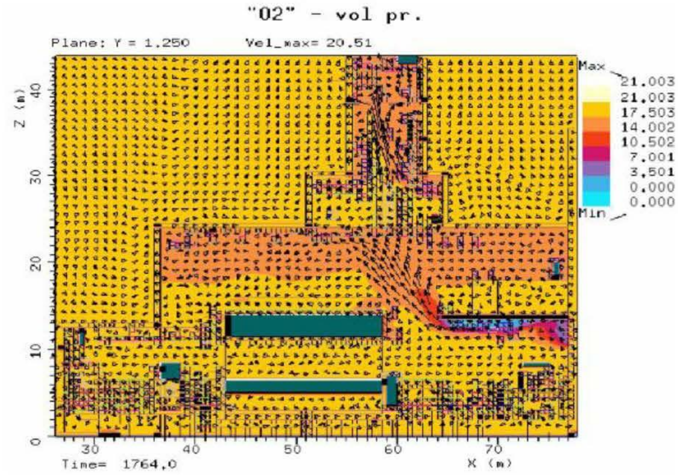


Figure 7-18: Oxygen percentage during the fire in case 10, with leak spray at "In front of engine", flow rate 2.3 kg/s, downwards.

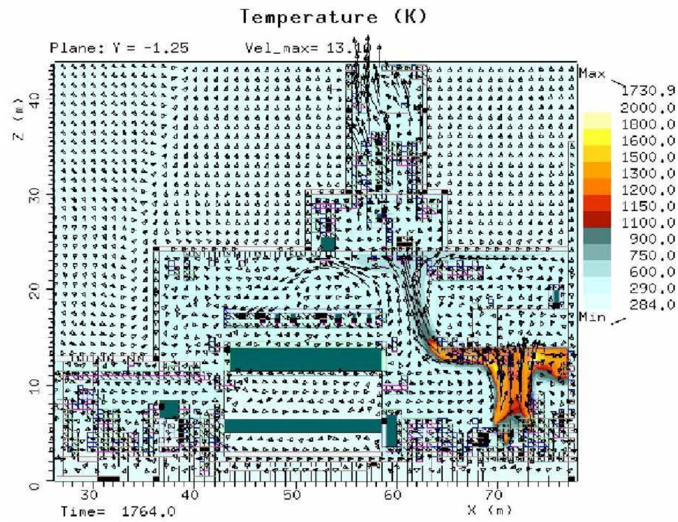


Figure 7-19: Temperature in Kelvin during the fire in case 10, with leak spray at "In front of engine", flow rate 2.3 kg/s, downwards.

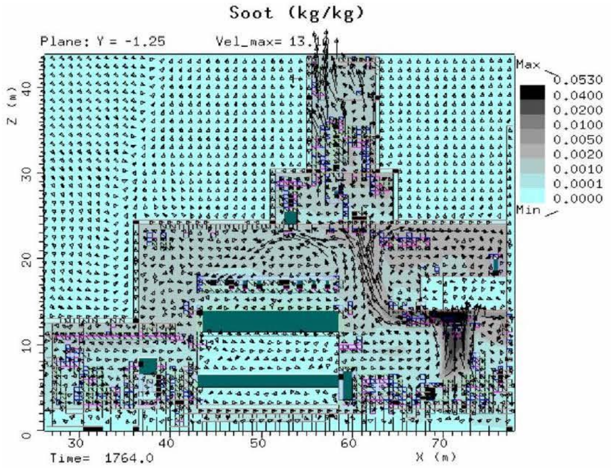


Figure 7-20: Soot ratio during the fire in case 10, with leak spray at “In front of engine”, flow rate 2.3 kg/s, downwards.

7.5 Summary of results

Based on the visibility results, the time for the 5 m or 10 m visibility smoke to reach the access of escape trunk is summarized as shown in Figure 7-21 and Table 7-1.

In Figure 7-21, the color bars indicate the time (in minutes) for fire when the 5 m or 10 m visibility smoke reaches the “upper escape” height or “lower escape” height. Figure 4-7 shows the definition of the upper escape level and lower escape level.

From the results, the benefit of moving down the access to escape trunk is observed in case Pool2, Case 7 and Case 10 with 100 MW fire; and Cases 11 and 13 with 30 MW fire.

For example, considering the 5 m visibility, the time to escape from upper trunk or from lower trunk is extended from 1 to 1.9 min for case Pool2; from 2.5 to 4.4 min for Case 10 and from 23 min to 42min for case 13. The 5 m visibility reaches upper escape at 30 min for Case 7 and 49 min for Case 11 but never reaches lower escape. However, the benefit is not believed to be significant, considering that the crew should have been evacuated within 15 min.

For the other smaller cases, the thick smoke (with visibility < 5 m) does not reach down to either the access of upper escape trunk or the lower floor level.

It should be noted that the 100 MW case is an extreme and worst case, and it is less likely than the smaller cases. For case 16,17,18 with more realistic leak location and leak rate, the 5 m or 10 m visibility smoke does not reach the escape trunk.

For the 100 MW cases, it is only the cases where the fuel and the fire are starting at a lower level that can cause smoke to reach the escape area. For the pool fire, the fuel is allowed to run down to the floor deck level before it is ignited after 5 minutes leak. The leak in the front of the engine is directed down causing the fire to start from a low level. This also causes smoke to reach the escape area quickly before 5 minutes with a short time difference between reaching the upper and lower escape levels.

It is noticed that in all cases the smoke fills the upper space of the engine room first, then the smoke may extend downwards to lower space. The dangerous radiation flux does not reach the access of the escape for any of the simulations.

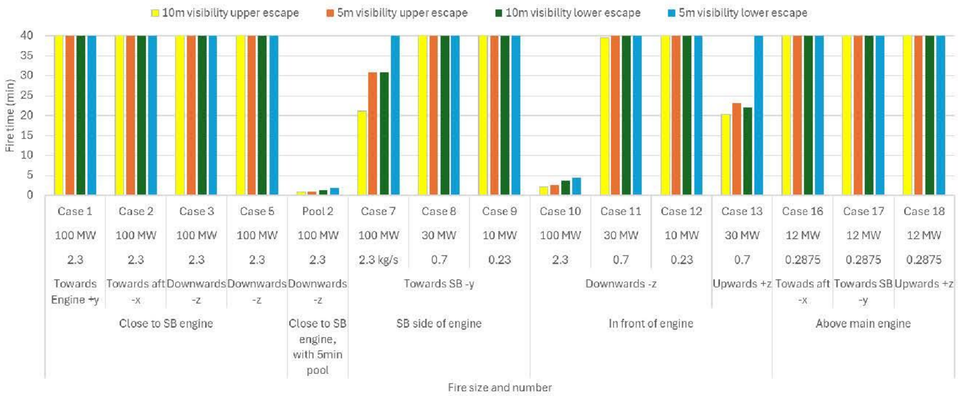


Figure 7-21: Summary of time for the smoke to reach the access of escape trunk for different fire cases.

Table 7-1: Summary of time in minutes of 10 m or 5 m visibility smoke to reach the upper escape or lower escape.

Case No	Leak locaction	Leak direction	Leak rate	Fuel energy	CFD simulation time	Time to reach upper escape		Time to reach lower escape	
			kg/s	MW	min	10 m visi.	5 m visi.	10 m visi.	5 m visi.
Case1	Close to SB engine	Towards Engine +y	2.3	100	29.7	>60	>60	>60	>60
Case2	Close to SB engine	Towards aft -x	2.3	300	37.6	>60	>60	>60	>60
Case3	Close to SB engine	Downwards -z	2.3	300	26.9	>60	>60	>60	>60
Case5	Close to SB engine	Downwards -z	2.3	100	28.4	>60	>60	>60	>60
Pool2	Close to SB engine, with 5min pool at floor	Downwards -z	2.3	100	24.0	0.95	1.02	1.38	1.88
Case7	SB side of engine	Towards SB -y	2.3	100	60.3	21.1	30.8	30.8	57.3
Case8	SB side of engine	Towards SB -y	0.7	100	53.3	>60	>60	>60	>60
Case9	SB side of engine	Towards SB -y	0.23	100	65.6	>60	>60	>60	>60
Case10	In front of engine	Downwards -z	2.3	100	29.2	2.2	2.5	3.7	4.4
Case11	In front of engine	Downwards -z	0.7	100	61.7	39.5	49.4	49.4	>60
Case12	In front of engine	Downwards -z	0.23	100	51.9	>60	>60	>60	>60
Case13	In front of engine	Upwards +z	0.7	100	45.1	20.3	23.3	22.0	42.0
Case16	Above main engine	Towards aft -x	0.2875	100	45.4	>60	>60	>60	>60
Case17	Above main engine	Towards SB -y	0.2875	100	44.5	>60	>60	>60	>60
Case18	Above main engine	Upwards +z	0.2875	100	40.0	>60	>60	>60	>60

8 REFERENCES

[1] Hyundai, “General Arrangement. DRAWING NO. 1G-7000-201. 15,600 TEU CLASS CONTAINER CARRIER. HULL NO. 8164-8169. DATE: 2022.03.25.,” 2022.

[2] HYUNDAI SAMHO HEAVY INDUSTRIES CO., LTD, “MACHINERY ARRANGEMENT IN ENGINE ROOM. DRAWING NO. 3K-2000-001. SHIP TYPE: 15,600 TEU CLASS CONTAINER CARRIER. DATE: 2022.03.25.,” 2022.

[3] HYUNDAI SAMHO HEAVY INTRUSTIRES CO., LTD. SAMHO SHIPYARD. KOREA. , “ARRANGEMENT OF MAIN FUNNEL. SHIP TYPE: 15,600 TEU CLASS CONTAINER CARRIER. DWG NO. 3U-2860-119. DATE: 2022.10.05.,” 2022.

[4] HYUNDAI SAMHO HEAVY INDUSTRIES CO., LTD. SAMHO SHIPYARD. KOREA, “ARRG'T & DETAIL FOR VENTILATION DAMPER REMOT CONTORL SYSTEM. DWG NO. 3K-2520-004. SHIP TYPE: 15,600 TEU CLASS CONTAINER CARRIER. SHIP NO. 8164-8169. DATE: 2022.09.13,” 2022.

[5] HYUNDAI SAMHO CO., LTD, “KEY PLAN OF VENT DUCT, LADDER & GRATING IN E/R. SHIP TYPE: 15,600 TEU CLASS CONTAINER CARRIER. DWG NO. 3K-2000-002. DATE: 2022.07.11,” 2022.

[6] “8164 ER VENT FAN CAPACITY CAL._PRE.pdf”.

[7] HYUNDAI SAMHO HEAVY INDUSTRIES CO., LTD, “PIPING SYSTEM DIAGRAM IN E/R. SHIP TYPE: 15,600 TEU CLASS CONTAINER CARRIER. DRAWING NO. 3U-2400-103-105. SHIP NO. 8164-8169. DATE: 2022-05-06,” 2022.

[8] “Engine Room Fire aboard Containership President Eisenhower.,” National Transportation Safety Board, MIR 22/15 (2022).

APPENDIX A: DEFINITION OF AIR NOZZLES

The drawings in this appendix are hided due to IP rights.

Floor deck

(Drawing for floor deck plan with indication of air nozzle locations and definitions)

4th deck

(Drawing for 4th deck plan with indication of air nozzle locations and definitions)

3rd deck

(Drawing for 3rd deck plan with indication of air nozzle locations and definitions)

2nd deck

(Drawing for 2nd deck plan with indication of air nozzle locations and definitions)

Nozzel number	X [m]	Y [m]	Z [m]	Q[m³/min)	Diameter[m]	DN[deg]	Area[m2]	Vel[m/s]	U[m/s]	V[m/s]	W[m/s]	Leak type
Floor plan 6.1m (locally 5.15m) A/B												
1	35.1	3.48	10.4	136	0.6	60	0.28	8.0	-4.0	0.0	-6.9	1
2	36.8	3.48	10.4	136	0.6	60	0.28	8.0	0.0	-4.0	-6.9	1
3	38.7	4.3	10.4	114	0.55	90	0.24	8.0	0.0	0.0	-8.0	1
4	41	5.1	10.4	94	0.5	60	0.20	8.0	0.0	-4.0	-6.9	1
5	48	6.84	10.15	159	0.65	90	0.33	8.0	0.0	0.0	-8.0	1
6	58	6.84	10.25	94	0.5	60	0.20	8.0	-2.8	-2.8	-6.9	1
7	58	6.84	9.55	94	0.5	60	0.20	8.0	0.0	-4.0	-6.9	1
4th deck plan 8.96m (locally 8.35m) A/B												
8	49.0	6.8	10.35	187	0.705	60	0.39	8.0	0.0	-4.0	-6.9	2
9	54.5	7.6	11.75	159	0.65	60	0.33	8.0	0.0	-4.0	-6.9	2
10	58.5	9.6	12.56	76	0.45	60	0.16	8.0	-3.4	-2.0	-6.9	3
11	59.3	9.6	12.16	76	0.45	60	0.16	8.0	-2.8	2.8	-6.9	3
12	60.1	9.6	12.26	76	0.45	90	0.16	8.0	0.0	0.0	-8.0	3
13	62.0	9.6	12.26	76	0.45	60	0.16	8.0	0.0	4.0	-6.9	3
14	63.5	9.6	12.26	76	0.45	90	0.16	8.0	0.0	0.0	-8.0	3
15	65.4	9.6	12.36	76	0.45	60	0.16	8.0	0.0	4.0	-6.9	3
16	67.5	9.6	12.26	76	0.45	90	0.16	8.0	0.0	0.0	-8.0	3
17	70.0	9.6	12.16	76	0.45	60	0.16	8.0	2.8	2.8	-6.9	3
18	70.0	9.6	12.36	76	0.45	60	0.16	8.0	3.4	-2.0	-6.9	3
19	71.7	6.8	14.65	76	0.45	70	0.16	8.0	2.7	0.0	-7.5	3
20	71.7	4.5	14.65	76	0.45	70	0.16	8.0	2.7	0.0	-7.5	3
21	71.7	4.2	14.65	76	0.45	70	0.16	8.0	-2.7	0.0	-7.5	3
22	71.7	2.6	14.65	76	0.45	70	0.16	8.0	2.4	-1.4	-7.5	3

Nozzel number	X [m]	Y [m]	Z [m]	Q[m³/min)	Diameter[m]	DN[deg]	Area[m2]	Vel[m/s]	U[m/s]	V[m/s]	W[m/s]	Leak type
23	71.7	0	14.65	76	0.45	70	0.16	8.0	-2.7	0.0	-7.5	3
24	71.7	-1.7	14.55	76	0.45	70	0.16	8.0	-1.9	-1.9	-7.5	3
25	71.7	-2.5	14.55	76	0.45	70	0.16	8.0	1.9	-1.9	-7.5	3
26	71.7	-5.0	14.55	76	0.45	70	0.16	8.0	1.9	-1.9	-7.5	3
27	71.7	-9.0	11.25	76	0.45	60	0.16	8.0	3.9	-0.7	-6.9	3
28	71.7	-11.0	11.25	34	0.3	45	0.07	8.0	0.0	-5.7	-5.7	4
29	68.8	-9.0	11.05	34	0.3	30	0.07	8.0	0.0	0.0	-8.0	5
30	66.7	-11.0	11.25	76	0.45	45	0.16	8.0	0.0	-5.6	-5.6	4
31	65.8	-9.0	11.05	34	0.3	45	0.07	8.0	0.0	0.0	8.0	5
32	64.1	-9.5	11.25	34	0.3	45	0.07	8.0	0.0	-5.7	-5.7	4
33	61.7	-9.0	11.05	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
34	59.0	-7.7	11.05	114	0.55	60	0.24	8.0	0.0	4.0	-6.9	6
35	57.4	-8.2	11.05	67	0.451	90	0.16	7.0	0.0	0.0	-7.0	6
36	55.7	-8.5	11.15	67	0.422	60	0.14	8.0	-2.8	-2.8	-6.9	6
37	50.3	-7.0	10.25	136	0.6	60	0.28	8.0	2.8	2.8	-6.9	6
38	47.4	-7.0	10.25	136	0.6	60	0.28	8.0	0.0	4.0	-6.9	6
39	46.5	-7.0	10.25	136	0.6	60	0.28	8.0	-2.8	2.8	-6.9	6
3rd deck 13.78m A/B												
40	47.7	6.4	20.48	94	0.5	60	0.20	8.0	-3.5	-2.0	-6.9	6
41	48.5	6.4	20.48	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7
42	49.3	6.4	20.48	114	0.55	60	0.24	8.0	0.0	-4.0	-6.9	8
43	53.2	6.4	20.48	114	0.55	60	0.24	8.0	0.0	-4.0	-6.9	8
44	55.3	6.4	20.48	114	0.55	90	0.24	8.0	0.0	0.0	-8.0	8
45	54.5	8.6	20.48	159	0.65	90	0.33	8.0	0.0	0.0	-8.0	10
46	53.7	13.6	20.88	185	0.7	60	0.38	8.0	4.0	0.0	-6.9	11
47	53.7	18.0	20.88	185	0.7	60	0.38	8.0	4.0	0.0	-6.9	11
48	53.7	21.0	20.88	185	0.7	60	0.38	8.0	2.8	2.8	-6.9	11
49	57.3	6.8	18.08	159	0.65	60	0.33	8.0	2.8	2.8	-6.9	10
50	60.0	10.1	20.28	76	0.45	60	0.16	8.0	2.8	-2.8	-6.9	3
51	60.0	13.4	20.28	76	0.45	60	0.16	8.0	4.0	0.0	-6.9	3
52	60.0	17.7	20.28	76	0.45	60	0.16	8.0	4.0	0.0	-6.9	3
53	60.0	21.5	20.28	76	0.45	60	0.16	8.0	4.0	0.0	-6.9	3
54	66.6	7.0	17.68	34	0.3	60	0.07	8.0	0.0	-4.0	-6.9	5
55	66.8	7.7	17.68	34	0.3	0	0.07	8.0	5.7	-5.7	0.0	14
56	68.0	11.4	16.58	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
57	67.3	11.3	17.48	114	0.55	60	0.24	8.0	-4.0	0.0	-6.9	8
58	68.0	16.3	16.98	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
59	67.3	15.7	17.48	114	0.55	60	0.24	8.0	-4.0	0.0	-6.9	8
60	68.0	20.5	17.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
61	67.3	20.4	17.18	114	0.55	60	0.24	8.0	-4.0	0.0	-6.9	8
62	67.3	21.6	17.18	34	0.3	60	0.07	8.0	-2.0	3.5	-6.9	5
63	71.8	11.4	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
64	71.8	8.8	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
65	76.2	9.5	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
66	71.2	5.0	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
67	72.9	-0.9	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
68	72.9	-5.0	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
69	73.2	-5.9	20.78	24	0.25	60	0.05	8.1	0.0	4.1	-7.1	5
70	74.0	-5.9	20.78	24	0.25	60	0.05	8.1	2.9	2.9	-7.1	5
71	69.0	-3.9	20.78	34	0.3	60	0.07	8.0	1.4	3.8	-6.9	5
72	69.0	-4.8	20.78	34	0.3	60	0.07	8.0	4.0	0.0	-6.9	5
73	69.4	-7.3	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
74	71.2	-11.7	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
75	71.4	-12.5	18.28	60	0.4	60	0.13	8.0	4.0	0.0	-6.9	7
76	75.9	-10.5	16.18	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
77	68.0	-11.7	17.38	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7
78	70.3	-11.9	18.28	60	0.4	60	0.13	8.0	0.0	4.0	-6.9	7
79	68.2	-13.8	17.38	24	0.25	90	0.05	8.1	0.0	0.0	-8.1	5
80	68.2	-16.7	17.38	24	0.25	90	0.05	8.1	0.0	0.0	-8.1	5
81	66.5	-15.0	17.78	185	0.7	60	0.38	8.0	-4.0	0.0	-6.9	11
82	67.0	-19.1	17.78	185	0.7	60	0.38	8.0	-4.0	0.0	-6.9	11
83	70.3	-20.5	17.88	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
84	73.3	-20.5	17.88	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
85	75.0	-20.5	17.88	34	0.3	60	0.07	8.0	4.0	0.0	-6.9	5
86	68.2	-23.3	17.98	34	0.3	90	0.07	8.0	0.0	0.0	-8.0	5
87	69.0	-24.7	17.98	24	0.25	60	0.05	8.1	4.1	0.0	-7.1	5
88	65.5	-10.4	17.38	76	0.45	60	0.16	8.0	0.0	4.0	-6.9	3
89	62.2	-11.7	17.38	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7

Nozzel number	X [m]	Y [m]	Z [m]	Q[m³/min]	Diameter[m]	DN[deg]	Area[m2]	Vel[m/s]	U[m/s]	V[m/s]	W[m/s]	Leak type
90	59.3	-10.5	19.48	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7
91	57.7	-6.6	17.58	1440	1.748	10	2.40	10.0	-9.7	1.7	-1.7	12
92	49.7	-6.5	18.08	1440	1.748	10	2.40	10.0	-4.9	8.5	-1.7	13
93	53.5	-10.5	17.78	185	0.7	90	0.38	8.0	0.0	0.0	-8.0	11
94	53.5	-13.3	17.88	136	0.6	90	0.28	8.0	0.0	0.0	-8.0	9
95	53.7	-17.2	18.18	185	0.7	60	0.38	8.0	4.0	0.0	-6.9	11
96	53.7	-20.0	18.18	136	0.6	60	0.28	8.0	2.8	-2.8	-6.9	9
2nd deck plan 23.9m A/B												
97	55.5	15	27.4	159	0.65	60	0.331831	8.0	-2.0	3.5	-6.9	10
98	55.5	13.3	27.3	159	0.65	90	0.33	8.0	0.0	0.0	-8.0	10
99	55.5	11.2	27.3	159	0.65	60	0.33	8.0	-4.0	0.0	-6.9	10
100	55.5	7.0	26.5	114	0.55	60	0.24	8.0	-2.8	-2.8	-6.9	8
101	55.5	5.7	26.5	114	0.55	90	0.24	8.0	0.0	0.0	-8.0	8
102	55.5	5.2	26.7	185	0.7	45	0.38	8.0	0.0	-5.7	-5.7	15
103	59.3	6.5	27.1	94	0.5	90	0.20	8.0	0.0	0.0	-8.0	6
104	62.2	4.9	26.7	114	0.55	45	0.24	8.0	0.0	-5.7	-5.7	15
105	64.3	4.7	27.1	159	0.65	45	0.33	8.0	0.0	-5.6	-5.6	15
106	53.9	-7.0	27.3	114	0.55	30	0.24	8.0	0.0	6.9	-4.0	8
107	54.2	-7.1	27.3	114	0.55	60	0.24	8.0	2.8	2.8	-6.9	8
108	54.2	-8.5	27.3	114	0.55	90	0.24	8.0	0.0	0.0	-8.0	8
109	55.7	-10.5	26.6	136	0.6	60	0.28	8.0	-2.8	-2.8	-6.9	9
110	57.0	-12.1	26.9	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7
111	57.0	-14.9	26.9	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7
112	57.0	-16.5	27	60	0.4	60	0.13	8.0	-4.0	0.0	-6.9	7
113	57.0	-18.2	27.3	114	0.55	60	0.24	8.0	4.0	0.0	-6.9	8
114	57.0	-19.1	27.3	136	0.6	45	0.28	8.0	4.0	-4.0	-5.7	15
115	60.8	-14.2	27.3	60	0.4	60	0.13	8.0	-2.0	-3.4	-6.9	7
116	60.8	-13.1	26.9	60	0.4	60	0.13	8.0	2.8	-2.8	-6.9	7
117	62.5	-8.4	26.5	60	0.4	90	0.13	8.0	0.0	0.0	-8.0	7
118	62.9	-7.6	26.7	60	0.4	60	0.13	8.0	0.0	4.0	-6.9	7
Total flow rate				12965								
Effective total				11993								

* The nozzles marked by grey colour are not modelled in CFD simulations, because they are located in closed room or space (where there is separate ventilation towards the outside) and they should have little contribute (if any) to the air flow inside the engine room and funnel.

* The effective rate is the total air flow rate into engine room excluding those closed rooms or space.

APPENDIX B: AIR INLET DEFINITION IN ENGINES

Inlet position	X [m]	Y [m]	Z [m]	Q[m³/min]	Length [m]	Wdith [m]	Area[m2]	Vel[m/s]	U[m/s]	V[m/s]	W[m/s]	Leak type
Main engine												
inlet 1 upper side	47.3	-4.1	15.5	537.3	2.0	0.5	1.0	9.0	0	0	-9.0	16
inlet 1 lower side	47.3	-4.1	13.7	537.3	2.0	0.5	1.0	9.0	0	0	9.0	17
inlet 1 +y side	47.3	-3.2	14.6	537.3	2.0	0.5	1.0	9.0	0	-9.0	0	18
inlet 1 -y side	47.3	-5.0	14.6	537.3	2.0	0.5	1.0	9.0	0	9.0	0	19
inlet 2 upper side	49.0	-4.1	15.5	537.3	2.0	0.5	1.0	9.0	0.0	0.0	-9.0	16
inlet 2 lower side	49.0	-4.1	13.7	537.3	2.0	0.5	1.0	9.0	0.0	0.0	9.0	17
inlet 2 +y side	49.0	-3.2	14.6	537.3	2.0	0.5	1.0	9.0	0.0	-9.0	0.0	18
inlet 2 -y side	49.0	-5.0	14.6	537.3	2.0	0.5	1.0	9.0	0.0	9.0	0.0	19
Generator Engines												
No. 1	64.5	-18.5	17.5	414.6	1.0	1.0	1.0	8.6	0	-8.6	0.0	20
No. 2	64.5	-14.0	17.5	414.6	1.0	1.0	1.0	8.6	0	-8.6	0.0	20
No. 4	64.5	16	17.5	414.6	1.0	1.0	1.0	8.6	0	-8.6	0.0	20
No. 5	64.5	20.3	17.5	414.6	1.0	1.0	1.0	8.6	0	-8.6	0.0	20
Total flow rate				5956.8								

APPENDIX C: VISIBILITY PLOTS OF SOME CASES

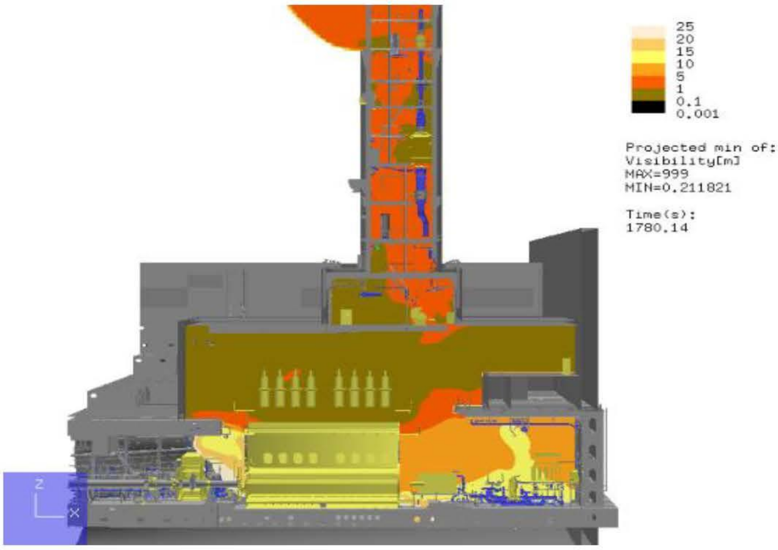


Figure C- 1: Case 1 with leak spray at “Close to SB engine”, flow rate 2.3 kg/s, towards port.

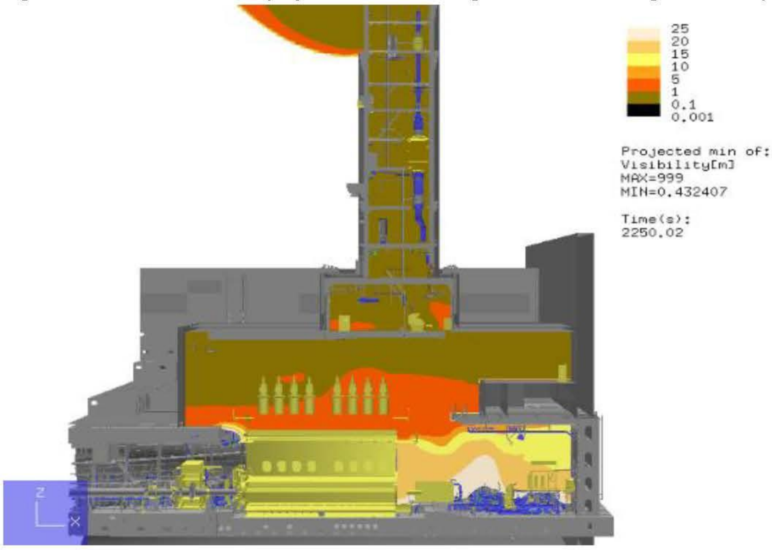


Figure C- 2: Case 2 with leak spray at “Close to SB engine”, flow rate 2.3 kg/s, towards aft.

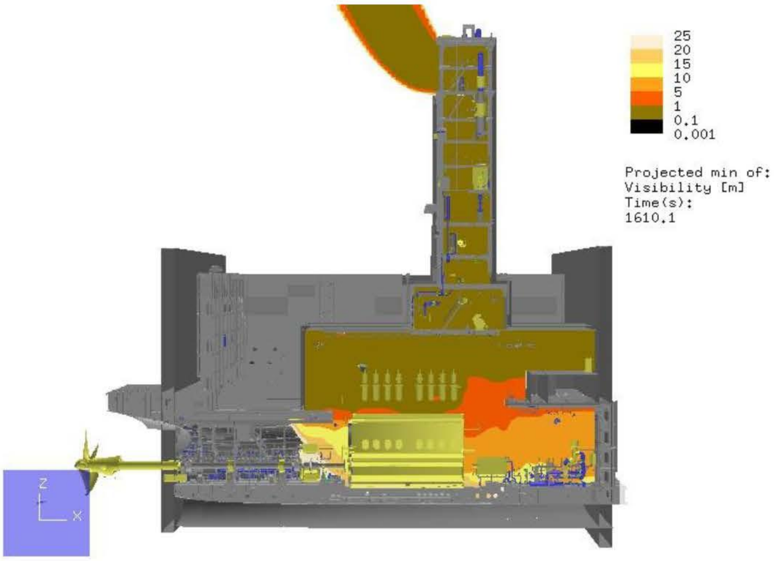


Figure C- 3: Case 3 with leak spray at “Close to SB engine”, flow rate 2.3 kg/s, downwards, 300°C fuel.

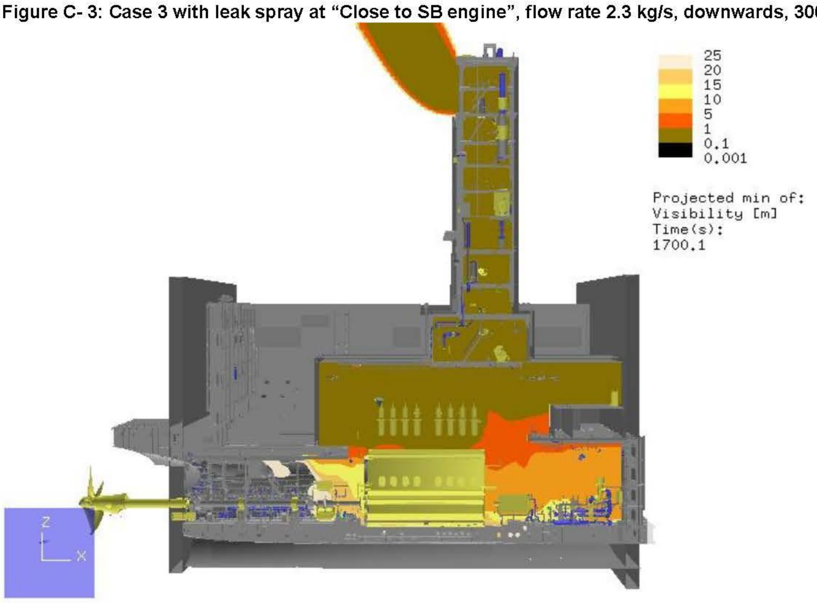


Figure C- 4: Case 5 with leak spray at “Close to SB engine”, flow rate 2.3 kg/s, downwards, 100°C fuel.

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