Plant Description **CO2 CAPTURE, CONCENTRATION, PURIFICATIN & LIQUIFACTION PLANT** BOC NORTH TEES HYDROGEN SITE	
Linde Project No. **3710 A1E6**	Client Project No. **043-69**
Linde Project Code **TEESSIDE_01**	Client Project Code **Teesside Carbon Dioxide**
Linde Doc. No. **&AE-S-RX 1011 (EN)**	Client Doc. No. **---** / Client Revision **---**

Dispersion Calculation for Safe Location

IFD	2.0	15.05.2024	S. Unger, TNP	T. Werner, TNP	T. Werner, TNP	Changes in red
IFD	1.0	06.02.2024	S. Unger, TNP	G. Wendsche, TNP	T. Werner, TNP	
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1 Scope

This document is the report of investigation of carbon dioxide and nitrogen dispersions in case of releases via silencers, control valves routed to atmosphere and relief devices in the project Teesside in the UK.
The dispersion calculations were done under consideration of different release cases and conditions. The release cases were given with release case definition from safety and process department at Linde office Dresden.

The current dispersion calculations in this report are based on the relief flow rates at 110% of the relief devices set pressure. The dispersion calculations are verified based on the certified mass flows from vendor data.

Note:
Direction specifications are regarding to plant north (refer to general layout plan, drawing number: &AE-L-ZP 1002).

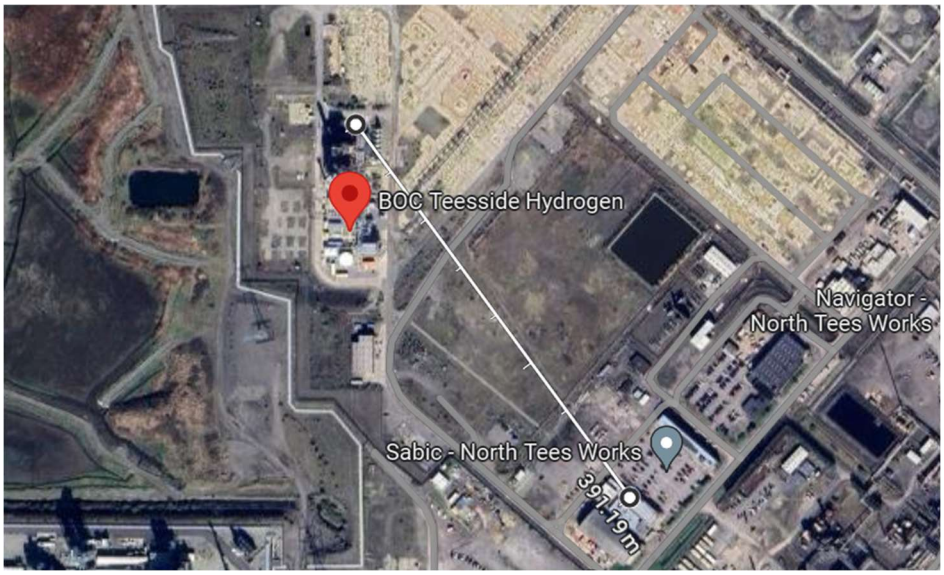
NOTE: This document provides specific requirements for safe locations. These need to be followed. Alternative vent locations need to be addressed to LE. A recheck will be necessary in that case.

Remark: The release point for ammonia (2-PSV8118.1) is removed from the report, since the vent line from 2-PSV8118.1 is routed to B.L. (TP06).

2 Site Overview

The BOC LiC Plant is located in the North Tees Works in Seal Sands, postcode TS2 1TT. The closest residential area to site is 2.84km Southwest in Port Clarence shown in the image below.

The BOC site is located within a larger SABIC site, within the SABIC site there are occupied offices 381m Southeast from the LIC Plant.



3 Executive Summary

The dispersion modelling shows that there is **no potential harm to occupiers and residents** in the proximity of the site. All of the dispersion clouds are released at high level beyond any occupied zones in the plant.

The plumes will dilute to a safe level before any occupied area of the SABIC site is reached. BOC will have procedures in place to protect their workers on site from any venting scenario. There is zero risk to any external members of public as they are significantly outside of an dispersion zone.

The table below summarises all of the dispersion distances and the height the dispersion clouds will reach. The CO2 has been modelled on the short and long term exposure limits, of 15000ppm and 5000ppm respectively.

The results show that all dispersion clouds will not reach land or residents outside of the BOC site. The clouds will be above any locally occupied areas on site.

Release cases	**Location, Source Note**	**Medium**	**Concentration [ppm]**	**Max Distance [m]**	**Height [m]**
1-PSV3010.1	Steel structure CA70	CO_2	15000	13	15
1-PSV8010.1	Steel structure CA70	N_2	62500	1.5	9
2-PSV2112.1	Steel structure CA02	CO_2	15000	12	12
2-PSV6111A/B/C.1A/B	Steel structure CA07	CO_2	15000	9.8	15
Silencer N4191	Steel Structure CA51				
2-PSV5110.2	Vent Gas Heater 2-E5411	CO_2	15000	7	13
2-PV1210.2A/B (both valves fully open, max emergency case)	Vent LP Scrubber	CO_2	15000	20	18
2-PV6110.1 (min flow operating case)	Boil off CO_2 storage tanks	CO_2	5000	11	11
2-PV6311A.2 & 2-PV1210.2A & 2-PV6110.1 (max flow operating case)	Normal operation (CO2 via 2-PV1210.2A to atm. + tank boil off + pressure relief truck)	CO_2	5000	48	21
CO_2 vent header for offspec dump	Steel structure CA03				
2-LV5110.1 (fully open valve)	CO_2 offspec from CO_2 column to atmosphere	CO_2	5000	37	37
Vent Header solution storage tank 1-D7210	Steel structure CA70				
Storage tank filling 1-PSV7210.4	1-D7210	N_2 N_2	62500 62500	8 8	1.8 2
1-PSV2060.1	Steel Structure CA70	CO_2, CO, CH_4, H_2	15000 20000	7 17	14 17

4 Abbreviation

AEGL	**A**cute **E**xposure **G**uideline **L**evel
CO_2	Carbon Dioxide
EIGA	**E**uropean **I**ndustrial **G**ases **A**ssociation
ERPG	**E**mergency **R**esponse **P**lanning **G**uidelines
OSHA	**O**ccupational **S**afety and **H**ealth **A**dministration
PSV	**P**ressure **S**afety **V**alve
STEL	**S**hort **T**erm **E**xposure **L**imit
TWA	**T**ime **W**eighted **A**verage
UK	**U**nited **K**ingdom

5 Normative References, Codes

The following codes and regulations have been used as references:

- UK EH40 Workplace Exposure Limits (WELs), as amended (2007)
- EIGA document IGC Doc 56/08 and IGC Doc 56/09/E
- EIGA Doc 154/16 - Safe location of oxygen and inert gas vents

6 Investigation basis

Following emission sources were investigated:

- 1-PSV3010.1 (pressure safety valve on stripper column 1-T3010)
- 1-PSV8010.1 (pressure safety valve on nitrogen header)
- 2-PSV2112.1 (CO2 compressor pressure safety valve on stage II coalescer)
- 2-PSV6111A/B/C.1A/B (pressure safety valves on CO2 tanks)
- Silencer 2-N4191 in CA51
- CO2 offspec dump via 2-PV5133
- Vent header solution storage tank 1-D7210
- 1-PSV2060.1 (pressure safety valve downstream HP Flash Column 1-D2060)

It is provided that the pressure relief valves are maintained accordingly and operating as specified. Hence no major releases via leakages through the PSV seat are considered (e.g. no spring damage etc.). Carbon dioxide dispersions via thermal pressure relief devices are a short-term event and limited to small relief rate and hence deemed to be negligible.
The shown dispersion plumes are based on a stationary release. Means for pressure safety valve releases the required mass flow is used for dispersion calculation. The PSV certified mass flow is only valid for a certain short time which is deemed to negligible for the dispersion.

There is the possibility of personnel risk of toxication due to carbon dioxide enrichment in air and asphyxiation by inhalation of nitrogen.

Dispersion calculations were carried out with program PHAST 8.6.

Investigation based on climatic conditions due to document “Climatic Condition, Design Loads, &AE 0000 A-SD 1001 (EN)”. Calculations have been performed at ambient conditions of 1 bar, absolute and average dry bulb temperature of 0°C. The weather parameters have been defined by:

- 1.5 m/s wind speed combined with a stable weather condition (Pasquill stability F) that usually leads to a "worst case" dispersion situation and
- 5 m/s wind speed combined with a neutral weather condition (Pasquill stability D)
- 10 m/s wind speed combined with a neutral weather condition (Pasquill stability D).

The outlet velocity has been calculated adequately to release scenario (shown in table “calculation cases” under chapter 6.2) and silencer geometry.

7 Concentrations of interest within the gas cloud

7.1 Consequences for humans – physiological effects of carbon dioxide

The following description is an excerpt from EIGA document IGC Doc 56/08 and IGC Doc 56/09/E. Carbon Dioxide is classified as a non-flammable, non-toxic liquefied gas. It is normally present in atmospheric air at a level of approximately 380 parts per million (0.038 %). It is a normal product of metabolism being held in bodily fluids and tissues where it forms part of the body’s normal chemical environment. In the body it acts in the linking of respiration, circulation and vascular response to the demands of metabolism both at rest and in exercise.

The effects of inhaling low concentrations of carbon dioxide are physiological reversible but in high concentrations the effects are toxic and damaging.

The effects of carbon dioxide are entirely independent of the effects of oxygen deficiency.

The oxygen content in the atmosphere is therefore not an effective indication of the danger. It is possible to have an acceptable low oxygen content of 18% and a high carbon dioxide content, being 14 % very dangerous.

Individual tolerances can vary widely, dependent on the physical conditions of the person and the temperature and humidity of the atmosphere, but as a general guide, the effects of inhaling varying concentrations of carbon dioxide are likely to be as follows:

Concentrations by Volume - Likely Effects
1-1,5% Slight effect on chemical metabolism after exposures of several hours.

3% The gas is weakly narcotic at this level, giving rise to deeper breathing, reduced hearing ability, coupled with headache, an increase in blood pressure and pulse rate.

4-5% Stimulation of the respiratory centre occurs resulting in deeper and more rapid breathing. Signs of intoxication will become evident after 30 minutes exposure.

5-10% Breathing becomes more laborious with headache and loss of judgement.

10-100% When the carbon dioxide concentration increases above 10%, unconsciousness will occur in under one minute and unless prompt action is taken, further exposure to these high levels will eventually result in death.

The recommended exposure limit for carbon dioxide is 5.000 parts per million (0,5%) by volume, calculated on an 8-hour time weighted average concentration in air.
Depending on regulations in individual countries carbon dioxide concentration peaks up to 30000 parts per million (3%) in air are allowed, whereby the duration of exposure is between 10 minutes and 1 hour.

Cardiac or respiratory defects are likely to increase the hazards of inhalation.

Results are based on STEL for carbon dioxide concentration of 1.5 Vol-% in air (15000 ppm) for PSV releases (emergency case) and TWA of 0.5 Vol-% in air (5000 ppm) for normal operation venting according to UK EH40 workplace exposure limits.

7.2 Oxygen Deficiency

Results are based on an ambient oxygen concentration of 20.8 Vol-%.

There are various definitions and consequences of oxygen deficiency safety criteria:

Oxygen concentration	Corresponding nitrogen or argon enrichment
< 19.5%	6.25 Vol-%
< 17%	18.27 Vol-%

7.2.1 Oxygen concentration < 19.5% O_2

The minimum safe oxygen concentration for entry into a confined space that is being controlled or measured because of the risk is **19.5%** total O_2.

7.2.2 Oxygen concentration < 17% O_2

For cases of leakage, venting or uncontrolled release of inert gases into the outdoor atmosphere, there is no anticipated risk of harm in clouds containing at least **17%** O_2.

Results are based on a limit for oxygen concentration of at least 19.5 Vol-% in air (minimum safe oxygen concentration acc. EIGA and OSHA).

7.3 Gas Dispersion

The gas dispersion is calculated by the UDM model implemented in the Phast® software.

The calculation methodology of the program is limited as follows:

- Graphs are inevitably idealized mathematical model shapes generated on input data. The graphs only approximate the cloud shapes which would result from actual venting under the same conditions.
- All dispersion calculations are based on a continuous material release until the steady state has been reached.
- Obstacles (buildings, equipment, structures) cannot be included in the dispersion calculation.
- The modelling assumes as worst-case conditions that any release, if not vertical, is being vented in the same direction as the wind prevailing at the time of release.

8 Results

8.1 Remarks

Release point is 1-PSV3010.1:
- Release: PSV outlet line at steel structure in CA70
- PID No.: &AE-1-PFP 3003 (EN)
- Nominal Diameter of piping at release point DN 200

Release point is 1-PSV8010.1:
- Release: PSV outlet line at steel structure in CA70
- PID No.: &AE-1-PFP 8001 (EN)
- Nominal Diameter of piping at release point DN 80

Release point is 2-PSV2112.1:
- Release: PSV outlet line at steel structure in CA02
- PID No.: &AE-2-PFP 2101 (EN)
- Nominal Diameter of piping at release point DN 150

Release point is 2-PSV6111A/B/C.1A/B:
- Release: vent header for CO2 storage tanks PSV at steel structure in CA07
- PID No.: &AE-2-PFP 6103/4/5 (EN)
- Nominal Diameter of piping at release point DN 100

Release point is silencer 2-N4191:
- Release: silencer 2-N4191 at steel structure in CA51
- PID No.: &AE-2-PFP 4104 (EN)
- Nominal Diameter of silencer/release point DN 200

Release point is CO_2 vent header for offspec dump:
- Release: offspec CO_2 vent header in CA03
- PID No.: &AE-2-PFP 9102 (EN)
- Nominal Diameter of release point DN 150

Release point is vent header solution storage tank 1-D7210:
- Release: vent outlet at steel structure in CA70
- PID No.: &AE-1-PFP 7201 (EN)
- Nominal Diameter of piping at release point DN 80

Release point is 1-PSV2060.1:
- Release: PSV outlet line at steel structure in CA70
- PID No.: &AE-2-PFP 8108 (EN)
- Nominal Diameter of piping at release point DN 250

8.2 Calculation and results

Following release cases were investigated:

Release cases	Location, Source Note	Medium	W [kg/s]	W_{eff} [m³/h]	T_{out} [°C]	v [m/s]
1-PSV3010.1	Steel structure CA70	CO_2	4.1	10682	117	94.4
1-PSV8010.1	Steel structure CA70	N_2	0.3	823	8	45.5
2-PSV2112.1	Steel structure CA02	CO_2	2.2	4855	62	76.3
2-PSV6111A/B/C.1A/B	Steel structure CA07	CO_2	1.1	1541	-60	54.5
Silencer N4191	Steel Structure CA51					
2-PSV5110.2	Vent Gas Heater 2-E5411	CO_2	0.1	192	-62	1.7
2-PV1210.2A/B (both valves fully open, max emergency case)	Vent LP Scrubber	CO_2	2.5	4677	6	41.4
2-PV6110.1 (min flow operating case)	Boil off CO_2 storage tanks	CO_2	0.2	285	-60	2.5
2-PV6311A.2 & 2-PV1210.2A & 2-PV6110.1 (max flow operating case)	Normal operation (CO2 via 2-PV1210.2A to atm. + tank boil off + pressure relief truck)	CO_2	3.0	5449	-3	48.2
CO_2 vent header for offspec dump	Steel structure CA03					
2-LV5110.1 (fully open valve)	CO_2 offspec from CO_2 column to atmosphere	CO_2	2.1	3039	-60	47.8
Vent Header solution storage tank 1-D7210	Steel structure CA70					
Storage tank filling 1-PSV7210.4	1-D7210	N_2 N_2	0.01 0.02	30 50	10 10	1.6 2.7
1-PSV2060.1	Steel Structure CA70	CO_2, CO, CH_4, H_2	4.04	33163	38	187.7

In chapter 6.3 the graphs for all cases can be found.

Under consideration of the present status of general plot plan (drawing number &AE L-ZP 1001) and the site information the evaluation of the simulation and graphs resulted in following conclusion:

8.2.1 For 1-PSV3010.1

For pressure safety valve 1-PSV3010.1 there is no influence of existing buildings/equipment's/platforms with carbon dioxide concentration of 1.5 Vol-% in air (see graph in chapter 6.3.1).

Hence the investigation resulted in the following requirements:

- Location of PSV outlet to atmosphere: structure Skid CA70
- height of release point: 9 m
- release direction of pipe section flanged at PSV: towards plant east,
- diameter of PSV outlet piping to atmosphere: DN200
- release of pipe section flanged at PSV (incline): 45° angled from horizontal.

8.2.2 For 1-PSV8010.1

For pressure safety valve 1-PSV8010.1 there is no influence of existing buildings/equipment's/platforms with oxygen concentration of less than 19.5 Vol-% in air (see graph in chapter 6.3.2).

Hence the investigation resulted in the following requirements:

- Location of PSV outlet to atmosphere: structure Skid CA70
- height of release point: 8 m
- release direction of pipe section flanged at PSV: vertical up,
- diameter of PSV outlet piping to atmosphere: DN80
- release of pipe section flanged at PSV (incline): vertical up.

8.2.3 For 2-PSV2112.1

For pressure safety valve 2-PSV2112.1 there is no influence of existing buildings/equipment's/platforms with carbon dioxide concentration of 1.5 Vol-% in air (see graph in chapter 6.3.3).

Hence the investigation resulted in the following requirements:

- Location of PSV outlet to atmosphere: structure Skid CA02
- height of release point: 6.9 m
- release direction of pipe section flanged at PSV: towards plant southwest,
- diameter of PSV outlet piping to atmosphere: DN150
- release of pipe section flanged at PSV (incline): 45° angled from horizontal.

8.2.4 For 2-PSV6111A/B/C.1A/B

For pressure safety valves 2-PSV6111A/B/C.1A/B there is no influence of existing buildings/equipment's/platforms with carbon dioxide concentration of 1.5 Vol-% in air (see graph in chapter 6.3.4).

Hence the investigation resulted in the following requirements:

- Location of PSV outlet to atmosphere: structure Skid CA07
- height of release point: 9.7 m
- release direction of pipe section flanged at PSV: towards plant north,
- diameter of PSV outlet piping to atmosphere: DN100
- release of pipe section flanged at PSV (incline): 45° angled from horizontal.

8.2.5 For silencer N4191

For silencer N4191 there is no influence of existing buildings/equipment's/platforms with carbon dioxide concentration of 1.5 Vol-% in air (see graph in chapter 6.3.5).

Hence the investigation resulted in the following requirements:

- Location of silencer: within structure Skid CA51
- height of release point: 13.1 m
- release direction of pipe section flanged at silencer: towards plant northwest,
- diameter of silencer outlet piping to atmosphere: DN200
- release of pipe section flanged at silencer (incline): 45° angled from horizontal.

8.2.6 For CO_2 vent header for offspec dump (via 2-PV5133)

For CO_2 offspec dump vent there is no influence of existing buildings/equipment's/platforms with carbon dioxide concentration of 0.5 Vol-% in air (see graph in chapter 6.3.6).

Hence the investigation resulted in the following requirements:

- Location of vent header outlet to atmosphere: structure Skid CA03
- height of release point: 6.4 m
- release direction of vent pipe section: towards plant north
- diameter of PV outlet piping to atmosphere: DN150
- release of pipe section flanged at PSV (incline): 45° angled from horizontal.

8.2.7 For solution vent header

For solution vent header there is no influence of existing buildings/equipment's/platforms with oxygen concentration of less than 19.5 Vol-% in air (see graph in chapter 6.3.7).

Hence the investigation resulted in the following requirements:

- Location of vent header outlet to atmosphere: structure Skid CA70
- height of release point: 7.9 m
- release direction of vent pipe section: towards plant south
- diameter of PSV outlet piping to atmosphere: DN80
- release of pipe section flanged at PSV (incline): 45° angled from horizontal.

8.2.8 For 1-PSV2060.1

For pressure safety valve 1-PSV2060.1 there is no influence of existing buildings/equipment's/platforms with carbon dioxide concentration of 1.5 Vol-% in air, 50% LEL for hydrogen (20000 ppm) and methane (22000 ppm) as well as UK/WEL for 8 hours and 10 minutes for carbon monoxide (23 ppm and 100 ppm) (see graph in chapter 6.3.8).

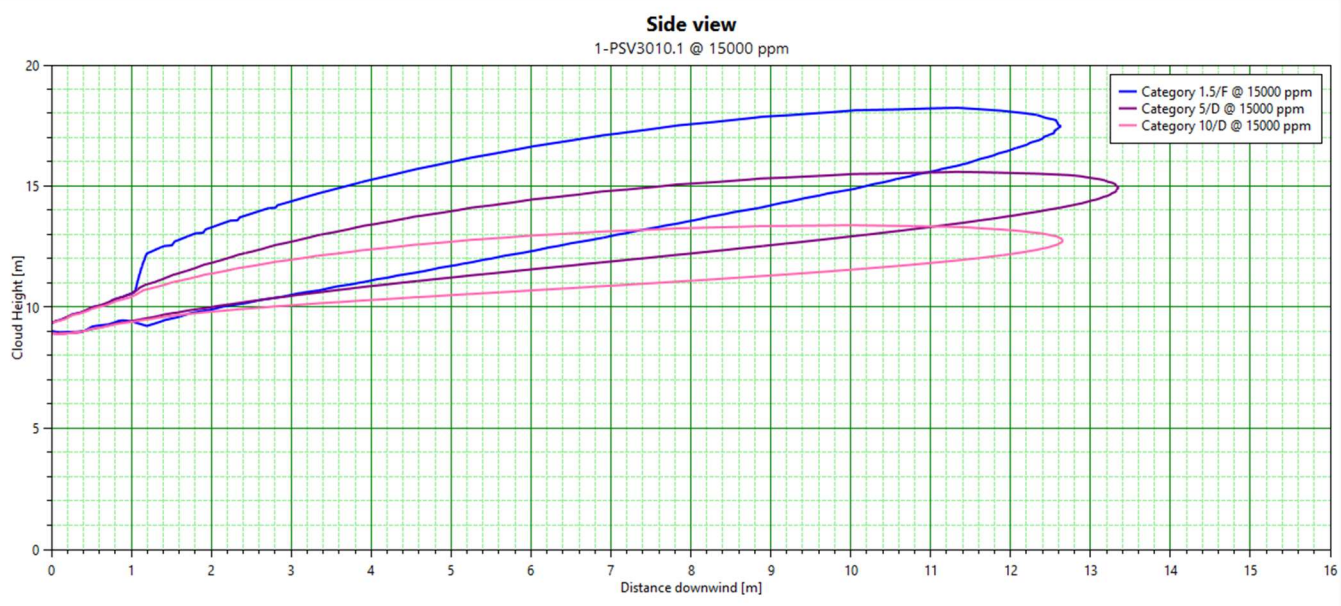
Hence the investigation resulted in the following requirements:

- Location of PSV outlet to atmosphere: structure Skid CA70
- height of release point: 9.0 m
- release direction of pipe section flanged at PSV: towards plant east,
- diameter of PSV outlet piping to atmosphere: DN250
- release of pipe section flanged at PSV (incline): 45° angled from horizontal.

8.3 Dispersion graphs

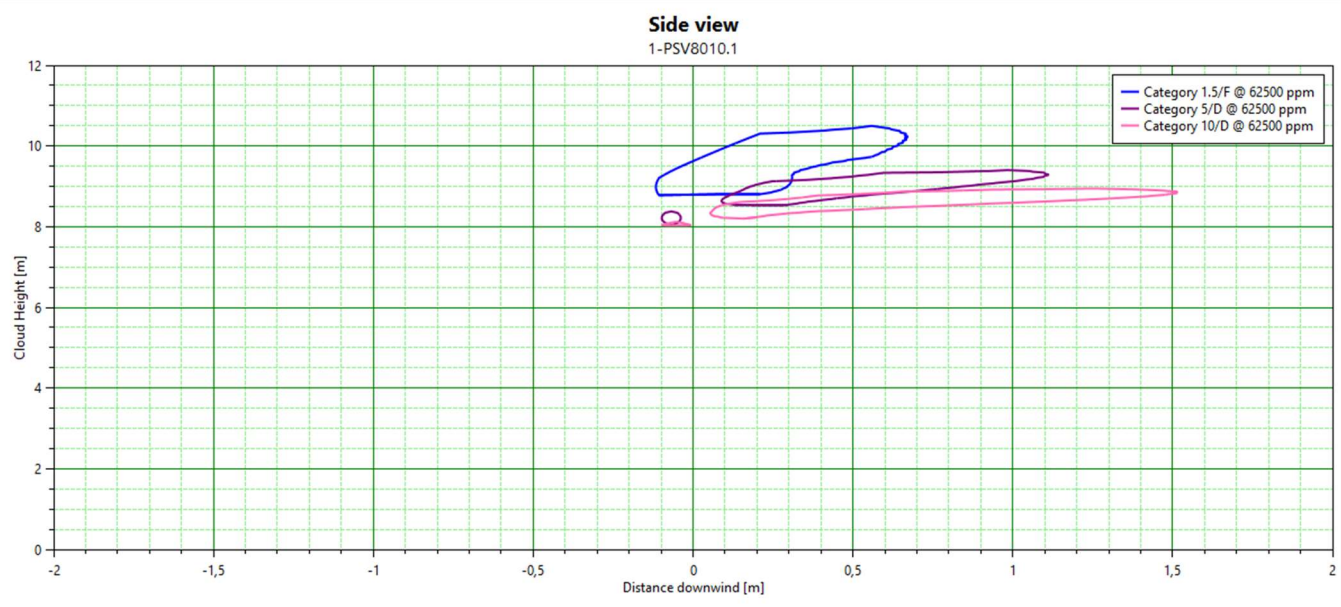
8.3.1 Dispersions of CO_2 via 1-PSV3010.1 at steel structure Skid CA70

Specified PSV mass flow rate, all weather: release (incline): 45° angled from horizontal towards plant east; limit for CO_2 concentration of 1.5 Vol-% in air.



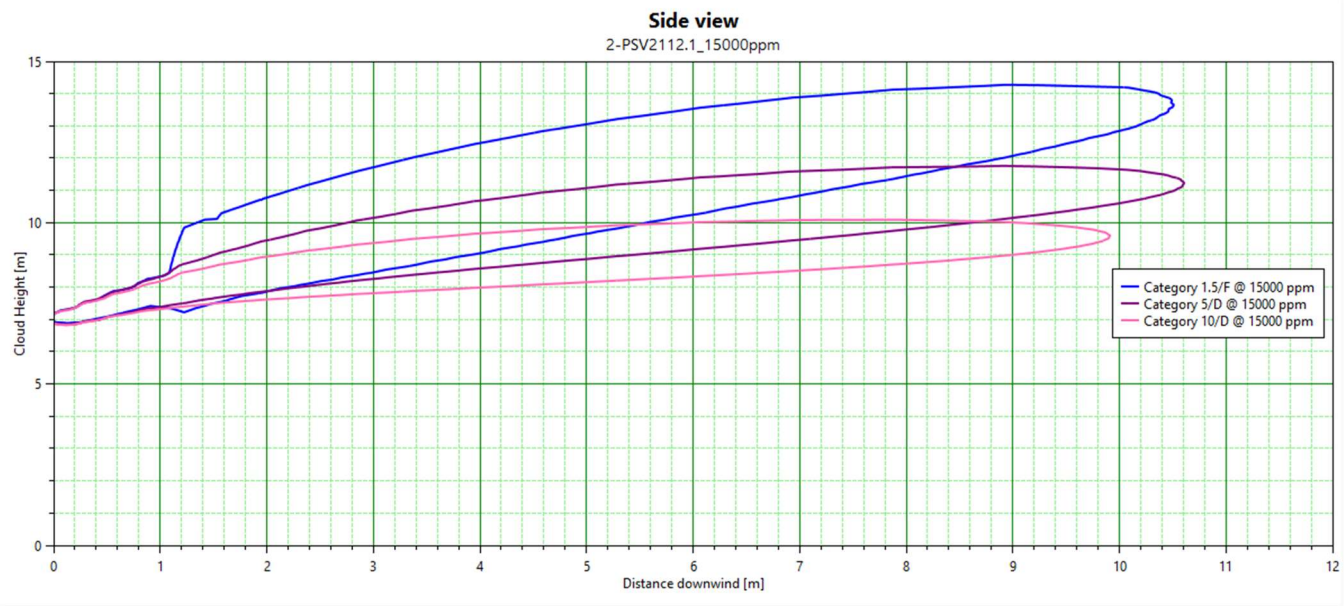
8.3.2 Dispersions of N_2 via 1-PSV8010.1 at steel structure Skid CA70

Specified PSV mass flow rate, all weather: release (incline): vertical up; limit for O_2 concentration of 19.5 Vol-% in air.



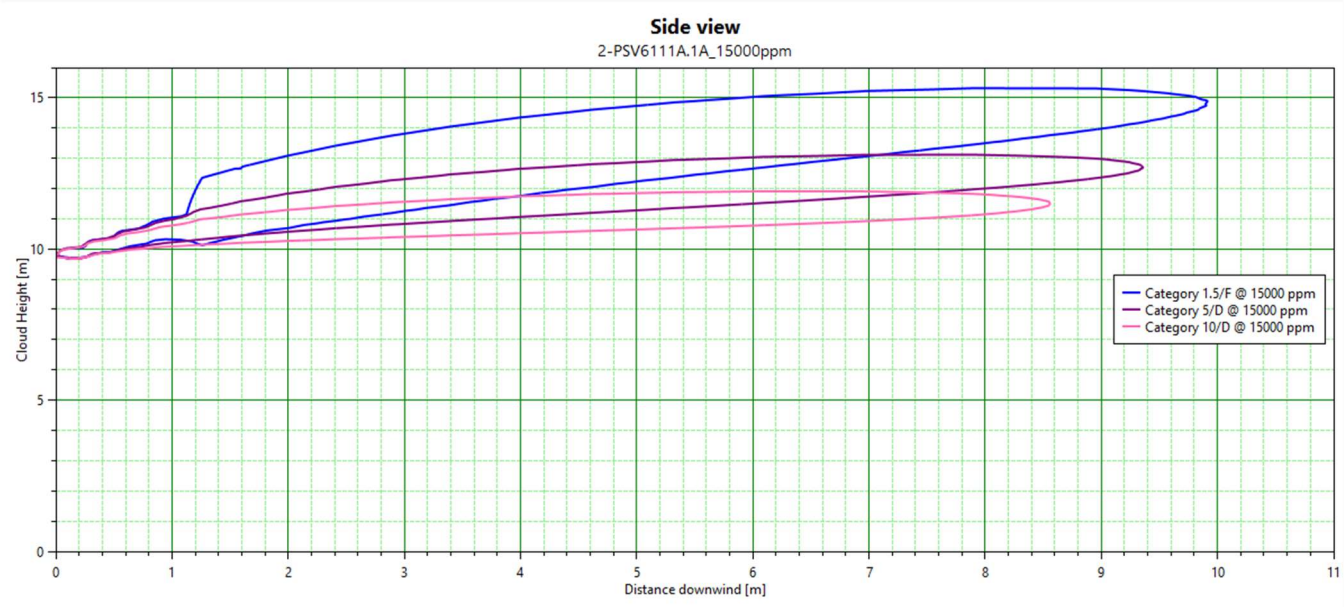
8.3.3 Dispersions of CO_2 via 2-PSV2112.1 at steel structure Skid CA02

Specified PSV mass flow rate, all weather: release (incline): 45° angled from horizontal towards plant southeast; limit for CO_2 concentration of 1.5 Vol-% in air.



8.3.4 Dispersions of CO2 via 2-PSV6111A/B/C.1A/B at steel structure Skid CA07

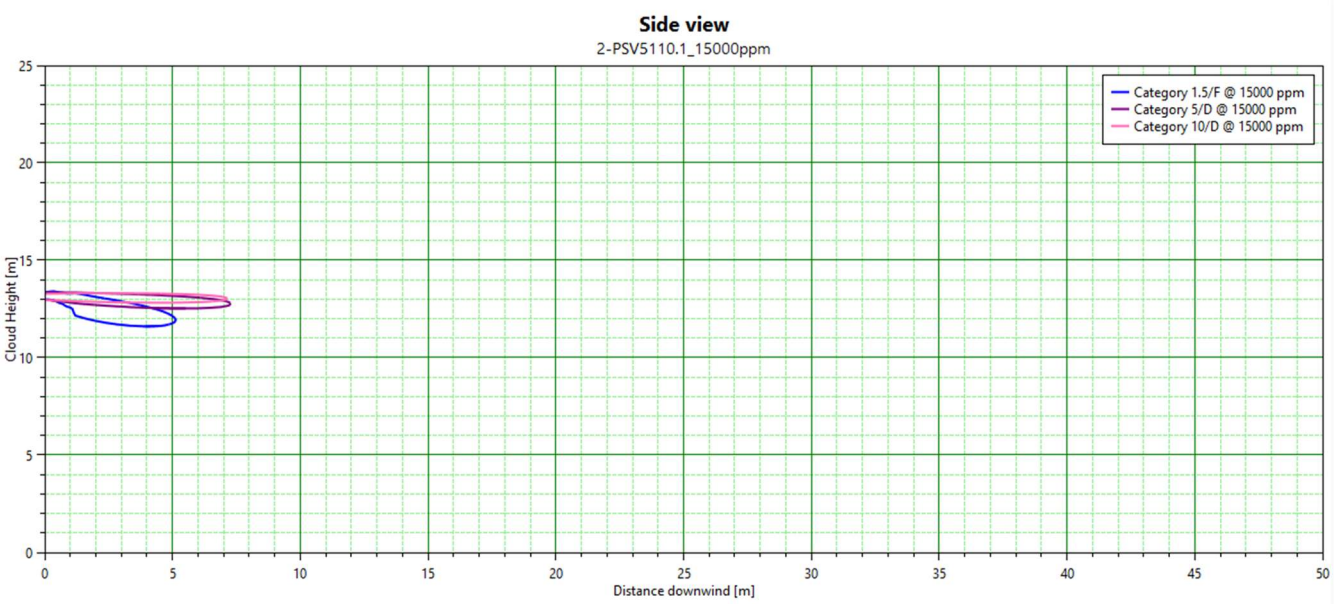
Specified PSV mass flow rate, all weather: release (incline): 45° angled from horizontal towards plant north; limit for CO_2 concentration of 1.5 Vol-% in air.



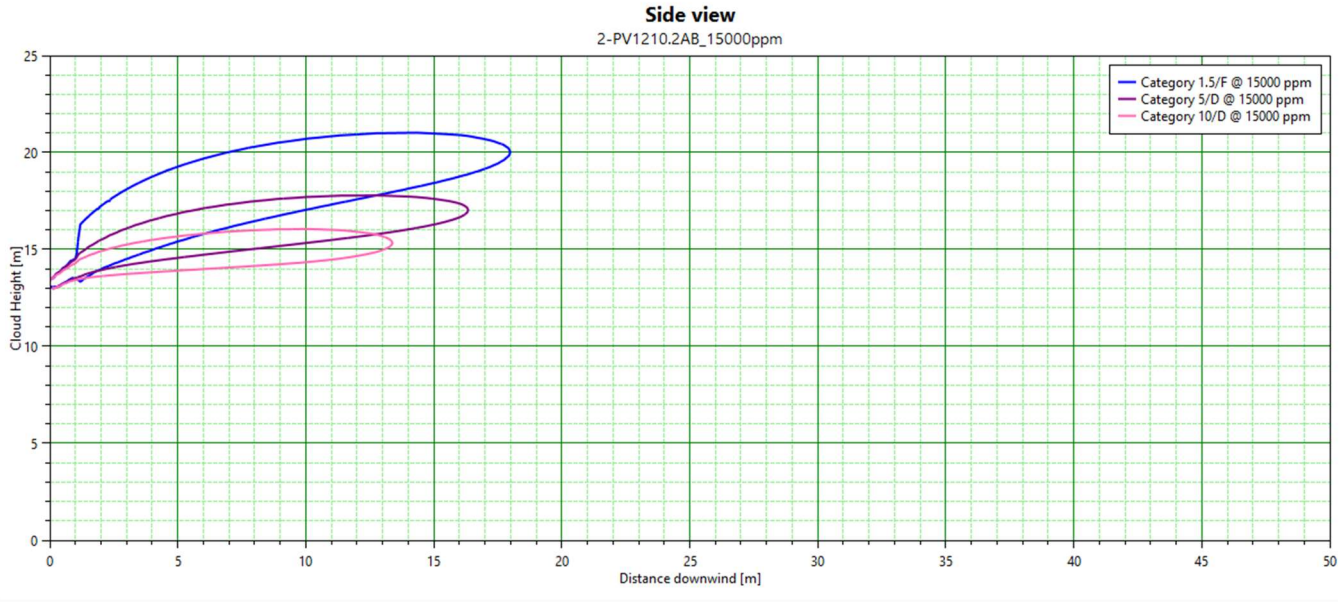
8.3.5 Dispersions of CO_2 via silencer 2-N4191 at steel structure Skid CA51

Specified silencer mass flow rate, all weather: release (incline): 45° angled from horizontal towards plant northwest; limit for CO_2 concentration of 1.5 Vol-% in air for emergency cases (e.g. PSV release) and 0.5 Vol-% in air for normal operating vents.

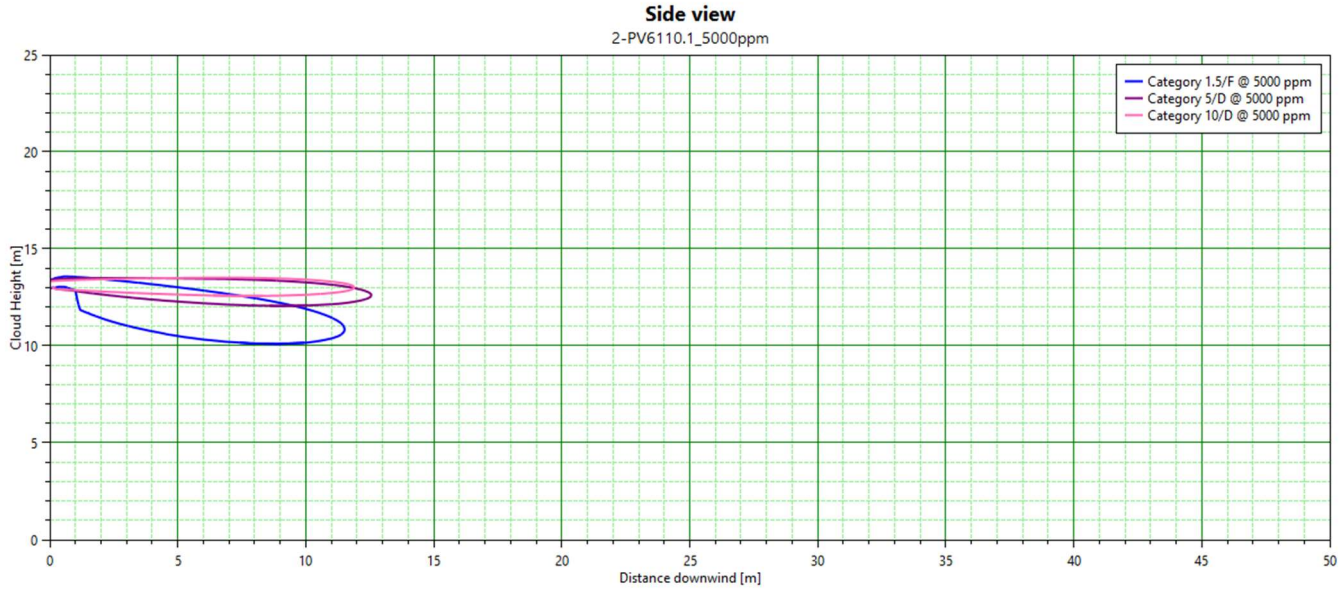
Specified mass flow rate over 2-PSV5110.1, all weather (1.5 Vol% CO_2 in air).



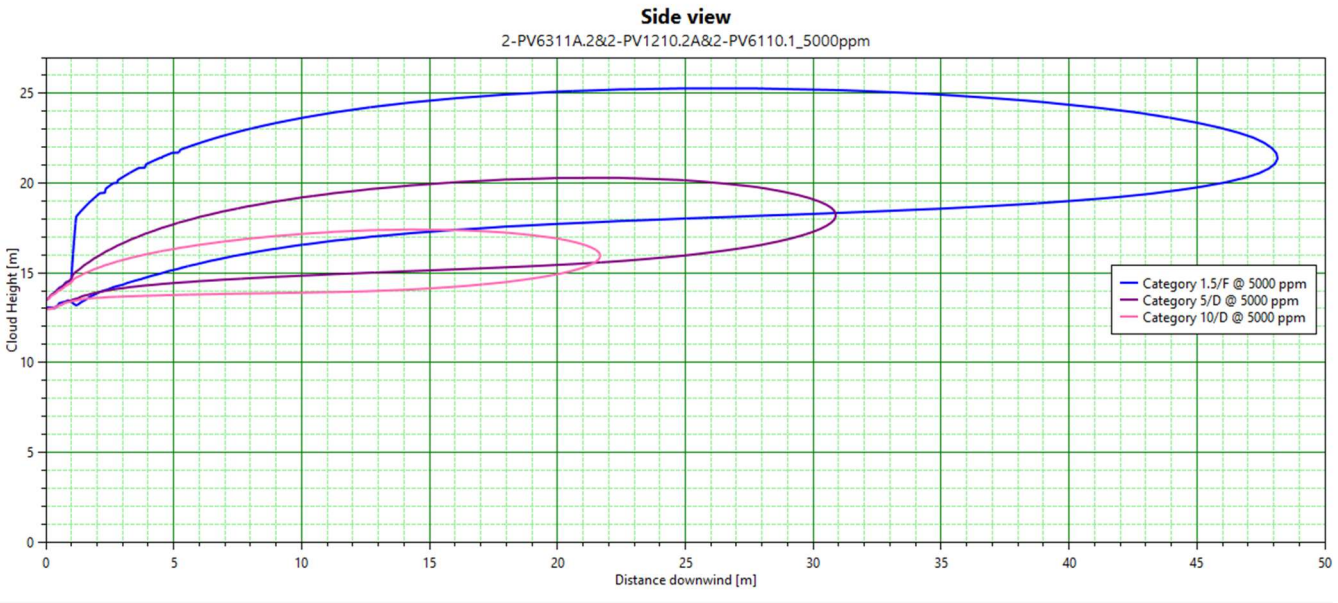
Mass flow rate over fully open 2-PV1210.2A/B (max. emergency case), all weather (1.5 Vol% CO_2 in air).



Boil off from CO2 storage tanks via 2-PV6110.1 (min. operating flow), all weather (0.5 Vol% CO_2 in air).

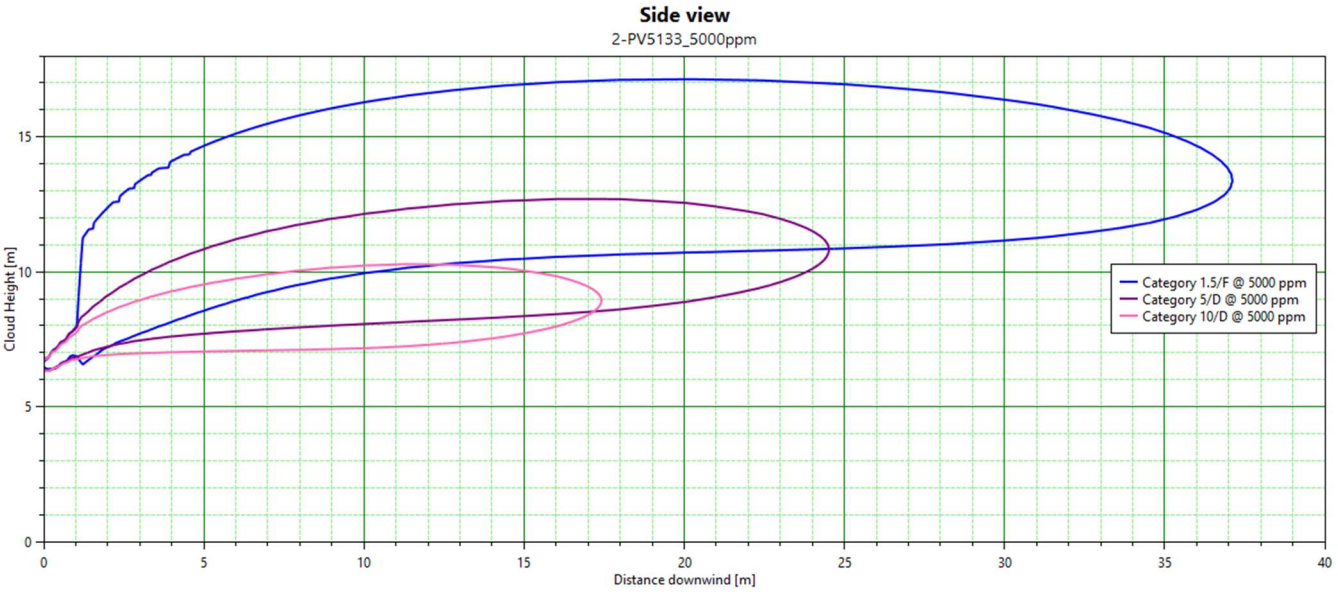


Normal operation (venting of CO2) + tank boil off + truck depressurization: simultaneous opening of 2-PV1210.2A & 2-PV6110.1 & 2-PV6311A.2 (max. operating flow), all weather (0.5 Vol% CO_2 in air).



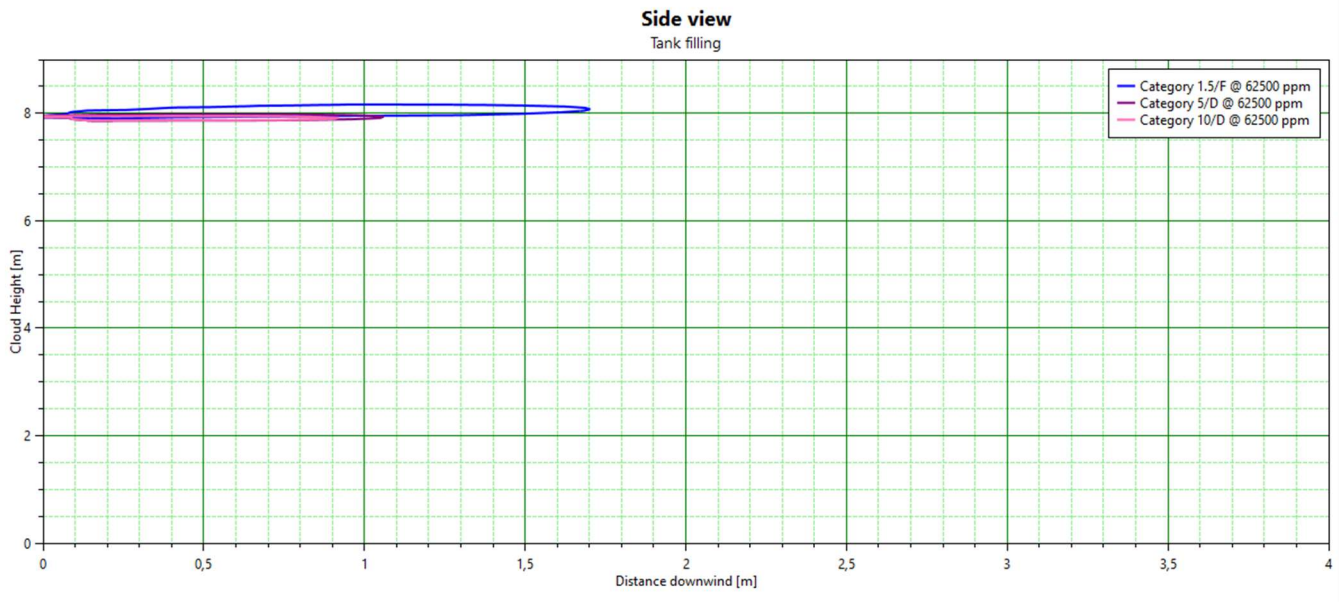
8.3.6 Dispersions of CO_2 via CO_2 vent header for offspec dump at steel structure CA03

Venting of offspec CO_2 from CO_2 column via 2-LV5110.1 (max. offspec flow), all weather: release (incline): 45° angled from horizontal towards plant north, limit for CO_2 concentration of 0.5 Vol% CO_2 in air.

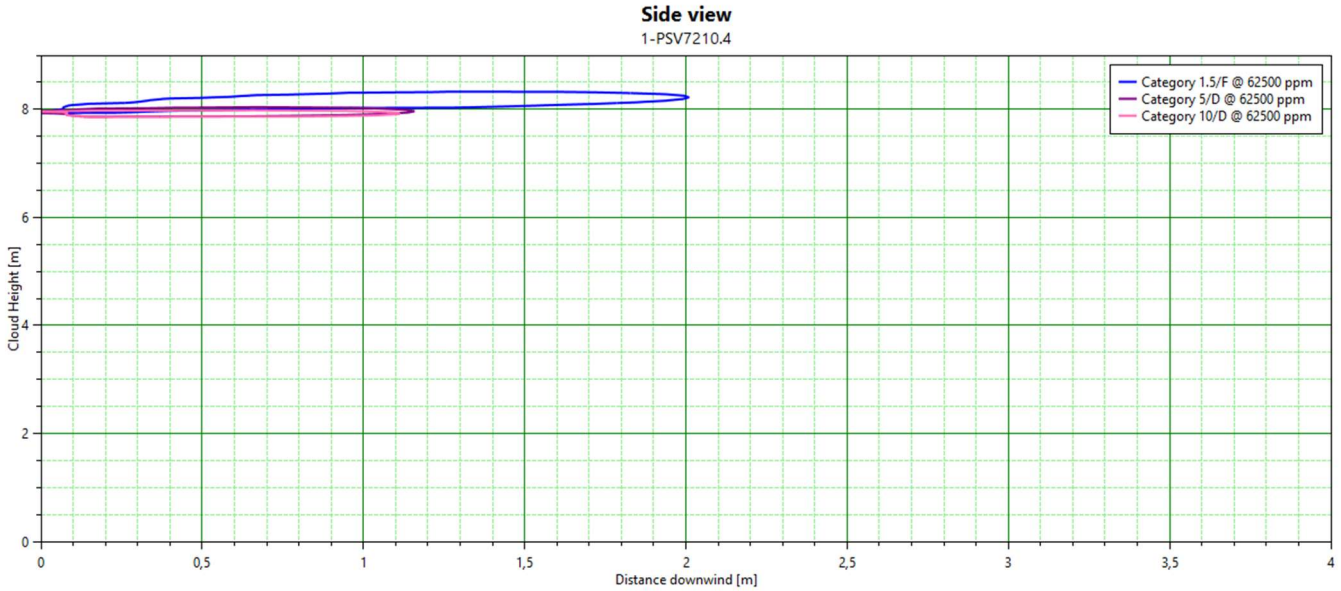


8.3.7 Dispersions of N_2 via solution vent header at steel structure Skid CA70

Specified mass flow rate of solution filling pump, all weather: release (incline): 45° angled from horizontal; limit for O_2 concentration of 19.5 Vol-% in air.

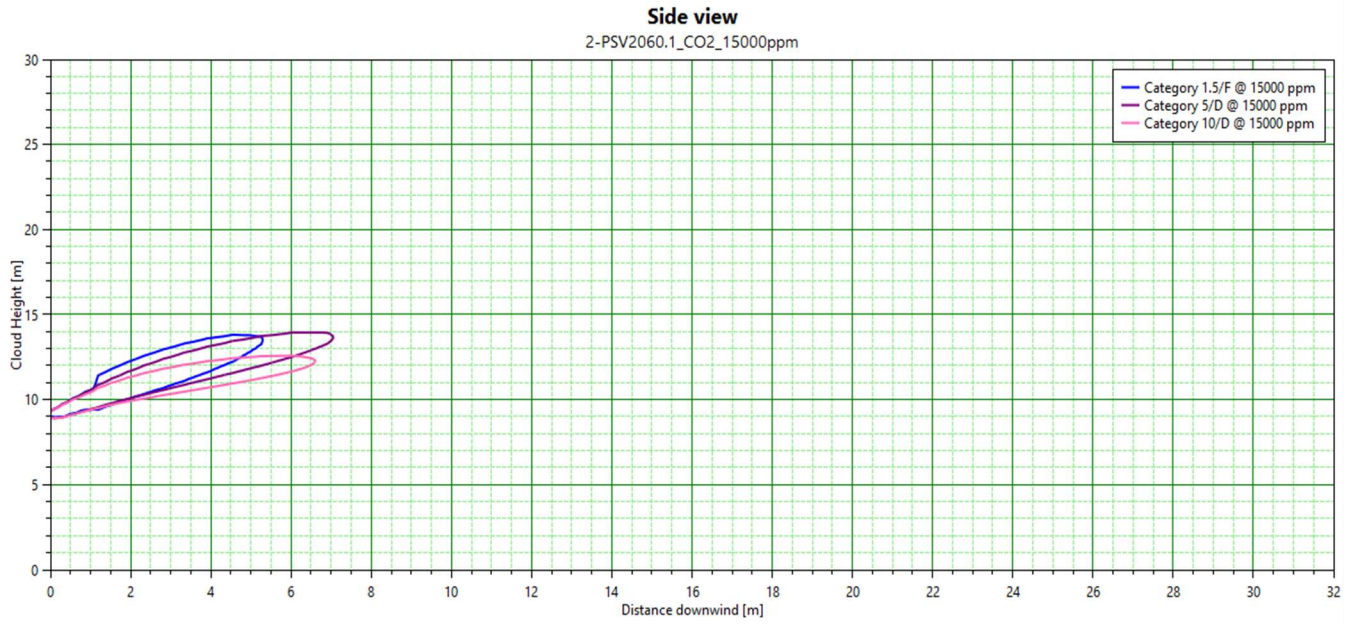


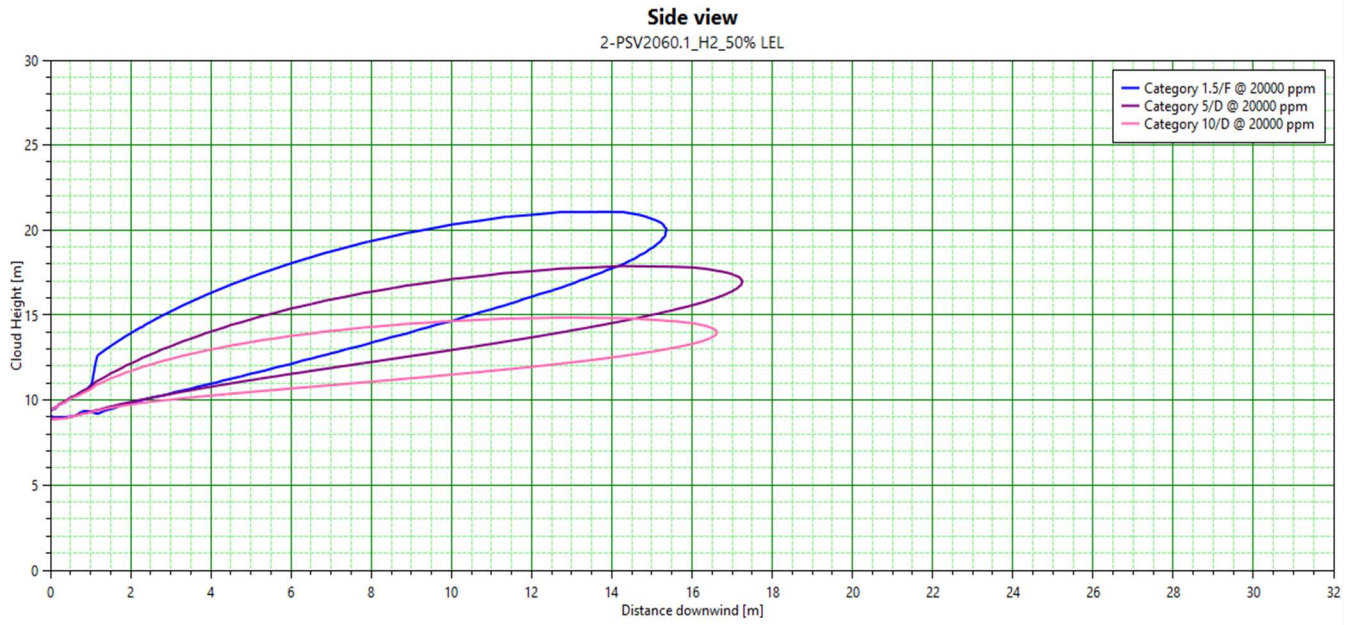
Specified mass flow rate of 1-PSV7210.4, all weather: release (incline): 45° angled from horizontal; limit for O_2 concentration of 19.5 Vol-% in air.

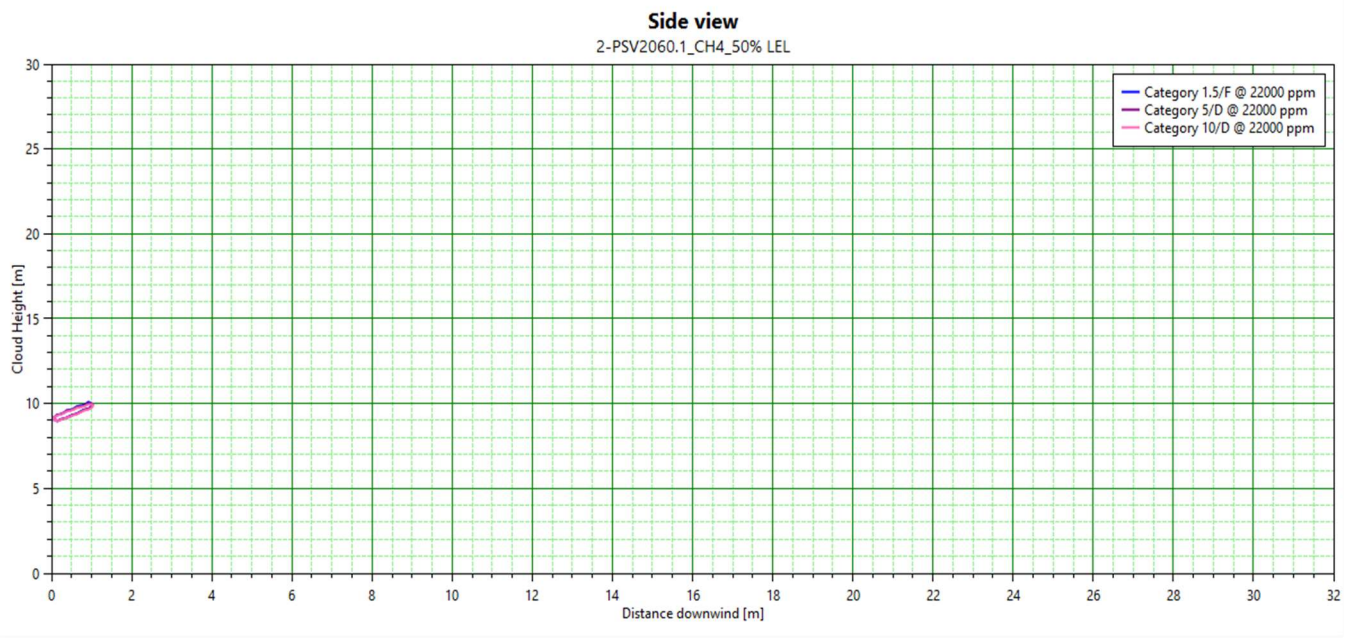


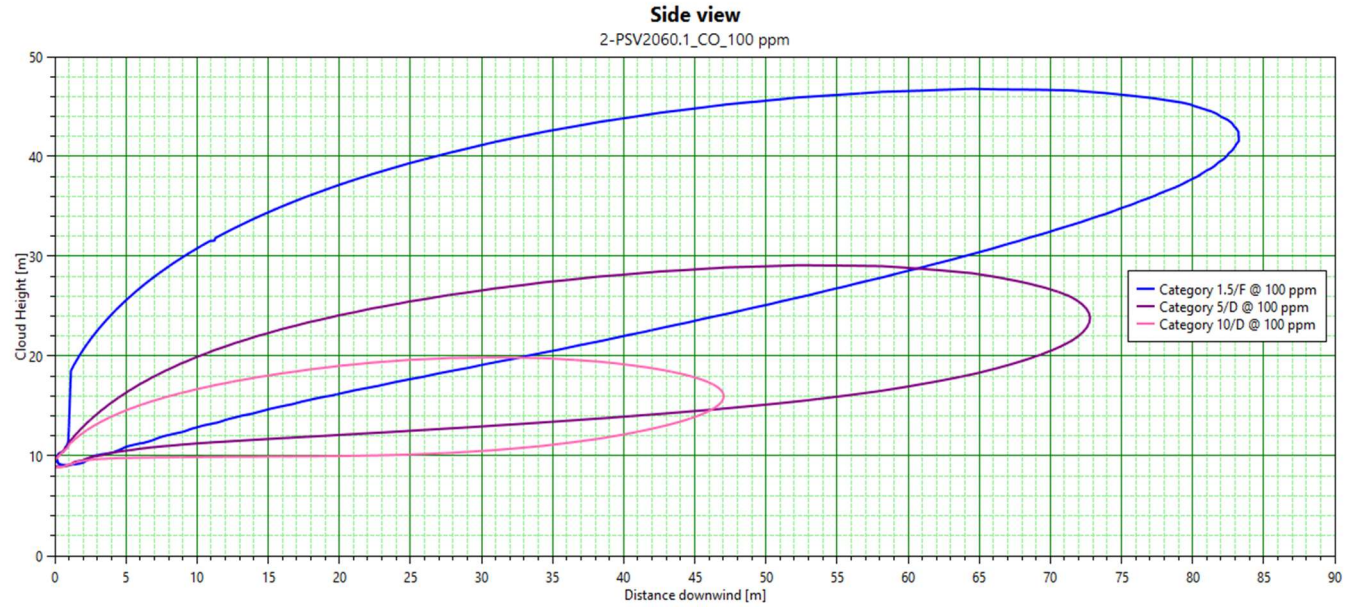
8.3.8 Dispersions of CO_2, H_2, CH_4 and CO via 1-PSV2060.1 at steel structure Skid CA70

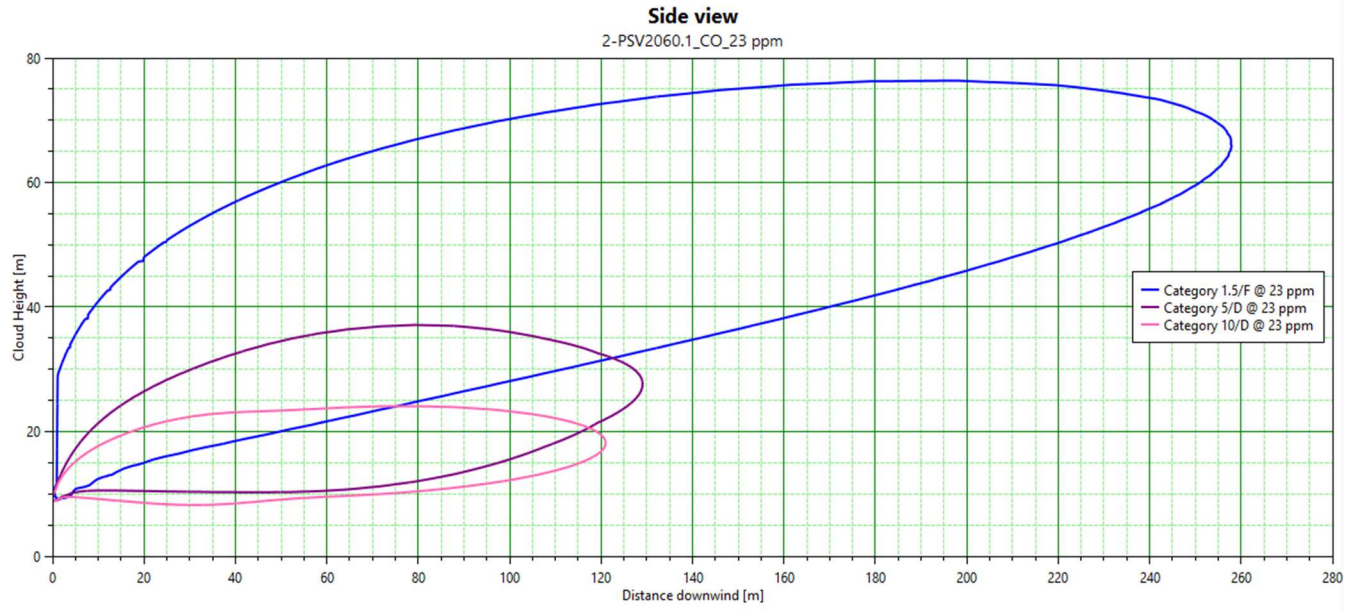
Specified PSV mass flow rate, all weather: release (incline): 45° angled from horizontal towards plant east; limit for CO_2 concentration of 1.5 Vol-% in air, 50% LEL for hydrogen (20000 ppm) and methane (22000 ppm) as well as UK/WEL for 8 hours and 10 minutes for carbon monoxide (23 ppm and 100 ppm).






Side view
2-PSV2060.1_CH4_50% LEL
Category 1.5/F @ 22000 ppm
Category 5/D @ 22000 ppm
Category 10/D @ 22000 ppm
Cloud Height [m]
Distance downwind [m]


Side view
2-PSV2060.1_CO_100 ppm
Category 1.5/F @ 100 ppm
Category 5/D @ 100 ppm
Category 10/D @ 100 ppm
Cloud Height [m]
Distance downwind [m]


Side view
2-PSV2060.1_CO_23 ppm
Category 1.5/F @ 23 ppm
Category 5/D @ 23 ppm
Category 10/D @ 23 ppm
Cloud Height [m]
Distance downwind [m]