Base Load Power Hub (BLPH)

Vent Gas Dispersion and Potential Radiation Study

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1 EXECUTIVE SUMMARY

The purpose of the vent gas dispersion and radiation study is to define the main characteristics of the vent of BLPH platform, in order to allow a safety depressurization in case of emergency of plant equipment handling hydrogen for equipment and operators.

According to project documentation "Relief, Vent and Blowdown Report [2]", the reference worst case scenario for the design to the stack is the simultaneous discharge of all 7 blowdown valves on platform.

The height of the stack is calculated in order to preserve the safety of the equipment which handled hydrogen and avoid impact on the health of operators during planned maintenance activity.

According to the project philosophy, hydrogen storage vessels are not depressurized during maintenance unless work is required in the restricted area. In such cases, the hydrogen storage vessels will be depressurized [8].

Several receptor points have been considered for sizing the stack heights, corresponding to the valves on the platform above storage vessel (the valves are the closest equipment to the stack) and working positions of operators in the platform.

Via FLARESIM software the stack diameter and height were calculated in order to verify that the thermal radiation will not exceed the values of 12.5 kW/m^2 on equipment and 6.31 kW/m^2 at receptors point where people presence should be possible during maintenance operation. Regarding flammable gas dispersion, via PHAST was possible to calculate the LFL and LFL/2 concentrations of dispersion in order to evaluate possible involvement of receptors.

Result of the present study are obtained considering following vent characteristic:

- Stack height: 3.2 m.
- Stack diameter: 20 inch.
- Tip height: 5 m.
- Tip Type: pipe.
- Tip diameter: 12 inch.

Please note that these heights are referred to the top deck platform above hydrogen storage vessel, which is at elevation of 38.6 m. Considering the upper deck elevation (+30.3 m), the total structure of the vent (stack and tip) is equal to 16.5 m. height from the upper deck.

The total height of the system, including the stack and tip length, reaches + 46.8 m.

According to the vent design, the reference receptors points for equipment (receptors A, B, C) shows values well below to the reference threshold of 12.5 kW/m^2 for each meteo climatic condition, thus the design of the vent is considered acceptable for thermal radiation on asset. Regarding thermal radiation of receptors on location where operators' presence is foreseen (receptors 1-10), for the receptors:

- 2, Operator on structure above storage vessel – west stair;
- 3, Operator on structure above storage vessel – east stair;

The expected thermal radiation is above 6.31 kW/m^2 for wind case 1 and 2. Thus, the second level of the platform above storage vessel on upper deck (elevation +38.6 m.), does not meet the target criteria for operator. In order to investigate potentially other areas, even if not normally manned during operator maintenance activities, which can be exposed to thermal radiation higher than 6.31 kW/m^2, additional evaluation was performed, considering the minimum elevation reached by such threshold in the worst meteo-climatic conditions. From this conservative analysis, two areas show thermal value potentially higher that 6.31 kW/m^2:

- The second level of the platform above storage vessel on upper deck (elevation +38.6 m.; the same already identified from the receptors point analysis);
- The roof of electrolyser package (elevation +36.8 m.). Note that in such areas, no stairs are provided, meaning that operator presence need to be considered unlikely.

Since these areas result to be over the acceptable limit of 6.31kW/m^2, it is necessary to foresee a sterile area where only people are allowed under strict procedures/ PPEs or when the platform is depressurized.

Specific recommendations are issued to limit the maintenance activities at such areas.

Note that during normal maintenance the operators are allowed to operate anywhere excluding these restricted area. Anyhow, in terms of frequency of occurrence, the exposure of operators to the vent fire is very unlikely, since:

- Operators shall be properly trained and informed on restricted areas;
- Presence of operators for maintenance activities is limited to 16h in a year (1 day each 6 months, meaning 2 days (16 hours) in 365 days (8760 hours);
- An emergency on platforms which required the depressurization shall happen during these 16h when no operation is ongoing;
- An ignition of the released H_2 is unlikely (note during bad weather maintenance activities will not occur, thus a lightning ignition is very remote).

Regarding flammable gas dispersion, for each meteo condition and wind direction, both the concentration of LFL and LFL/2 shows no impact on platform equipment/structures (unless at top of vent tip): according to characteristic of H_2, the gas clouds move towards the wind direction but always at elevation higher than the stack. As the vent is the highest structure on the upper deck, the release from the vent is vertical upwards and H_2 is lighter than air, there is no impairment from dispersion to any other structure.

In conclusion, the present vent design allows a safety depressurization both in case of dispersion and ignition for asset and operator, considering the recommendations in place.

2 INTRODUCTION

2.1 PROJECT OVERVIEW

Crosswind, a Shell and Eneco joint venture, was awarded the tender to develop the offshore Hollandse Kust Noord (HKN) wind farm, located 18.5km off the coast of Netherlands near the town of Egmond aan Zee. The consortium plans to have HKN operational in 2023 with an installed capacity of 759MW generating at least 3.3TWh per year. This is sufficient renewable power to supply more than 1 million Dutch households with green electricity.

Offshore wind farms produce intermittent electricity and balancing these dips and peaks and integrating this electricity into the national energy system requires new technologies. For this reason, the offshore wind farm will include several new technologies that could be implemented at full-scale in the future. The new technologies being explored include a floating solar park, a short-duration battery storage as well as long-term storage via green hydrogen produced by water electrolysis and subsequently consumed in a fuel cell. The combination of these individual measures, herein referred to as the Base Load Power Hub (BLPH) will ensure a continuous power supply regardless of the wind situation.

2.1.1 Project Location

The Hollandse Kust Noord (HKN) wind farm is located 18.5km off the coast of the Netherlands near the town of Egmond aan Zee.

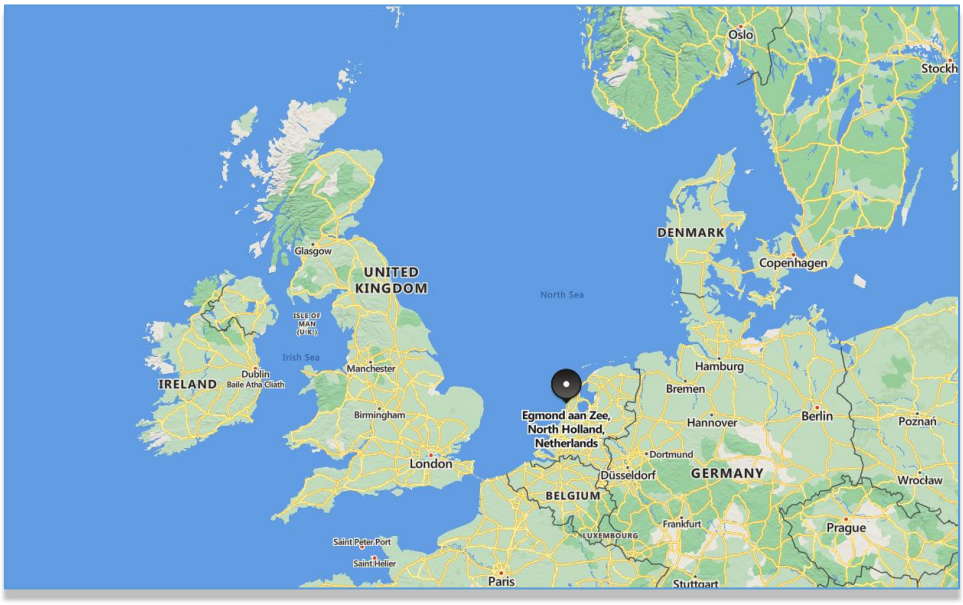


Figure 1 HOLLANDSE KUST NOORD WIND PARK Location Map

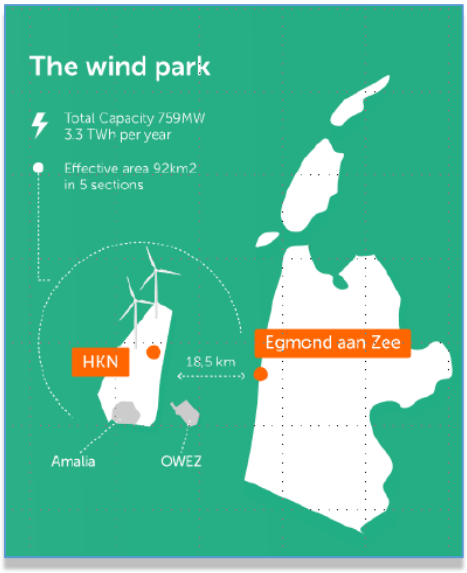


Figure 2 - Wind Park Details

The wind farm will consist of No. 69 x 11.5MW wind turbine generators each to be installed on a dedicated monopile structure. A 70th monopile located on coordinates E 590719.1, N 5841602.3 is reserved for installing the platform accommodating the BLPH. The monopile structure was designed and installed by Van Oord Offshore Wind (VooW) and therefore not part of the BLPH scope.

2.1.2 Project Concept

All components included in the BLPH will be integrated onshore on a topsides and installed in an offshore location within the boundaries of the HKN wind farm. At its simplest, the BLPH will store energy during periods of high electricity generation from renewable sources (a wind turbine generator and the floating solar PV farm) and release it during periods of low generation. In practice. It is expected that the energy stored will supplement generation from renewable sources to ensure that at least 1.0MW of power is exported to the electrical grid regardless of wind/solar availability.

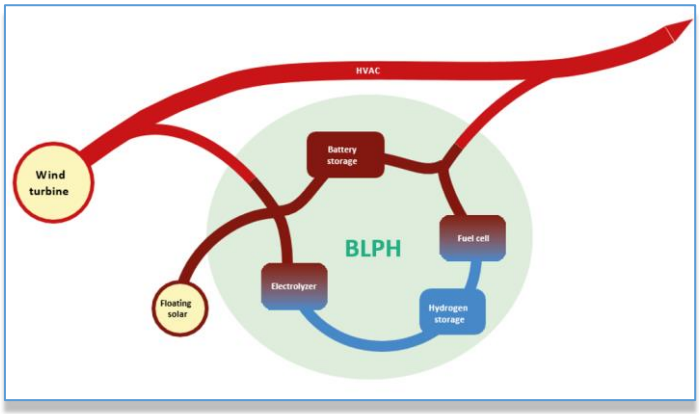


Figure 3 – BLPH Concept

Electricity in the BLPH will be stored in the form of electrons in a battery energy storage system (BESS) as well as converted into green hydrogen via water electrolysis. When the power output from the connecting wind turbine drops to below 1 MWe, the BLPH will return its stored energy to supplement the remaining power output. This will be by discharging the BESS, while stored hydrogen will be converted back into electricity using a fuel cell to extend the discharge duration.

The purpose of the BLPH s to function as a testbed for the integration of energy storage technologies with renewable generation. It is expected that equipment installed on the BLPH will operate as Normally Unmanned Installation for at least two (2) years with no or minimal maintenance and it will have its own independent control room with the ability to communicate with Crosswind's control room.

3 DOCUMENT SCOPE

According to project documentation, the scope of the vent system is to allow depressurization during emergencies. Thus, the purpose of the vent gas dispersion and radiation study is to define the main characteristics of the vent of BLPH platform, in order to allow a safety depressurization in case of emergency for plant equipment handling hydrogen and for operators, which can be present in the platform during maintenance activities. According to the project philosophy, hydrogen storage vessels are not depressurized during maintenance unless work is required in the restricted area. In such cases, the hydrogen storage vessels will be depressurized [8].

As for cause and effect diagram, the depressurization is foreseen in case of:

- Confirmed fire
- Push buttons
- LLP on nitrogen
- H_2 confirmed
- H_2/smoke inside B-100 / B200 / WTP
- Loss of onshore comm

The present report is focussed on :

- Flammable gas dispersion analysis;
- Heat radiation analysis (in case of unlikely event of ignition of the hydrogen during the release).

3.1 MAIN REFERENCES

Ref.	Description
1	K559-2254-PM-PLN-003 – Basis Design Engineering Package rev-02, 06/07/23
2	123A90-DDL-PR-RE-80030_01, Relief, Vent and Blowdown Report, 01, 05/02/2024
3	123A90-DDL-SAF-LIS-30014, Assumption Register, revision 01
4	Risk assessment data directory, document no. IOGP 434_14 – 2013 - Vulnerability of humans
5	BLPH-CROSSWIND-25-03-2024 (3D model of platform, last issue available during vent study preparation
6	K559-2254-PR-REP-001 – Process Description (note: study for FEED phase)
7	API Standard 521 Pressure-relieving and Depressuring Systems, 2020
8	123A90-DDL-PR-MAN-80001 Operations and Maintenance Manuals, 00

Table 1 - Reference Documents

3.2 DEFINITIONS AND ABBREVIATIONS

3.2.1 Definitions

COMPANY or Client (CPY):	Crosswind
EPC CONTRACTOR (CTR):	ROSETTI MARINO S.p.A.
PROJECT:	HOLLANDSE KUST NOORD WIND PARK Project

Table 2 - Definitions

3.2.2 Abbreviations

API	American Petroleum Institute
BDV	Blow down valve
BESS	Battery energy storage system
BLPH	Base Load Power Hub
DNV	Det Norske Veritas
FLARESIM	A specialized software used for modeling and analyzing flare systems in industrial plants.
HKN	Hollandse Kust Noord
HyRAM	Hydrogen Risk Assessment Model
IOGP	International Association of Oil & Gas Producers
LFL	Lower Flammable Limit
LLP	Low Low Pressure
MW	MegaWatt
PHAST	DNV software for modelling discharge, dispersion, fires, explosion and toxic effects of a wide range of loss of containment scenarios.
PSV	Pressure Safety valve
PV	Photovoltaic
RP	Receptor point
TOS	Top Of Steel
VooW	Van Oord Offshore Wind
WTP	Water Treatment Package

Table 3 - Abbreviations

4 METHODOLOGY

The study is developed according to the following main steps:

- Identification of reference case: identification of plant depressurization worst case scenario.
- Reference thresholds: identification of reference thermal radiation/flammable concentration thresholds.
- Consequences evaluation: development of fire and flammable gas dispersion scenario for the reference case.

The application of the methodology described above is reported in the following sections.

4.1 IDENTIFICATION OF REFERENCE CASES

The first step in the design of the new stack is the identification of the possible depressurization scenarios. According to Relief, Vent and Blowdown Report [2], the following depressurization scenarios have been identified as critical.

Relieving Device	Service	Calculated Relief PEAK Flowrate (kg/h)	Relief Pressure (barg)	Relief Temperature (°C) (at peak flowrate)	Scenario
25-PSV-001A	H2 Storage Vessel Protection	627	48.4(*)	213.6	Fire
25-PSV-001B	H2 Storage Vessel Protection	627	48.4(*)	213.6	Fire
25-PSV-001C	H2 Storage Vessel Protection	627	48.4(*)	213.6	Fire
25-PSV-001D	H2 Storage Vessel Protection	627	48.4(*)	213.6	Fire
25-PSV-001E	H2 Storage Vessel Protection	627	48.4(*)	213.6	Fire
25-PSV-001F	H2 Storage Vessel Protection	627	48.4(*)	213.6	Fire
80-PSV-001	FC feed line	2679	11	25	CV failure
64-PSV-001	Nitrogen system protection	61.4	11	AMB	Bloc.disch
25-BDV-005	Emergency depressurizzation	2047	30	25	Fire
25-BDV-007	Emergency depressurizzation	2047	30	25	Fire
25-BDV-010	Emergency depressurizzation	2047	30	25	Fire
25-BDV-013	Emergency depressurizzation	2047	30	25	Fire
25-BDV-016	Emergency depressurizzation	2047	30	25	Fire
25-BDV-019	Emergency depressurizzation	2047	30	25	Fire
25-BDV-022	Emergency depressurizzation	119	30	25	Fire

Table 4 – Depressurization scenarios

(*) and from [2], during the dynamic simulation with orifice "E" the PSV set pressure is reached after about 4.8 min.

The report [2] concludes that the worst-case scenario ("governing case" for blowdown network) is the simultaneous discharge of all 7 (seven) blowdown valves listed in the above table, even though, depending on the fire attack scenario, it may happen that only some of the PSVs will discharge through the network.

This scenario is considered the "reference worst case scenario" and thermal radiation and flammable gas dispersion was investigated with software simulation. The main data is summarized below.

Case	Scenario description	Total Flowrate (kg/h)
Emergency depressurization	Simultaneous discharge of all 7 blowdown valves	13485

Table 5 – Reference depressurization scenarios

4.2 REFERENCE THRESHOLDS

According to project documentation, the scope of the vent system is to allow depressurization during emergencies. Thus, the purpose of the vent gas dispersion and radiation study is to define the main characteristics of the vent of BLPH platform, in order to allow a safety depressurization in case of emergency for plant equipment handling hydrogen and for operators, which can be present in the platform during maintenance activities. According to the project philosophy, hydrogen storage vessels are not depressurized during maintenance unless work is required in the restricted area. In such cases, the hydrogen storage vessels will be depressurized [8].

As for cause and effect diagram, the depressurization is foreseen in case of:

- Confirmed fire
- Push buttons
- LLP on nitrogen
- H_2 confirmed
- H_2/smoke inside B-100 / B200 / WTP
- Loss of onshore comm

Two reference scenarios are considered:

- An ignition of H_2 after the release, leading to the formation of a flame in the top of the stack;
- A H_2 flammable gas dispersion from the stack (without ignition).

Reference thresholds below are reported.

Fire scenario

The following heat radiation threshold values have been considered [4], for structures:

- the radiation of 12.5 kW/m^2 (including solar radiation) shall not be reached by equipment installed near the stack. At this threshold, "*thin steel with insulation on the side away from the fire may reach thermal stress level high enough to cause failure in load bearing structure*".
- the radiation of 25 kW/m^2 (including solar radiation) shall not be reached by equipment installed near the stack. At this threshold, "*unprotected steel will reach thermal stress temperature that can cause failure*".

And the following heat radiation threshold values have been considered [7]:

- The radiation of 6.31 kW/m^2 (including solar radiation) shall not be reached in location where people presence can be possible. According to API, 6.31 kW/m^2 is "*the maximum radiant heat intensity in areas where emergency action lasting up to 30 s can be required by personnel without shielding but with appropriate clothing*";

Flammable Gas Dispersion

In case of dispersion without ignition (normal case), a hydrogen flammable gas cloud will be released from the stack. The stack height will be designed in order to ensure that the flammable envelopes corresponding to LFL and ½ LFL concentrations shall not reach areas where ignition sources could be present.

4.3 CONSEQUENCES EVALUATION

Fire scenario

Calculation of thermal radiation from the stack was performed by means of Flaresim Software (revision 2023.3.131, last release) by Schlumberger. The results are reported in the tables and figures shown in chapter 5. The software has dedicated formulas in order to calculate the thermal radiation from H_2. In particular, the flame length and the heat radiation reached at the critical receptor points have been indicated.

Flammable Gas Dispersion

Modelling is performed by means of PHAST - DNV Technica software release 9 (last release), in order to determine physical effects in terms of flammable gas cloud dispersion on the basis of the threshold values detailed in section 4.2.

Climatic conditions

The climatic conditions used for the heat radiation and flammable gas dispersion studies are in accordance with project documentation [3] and are summarized in the table below.

Case	Scenario description
Ambient temperature (nom)	10.5°C
Relative humidity (%):	83
Solar Radiation	0.5 kW/m^2
Stability class/wind speed	2F, 5D, 10D

Table 6 – Reference climatic condition

Detailed location of vent is reported below, according to 3D model [5]. The stack base is located at the upper deck, in the west side, near the platform above storage vessel.

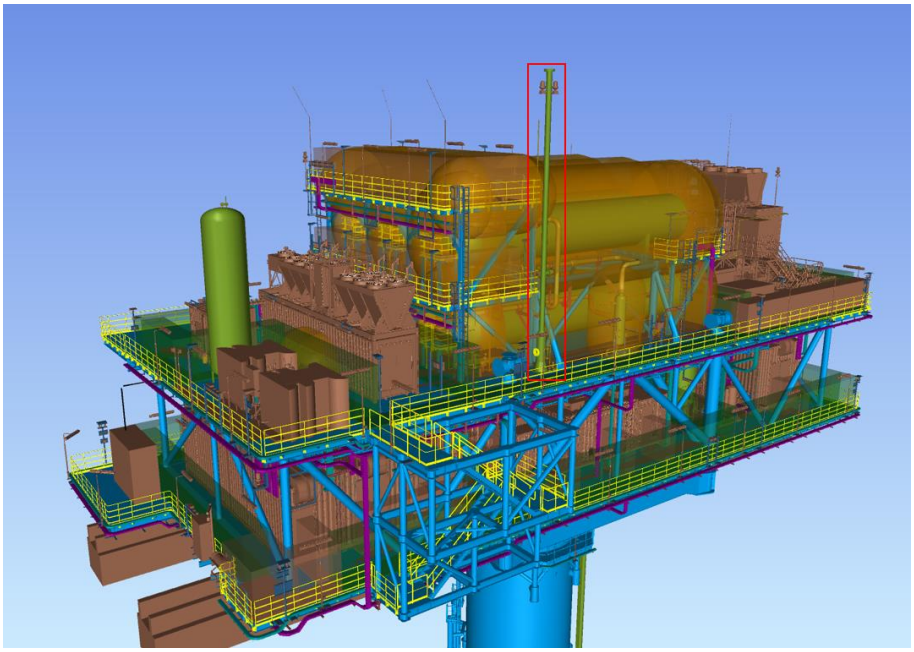


Figure 4 – Stack location – view from north-west

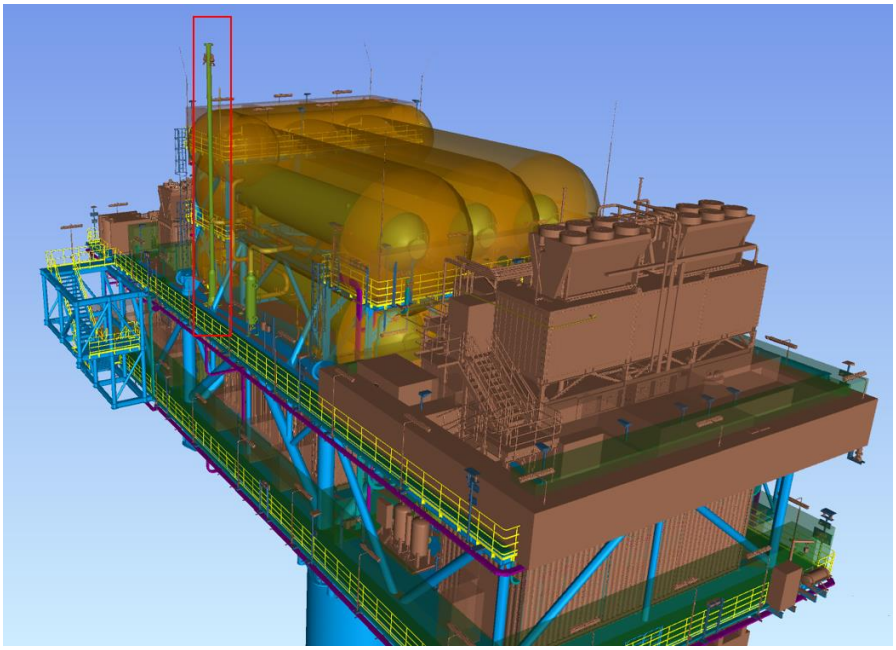


Figure 5 – Stack location – view from south-west

Receptor Points

The scope of the vent is to allow a safety depressurization in case of emergency for plant equipment handling hydrogen and for operators, which can be present in the platform during maintenance activities.

Two types of receptors are investigated:

- equipment near the stack;
- possible location where operator can be present due maintenance activity.

Equipment near the stack

The following receptor points (i.e. critical equipment) have been identified as critical. The heat radiation and the flammable gas dispersion have been analysed in particular in these points:

- Existing equipment: BDV/PSV valves located on the platform above storage vessels.

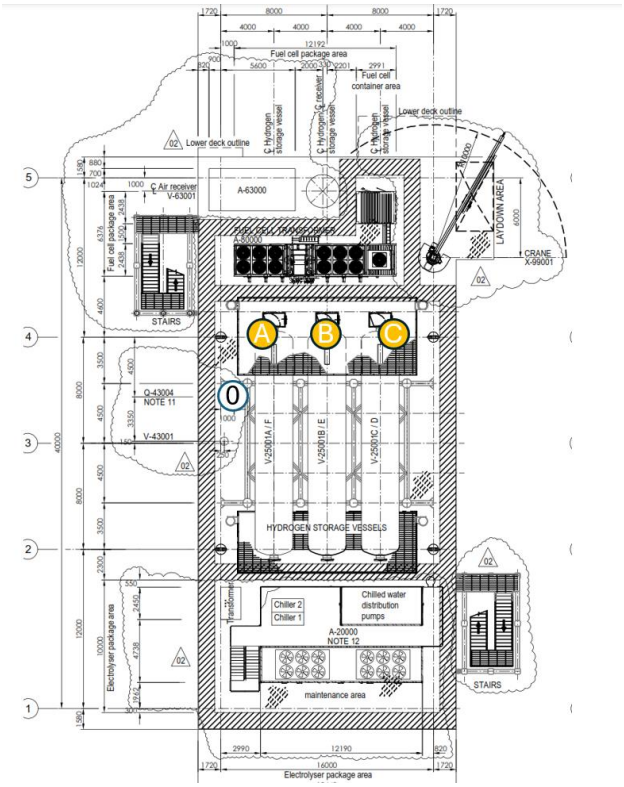


Figure 6 – Location of receptors (equipment)

The location of identifies points are described in the below table.

RP	Description	Distance from the stack E (m)	Distance from the stack N (m)	Elevation (m) from the TOS
0	Stack origin	0	0	+38.6 (30.3 m of upper deck + 8.3 m of the structure above storage vessel)
A	Valves area (V-25001E)	-3.4	-3.8	+39.1 (30.3 m of upper deck + 8.3 m of the structure + 0.5 m of the valves)
B	Valves area (V-25001F)	-3.4	-7.8	
C	Valves area (V-25001D)	-3.4	-11.8	

Table 7 – Receptor points location (equipment)

These valves are the nearest to the stack origin and are selected as dimensional scenario in order to evaluate stack impact on equipment.

Note that the origin of the stack (in terms of elevation) is considered equal to the elevation of the platform above storage vessel, meaning that the calculation of flare characteristics is referred to a starting elevation of 38.6 m (30.3 m of upper deck plus 8.3 m of the structure above storage vessel).

Location of operators during maintenance

According to the project philosophy, hydrogen storage vessels are not depressurized during maintenance unless work is required in the restricted area. In such cases, the hydrogen storage vessels will be depressurized [8]. In the contrary, electrolyser and fuel cell package are always not in service and depressurized.

As for cause and effect diagram, the depressurization is foreseen in case of:

- Confirmed fire
- Push buttons
- LLP on nitrogen
- H_2 confirmed
- H_2/smoke inside B-100 / B200 / WTP
- Loss of onshore comm

During maintenance activities, the worst scenario for operators is an emergency which requires the depressurization of storage vessel.

The nearest receptors point to the stack for operator during maintenance activity considered in the present report are reported in the following figure.

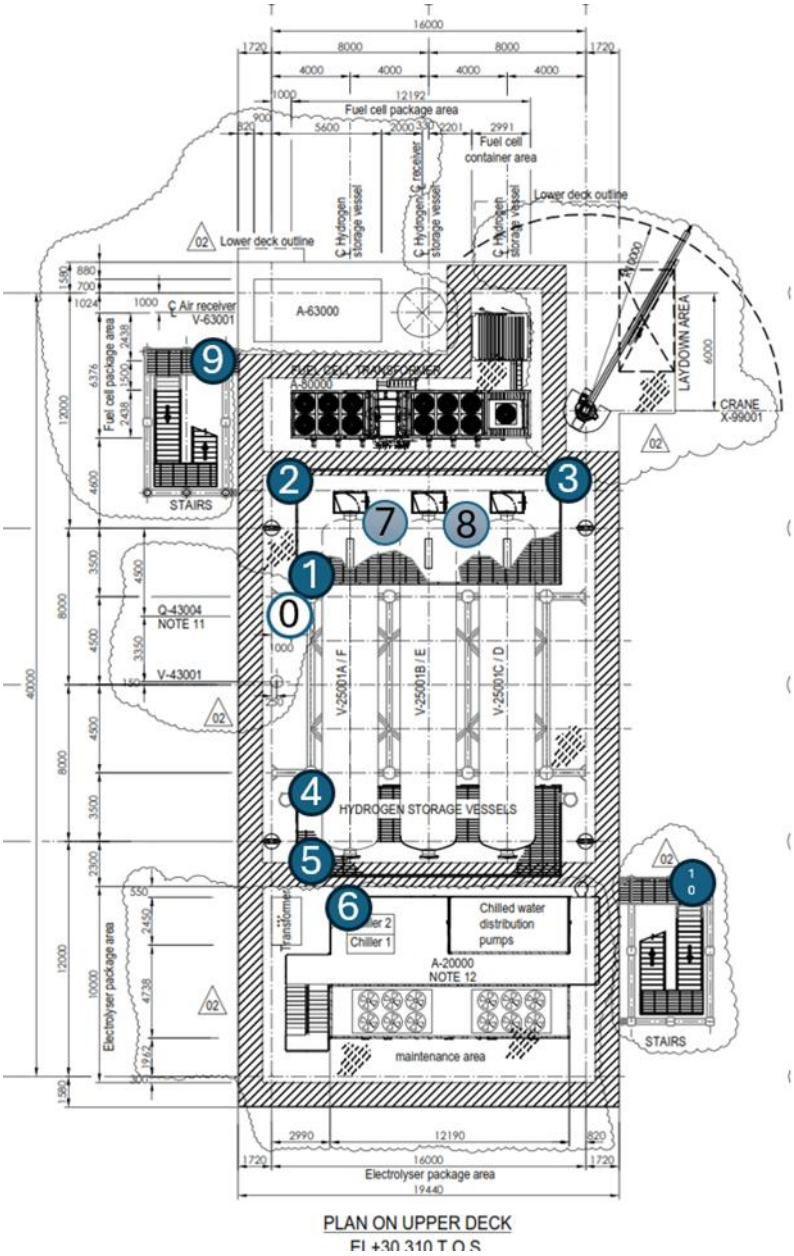


Figure 7 – Location of receptors (operators)

The location of identifies points are described in the below table.

RP	Description	Distance from the stack E (m)	Distance from the stack N (m)	Elevation (m) from the TOS
0	Stack origin	0	0	+38.6 (30.3 m of upper deck + 8.3 m of the structure above storage vessel)
1	Operator on structure above storage vessel – nearest corner to the stack (fuel cell package side)	-1.6	-0.8	+40.6 (30.3 m of upper deck + 8.3 m of the structure + 2 m of operator)
2	Operator on structure above storage vessel – west stair (fuel cell package side)	-7.5	-0.8	+40.6 (30.3 m of upper deck + 8.3 m of the structure + 2 m of operator)
3	Operator on structure above storage vessel – east stair (fuel cell package side)	-7.5	-14.2	+40.6 (30.3 m of upper deck + 8.3 m of the structure + 2 m of operator)
4	Operator on structure above storage vessel – nearest corner to vessels (electrolyser package side)	+13	+1.32	+36.8 (30.3 m of upper deck + 4.5 m of the structure + 2 m of operator)
5	Operator on structure above storage vessel – nearest corner to electrolyser package (electrolyser package side)	+9.1	+1.32	+36.8 (30.3 m of upper deck + 4.5 m of the structure + 2 m of operator)
6	Operator on electrolyser package – corner to storage vessel	+14.5	+3	35.8 (30.3 m of upper deck + 3.5 m of the structure + 2 m of operator)
7	Operator on structure above storage vessel – first level (fuel cell package side)	-4.5	-5.6	+36.3 (30.3 m of upper deck + 4 m of the structure + 2 m of operator)
8	Operator on structure above storage vessel – first level (fuel cell package side)	-4.5	-9.6	+36.3 (30.3 m of upper deck + 4 m of the structure + 2 m of operator)
9	Operator on upper deck stair (west side)	-2.8	+13	32.3 (30.3 m of upper deck + 2 m of operator)
10	Operator on upper deck stair (east side)	+13.7	-17.9	32.3 (30.3 m of upper deck + 2 m of operator)

Table 8 – Receptor points location (operators)

5 RESULTS

The results of the heat radiation and flammable gas dispersion calculation are presented in the following chapter.

The evaluation of the impact of thermal radiation is calculated following two approaches:

- In section 5.1 and 5.2 the thermal radiation results are reported for some selected receptors points representative for equipment and for main expected work position for operators;
- In section 5.3, the maximum thermal radiation (considered the worst meteo-climatic condition) is identified and, as conservative approach, the lowest height of the value 6.31 kW/m^2 is reported in the layout in order to identify areas where the thermal radiation are equal or above the safety threshold of 6.31 kW/m^2, which can be considered not-tolerable for operators.

5.1 THERMAL RADIATION EVALUATION: RECEPTORS POINTS

The results of the heat radiation and flammable gas dispersion calculation are reported in the following figures and in the tables on section 5.2.

Three meteo-condition are performed:

- 2F;
- 5D;
- 10D.

And three wind direction:

- Case 1: east to west (downwind flare stack, towards the platform above storage vessel);
- Case 2: south to north (wind towards fuel cell package)
- Case 3: north to south (wind towards electrolyze package)

The detailed graphs (elevation-easting, and elevation northing) showing the thermal profile for the “short” a “long” side of the platform was performed. The figures on sections 5.1.1, 5.1.2, 5.1.3 (figures from 8 to 16) reports, as example, the thermal radiation at location of receptor point 1 and 2 (operators located on structure above storage vessel).

A summary result table for each meteo-condition reports the expected thermal radiation values on each receptors.

Note that the most-unfavourable weather condition 10D (higher bending of the flame) is the reference cases for the stack design.

5.1.1 10D cases

Case 1

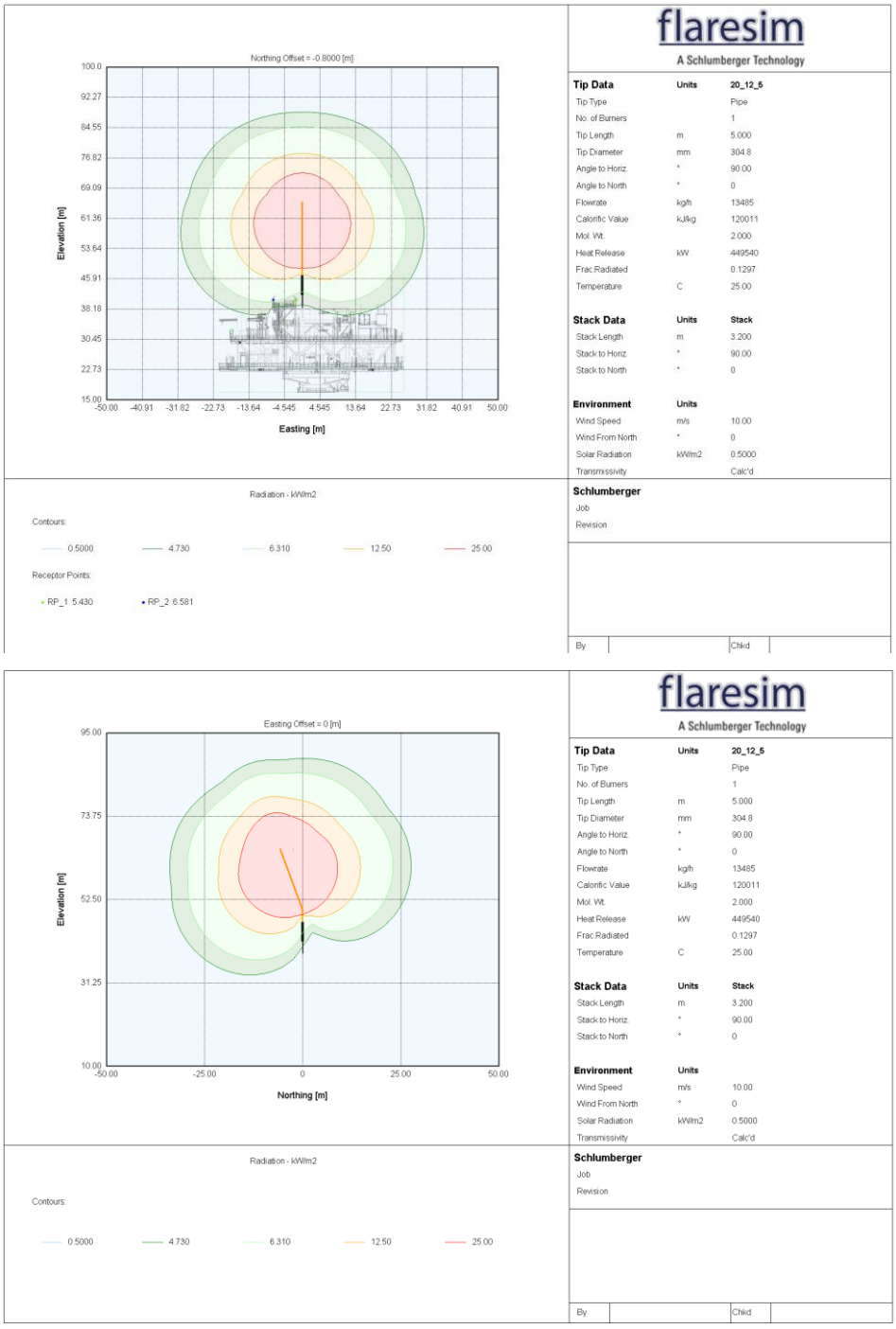


Figure 8 – Flaresim results views (elevation easting/northing, 10D, case 1)

Case 2

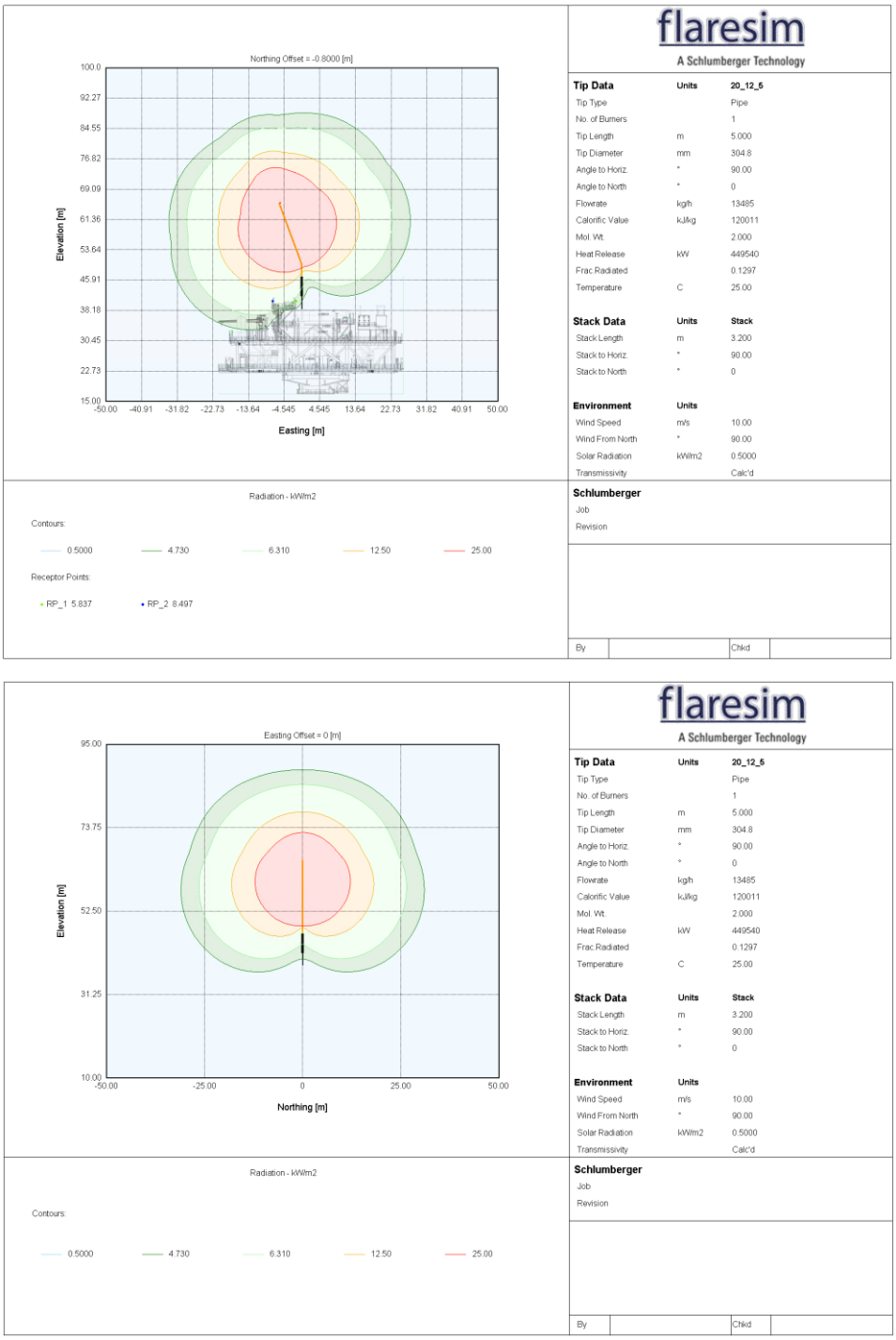


Figure 9 – Flaresim results views (elevation easting/northing,10D, case 2)

Case 3

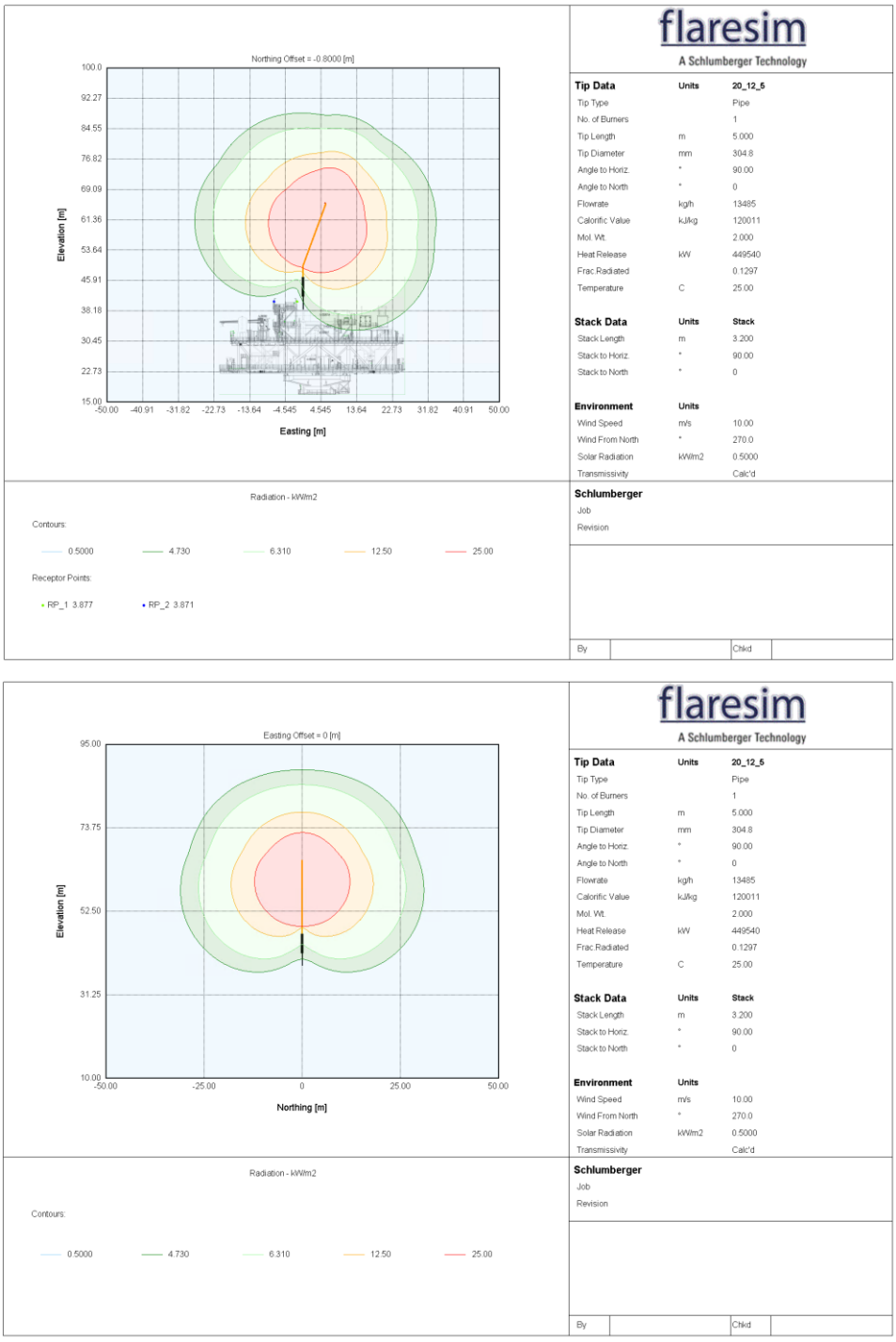


Figure 10 – Flaresim results views (elevation easting/northing,10D, case 3)

5.1.2 5D cases

Case 1

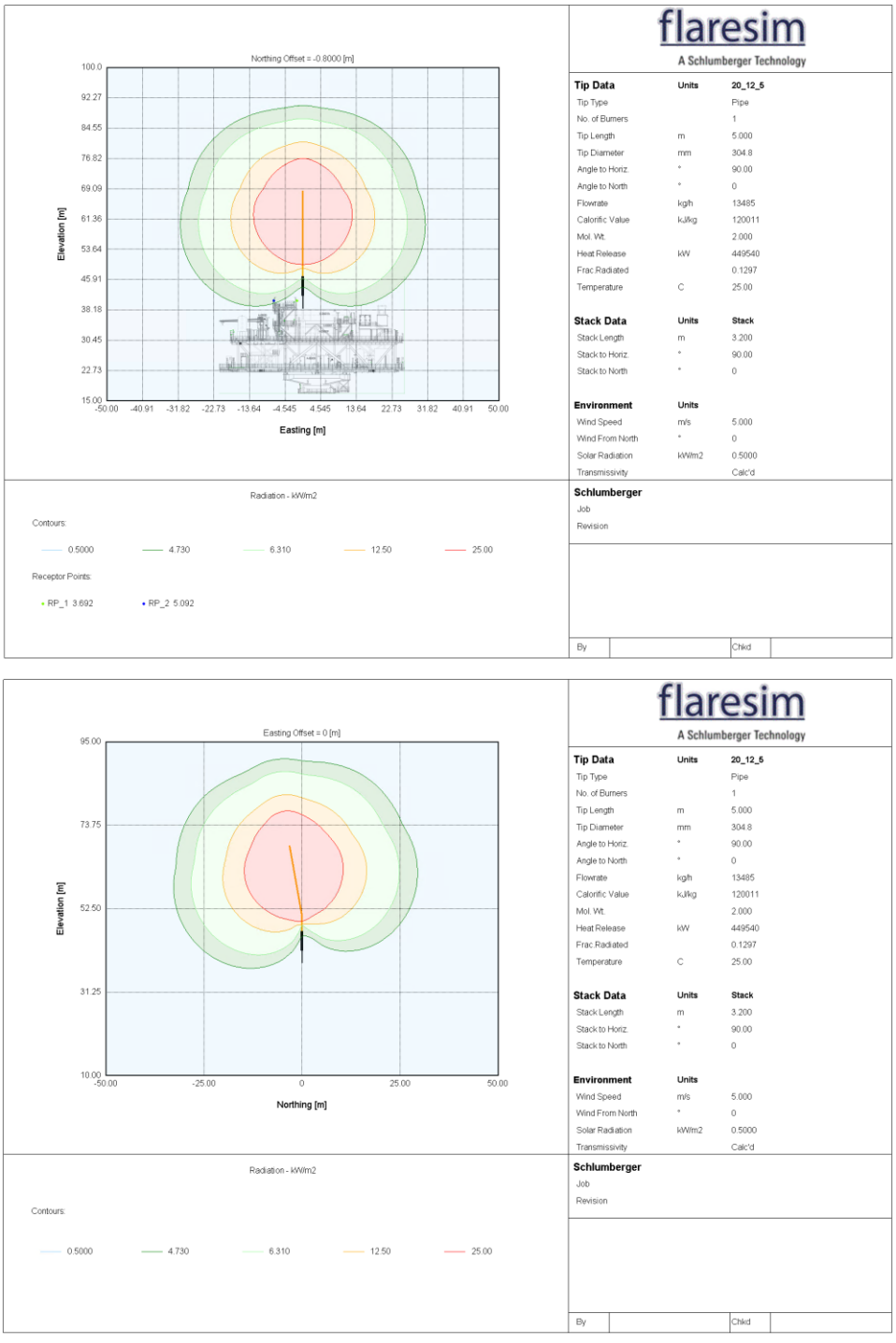


Figure 11 – Flaresim results views (elevation easting/northing,5D, case 1)

Case 2

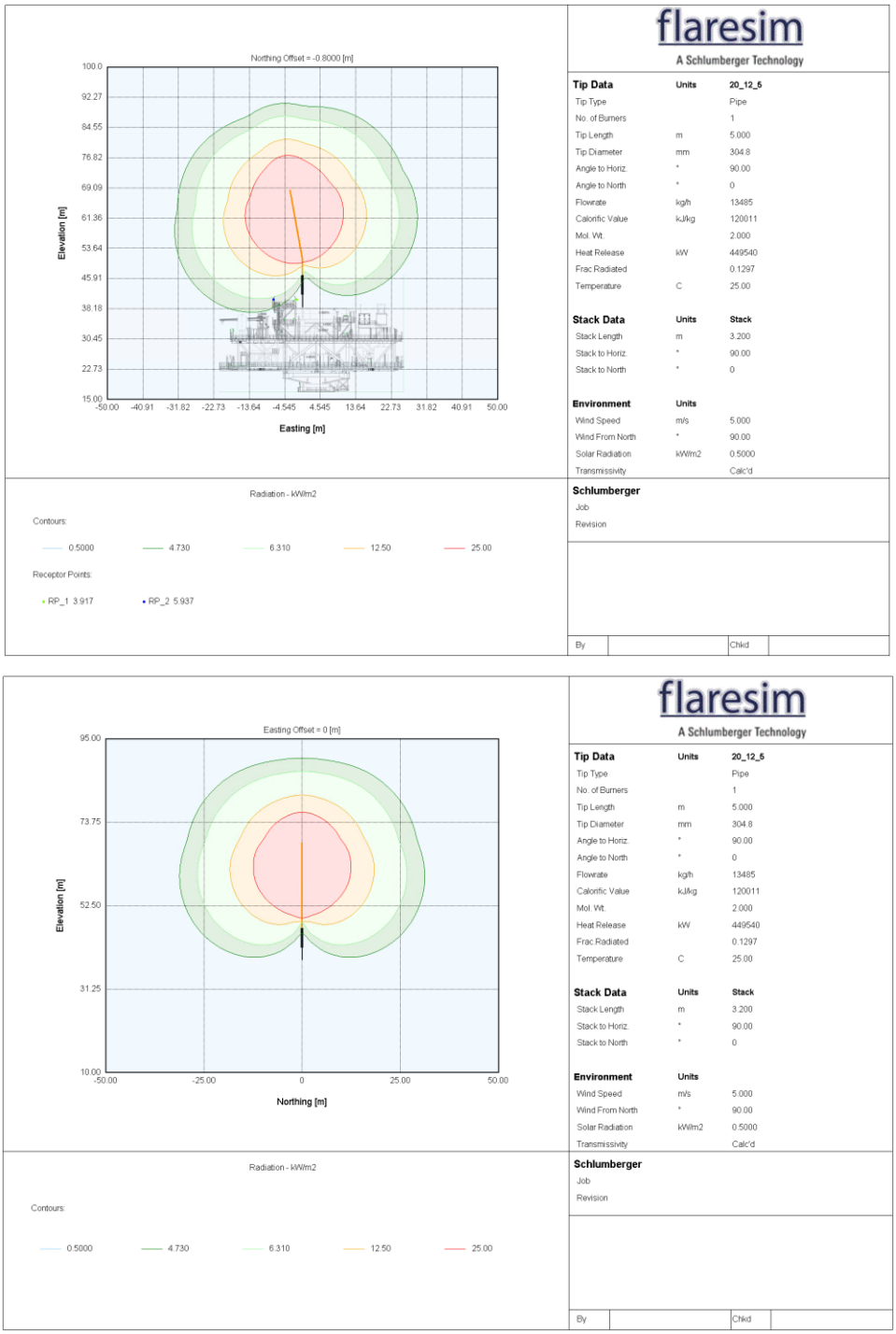
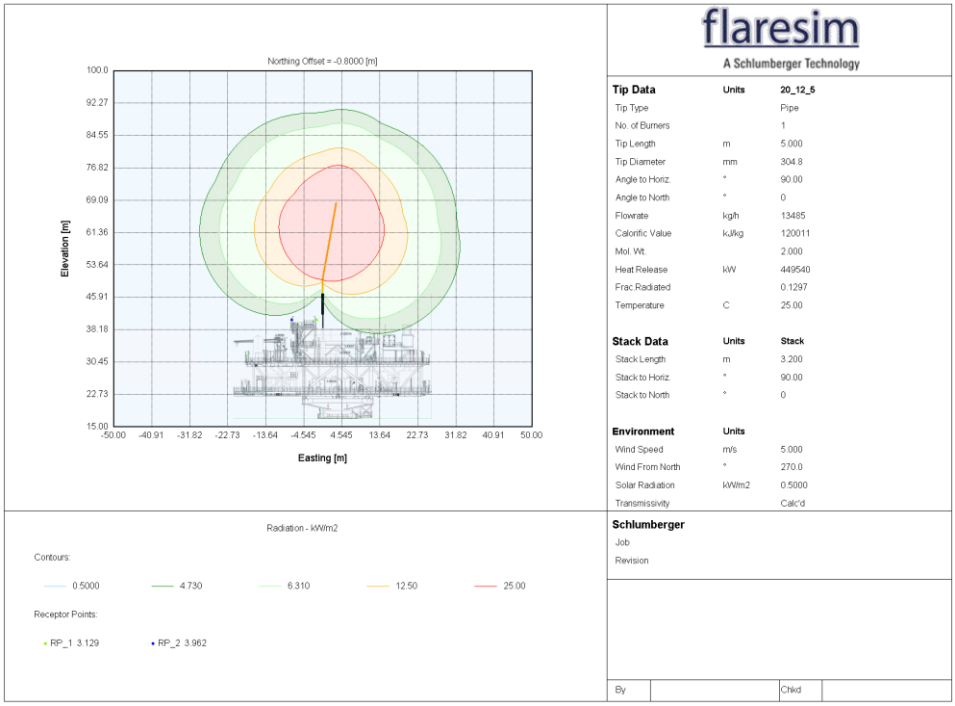


Figure 12 – Flaresim results views (elevation easting/northing,5D, case 2)

Case 3



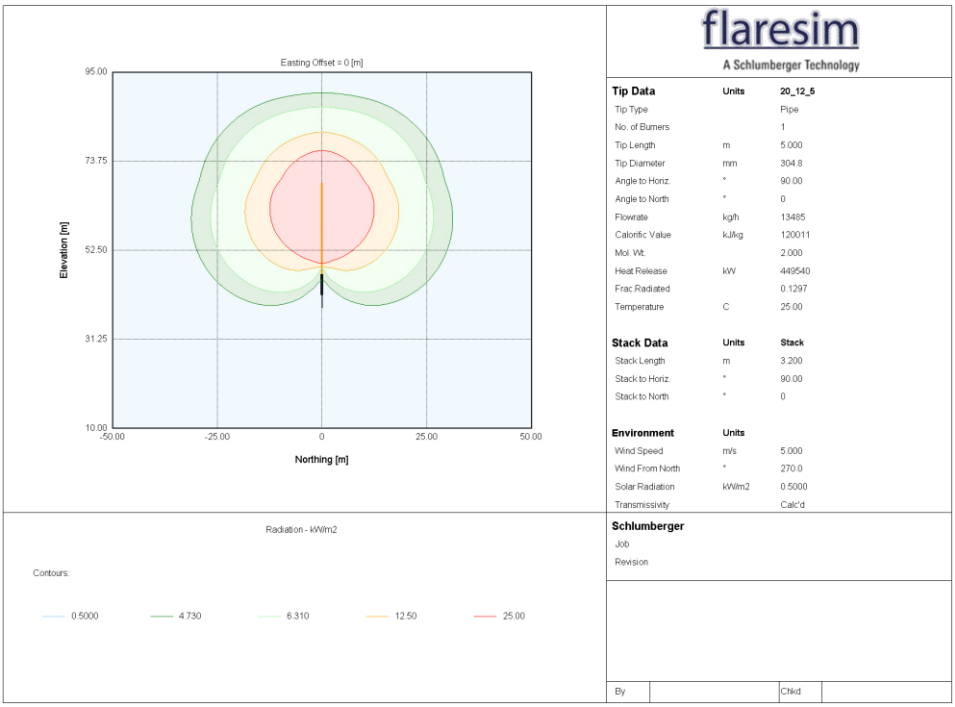


Figure 13 – Flaresim results views (elevation easting/northing,5D, case 3)

5.1.3 2F cases

Case 1

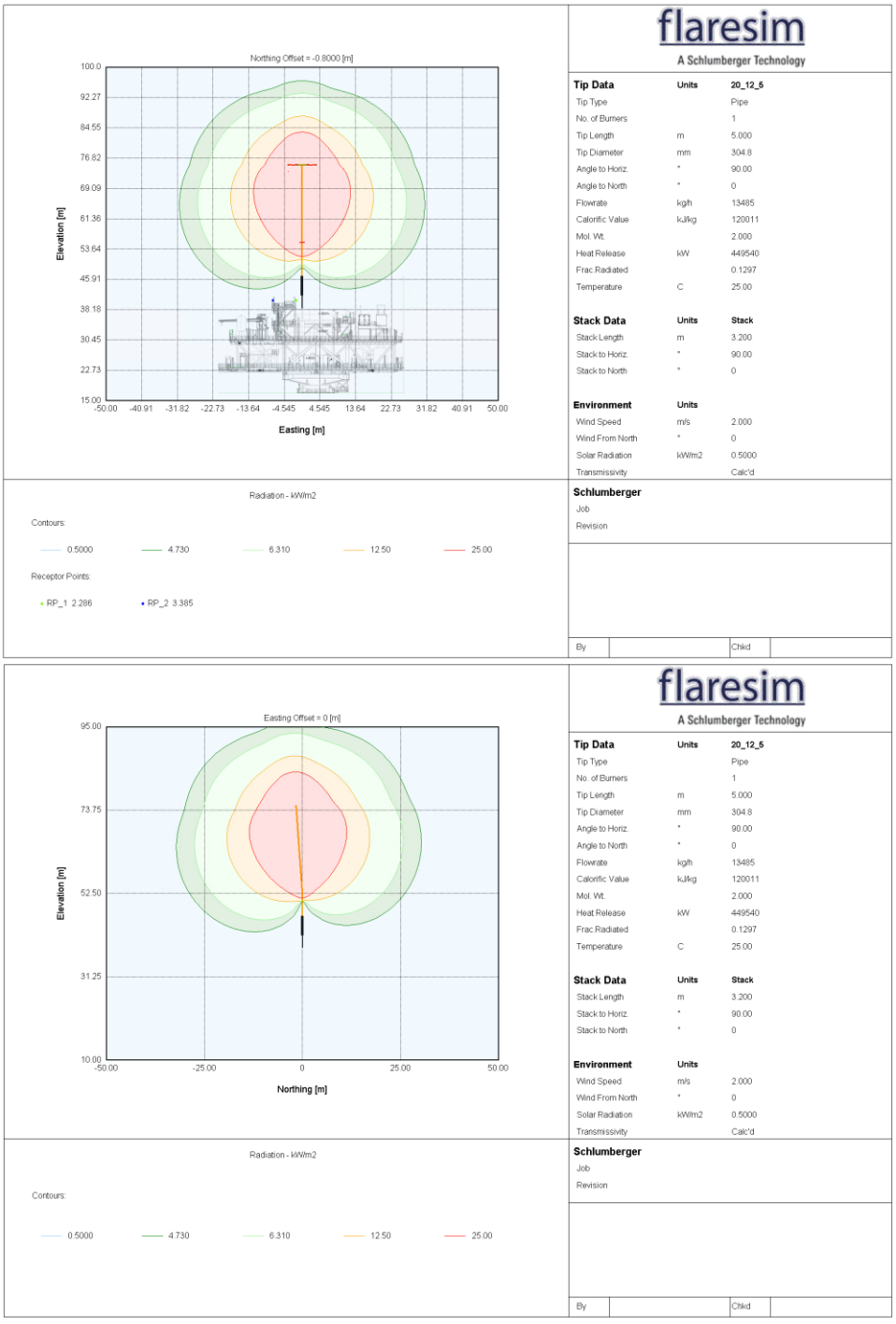


Figure 14 – Flaresim results views (elevation easting/northing,2F, case 1)

Case 2

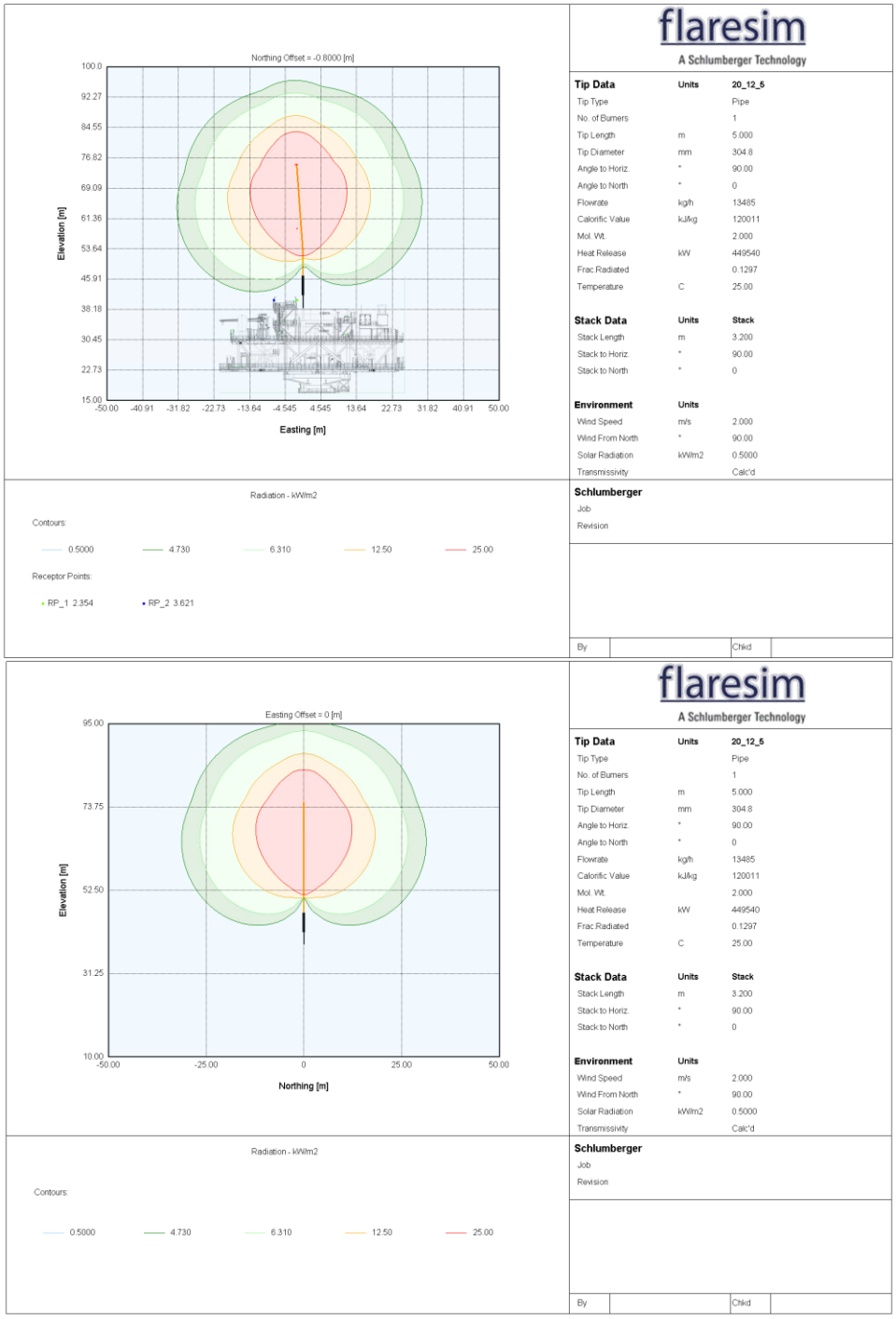


Figure 15 – Flaresim results views (elevation easting/northing,2F, case 2)

Case 3

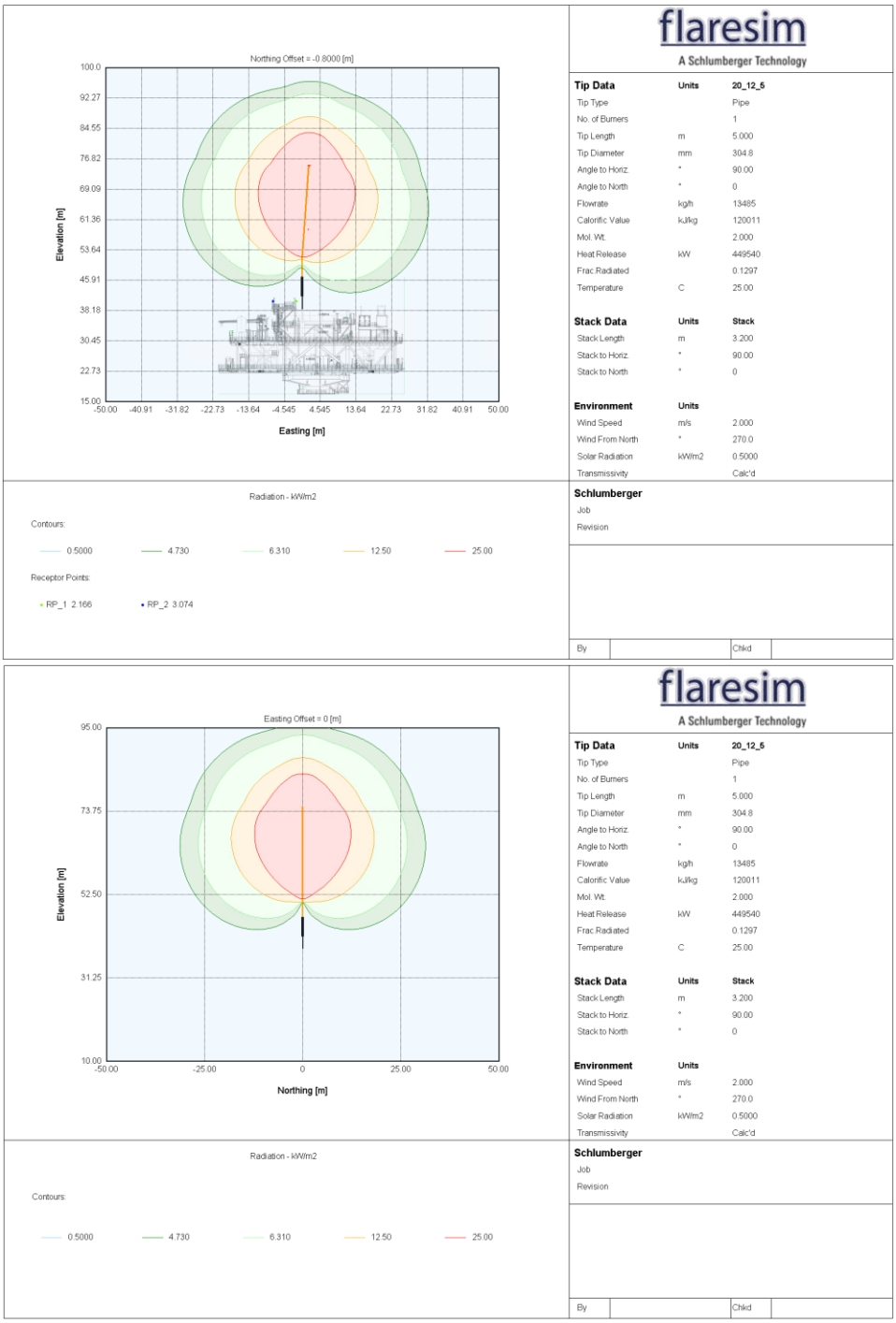


Figure 16 – Flaresim results views (elevation easting/northing,2F, case 3)

5.2 SUMMARY OF RESULTS FROM THERMAL RADIATION: RECEPTORS POINT

The software Flaresim calculates the minimum height of the stack in order to ensure that the thermal radiation will not exceed the values of 12.5 kW/m^2 on equipment and 6.31 kW/m^2 on location where operator presence is expected.

The maximum calculated thermal radiation values for each receptor point in the table below are summarized for each meteo condition and wind direction.

Receptors	10 D condition (kW/m²)			5 D condition (kW/m²)			2 F condition (kW/m²)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
A Valves area (V-25001E)	6.2	6.1	3.8	4.4	4.4	3.3	2.8	2.7	2.4
B Valves area (V-25001F)	7.2	6.3	4.8	5.2	4.8	4.1	3.3	3.2	3.0
C Valves area (V-25001D)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
1 Operator on structure above storage vessel	5.4	5.8	3.9	3.7	3.9	3.1	2.3	2.4	2.2
2 Operator on structure above storage vessel – west stair	6.6	8.5	3.9	5.0	5.9	4.0	3.4	3.6	3.1
3 Operator on structure above storage vessel – east stair	7.5	6.7	4.9	5.8	5.4	4.6	3.9	3.8	3.6
4 Operator on structure above storage vessel – nearest corner to vessels	4.5	3.0	6.1	3.8	3.2	4.6	2.8	2.7	3.1
5 Operator on structure above storage vessel – nearest corner to electrolyser package	4.4	2.8	6.0	3.6	3.0	4.4	2.6	2.4	2.9
6 Operator on electrolyser package – corner to storage vessel	4	2.9	5.6	3.5	3.0	4.3	2.7	2.6	2.9
7 Operator on structure above storage vessel – first level	2.9	2.8	1.9	2.1	2.1	1.7	1.5	1.5	1.4
8 Operator on structure above storage vessel – first level	3.2	2.8	2.2	2.4	2.2	2.0	1.7	1.6	1.6

Receptors	10 D condition (kW/m²)			5 D condition (kW/m²)			2 F condition (kW/m²)		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
9 Operator on upper deck stair (west side)	2.2	3.6	3.2	2.4	3.0	2.8	2.0	2.2	2.2
10 Operator on upper deck stair (east side)	3.8	2.6	3.6	3.1	2.5	3.0	2.4	2.2	2.3

Table 9 – Thermal radiation on receptors points

5.3 THERMAL RADIATION EVALUATION: MAXIMUM THERMAL RADIATION ENVELOPE

In the above figure is reported the thermal radiation for 10D condition, which is the design case for thermal radiation evaluation. The figure reports the thermal radiation at the same location of the flare stack (northing =0) and represents the maximum expected thermal radiation for downwind cases.

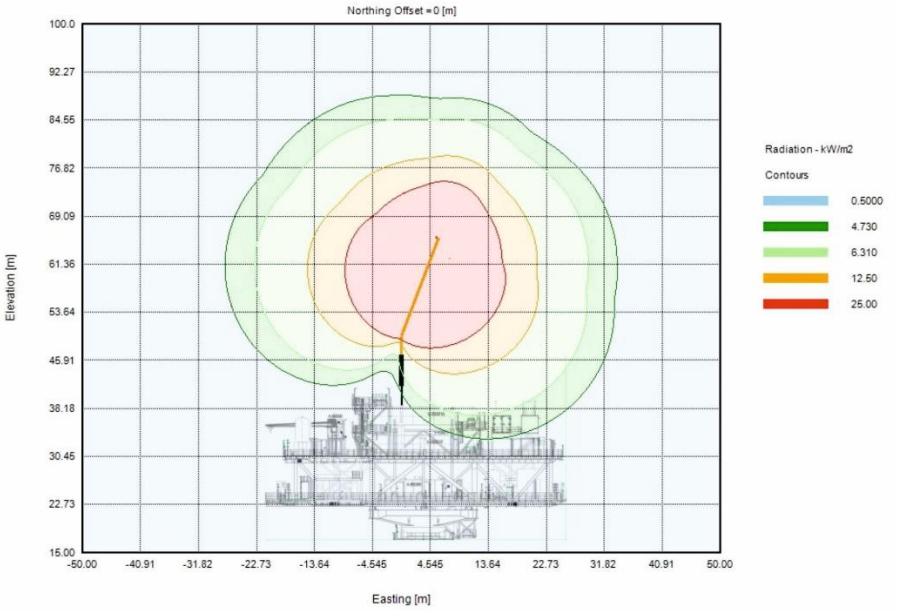


Figure 17 – Flaresim results views downwind

A detail regarding the distances reached by the 6.31 kW/m², in the figure below is reported.

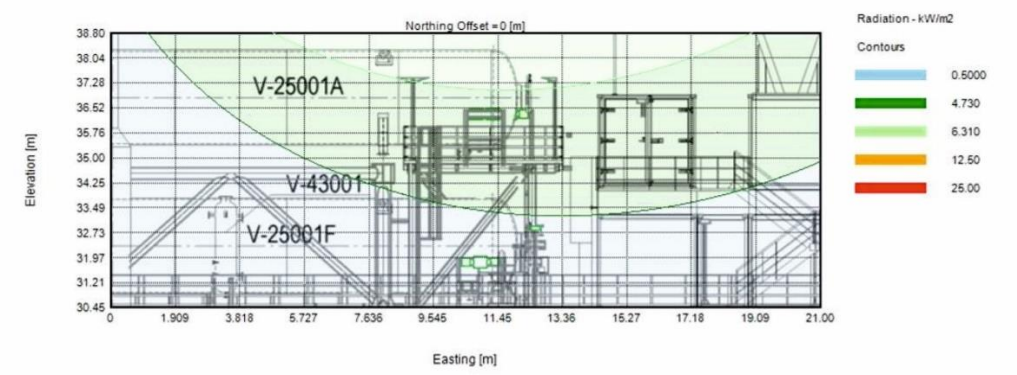


Figure 18 – Flaresim results views downwind – detail of 6.31kW/m^2

The lowest point of 6.31 kW/m^2 is reached at about 12 m. from the stack origin ("easting" side) at about 37 m. of elevation.

In order to identify possible areas involved in thermal radiation equal or higher than 6.31 kW/m^2, which is the threshold for operator exposure during an emergency, the 3D model is sub-divided considering the elevation of 37 m. The two figure which describes the elevation of 37 m. are reported below.

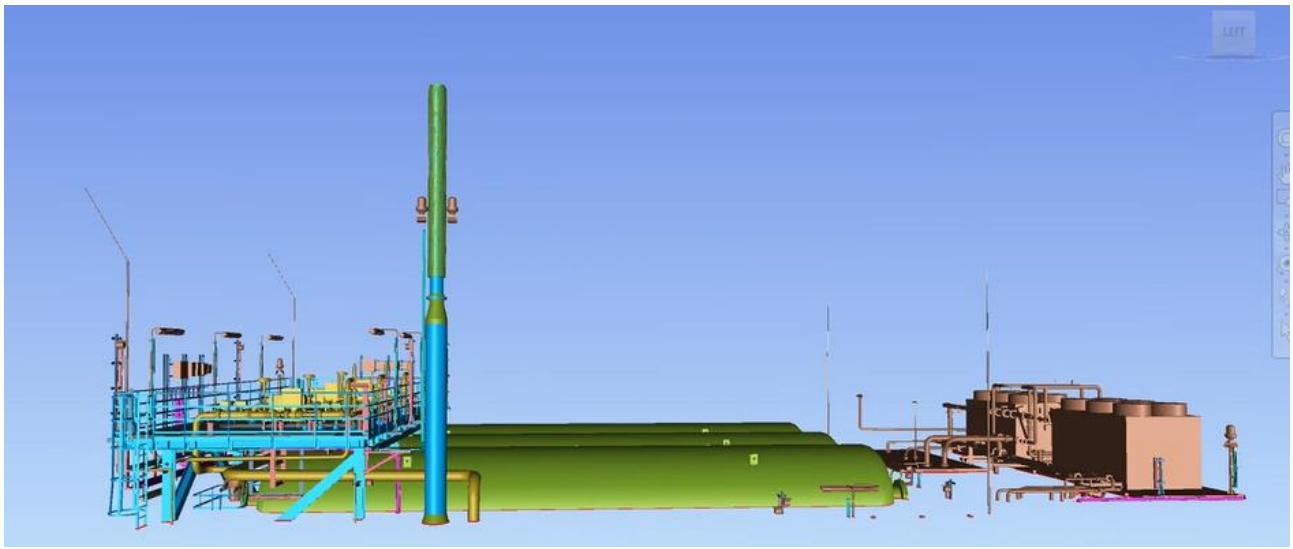


Figure 19 – Elevation of 37 m. - A

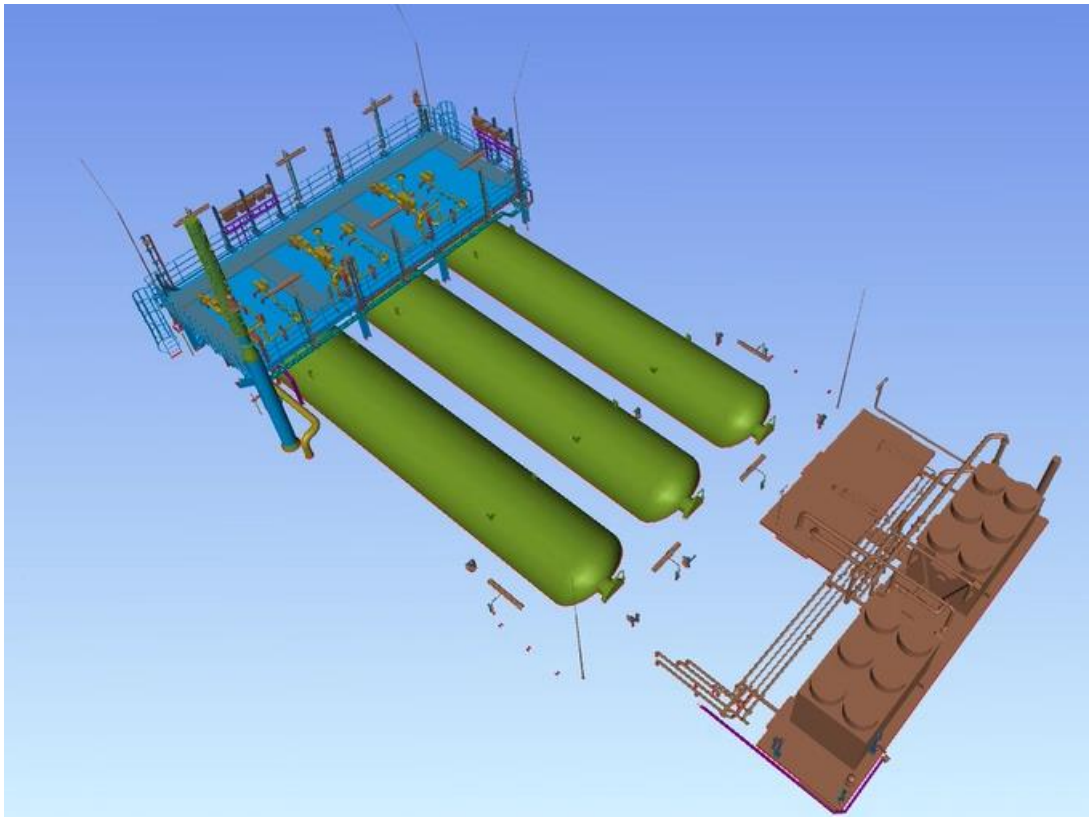


Figure 20 – Elevation of 37 m. - B

From the figures 19 and 20, it is possible to concluded that the areas potentially involved in a thermal radiation equal or higher than 6.31 kW/m^2 are:

- the second level of the platform above storage vessel on upper deck (elevation +38.6 m., the blue platform in the figure);
- the roof of electrolyser package (elevation +36.8 m., the brown structure). Note that in such areas, no stairs are provided, meaning that operator presence need to be considered unlikely).

This approach is quite conservative because is assumed:

- a constant value of the thermal radiation profile for all the extension in the "easting" side without taking credit of the distance from the stack. As for figure 17, the 6.31 kW/m^2 curve increase in elevation with distance from the stack. Thus, not all the roof of the electrolyser package area should be completely involved in the 6.31 kW/m^2 threshold, at least at operator elevation.
- it is not considered the "shield" effect of the equipment/structures which decrease the thermal radiation reached to the operators in some direction.

5.4 VERIFICATION OF FLAMMABLE GAS DISPERSION

The flammable gas dispersions are assessed by means of the software PHAST for the three atmospheric conditions (Pasquill classes 10D, 5D and 2F, in order to maximize gas cloud dispersion). The results are reported in the table below. In particular, the LFL values and the maximum downwind distances reached by flammable envelope curve corresponding to ½ LFL are reported. The simulations are performed considering the stack design as for the results of section 5.2. The results in the below table are summarized.

Weather condition	LFL (m)	LFL/2 (m)
2F	14.5	31.5
5D	18.5	39
10D	30	57

Table 10 – Flammable gas clouds dispersion distances

The profiles of the clouds are reported in the following figure.

10D

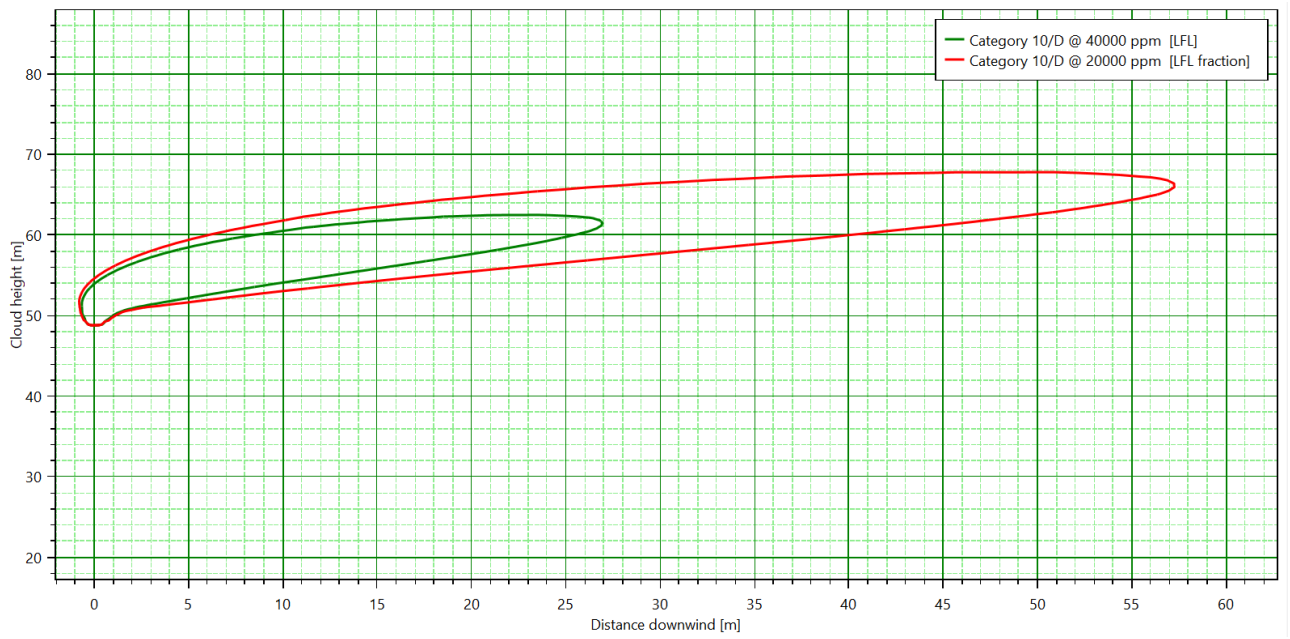


Figure 21 – Phast results, 10D, sideview

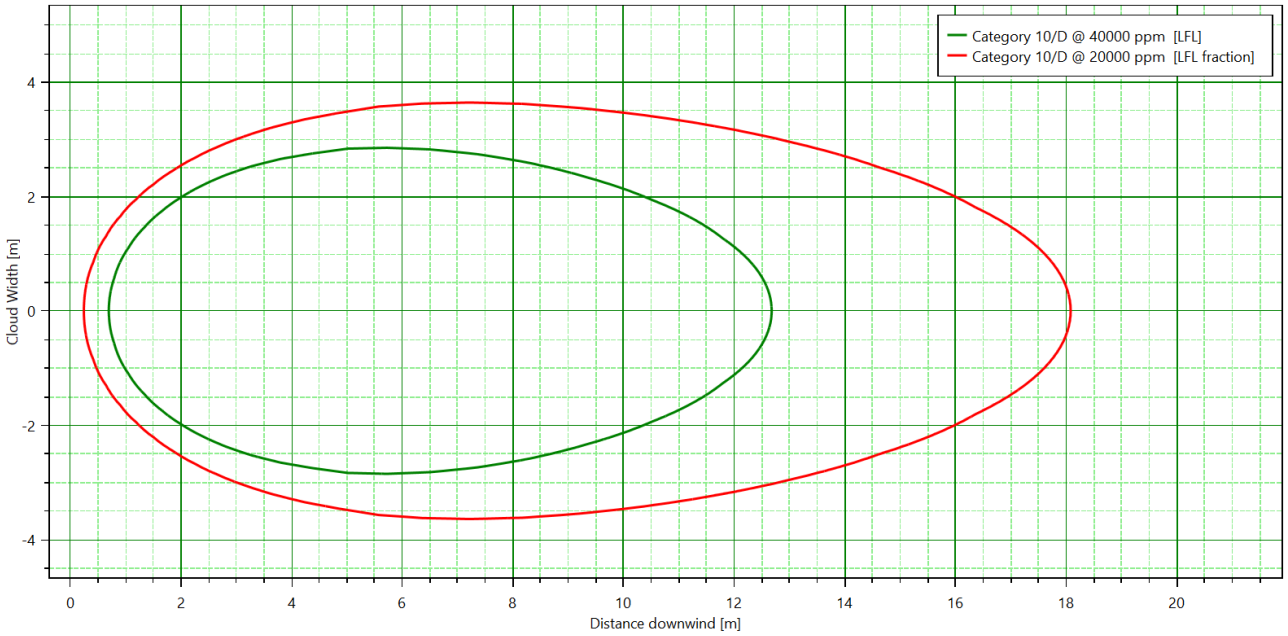


Figure 22 – Phast results, 10D, footprint, 55 m. height

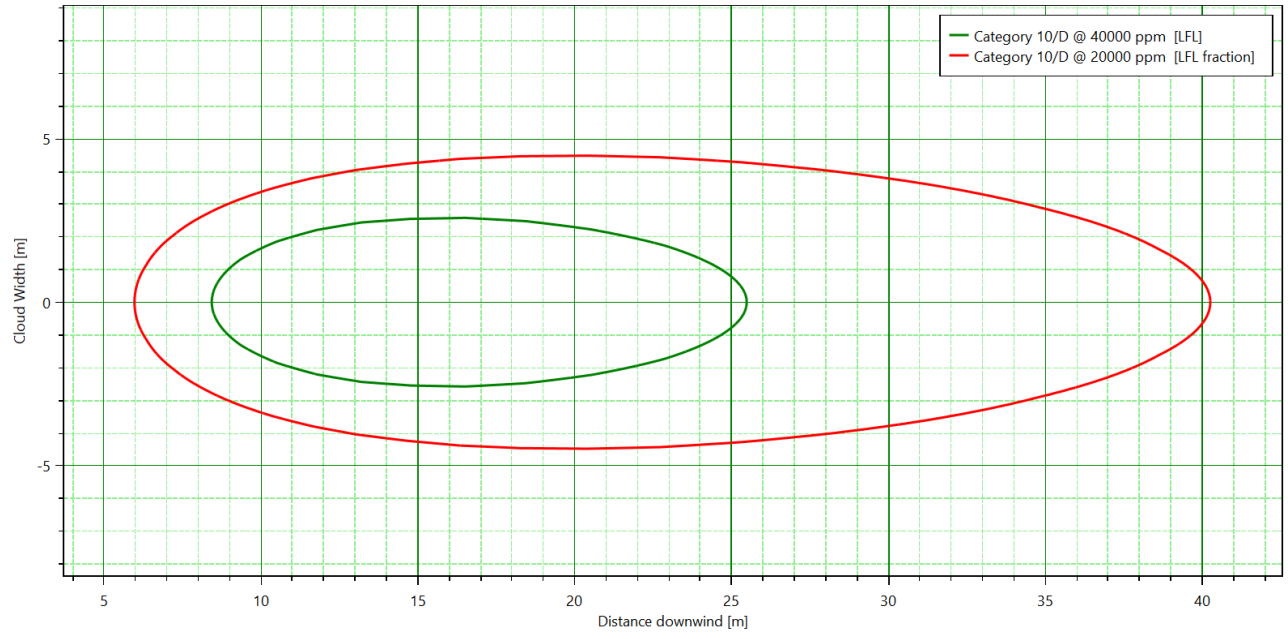


Figure 23 – Phast results, 10D, footprint, 60 m. height

5D

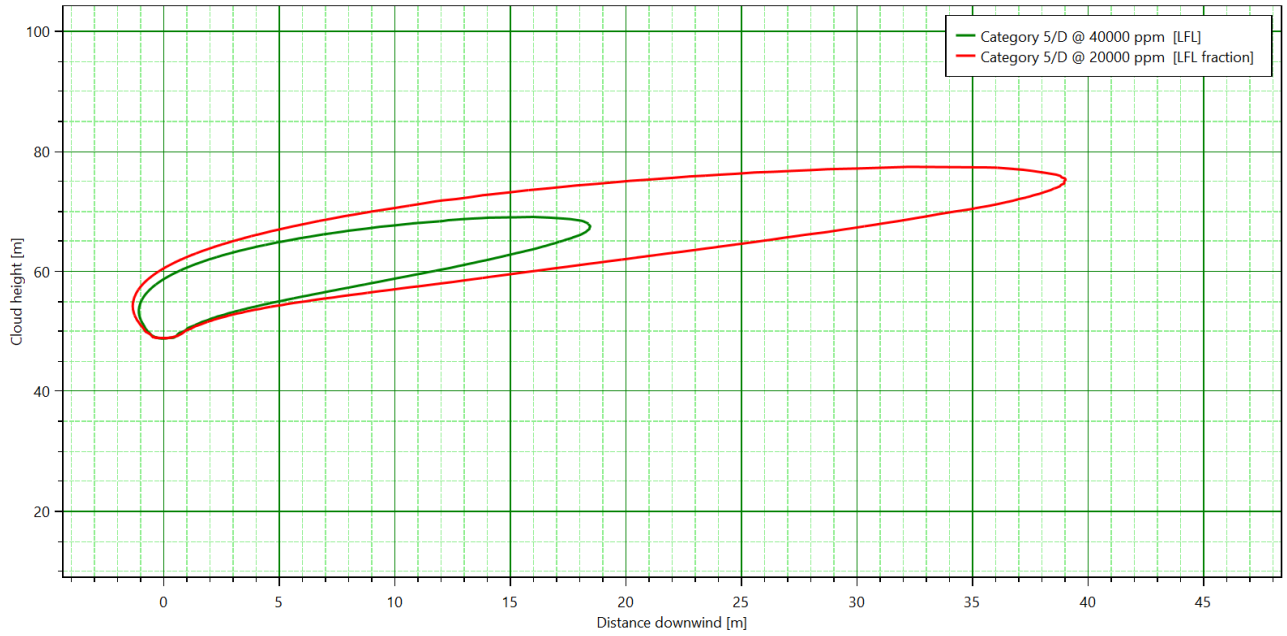


Figure 24 – Phast results, 5D, sideview

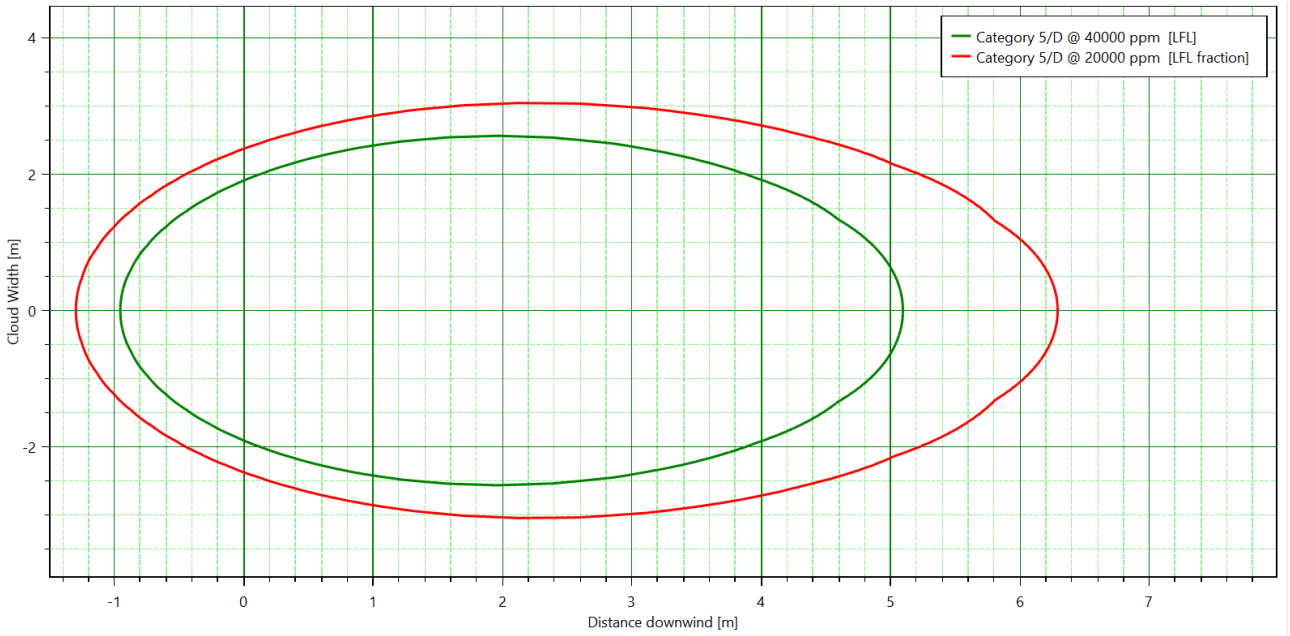


Figure 25 – Phast results, 5D, footprint, 55 m. height

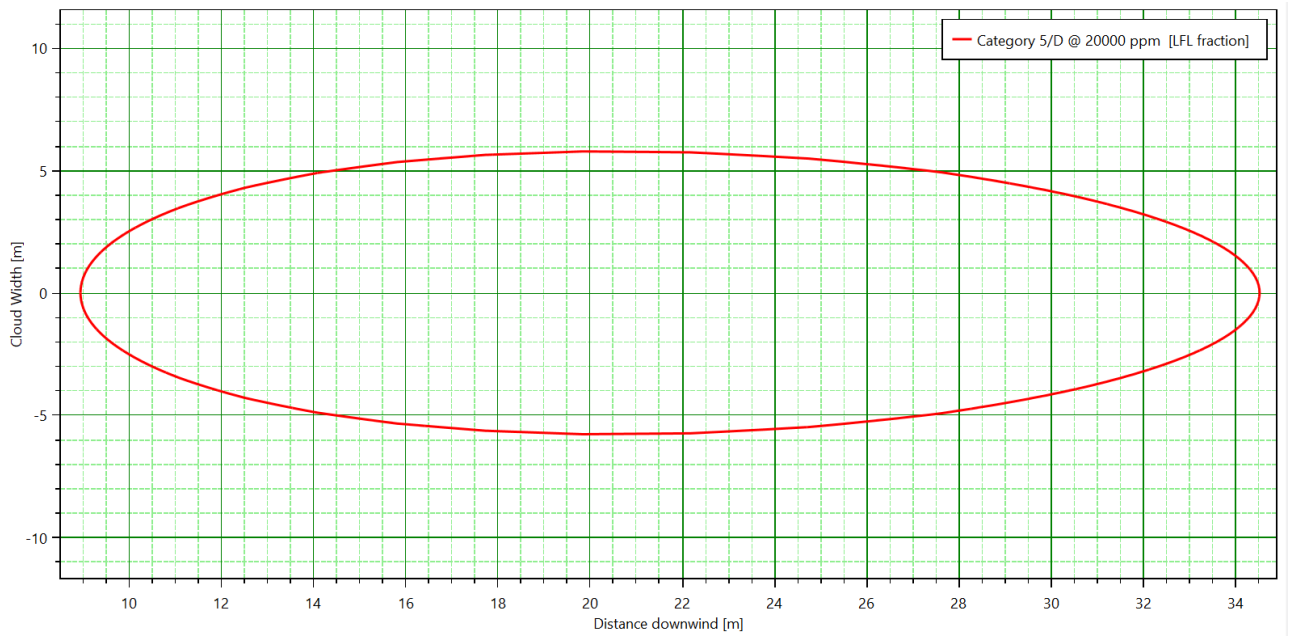


Figure 26 – Phast results, 5D, footprint, 70 m. height

2F

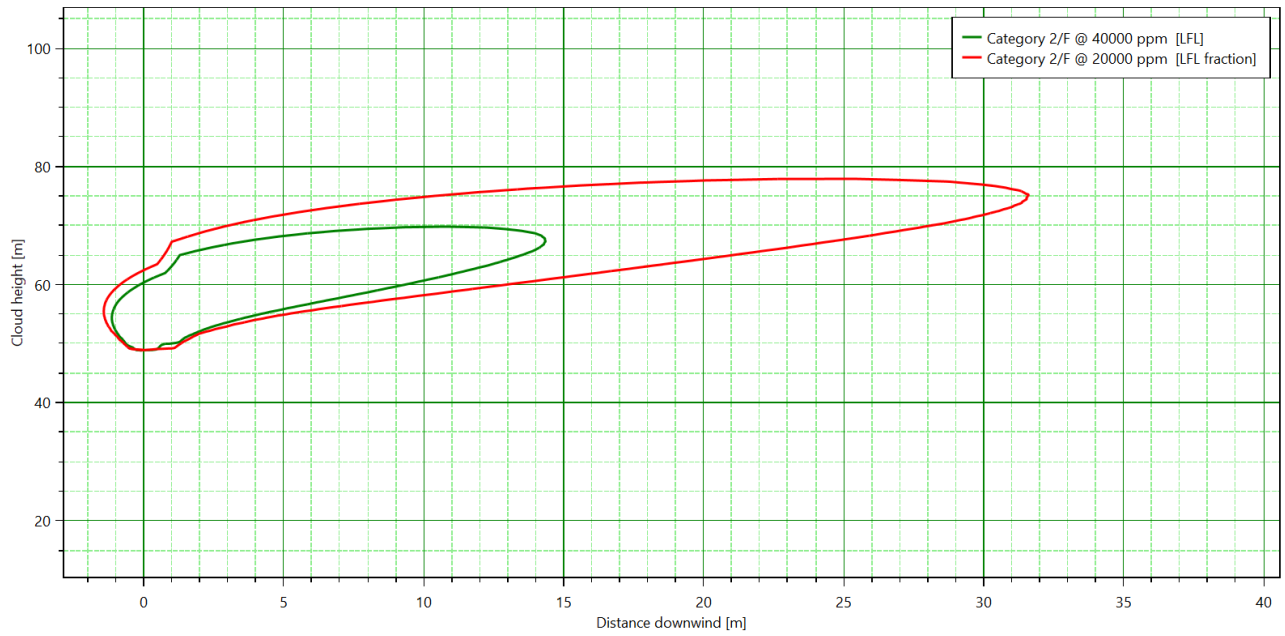


Figure 27 – Phast results, 2F, sideview

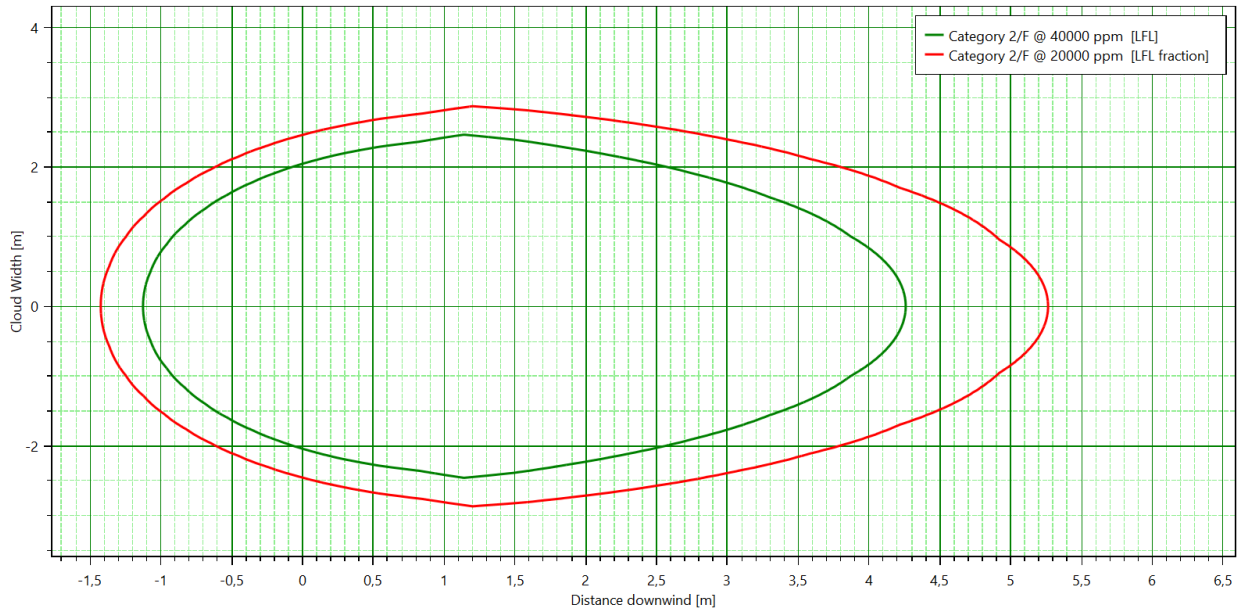


Figure 28 – Phast results, 2F, footprint, 55 m. height

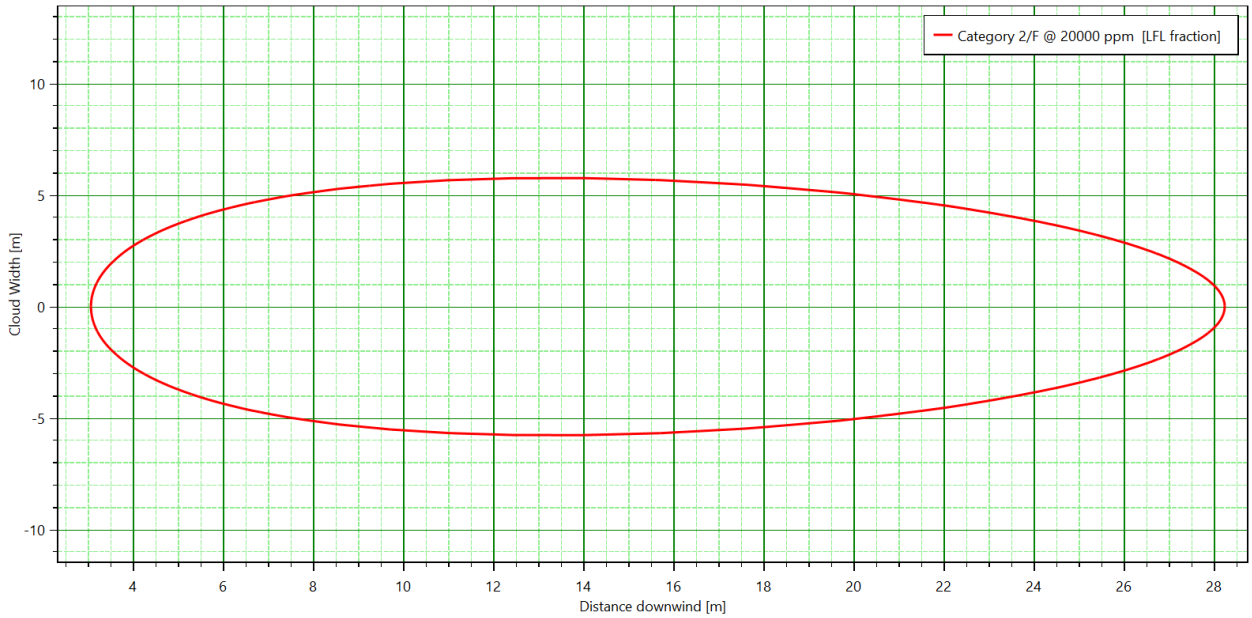


Figure 29 – Phast results, 2F, footprint, 70 m. height

On the basis of the results, considering the vent is at +46.5 TOS , both the concentration of LFL and LFL/2 shows no impact on platform equipment/structures: according to characteristic of H_2, the gas clouds move according to the wind direction but always at elevation higher than the stack. Considering than the stack is the higher structure of the upper deck, no impact is expected in other platform equipment.

6 CONCLUSION

Via FLARESIM software the stack diameter and height were calculated in order to verify that the thermal radiation will not exceed the values of 12.5 kW/m^2 on equipment and 6.31 kW/m^2 at receptors point where people presence should be possible during maintenance operation. Regarding flammable gas dispersion, via PHAST was possible to calculate the LFL and LFL/2 concentrations of dispersion in order to evaluate possible involvement of receptors.

Result of the present study are obtained considering following vent characteristic:

- Stack height: 3.2 m.
- Stack diameter: 20 inch.
- Tip height: 5 m.
- Tip Type: pipe.
- Tip diameter: 12 inch.

Please note that these heights are referred to the top deck platform above hydrogen storage vessel, which is at elevation of 38.6 m. Considering the upper deck elevation (+30.3 m), the total structure of the vent (stack and tip) is equal to:

- 16.5 m. height from the upper deck.

The total height of the system, including the stack and tip length, reaches + 46.8 m.

According to the vent design, the reference receptors points for equipment (receptors A, B, C) shows values well below to the reference threshold of 12.5 kW/m^2 for each meteo climatic condition, thus the design of the vent is considered acceptable for thermal radiation on asset.

Regarding thermal radiation of receptors on location where operators' presence is foreseen (receptors 1-10), for the receptors:

- 2, Operator on structure above storage vessel – west stair;
- 3, Operator on structure above storage vessel – east stair;

The expected thermal radiation is above 6.31 kW/m^2 for wind case 1 and 2. Thus, the second level of the platform above storage vessel on upper deck (elevation +38.6 m.), does not meet the target criteria for operator.

In order to investigate potentially other areas, even if not normally manned during operator maintenance activities, which can be exposed to thermal radiation higher than 6.31 kW/m^2, additional evaluation was performed, considering the minimum elevation reached by such threshold in the worst meteo-climatic conditions. From this conservative analysis, three areas show thermal value potentially higher than 6.31 kW/m^2:

- The second level of the platform above storage vessel on upper deck (elevation +38.6 m.; the same already identified from the receptors point analysis);
- The vent itself is also interdicted;

- The roof of electrolyser package (elevation +36.8 m.). Note that in such areas, no stairs are provided, meaning that operator presence need to be considered unlikely.

Since these areas result to be over the acceptable limit of 6.31kW/m^2, it is necessary to foresee a sterile area where only people are allowed under strict procedures/ PPEs or when the platform is depressurized.

Specific recommendations are issued to limit the maintenance activities at such areas.

Note that during normal maintenance the operators are allowed to operate anywhere excluding these restricted area. Anyhow, in terms of frequency of occurrence, the exposure of operators to the vent fire is very unlikely, since:

- Operators shall be properly trained and informed on restricted areas;
- Presence of operators for maintenance activities is limited to 16h in a year (1 day each 6 months, meaning 2 days (16 hours) in 365 days (8760 hours);
- An emergency on platforms which required the depressurization shall happen during these 16h when no operation is ongoing;
- An ignition of the released H_2 is unlikely (note during bad weather maintenance activities will not occur, thus a lightning ignition is very remote).

Regarding flammable gas dispersion, for each meteo condition and wind direction, both the concentration of LFL and LFL/2 shows no impact on platform equipment/structures (unless at top of vent tip): according to characteristic of H_2, the gas clouds move towards the wind direction but always at elevation higher than the stack. As the vent is the highest structure on the upper deck, the release from the vent is vertical upwards and H_2 is lighter than air, there is no impairment from dispersion to any other structure.

In conclusion, the present vent design allows a safety depressurization both in case of dispersion and ignition for asset and operator, considering the recommendations in place.

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7 RECOMMENDATION

Considering that some areas in the platform should be involved, for some meteo -climatic condition, in thermal radiation higher than 6.31 kW/m^2, is recommended to:

- Ensure that the access to the second level of the platform above storage vessel on upper deck (elevation +38.6 m.) will be limited to the maintenance activity (e.g BDV/PSV valves) after total depressurization of storage vessels, in order to avoid excessive thermal radiation on operator in case of accidental ignition of gas released during an emergency depressurization.

  The platform above storage vessels with limited access is highlighted in the below figure (yellow).

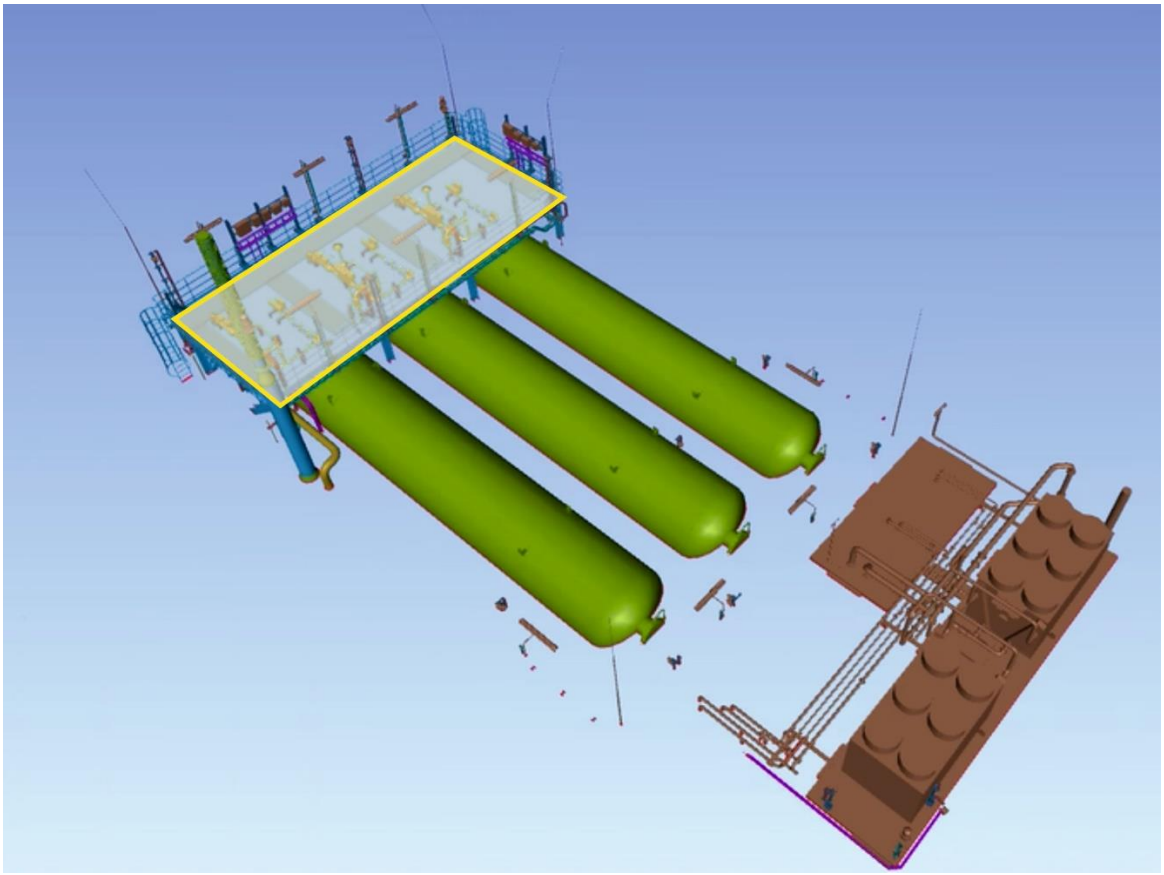


Figure 30 – Platform above storage vessels with limited access

- Ensure that the access to the roof of electrolyser package on upper deck (elevation +36.8 m.) will be limited to the maintenance activity after total depressurization of storage vessels, in order to avoid excessive thermal radiation on operator in case of accidental ignition of gas released during an emergency depressurization.

  The roof area of electrolyser package with limited access is highlighted in the below figure (green).

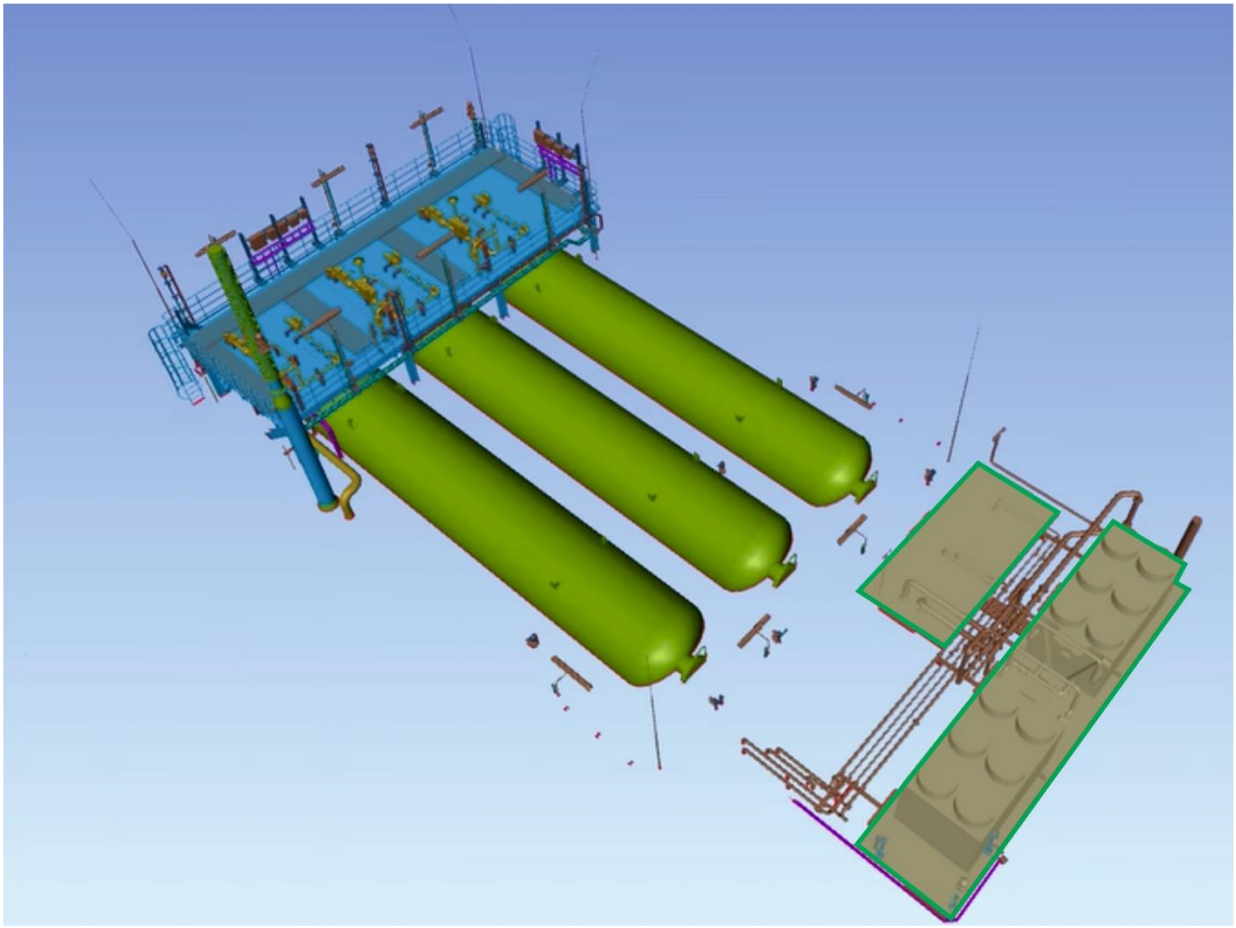


Figure 31 – Roof area of electrolyser package with limited access

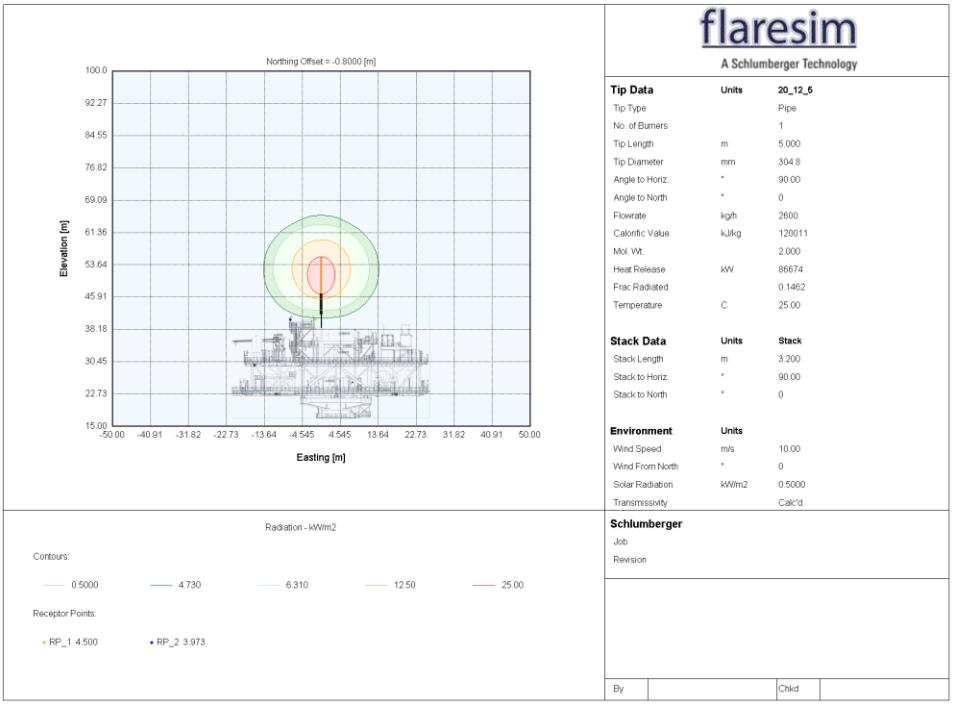
8 APPENDIX 1: DESIGN PRESSURE/FLOW RATE EVALUATION

An additional investigation was conduced in order to identify the maximum flow rate to the vent which verify an exposure value equal to 6.31 kW/m^2 for the receptors located in the platform above storage vessel (+38.6 m.), where operator presence will be possible:

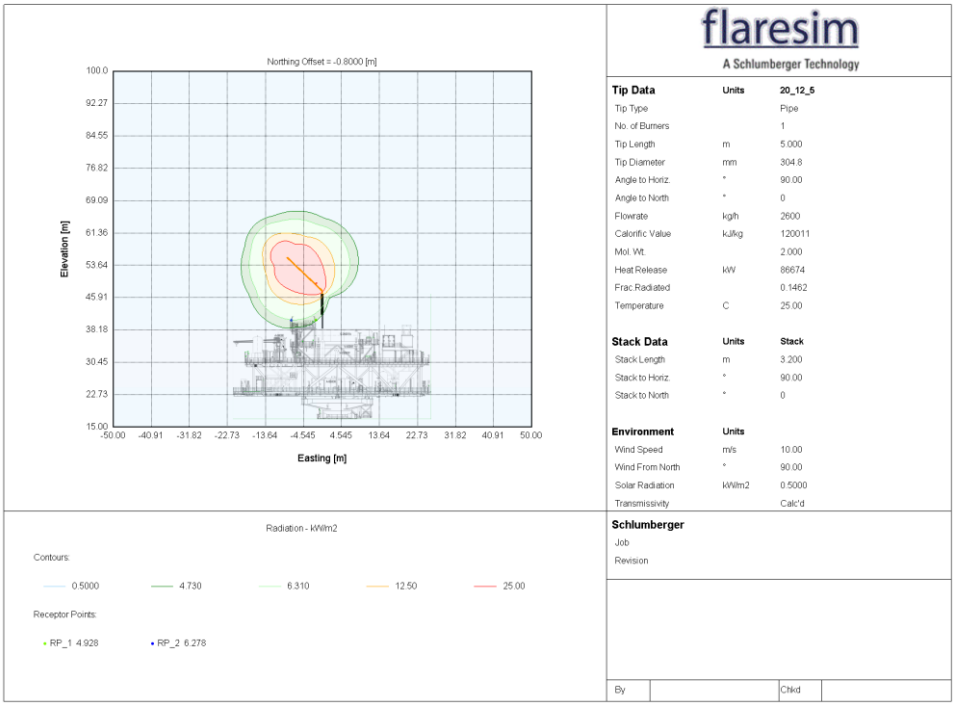
- Receptor 1, operator on structure above storage vessel;
- Receptor 2, operator on structure above storage vessel – west stair;
- Receptor 3, operator on structure above storage vessel – east stair;

In the following figures are reported the result of simulations, considering the design of the vent as for the results of the present study and the flow rate equal to 2600 kg/h, which is the maximum flow rate which verify an exposure value equal to 6.31 kW/m^2 for the receptors. The calculation was performed for the worst-case scenario in terms of thermal radiation (meteo condition 10D) and the three wind direction as for section 5.1.

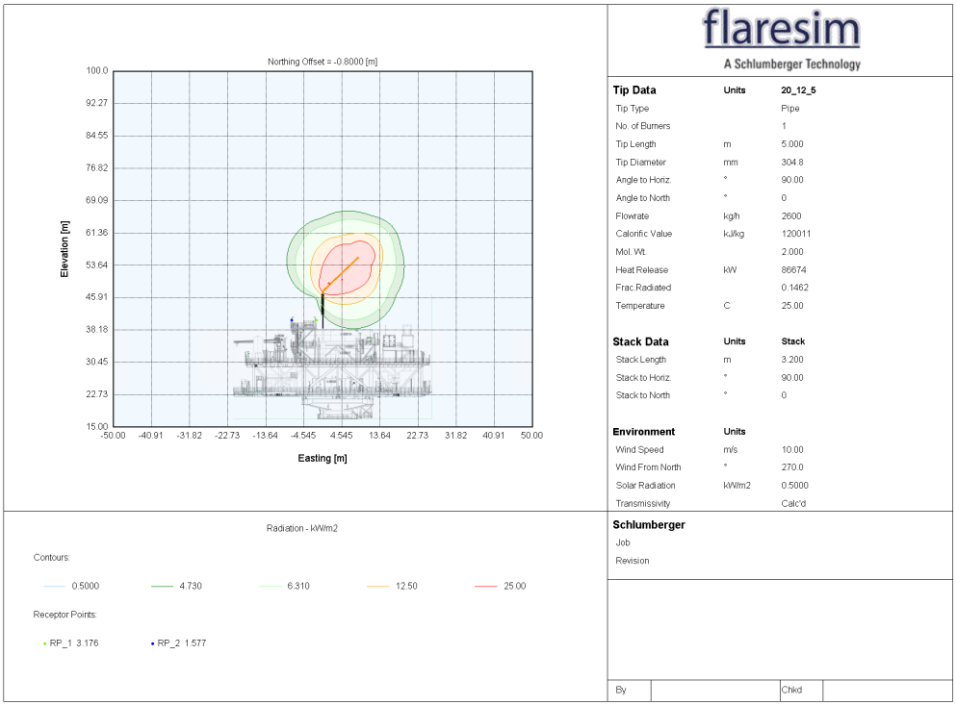
Case 1



Case 2


Northing Offset = -0.8000 [m]
Elevation [m]
Easting [m]
flaresim
A Schlumberger Technology
Tip Data
Stack Data
Environment
Schlumberger
Radiation - kW/m2
Contours:
0.5000
4.730
6.310
12.50
25.00
Receptor Points:
RP_1 4.928
RP_2 6.278

Case 3


Northing Offset = -0.8000 [m]
Elevation [m]
Easting [m]
flaresim
A Schlumberger Technology
Tip Data
Stack Data
Environment
Schlumberger
Radiation - kW/m2
Contours:
0.5000
4.730
6.310
12.50
25.00
Receptor Points:
RP_1 3.176
RP_2 1.577

The thermal radiation on each receptor points in the table below are summarized.

Receptors	10 D condition (kW/m²)		
	Case 1	Case 2	Case 3
1 Operator on structure above storage vessel	4.5	4.9	3.2
2 Operator on structure above storage vessel – west stair	4.0	6.3 (6.278)	1.6
3 Operator on structure above storage vessel – east stair	3.7	3.1	2.0

On the basis of simulation results and considering the vent design, a flow rate equal to 2600 kg/h allows to verify the requirements in terms of thermal radiation on receptors points, which is always lower than 6.31 kW/m^2.

Using the "Depressuring Utility" tool in HYSYS, the calculated pressure corresponding to the identified flow rate is equal to 4.5 barg.