Humber Zero VPI-Immingham Post-Combustion Carbon Capture Project FEED

CO2 Venting Environmental Assessment

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Holds

Hold No.	Section	Description of Hold

Document Revisions

Rev.	Section	Description of Change
A	All	Initial revision
0	All	Minor text corrections
	5.9	New section on Impact on Receptors

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1. Executive Summary

This study has been conducted to assess the impact of CO_2 from planned or unplanned venting, on the environment and the local population.

The assessment has been carried out in line with the UK Environment Agency (EA) "Risk Assessments for Specific Activities: Environmental Permits guidance [Defra and EA, 2016, Ref. 2]

The assessment demonstrates that public exposure levels of CO_2 are well below the levels at which the onset of symptoms and effects are reported, and the modelling indicates that even the Long-Term Exposure Limit (LTEL) of 0.5% (5,000ppm) does not reach the ground for any of the cases considered. Overall, the dispersion modelling indicates that the gas plumes from planned or unplanned venting will be of very limited extent, and at a height that will not impact people, fauna or flora.

In the worst case, the plume may touch down between 200m and 1,500m at between 1,000ppm and 2,000ppm.

To put this in perspective:

400 - 1,000ppm	Concentrations typical of occupied indoor spaces with good air exchange
1,000 - 2,000ppm	Complaints of drowsiness over extended periods and poor air exchange. *

* (What are safe levels of CO and CO_2 in rooms? | Kane International Limited)

"*CO_2 levels consistently higher than 1500ppm in an occupied room indicate poor ventilation and you should take action to improve it.*" (Using CO_2 monitors - Ventilation in the workplace (hse.gov.uk))

The only cases that exceed 1,500ppm (but less than 2,000ppm) are likely to be of short duration < 1 hour. Any longer duration venting for instance with depressurising, will not exceed 1,500ppm at ground level.

2. Project Description

Humber Zero is a combined set of projects that aim to decarbonise the world-scale industrial complex at Immingham, comprising VPI's 1260 MW Combined Heat and Power plant and the adjacent Humber Oil Refinery operated by Phillips 66.

Humber Zero's initial phase focuses on the post-combustion carbon capture components of this strategy. At VPI-Immingham this phase will deliver up to 3.3 MTPA of abated CO_2 emissions via a post-combustion carbon capture retrofit to two gas turbines and two auxiliary gas boilers.

Shell have been selected as the carbon capture technology provider for the VPI-Immingham project.

Worley as the selected FEED contractor for the VPI-Immingham project will deliver an overall FEED package integrating the Shell Process Design Package (PDP). The project scope includes the existing site flue gas, utility and power tie-ins as well as CO_2 treatment, conditioning and compression for export into a regional dense phase CO_2 Transport & Storage (T&S) system.

2.1 Purpose

This study report covers the impact of CO_2 on the environment and the local population from planned or unplanned venting from the Humber Zero VPI-Immingham Post-Combustion Carbon Capture Project.

The existing environmental Air Dispersion modelling does not include Carbon Dioxide (CO_2), as it is not considered a toxic gas. However, in high concentrations it can be hazardous to both human health and to the environmental flora and fauna. This report is intended to cover that gap and demonstrate that the vent emissions are not high enough to be harmful to the population or the environment.

2.2 Acronyms List

Table 2-1 - Acronyms

Abbreviation	Definition
ALARP	As Low As Reasonably Practicable
CO_2	Carbon Dioxide
DEFRA	(UK) Department for Environment, Food & Rural Affairs
DTL	Dangerous Toxic Load
EA	(UK) Environment Agency
HSE	(UK) Health and Safety Executive
IDLH	Immediately Dangerous to Life or Health
LTEL	Long-Term Exposure Limit
LUP	Land Use Planning
PDP	Shell Process Design Package

SLOD	Significant Likelihood of Death
SLOT	Significant Level of Toxicity
STEL	Short-Term Exposure Limit
T&S	Transport & Storage
VPI-I	Vitol Power International Immingham

2.3 References

1. UK EA & DEFRA, 2014 – 2021, Guidance on Environmental permitting: air dispersion modelling reports (Environmental permitting: air dispersion modelling reports - GOV.UK (www.gov.uk))
2. UK EA & DEFRA, 2016 – 2023, Guidance on Air emissions risk assessment for your environmental permit (Air emissions risk assessment for your environmental permit - GOV.UK (www.gov.uk))
3. Worley, Rev. 0, 415000-00201-8150-TN-0001- VPI Technical Note: Vent Dispersion Modelling Results
4. Dr Peter Harper, UK Health and Safety Executive (HSE), Assessment of the major hazard potential of carbon dioxide (CO_2).
5. UK Health and Safety Executive (HSE), Fourth Edition 2020, EH40/2005 Workplace exposure limits.
6. UK Health and Safety Executive (HSE), Ver 3, SPC/Tech/OSD/30, Indicative human vulnerability to the hazardous agents present offshore for application in risk assessment of major accidents
7. Energy institute, Rev. C Draft 2023, EI123/013, Hazard Analysis for Onshore and Offshore Carbon Capture Installations and Pipelines
8. C.M. Dixon Et Al, 2012, Validation of Dispersion Models for High Pressure Carbon Dioxide Releases, Hazards XXIII Symposium Series no 158
9. DNV, Rev. 3 (June 2023), Application of Phast and Safeti to carbon dioxide consequences and risks,
10. Holt, H., Brown, J., Witlox, H.W.M., Armstrong, K., 2015. "Discharge and dispersion for CO_2 releases from a long pipe: Experimental data and data review", Hazards 25, Symposium Series NO 160.
11. Witlox, H.W.M, Brown, J, Holt, H., Armstrong, K., Allason, D., 2015. "Discharge of CO_2 from large-diameter orifices: Experimental data and data review", Process Safety Progress, Volume 34.
12. Ahmad, Mohammad, Lowesmith, Barbara, Koeijer, Gelein De, Nilsen, Sandra, Tonda, Henri, Spinelli, Carlo, Cooper, Russell, Clausen, Sigmund, Mendes, Renato, Florisson, Onno., 2015. "COSHER joint industry project: Large scale pipeline rupture tests to study CO_2 release and dispersion", International Journal of Greenhouse Gas Control, 37, 340-353.
13. Witlox, H.W. M., Harper, M., & Oke, A. (2009). "Modelling of discharge and atmospheric dispersion for carbon dioxide releases". Journal of Loss Prevention, 22(6), 795-802.
14. Witlox, H.W.M, Harper, M., Oke, A., Stene, J., 2014. "Phast validation of discharge and atmospheric dispersion for pressurised carbon dioxide releases". Journal of Loss Prevention in the Process Industries, Volume 30, Pages 243-255, ISSN 0950-4230. https://doi.org/10.1016/j.jlp.2013.10.006.
15. Witlox, H.W. M., Harper, Mike, Oke, Adeyemi, Stene, Jan., 2014. "Validation of discharge and atmospheric dispersion for unpressurised and pressurised carbon dioxide releases", Process Safety and Environmental Protection, 3-16.
16. Witlox, H.W.M, Fernandez, M., Harper, M., Oke, A., Stene, J., Xu, Y., 2018. "Verification and validation of Phast consequence models for accidental release of toxic or flammable chemicals to the

atmosphere". Journal of Loss Prevention in the Process Industries, Volume 55, Pages 457-470, ISSN 0950-4230. https://doi.org/10.1016/j.jlp.2018.07.014.

17. S.E. Gant, V.D. Narasimhamurthy, T. Skjold, D. Jamois, C. Proust, 2014. "Evaluation of multi-phase atmospheric dispersion models for application to Carbon Capture and Storage". Journal of Loss Prevention in the Process Industries, Volume 32, Pages 286-298
18. S. Gant, M. Pursell, A. McGillivray, J. Wilday, M. Wardman, A. Newton, 2017, "Overview of carbon capture and storage (CCS) projects at HSE's Buxton Laboratory", HSE RR1121

3. Modelling Description

3.1 Methodology

The overall objective of air modelling is to understand the effect of HZ VPI-I PCC operations on the ambient air quality. For this purpose, it is necessary to model the key emission sources of the PCC to estimate contribution of the PCC operations in the concentration of the key atmospheric pollutants in the ambient air. Then, the result of the model should be added to the background concentration of the pollutants to estimate the total concentrations of the pollutants which should be compared to the ambient air quality standards and to identify any exceedance from the standard limits.

This report is only focused on the CO_2 emissions which are not considered pollutants, and do not have any existing air quality standards. There is some guidance on unacceptable concentrations of CO_2 and on the concentrations that can cause harm to people or the environment.

The modelling methodology can be summarised in the following steps:

1. Identifying sources of CO_2 releases within the process design, including the physical parameters and estimated frequency of release and the release points including the two absorber stacks and the dedicated HP Vent stack.
2. Identify the release cases that have sufficient information and high enough concentrations to potentially contribute to raised CO_2 concentrations at ground level.
3. Modelling the CO_2 venting cases for different weather conditions and plotting the dispersion of the gas plume.
4. Identifying any cases causing high concentrations at ground level above predetermined criteria.
5. Carrying out sensitivity analysis on any cases considered potentially critical.

3.2 Modelling Software

DNV PHAST Version V8.7 was adopted to model vent gas dispersion. This is an industry standard consequence modelling software which examines the progress of a potential incident from the initial release (source term) to far-field dispersion analysis, together with gas dispersion, jet fire thermal radiation modelling, flash fire and explosion effects calculation.

The current versions of PHAST software are capable of modelling carbon dioxide. Carbon dioxide has a special property in that it can exist as a solid or vapour at atmospheric pressure. When pure carbon dioxide is released from containment to the external environment, the storage pressure will be reduced to atmospheric pressure so this is when carbon dioxide, from its original state will transform into either solid or vapour. In the discharge or dispersion results reporting, any liquid fraction should be read as solid fraction.

The Peng-Robinson equation of state was used for carbon dioxide releases for more accurate and robust behaviour particularly for temperatures closer to critical temperature. There are several validations for leak scenario which indicate that flowrates are predicted better with Peng-Robinson compared to the default equations of state [Ref. 9]. DNV recommends using the Peng-Robinson equations of state for CO_2 modelling.

Vertical concentration contours were generated covering the concentrations of concern at different weather conditions as stated below. DNV recommended using release angles slightly less than 90° for vertical releases such as from the vent stack. See PHAST 8.71 Release notes extract Figure 3-1 below:

DNV

67975	Dispersion results for vertical releases
Description	The dispersion calculations for vertical releases can be problematic, particularly when determining downwind concentrations. The algorithms are based on tangents to the centreline, and therefore vertical or near vertical clouds can run into difficulties that require special handling. In some cases, it has become apparent that this can lead to concentration predictions that are generally over-conservative. In most cases these problems can be solved by reducing the release angle, so it is just off vertical, e.g., to 85 degrees from the horizontal.

Figure 3-1: PHAST Release Notes Extract on vertical releases

3.3 Model Uncertainty

The PHAST software includes a large number of mathematical models. The theory, verification and validation of these models is included in the technical documentation provided with PHAST and in various technical publications. References to detailed validation analysis are provided rather than repeating the information here. For CO_2 (and other materials), an overview of key verification and validation is given in Witlox et al., (2018) [Ref. 16] and provides a good general introduction.

Experiments used to validate PHAST models are listed in Table 3-1.

	BP	Shell	CO2PIPETRANS: Pipe releases	CO2PIPETRANS: Orifice releases	COSHER
Scenario	Orifice, horizontal	Orifice, horizontal	Long pipe, horizontal	Orifice, horizontal	Buried long pipe
Pressure [bar]	82 - 158	80 - 152	98 - 105	26 - 78	152
Temperature [°C]	5 - 149	0 - 71	3 - 14	-10 - 14	13.1
Fluid phase	Dense liquid, super-critical	Dense liquid, super-critical	Dense liquid	Liquid, dense liquid	Dense liquid
Hole diameter [mm]	6 - 26	6 - 25	10 – 50	25 - 150	219.1 (full-bore rupture)
Year	2006-07	2010-11	2012-13	2013	2013
Location	Spadeadam	Spadeadam	Spadeadam	Spadeadam	Spadeadam
Reference	(Witlox, et al., 2014) [14]	(Witlox, et al., 2014)[14]	(Holt, et al., 2015)[10]	(Witlox, et al., 2015)[11]	(Ahmad, et al., 2015)[12]

Table 3-1 - List of CO_2 experiments used for PHAST model validation

Over the past 10 years there have been several improvements in PHAST CO_2 modelling. These relate to the modelling of solid-vapour equilibrium calculations and solid properties, and special considerations for some physical properties (particularly density). This affects models from discharge through to dispersion. There is also a crater model which, while more generally applicable, was derived based on CO_2 buried pipeline experiments. The toxic effects of CO_2 are taken into account by using probit values derived from the HSE.

3.4 Model Confidence

3.4.1 DNV Tests for CO2PIPETRANS JIP8

The PHAST Model has been validated against BP and Shell experimental data made available via the CO2PIPETRANS JIP8. The experiments were of pressurised CO_2 releases involving steady-state and transient dense liquid phase releases, and time-varying supercritical releases. Initial pressure ranged from 80 bar to 158 bar, initial temperatures from 0°C to 149°C, and orifices diameters from 6 mm to 26 mm. The releases were horizontal and not impinged.

The releases were all modelled by the UDM as steady-state releases, with 20-seconds averaged flow rates applied for the time-varying BP releases and with the initial maximum flow rate applied for the time-varying Shell releases. For all cases the solid carbon dioxide was found to sublime rapidly, and no fallout was predicted, which was in line with experimental observations. The concentrations were found to be predicted accurately, as indicated in Figure 3-2 to Figure 3-4, where the vast majority of predicted concentrations are well within a factor of two. Details of this validation have been published [Ref. 14, 2014].

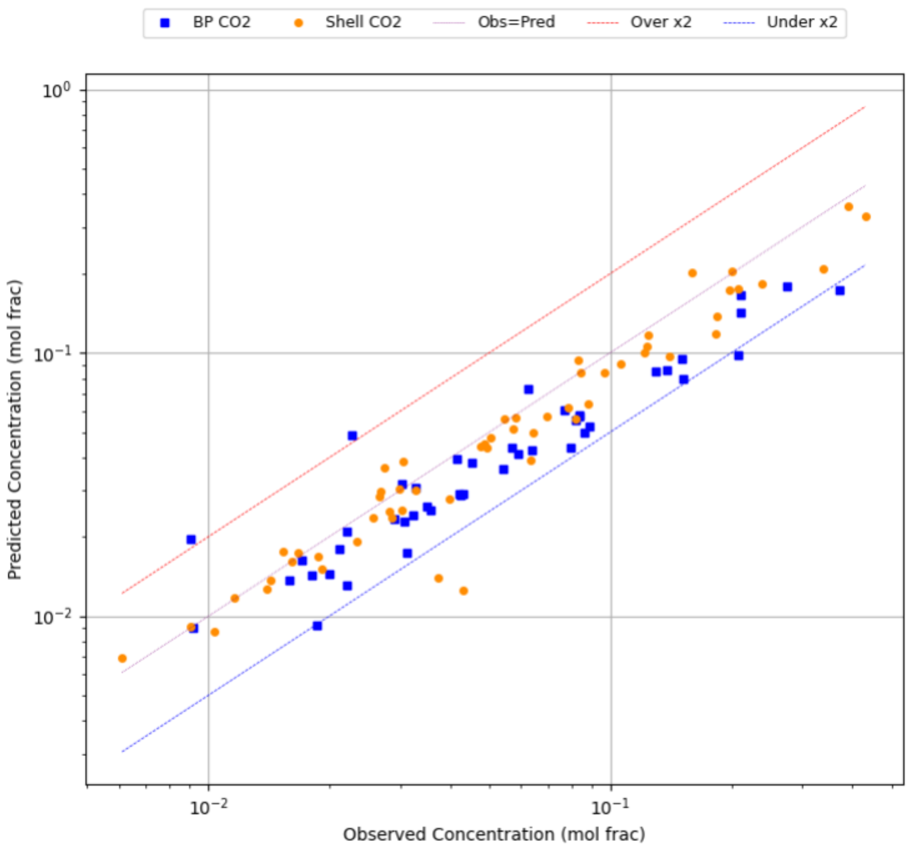


Figure 3-2 – PHAST validation of Shell and BP CO_2 dispersion experiments

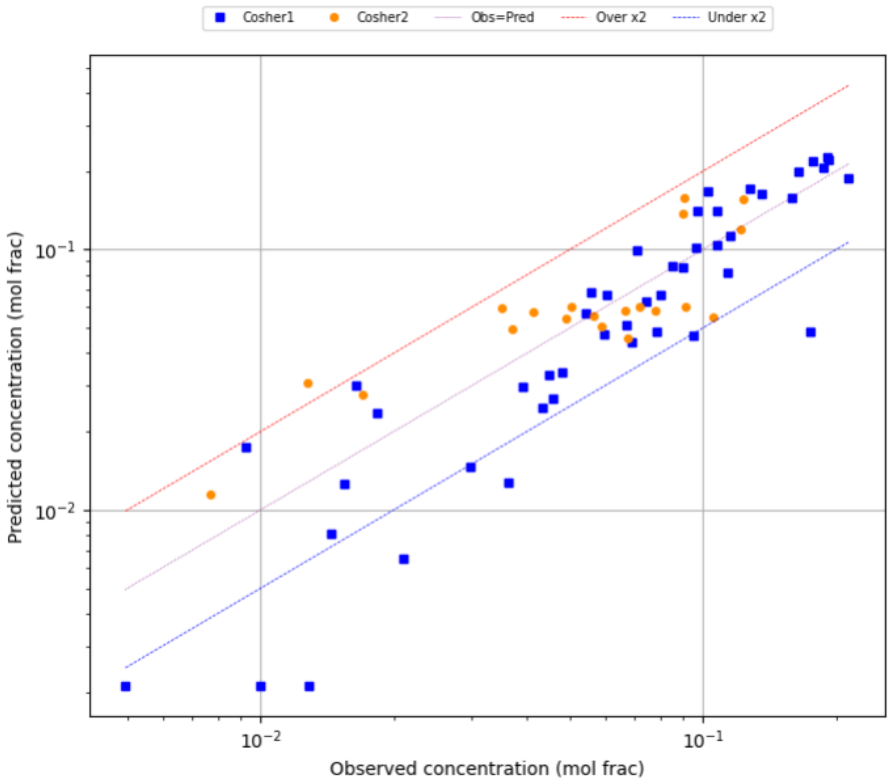


Figure 3-3 - Pointwise observed vs predicted maximum concentrations for COSHER experiments

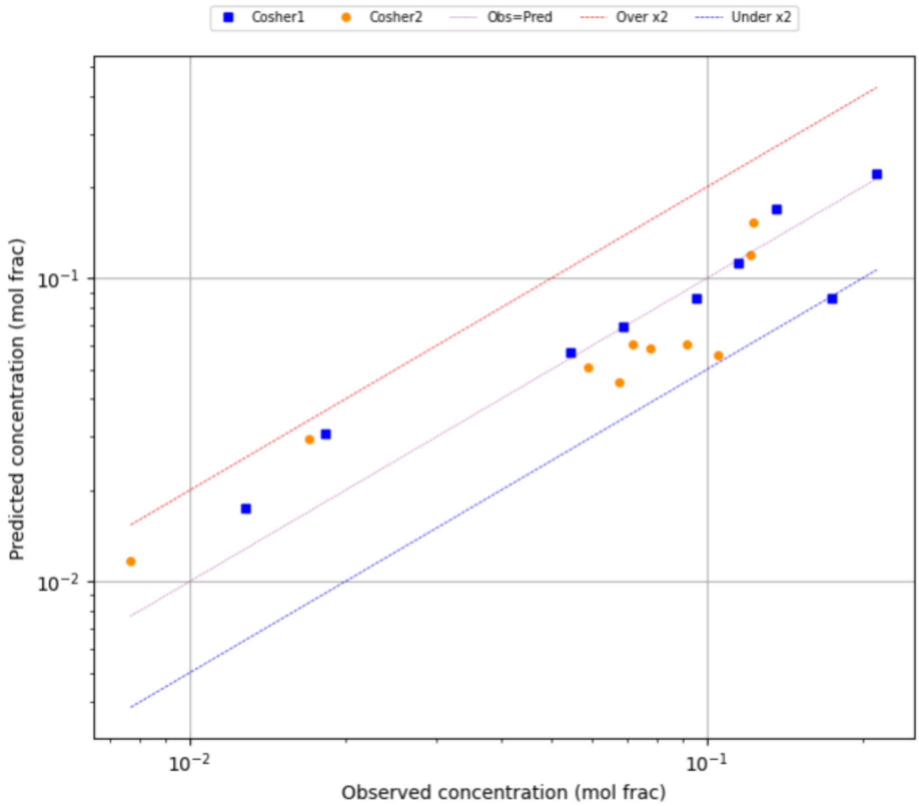


Figure 3-4 - Arcwise observed vs predicted maximum concentrations for COSHER experiments

Findings show that the Peng-Robinson equation of state (PR EoS) more accurately predicts CO_2 density in some regimes than the default method in PHAST. The results used for the Project used this setting.

3.4.2 INERIS tests as part of the CO2PipeHaz project.

Dispersion model predictions from PHAST, FLACS and ANSYS-CFX have been compared to measurements from two dense-phase CO_2 jet release experiments conducted by INERIS, as part of the EU-funded CO2PipeHaz project [Ref. 17]. Overall, the predicted concentrations from the various models were in reasonable agreement with the measurements, but generally in poorer agreement than has been reported previously for similar dispersion models in other dense-phase CO_2 release experiments. In the first experiment (INERIS Test 2), all of the models consistently over-predicted the CO_2 concentrations by between 3 and 7% vol/vol. As a result, the distance from the orifice to the point where the CO_2 concentration fell to the IDLH value of 4% vol/vol was over-predicted by a factor of two.

In the second experiment with a larger orifice, a wide range of predictions were obtained using the different models. PHAST produced similar results to the ANSYS-CFX model that used averaged top-hat inlet profiles, i.e. it consistently under-predicted the centreline temperatures by up to 20°C and over-predicted the centreline concentrations by up to 8% v/v.

4. Input Data and Assumptions

4.1 CO_2 Phase Diagram

CO_2 has an unusual phase diagram, from solid CO_2 directly sublimating to vapour at atmospheric pressure, to liquid and vapour at higher pressures, and to dense phase supercritical CO_2 above the critical point (See Figure 4-1 below).

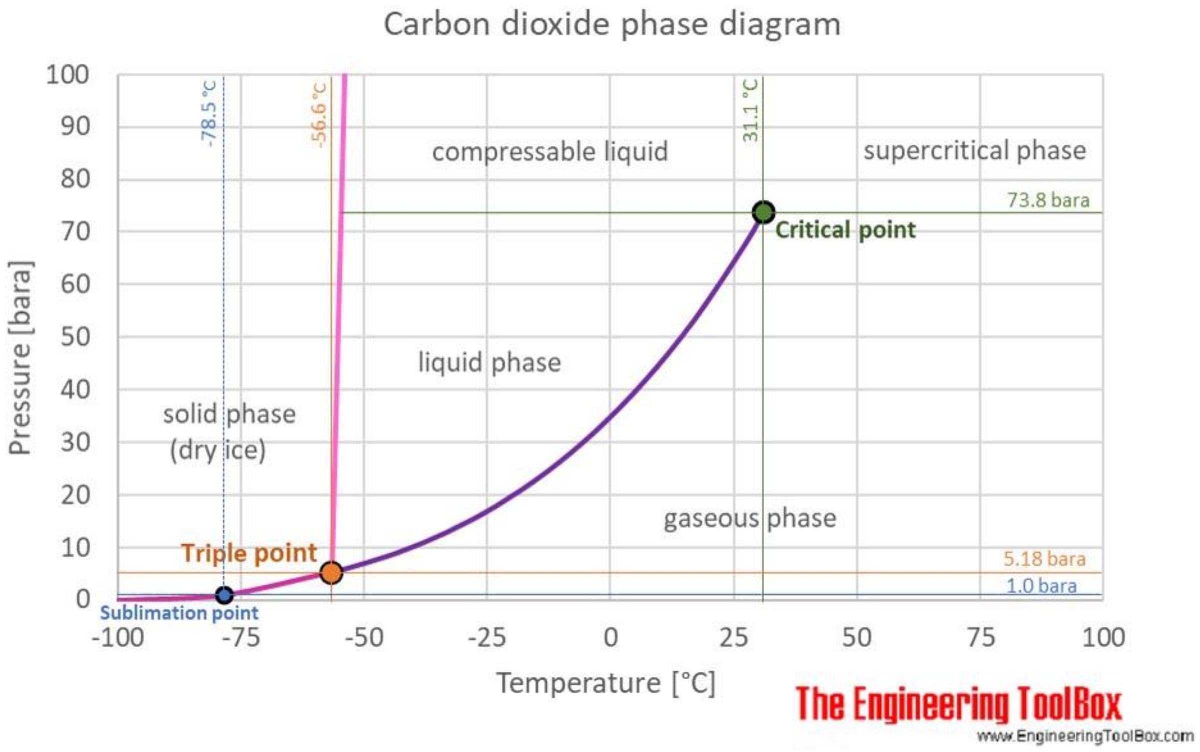


Figure 4-1: CO_2 Phase Diagram

In its dense phase, the CO_2 is a highly compressed fluid that demonstrates properties of both a liquid and a gas. It is called a dense fluid, or supercritical fluid, to distinguish it from normal vapor and liquid.

4.2 Vent Locations and Releases

The VPI PCC project has two fixed vent locations for normal operational use:

1. LP CO_2 Vent gases are directed to the CO_2 Absorber and comingled with normal flue gases from the gas turbines before the CO_2 is removed by the Absorber solvents and the residual gases are vented above the Absorber column.
2. HP CO_2 Vent gases (after compression) are vented from a new HP vent stack with vent tip 40m above grade.

4.2.1 LP CO_2 Vent

The LP CO_2 Vent is directly above the Absorber Column at a height of 110m above grade. It is higher than the existing Flue Stacks for the GTGs, with similar conditions but slightly higher velocities. There is an existing environmental air dispersion report for this vent covering pollutants but excluding CO_2. Depending on the amount of CO_2 removed from the flue gases, the concentration of CO_2 never exceeds 5.2% of the flue gas flow, and by the time it mixes with air, it is not credible to have significant concentrations at grade.

The LP CO_2 vent cases have therefore been excluded from the modelling.

4.2.2 HP CO_2 Vent

Potential gas plumes from representative release cases were modelled previously during FEED for the HP CO_2 Vent Stack above using a range of flow rates, temperatures, and concentrations. This modelling was used to establish hazardous safety distances for personnel, and a minimum height for the vent stack.

This report has considered all known controlled and uncontrolled releases from the HP CO_2 Vent and selected the cases where sufficient information is available to model. There are a number of cases identified where there is insufficient data available during the FEED phase of the project. When vendors are selected for key equipment in the next project phase and the detailed equipment designs are finalised, this data will become available and will be included in future models.

4.2.3 Emitter Locations

The location of the receptors with respect to the emissions sources is shown below:

Emitter	Latitude	Longitude	NGR Grid Reference Easting	NGR Grid Reference Northing
Existing Flue Stack 1	53.636865°	-0.238316°	516576	417036
Existing Flue Stack 2	53.637957°	-0.23604110°	516723	417161
LP CO2 Vent1 (Absorber)	53.636489°	-0.235462°	516765	416999
LP CO2 Vent2 (Absorber)	53.635774°	-0.234753°	516814	416920
HP CO2 Vent Stack	53.635713°	-0.232307°	516976	416917

Table 4-1: Emitter locations

The relative heights of the stacks can be seen here:

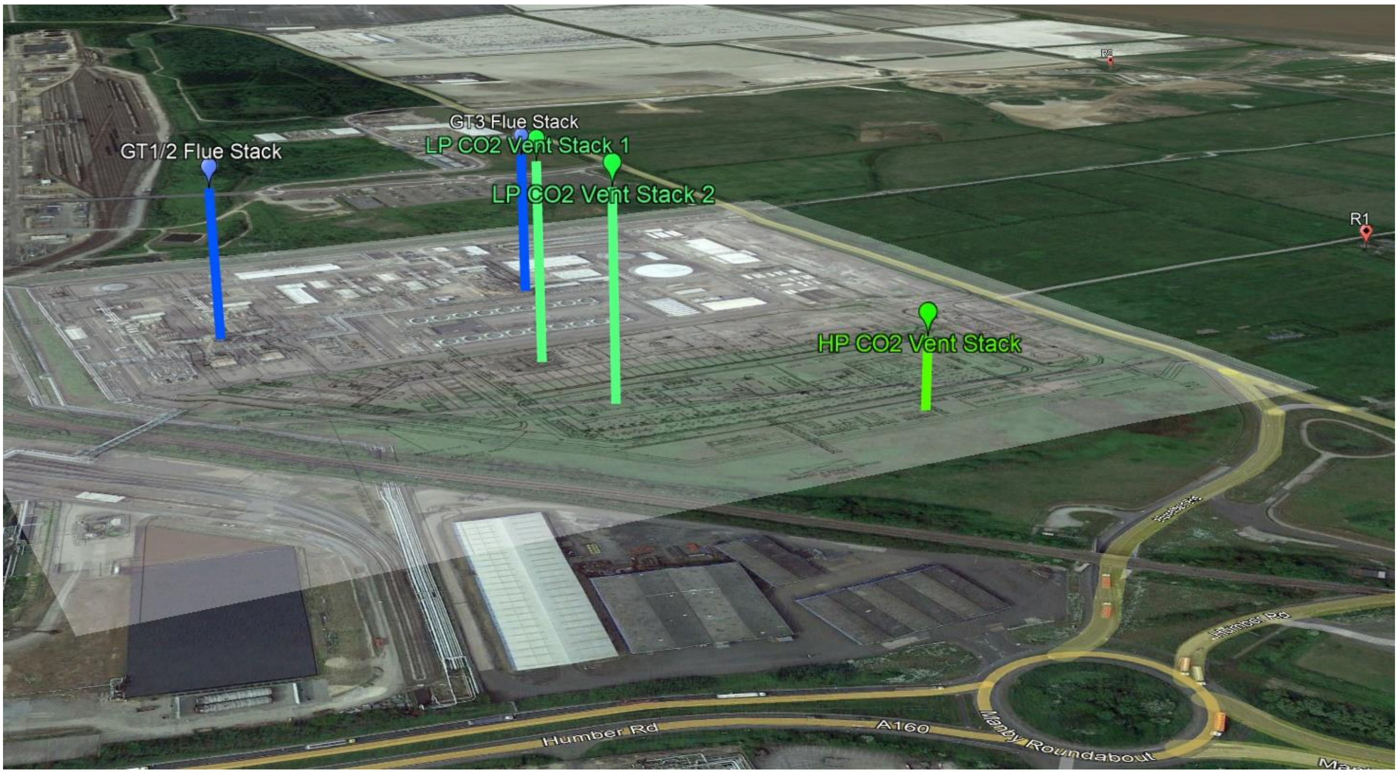


Figure 4-2: Emitter heights and locations

4.3 Vent Release Cases

A summary of the LP vent release cases considered is presented in Table 4-2

Case	Valve	Description	Temp	CO_2	Mass Flow	Vol Flow	Velocity	Frequency	Notes
			°C	%	kg/s	m³/s	m/s	Release/Yr	
LP01		Normal operation	44	0.27%	667.7	622.1	22.0	Normal	
LP02	PV-1111A	Start-up (Full LP Recycle)	44	5.2%	333.9	311.0	11.0	10	50% of full production
LP03		Loss of Solvent in Absorber	40	5.2%	714.30	605.03	21.4	0.1	Full rate, no CO_2 removal or cooling
LP04	PSV-1111 A-G	CO_2 Stripping	94.5	56.0%	79.7			0.1	Blocked outlet case

Table 4-2: LP Vent Cases

These have not been modelled as explained in 4.2.1 above. Case LP04 is introduced back into the Absorber and may be partly absorbed and removed from the flue gas, but if not, will still not exceed the 5.2% of the total combined flow once comingled with the flue gas.

A summary of the HP vent release cases considered is presented in Table 4-3.

Case	Valve	Description	Source Temp	Source Press	Vent Location	Mass Flow	Velocity	Valve Orifice	Freq	Notes
			°C	Bara		kg/s	m/s	mm	Rel/yr	
HP01	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	HP Vent Stack	27.78	38.7		10	Fully open: 50% of one compressor
HP01A	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	HP Vent Stack	13.89	19.36		1	50% Open (i.e. ~25% of one compressor)
HP01B	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	HP Vent Stack	2.78	3.89		1	10% Open (i.e. ~5% of one compressor)
HP01C	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	HP Vent Stack	55.56	71.76		0.5	2 x fully open from 2 compressors (2 x 50%)
HP02	70-XDV-1538	Final CO2 Cooler 70-E-1110 - See HP04 which is identical	25	137.5	Vent KO Drum 70-D-0101	2.78	2.54		0.5	This is identical to HP04 below, but with smaller inventory and faster depressurising
HP03	70-XDV-1539	Final CO2 Cooler 70-E-1110 - See HP05 which is identical	-43	8	HP Vent Stack	2.78			0.5	This is identical to HP05 below, but with smaller inventory and faster depressurising
HP04	70-XDV-0501	CO2 Station metering (Dense Phase)	25	137.5	Vent KO Drum 70-D-0101	2.78	2.54		0.5	Initial conditions for dense phase depressurising through Vent KO Drum. Release modelled from Vent KO Drum only at 8barg and -42C with 10 000kg/h initial flow rate (vapour)
HP04A	70-XDV-0501	CO2 Station metering (Liquid Phase)	25	54.2	Vent KO Drum 70-D-0101	1.16	1.06		0.5	Liquid phase depressurising through Vent KO Drum after 48 mins dense phase depressurising. Release modelled from Vent KO Drum only at 8barg and -42C with 4 196kg/h initial flow rate (vapour)
HP05A	70-XDV-0502	CO2 Station metering (Vapour Phase 1)	8	42	HP Vent Stack	2.31	0.92		0.5	Vapour phase depressurising direct to vent after about 8 hours of liquid phase depressurising. Flow rate may be reduced to limit low temperatures in piping
HP05B	70-XDV-0502	CO2 Station metering (Vapour Phase 2)	-37	10	HP Vent Stack	1.33	1.227		0.5	Vapour phase after about 2½ hours

Case	Valve	Description	Source Temp	Source Press	Vent Location	Mass Flow	Velocity	Valve Orifice	Freq	Notes
			°C	Bara		kg/s	m/s	mm	Rel/yr	
HP06	70-TSV-0513	CO2 Station metering	65	170	Vent KO Drum 70-D-0101	2.778	2.54	1.5D2	0.5	Release modelled from Vent KO Drum only at 8barg and -42C with max 10 000kg/h initial flow rate (vapour) assuming additional restriction orifice in line to limit flow rate Only opens for < 10mins so no STEL/LTEL
HP07	70-PSV-1501A/B	CO2 Compressor Suction Knock Out Drum 70-D-1101		7	HP Vent Stack					More data available when CO2 Compressor vendor is selected
HP08	70-PSV-1502A/B	CO2 Compressor 2nd Stage Knock Out Drum 70-D-1102		10	HP Vent Stack					More data available when CO2 Compressor vendor is selected
HP09	70-PSV-1503A/B	CO2 Compressor 3rd Stage Knock Out Drum 70-D-1103		14	HP Vent Stack					More data available when CO2 Compressor vendor is selected
HP10	70-PSV-1504A/B	CO2 Compressor 4th Stage Knock Out Drum 70-D-1104		24	HP Vent Stack					More data available when CO2 Compressor vendor is selected
HP11	70-PSV-1505A/B	CO2 Compressor 4th Stage Discharge 18"-CO1-70-3031-D0LA-PP	119	38	HP Vent Stack	60.04	100.84	6Q8	0.05	PSV on discharge of LP compressor section. 100% flow.
HP12	70-PSV-1506A/B	Oxygen Removal Reactor (70-RE-1101)		48	HP Vent Stack					More data available when vendor is selected
HP13	70-PSV-1507A/B	Dehydration Knock Out Drum 70-D-1105		48	HP Vent Stack					More data available when vendor is selected
HP14	70-PSV-1514A/B	CO2 Compressor HP Discharge line 10"-CO2-70-3096-F2GA-PP	155.5	165	HP Vent Stack	59.91	110.00	4L6	0.05	PSV on discharge of HP compressor section. 100% flow.
HP15	70-PSV-1511	Regeneration Heater 70-E-1112		49	HP Vent Stack			1D2		More data available when vendor is selected
HP16	70-PSV-1512A/B	Regeneration KO Drum 70-D-1111		49	HP Vent Stack			1D2		More data available when vendor is selected
HP17	70-PSV-1513A/B	Regeneration Compressor 70-C-1103		49	HP Vent Stack			1D2		More data available when vendor is selected

Case	Valve	Description	Source Temp	Source Press	Vent Location	Mass Flow	Velocity	Valve Orifice	Freq	Notes
			°C	Bara		kg/s	m/s	mm	Rel/yr	
HP18	70-PSV-1509A/B	Desiccant Bed 70-D-1113A		49	HP Vent Stack			1D2		More data available when vendor is selected
HP19	70-PSV-1510A/B	Desiccant Bed 70-D-1113C		49	HP Vent Stack			1D2		More data available when vendor is selected
HP20	70-PSV-1517A/B	Desiccant Bed 70-D-1113B		49	HP Vent Stack			1D2		More data available when vendor is selected
HP21	70-TSV-1519A/B	Dry CO2 Filter 70-F-1102A/B		49	HP Vent Stack			1D2		More data available when vendor is selected
HP22	70-PSV-1520A/B	16"CO2-70-3060-D2GA-NI	89	49	HP Vent Stack	26.60	36.57	4L6	0.05	PSV on discharge of Dehydration package upstream of isolation valve and NRVs Flow rate set from PSV orifice size rather than Relief Summary
HP23	70-PSV-1521A/B	Regeneration Filter 70-F-1101A/B		49	HP Vent Stack			1D2		More data available when vendor is selected
HP24	70-PSV-1522A/B	16"-CO2-70-3060-D2GA-NI	117	73	HP Vent Stack	85.85	121.58	4P6	0.05	PSV on suction of HP Compressor downstream of isolation valve and NRVs Flow rate set from PSV orifice size rather than Relief Summary

Table 4-3: HP Vent Cases

The cases that were modelled are highlighted

See 4.2.2 for a description of the reasons that not all cases could be modelled in FEED.

4.3.1 Depressurising Dense Phase CO_2

The Depressurising from dense phase is split into 3 stages:

A) Dense phase venting via the Vent KO Drum (up to 50 minutes)

B) Liquid draining from the bottom of the pipe via the Vent KO Drum (up to 8 hours)

C) Vapour Phase venting via direct to the HP CO_2 Vent Stack (up to 4 hours)

Provisions for sectional isolation and depressurisation of CO_2 are illustrated in Figure 4-3 below.

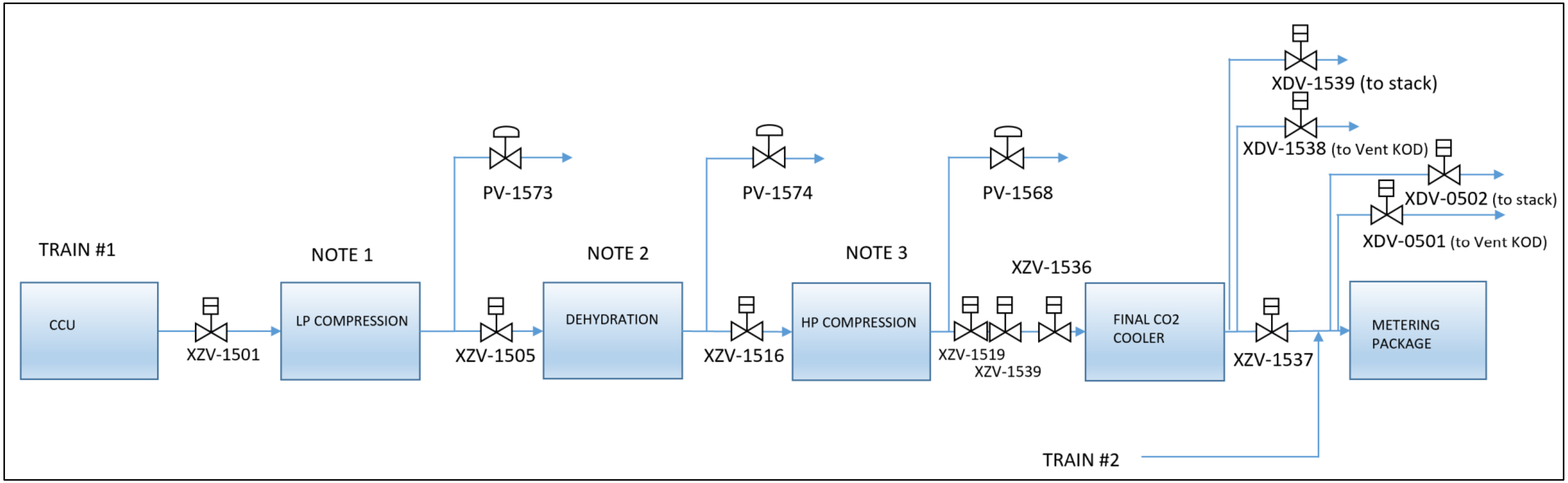


Figure 4-3: CO_2 Isolation and Depressurising

When venting the CO_2 straight to atmosphere the final temperature due to pressure drop is -88°C which is below the dry ice formation temperature. Dry ice can cause blockages in the vent lines. It is important to avoid this scenario during depressurisation.

Therefore, these vent streams downstream of the Final CO_2 Cooler will be routed to a Vent Knock-Out Drum which will be pressurised above the triple point of CO_2 (5.18 bara) with instrument air (assumed 8 barg). At this pressure, direct phase change from vapour to solid (deposition) is not possible. The pressure will be held in the KOD by a control valve on the discharge to the vent stack.

As mentioned in A) above, the dense phase CO_2, downstream of the Final CO_2 Cooler will be vented via the Vent KO Drum. The time taken to depressurise the entire CO_2 inventory, between the final stage CO_2 Compressor discharge and the pipeline battery limit, to 8 barg is approximately 9 hours and the final CO_2 temperature is -43°C. The final temperature is above the dry ice formation temperature, however there is vapour-liquid equilibrium at the final conditions and therefore a heater is used to vaporise the remaining liquid in the Vent KO Drum.

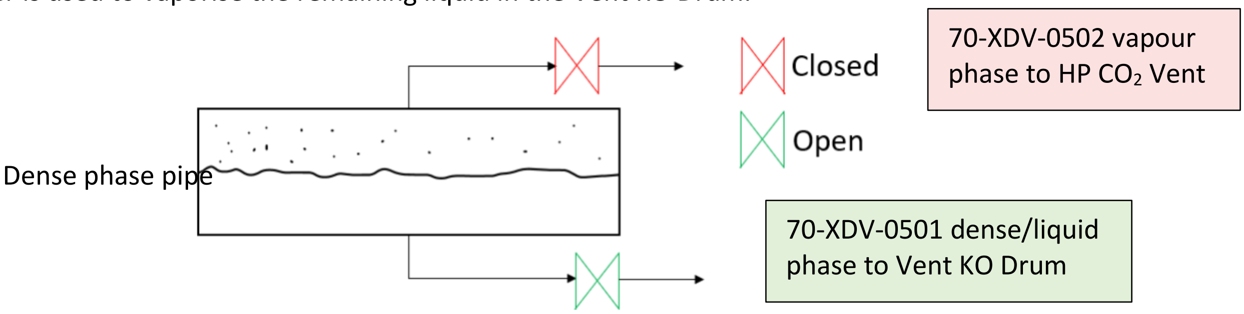


Figure 4-4: Vent and Drains valves

Figure 4-4 shows a sketch of the vent lines on the main process pipeline. The dense phase CO_2 will initially be drained from the bottom of the pipeline. The pressure will gradually reduce until the fluid reaches the two-phase boundary where the CO_2 will separate into vapour-liquid equilibrium. Once the fluid is two-phase, the liquid phase will continue to drain from the bottom of the pipeline. When all liquid is removed the valve on the liquid line will turn to a closed position and the valve on the vapour line above the pipe will open to the Vent Stack.

Depressurising the system in this way is inherently safe as it avoids the very low temperatures that would occur if the system were directly vented to atmospheric pressure, whereby the latent heat for the vaporisation would come at the expense of significantly cooling the CO_2.

The flow rate used was based on the initial discharge rate at the start of depressurisation. It should be noted that as the depressurisation proceeds the process pressure and hence the flow and velocity (and temperatures) will decrease as a time-varying release. The plume extent is rapidly established, and the results depict the stable, "steady state" plume formed early in the release. As the velocities drop, the extent of the associated cloud typically decreases.

The model includes one case for Dense phase (HP04: less than an hour); one case for liquid draining (HP04A: 8 hours but with little change in temperature and pressure); and two cases for vapour (HP05A and HP05B where pressure and temperature change significantly).

Note that HP02 and HP03 (70-XDV-1538 and 70-XDV-1539) operate identically to HP04 and HP05 (70-XDV-0501 and 70-XDV-0502), but with less inventory, and a shorter period of venting. Only HP04 and HP05 (70-XDV-0501 and 70-XDV-0502) was modelled for this report.

4.4 HP Vent Stack Data

HP Vent stack height: 40 m from grade.

HP Vent pipe size: 30” (0.76m Outside Diameter / 0.74m Inside Diameter)

The composition of the vent is taken as 100% CO_2. (Actual values vary between 99.43 and 99.98%, depending primarily on water content.)

4.5 Weather Data

The following conditions were considered:

Pasquill Stability Classes:

- D: Neutral conditions, with wind speeds of 5 m/s (“5D”)
- F: Moderately stable conditions, with wind speeds of 2 m/s (“2F”)
- F: Moderately stable conditions, with wind speeds of 1 m/s (“1F”)

Ambient Air temperature = 10 °C

Relative Humidity = 80%

4.6 Concentrations of interest

Concentrations of interest are based on HSE Workplace Exposure Limit guidance [Ref. 5]:

- 5,000 ppm (concentration of CO_2 of 0.5 % v/v in air): The Long-Term Exposure Limit (LTEL, based on an 8-hour time weighted average period)
- 15,000 ppm (concentration of CO_2 of 1.5 % v/v in air): The Short-Term Exposure Limit (STEL, based on a 15-minute time weighted average period)

The HSE also publishes a document SPC/Tech/OSD/30 “Indicative human vulnerability to the hazardous agents present offshore for application in risk assessment of major accidents” which indicates that at 3% (30,000ppm), after 30 minutes exposure, there is the start of indications of impairment – i.e. inability to think clearly and respond, but is considered at a level of “survivable”. (Survivability: the maximum exposure (dose) that may be received with a negligible statistical probability of fatality and without impairment of an individual's ability to escape) [Ref. 6]

% V/v	ppmv	Physiological effects
0.1%	1,000	Comfort limit
0.2%	2,000	Increase in breathing rate
2%	20,000	50% increase in breathing rate
3%	30,000	100% increase in breathing rate
5%	50,000	~300-400% increase in breathing rate; headache and sweating may begin in 1 hour. Symptoms of intoxication become evident and slight choking may be felt. Note that this is tolerated by most persons, but is physically burdening
8 - 10%	80 - 100,000	Headache after 10 to 15 minutes, dizziness, buzzing in ears, rise in blood pressure, high pulse rate, excitation, and nausea
10 - 18%	100 - 180,000	Cramps after a few minutes, epileptic fit, loss of consciousness, sharp drop in blood pressure
18 - 20%	180 - 200,000	Symptoms similar to stroke
30%	300,000	Unconsciousness in 24 seconds

Table 4-4 Exposure reactions to CO_2, SAE International (2019)

Finally, the Energy Institute Draft guidelines for "Hazard Analysis for Onshore and Offshore Carbon Capture Installations and Pipelines" [Ref. 7] uses 5% for their dispersion modelling, based on the highest concentration before significant and potentially fatal health effects are possible:

For this report, we have chosen the following concentrations of interest:

ppmv	% V/v	Description
5,000	0.5%	HSE Long-Term Exposure Limit (LTEL), based on an 8-hour time weighted average period
15,000	1.5%	HSE Short-Term Exposure Limit (STEL), based on a 15-minute time weighted average period
30,000	3.0%	HSE Maximum survivability level without impairment from SPC/Tech/OSD/30
50,000	5.0%	EI maximum non-fatal dosage limit from draft EI123/013

Table 4-5 Selected concentrations of interest

Note the following additional reference concentrations:

- Average background outdoor CO_2 concentrations in air are typically ~380 ppm.
- 400 - 1,000 ppm: Concentrations typical of occupied indoor spaces with good air exchange
- 1,500 ppm: "CO_2 levels consistently higher than 1500ppm in an occupied room indicate poor ventilation and you should take action to improve it." (Using CO_2 monitors - Ventilation in the workplace (hse.gov.uk))
- 1,000 - 2,000 ppm: Complaints of drowsiness over extended periods and poor air exchange (What are safe levels of CO and CO_2 in rooms? | Kane International Limited)
- 50 000 ppm: the upper end of the range of CO_2 concentrations in exhaled air by an average adult

This study includes some sensitivity results for 1,000ppm, 1,500ppm, 2,000ppm and 5,000ppm.

4.7 Receptors

4.7.1 Human Health Receptors

Receptors potentially affected by the emissions from the Installation, including local residential and amenity receptors, have been identified through site knowledge and desk study of local mapping. Isopleth figures of pollutant dispersion have been examined to identify the receptors that will receive the highest point source contributions and these receptors have been included in the model set up as discrete receptors.

The closest residential receptor to the Installation is a single residence along Marsh Lane, Hazel Dene, approximately 330m to the east of the Installation.

The receptors are selected to be representative of residential dwellings and recreational areas around the Installation and are shown in the following table.

Receptor I.D	Receptor	NGR Grid Reference	Approximate Distance and Direction from Installation
R1	Hazel Dene, Marsh Lane	517330, 417311	330m east
R2[1]	Station House, Station Road	517333, 418345	1.1km northeast
R3	Fairfield House, North Garth	514687, 418769	2.4km northwest
R4	Old Vicarage, North Garth	514428, 418197	2.3km northwest
R5	Manor Farm, North Killingholme	514515, 417653	1km northwest
R6	Church Lane, North Killingholme	514763, 417331	1.5km west
R7	Westfield Farm, North Killingholme	514708, 416785	1.7km west
R8	Melrose, South Killingholme	515115, 416417	1.4km southwest
R9	Town St/ Humber Road, South Killingholme	515516, 416120	1.3km southwest
R10	South Killingholme Primary School	514880, 416120	2km west
R11	East End Farm	515935, 415730	1.1km south
R12	Immingham	517765, 415255	1.7km south

[1] R2 is currently understood to be an unoccupied residence owned by Able Humber Ports Limited, which is proposed to be demolished as part of Able Marine Energy Park enabling works

Table 4-6: Human Receptor Locations for Air Quality Assessment

4.8 Other assumptions

Height of interest: 1m (Typical minimum height to inhale the gas)
Roughness: 10cm (Low crops, Occasional large obstacles)

5. Results

5.1 Case HP01: Controlled Venting of HP CO_2

This valve is normally used for start-up and shut-down, but also for emergency venting. Not expected to exceed 1 hour of venting (typically less).

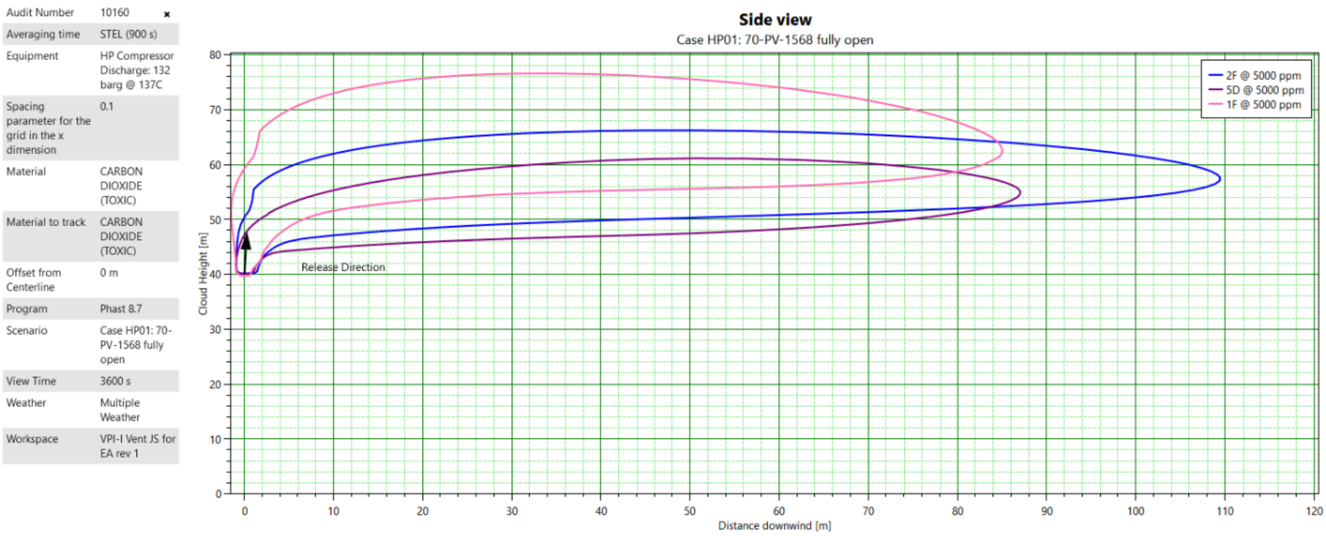


Figure 5-1: Case HP01 - 70-PV-1568 fully open

Cases HP01A and HP01B cover reduced flow with the valve only open 50% or 10% respectively.

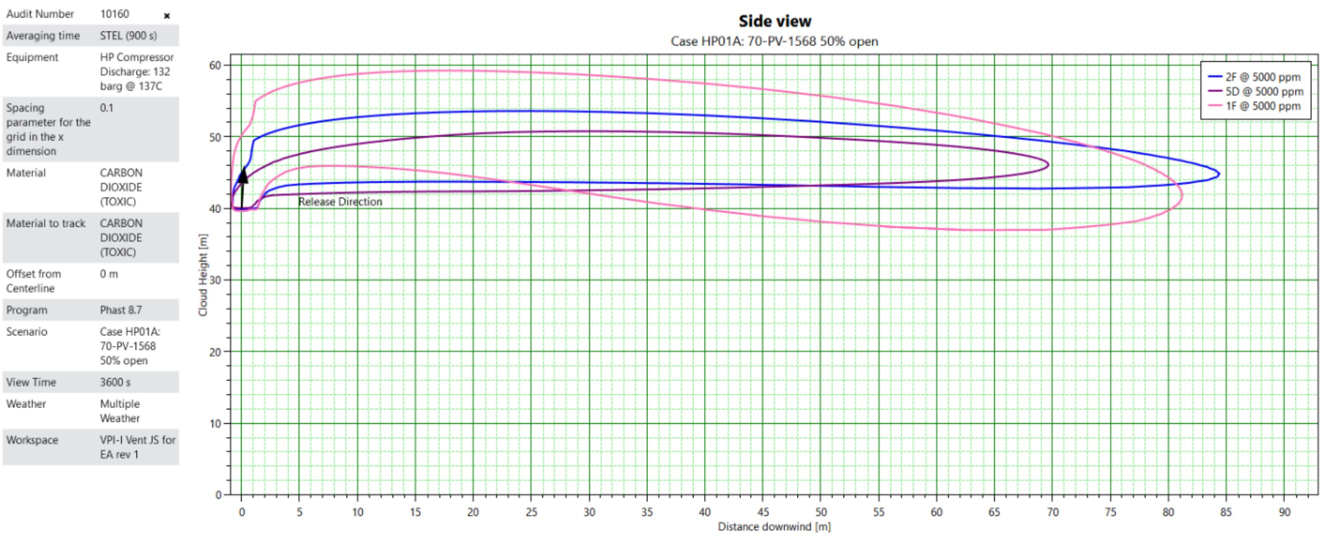


Figure 5-2: Case HP01A - 70-PV-1568 open 50%

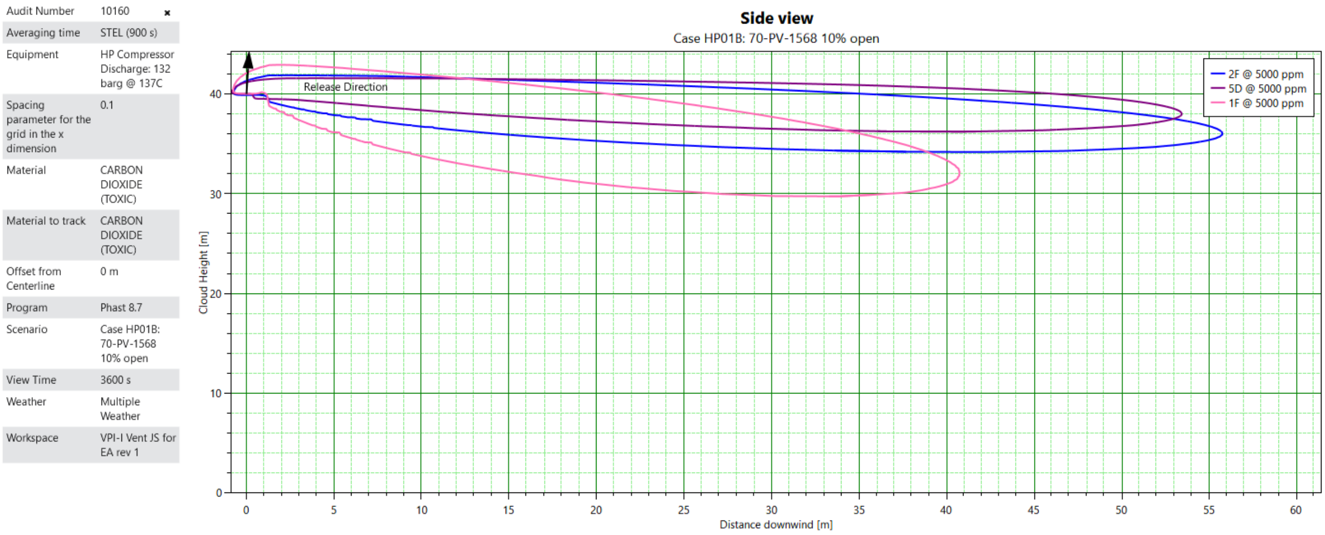


Figure 5-3: Case HP01B - 70-PV-1568 open 10%

Case HP01C covers two compressors venting at the same time (for example if export pipeline closes). There are three graphs:

- 5, 000ppm for three weather conditions;
- 4 concentrations of concern for weather condition 1F; and
- A sensitivity case of 4 concentrations from 1,000ppm to 5,000ppm

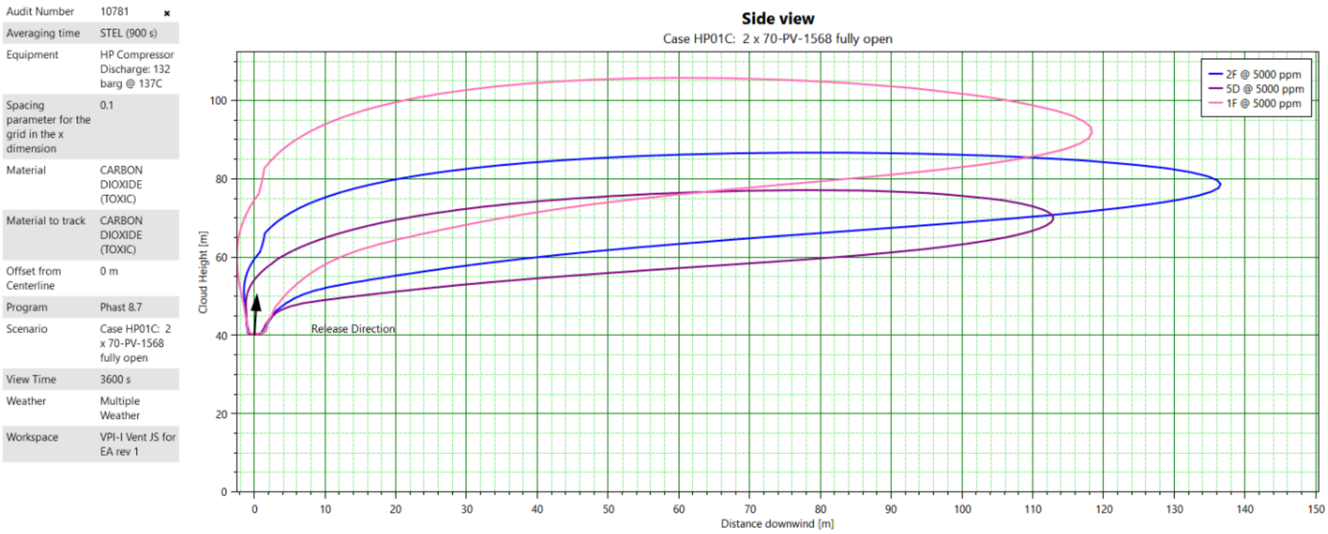


Figure 5-4: Case HP01C -2 x 70-PV-1568 fully open (2 compressors) 5,000 ppm (3 x weather)

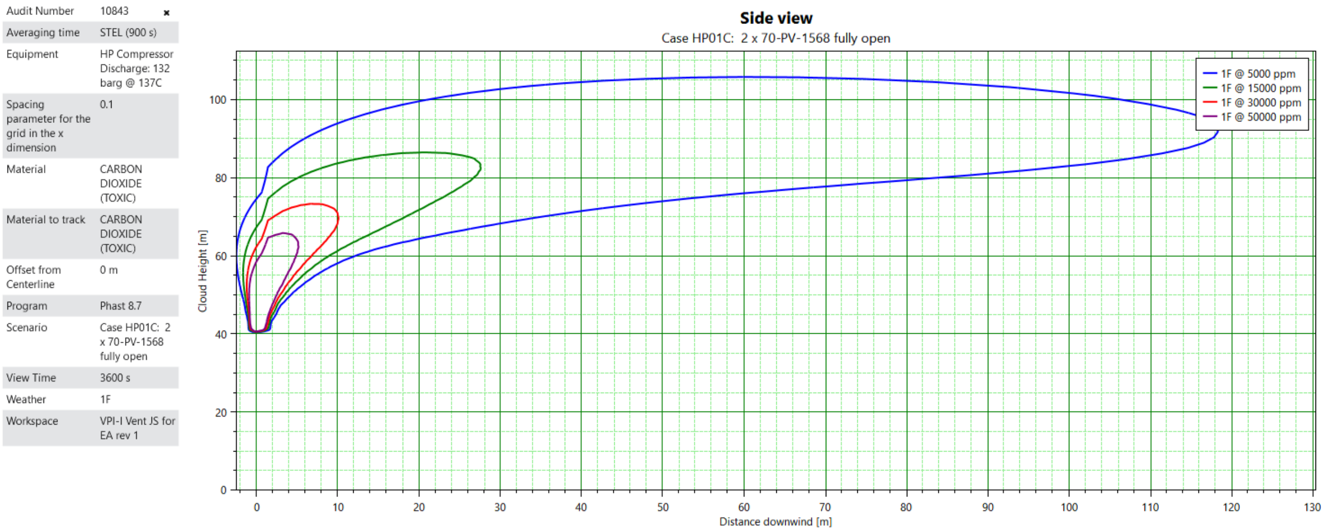


Figure 5-5: Case HP01C -2 x 70-PV-1568 fully open (2 compressors) 5,000 - 50,000 ppm

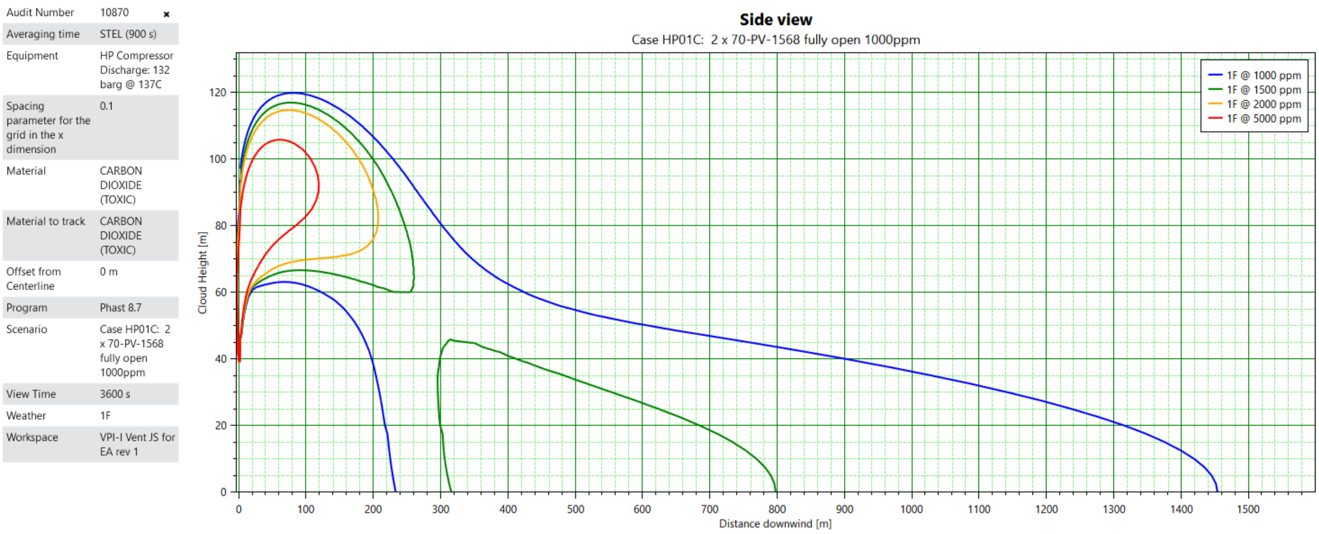


Figure 5-6: Case HP01C -2 x 70-PV-1568 fully open (2 compressors) Sensitivity: 1,000 - 5,000 ppm

5.2 Case HP04: Depressurising Dense Phase to Vent KO Drum

This valve is intended to be used for controlled depressurising to the Vent Knockout (KO) drum at 8 barg and then to the HP CO_2 Vent Stack after shut-down. It is used initially for Dense phase depressurising for about 1 hour (Case HP04), and then for Liquid draining once the pressure and temperature are below the critical point (Case HP04A). The liquid phase can continue for 8-9 hours, but the pressure, temperature and flow rate do not change significantly until it reaches vapour phase (liquid is all drained).

Case HP04 -70-XDV-0501 open in Dense Phase has two graphs:

- 5, 000ppm for three weather conditions; and
- 4 concentrations of concern for weather condition 1F.

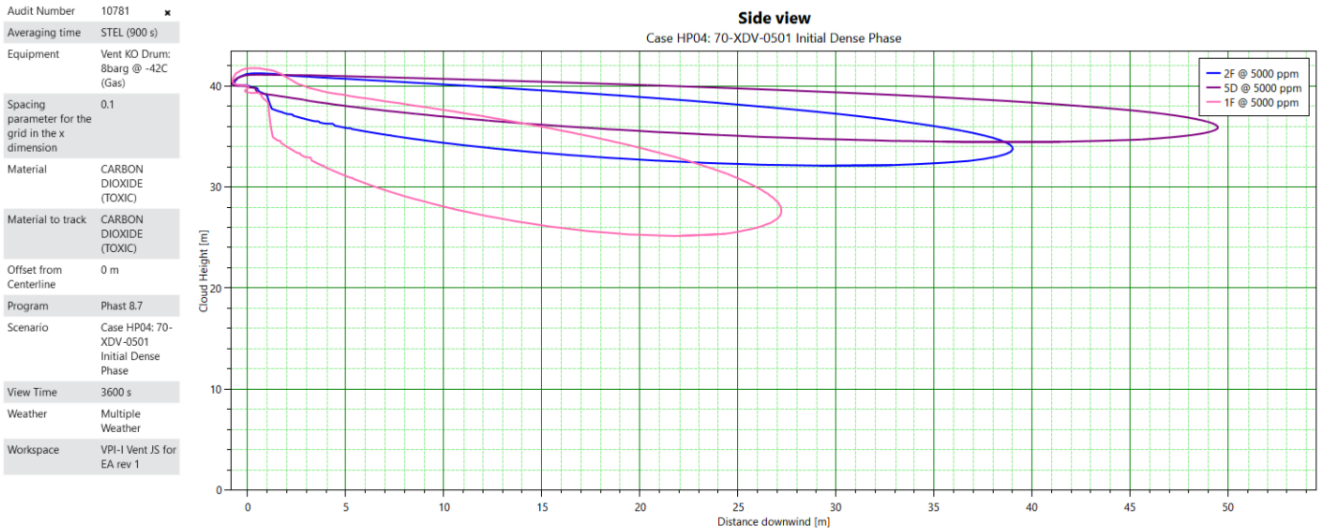


Figure 5-7: Case HP04 -70-XDV-0501 open in Dense Phase 5,000 ppm (3 x weather)

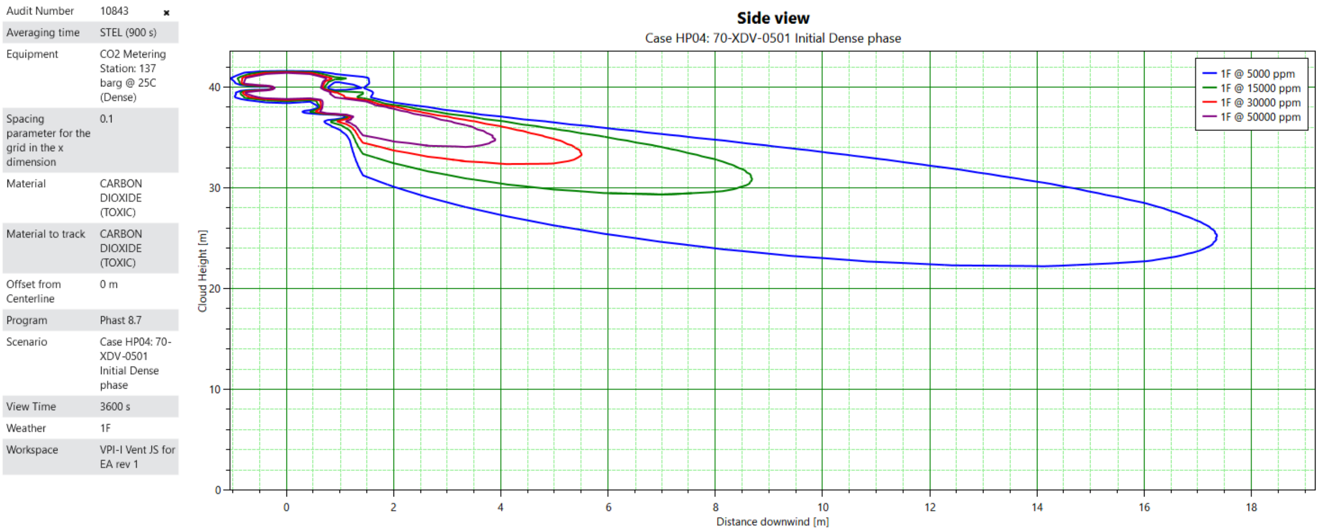


Figure 5-8: Case HP04 -70-XDV-0501 open in Dense Phase 5,000 - 50,000 ppm

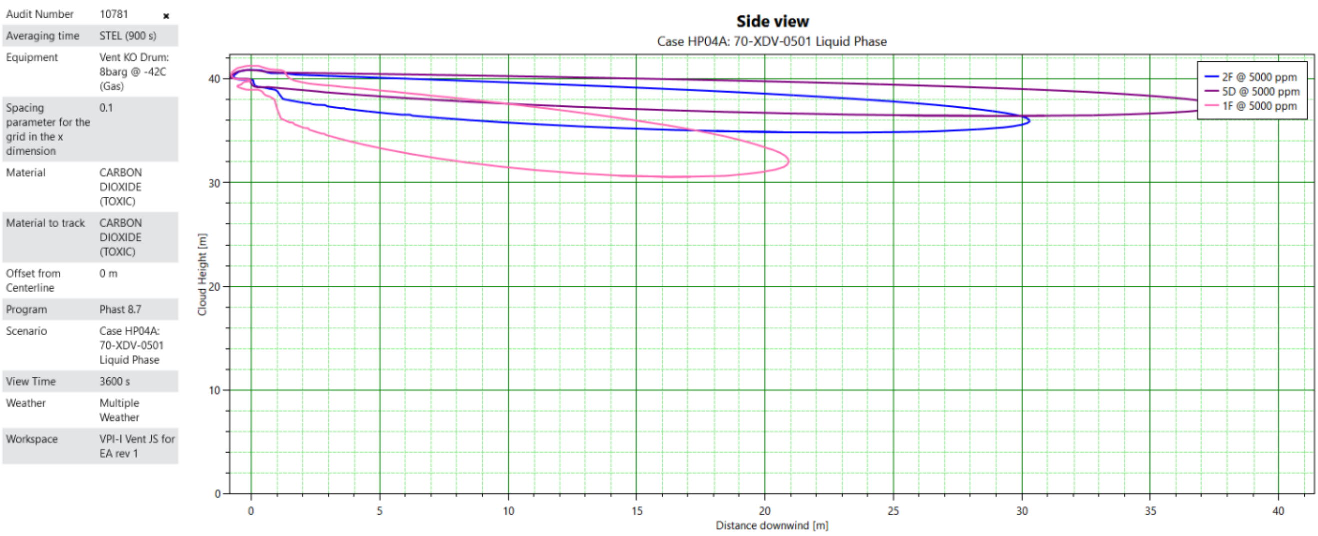


Figure 5-9: Case HP04 -70-XDV-0501 open in Liquid Phase

The graph below shows a sensitivity case of 4 concentrations from 1,000ppm to 5,000ppm during depressurising from dense phase.

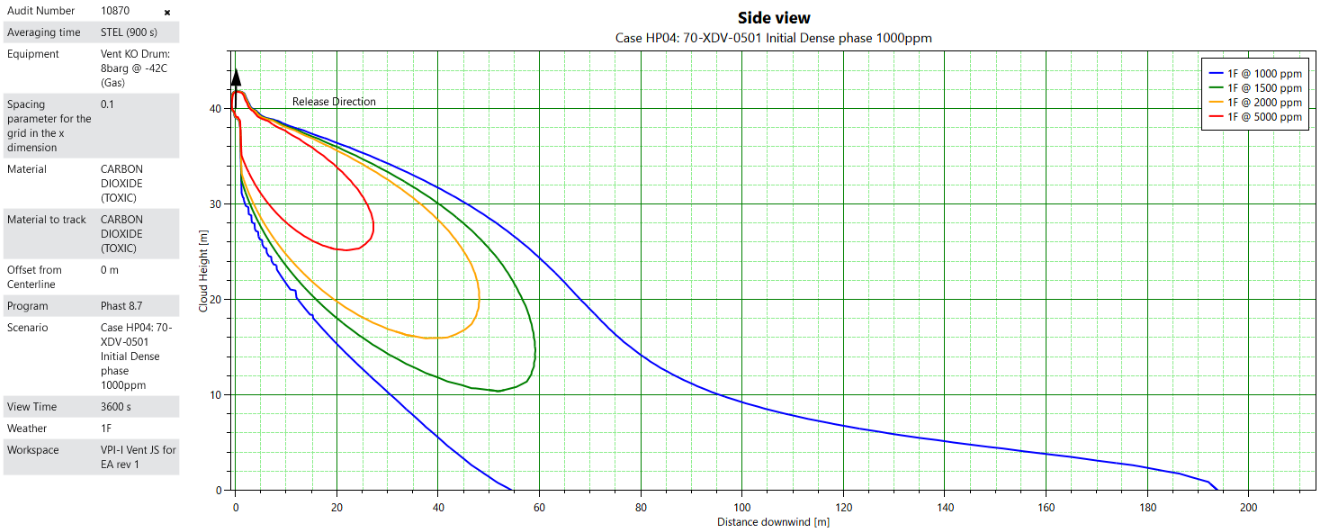


Figure 5-10: Case HP04 -70-XDV-0501 open in Dense Phase Sensitivity: 1,000 - 5,000 ppm

5.3 Case HP05: Depressurising Vapour Phase to Vent Stack

This valve is intended to be used for controlled depressurising of the vapour phase only directly to the HP CO_2 Vent Stack after shut-down. It is once XDV-0501 has been open for about 9 hours to drain all the dense and liquid phase CO_2 to the Vent KO Drum (See 4.3.1 above for an explanation).

There are two graphs showing the initial vapour phase depressurising, and the second showing the vapour phase after about 3 hours when the temperature and pressure has dropped.

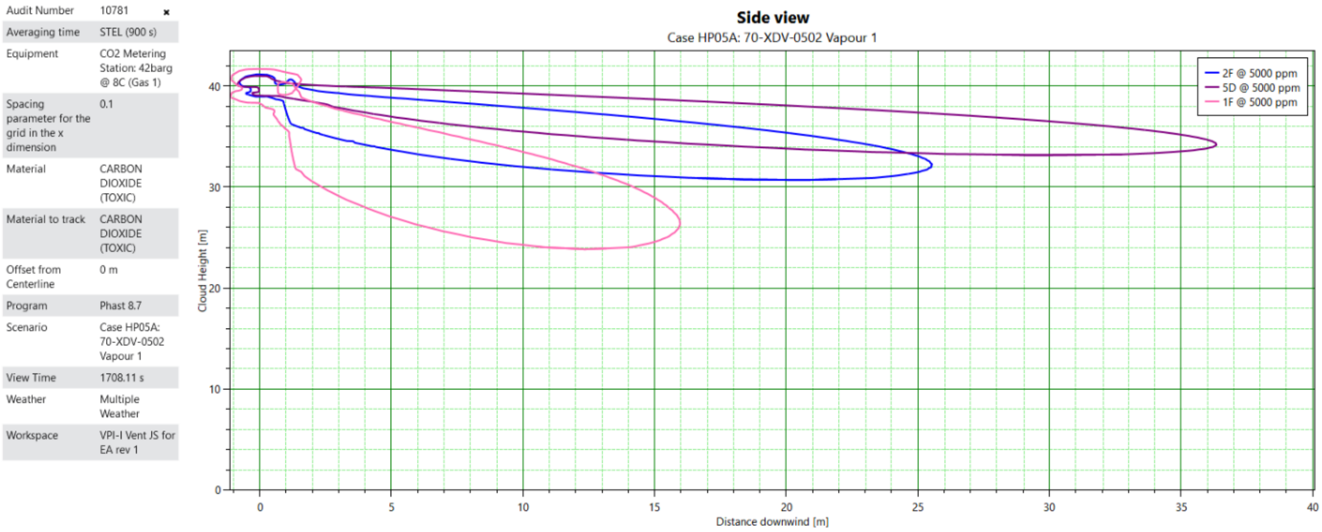


Figure 5-11: Case HP05A -70-XDV-0502 open in Vapour Phase (Initial)

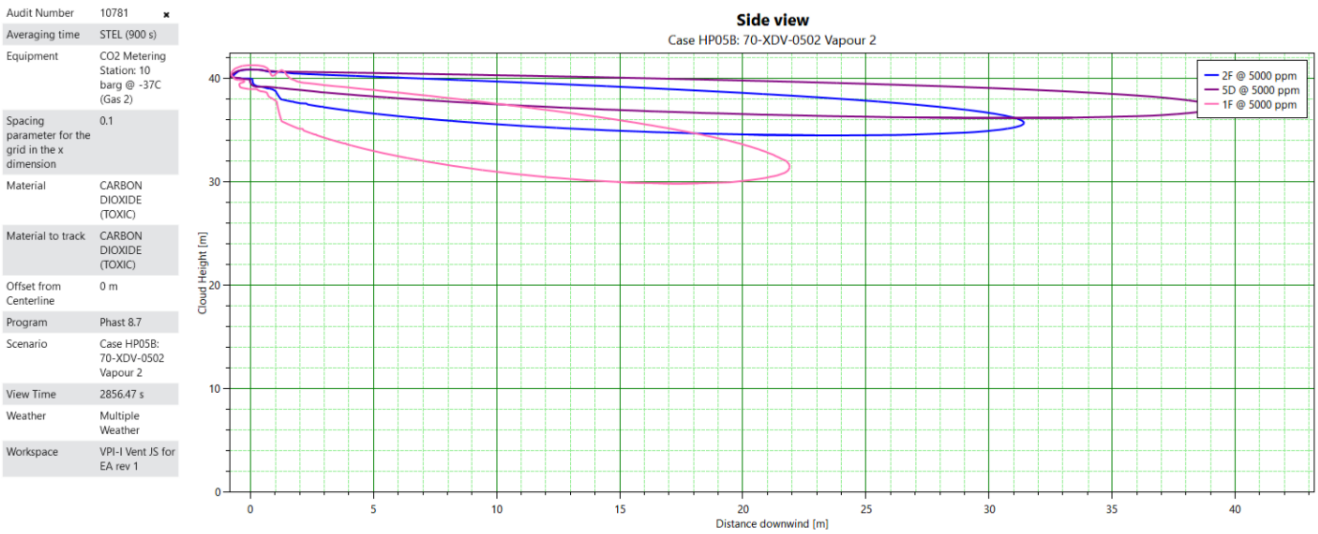


Figure 5-12: Case HP05B -70-XDV-0502 open in Vapour Phase (After 3 hours)

The final graph shows all the stages of depressurising from dense, liquid and vapour phases for weather condition 1F and 5,000ppm cloud contour.

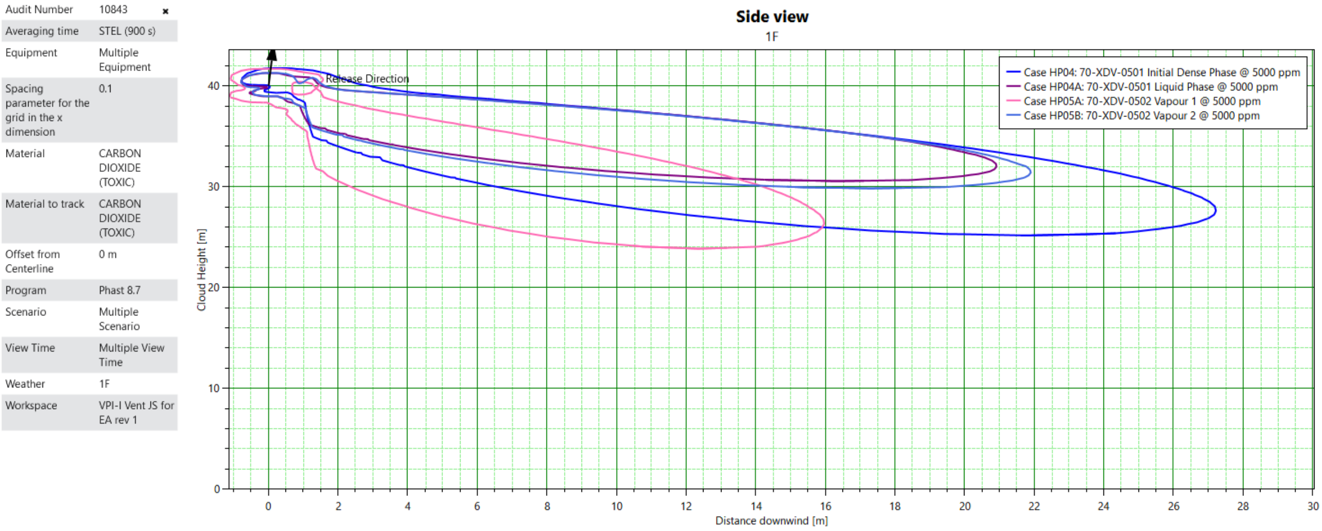


Figure 5-13: Case HP04/05 - Dense, liquid and vapour phases for weather condition 1F and 5,000ppm

5.4 Case HP06: Thermal Relief to Vent KO Drum

70-TSV-0513 provides thermal relief for the dense phase piping in case the piping is isolated with solar radiation increasing the temperature and pressure. It is unlikely to operate for more than 10 minutes before the pressure drops and it closes again.

Audit Number	10781
Averaging time	STEL (900 s)
Equipment	Vent KO Drum: 8barg @ -42C (Gas)
Spacing parameter for the grid in the x dimension	0.1
Material	CARBON DIOXIDE (TOXIC)
Material to track	CARBON DIOXIDE (TOXIC)
Offset from Centerline	0 m
Program	Phast 8.7
Scenario	Case HP06: 70-TSV-0513
View Time	3600 s
Weather	Multiple Weather
Workspace	VPI-I Vent JS for EA rev 1

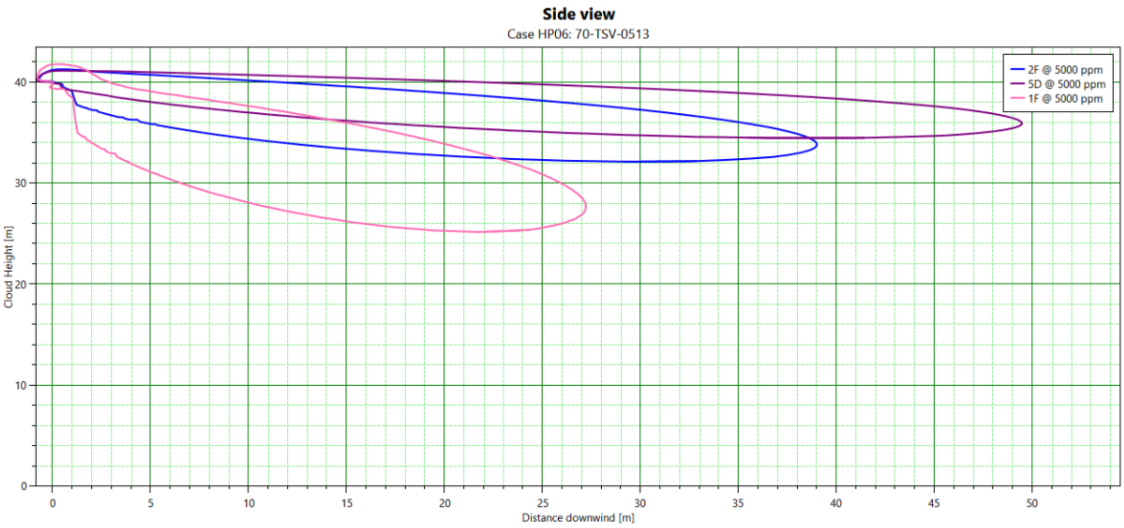


Figure 5-14: Case HP06 - 70-TSV-0513 Thermal Relief to Vent KO Drum

5.5 Case HP11: LP Discharge Pressure Relief to Vent Stack

70-PSV-0505A/B provides full flow pressure relief on the CO_2 Compressor LP Discharge line. It vents directly to the HP Vent Stack as it is hot from the compressor.

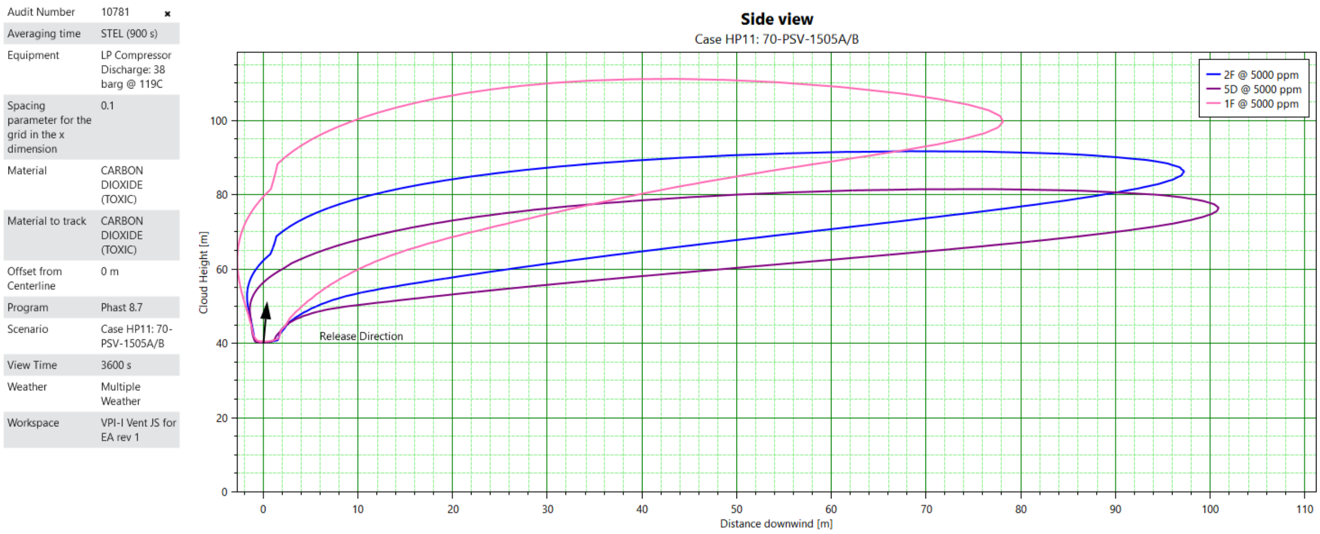


Figure 5-15: Case HP11 - 70-PSV-0505A/B Pressure Relief from LP Discharge to Vent Stack

5.6 Case HP14: HP Discharge Pressure Relief to Vent Stack

70-PSV-1514A/B provides full flow pressure relief on the CO_2 Compressor HP Discharge line. It vents directly to the HP Vent Stack as it is hot from the compressor.

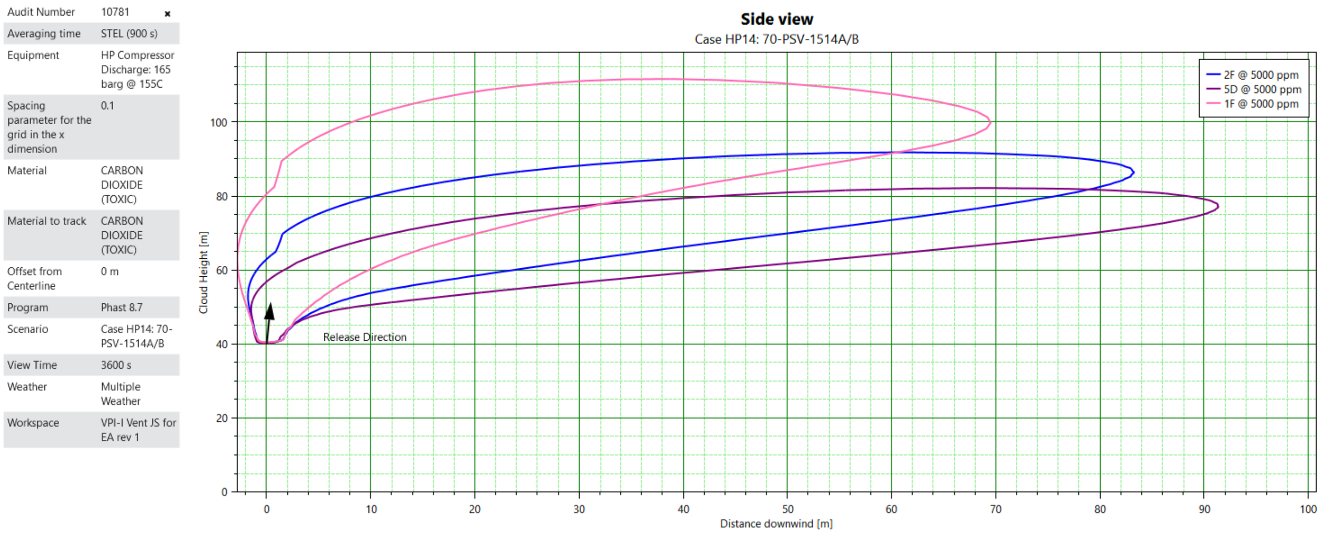


Figure 5-16: Case HP14 - 70-PSV-0514A/B Pressure Relief from HP Discharge to Vent Stack

5.7 Case HP22: LP Discharge Pressure Relief to Vent Stack

70-PSV-1520A/B provides pressure relief on the CO_2 Dehydration outlet line. It vents directly to the HP Vent Stack.

Audit Number	10784
Averaging time	STEL (900 s)
Equipment	Dehydration Discharge: 49 barg @ 89C
Spacing parameter for the grid in the x dimension	0.1
Material	CARBON DIOXIDE (TOXIC)
Material to track	CARBON DIOXIDE (TOXIC)
Offset from Centerline	0 m
Program	Phast 8.7
Scenario	Case HP22: 70-PSV-1520A/B Orifice
View Time	3600 s
Weather	Multiple Weather
Workspace	VPI-I Vent JS for EA rev 1

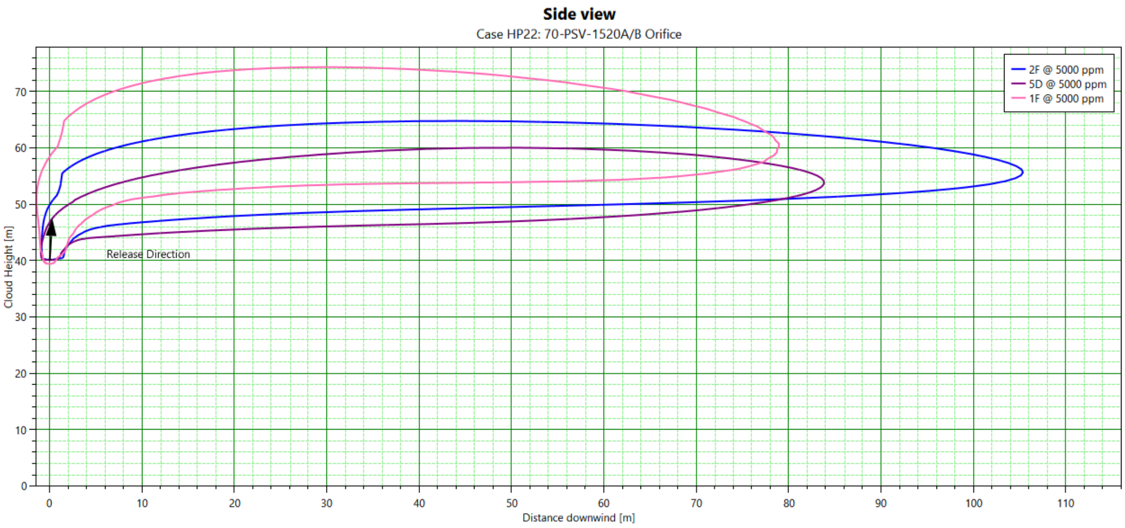


Figure 5-17: Case HP22 - 70-PSV-0520A/B Pressure Relief from CO_2 Dehydration outlet to Vent Stack

5.8 Case HP24: Pressure Relief from CO_2 Compressor HP suction to Vent Stack

70-PSV-1522A/B provides pressure relief on the CO_2 Compressor HP Suction KO drum. It vents directly to the HP Vent Stack.

Audit Number	10843
Averaging time	STEL (900 s)
Equipment	HP Compressor Suction: 73 barg @ 117C
Spacing parameter for the grid in the x dimension	0.1
Material	CARBON DIOXIDE (TOXIC)
Material to track	CARBON DIOXIDE (TOXIC)
Offset from Centerline	0 m
Program	Phast 8.7
Scenario	Case HP24: 70-PSV-1522A/B Orifice
View Time	3600 s
Weather	Multiple Weather
Workspace	VPI-I Vent JS for EA rev 1

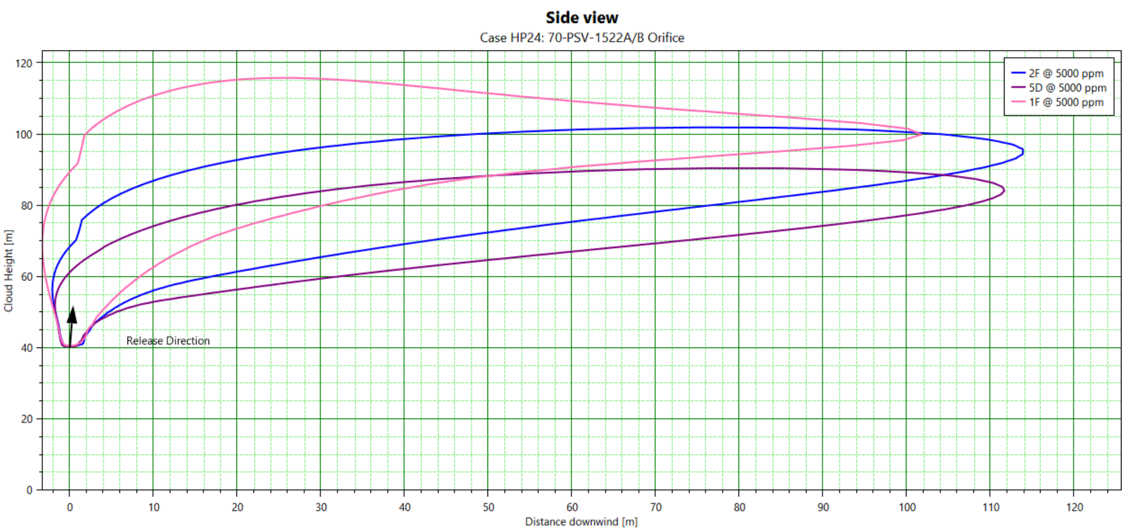


Figure 5-18: Case HP24 - 70-PSV-0522A/B Pressure Relief from CO_2 Compressor HP suction to Vent Stack

5.9 Impact on Receptors

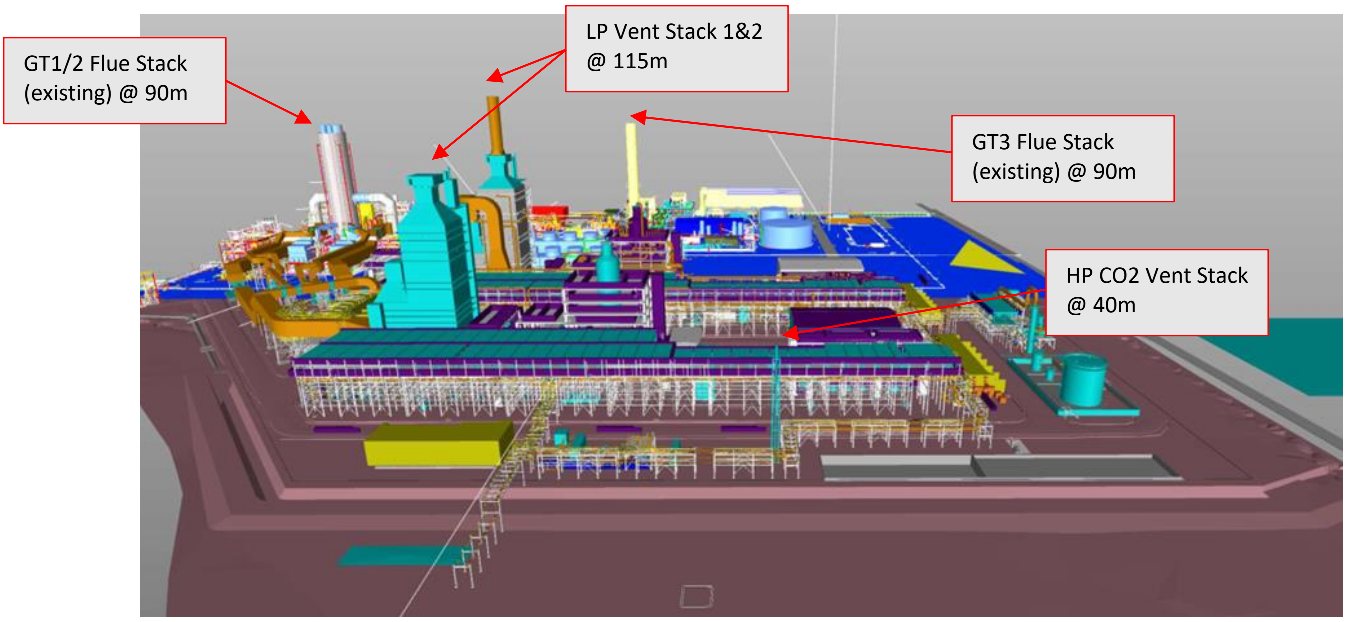
5.9.1 Locations of Vents:

The two existing flue gas stacks (GT1/2 and Aux Boiler1/2 in one stack and GT3 in the other) are 90m high. When the PCC plant is running, GT1/2 flue stack will not have any emissions except in upset or start-up/shutdown conditions. GT3 will continue operating as per current conditions.

There are two LP Vent stacks above each of the two Absorber columns with the tips 115m above grade. As discussed in 4.2.1 above, these will not produce significant quantities of CO_2 (< 5.2% CO2 emitted) in normal or upset conditions.

There is a single HP CO2 Vent Stack with a tip at 40m above grade. This is the vent that has been modelled in detail in this study. It is more than 97% CO_2 in all cases, and with a range of flows, temperatures, and velocities.

The locations can be seen in the 3D model below:



5.9.2 Human Health Receptors

Receptors potentially affected by the emissions from the Installation, including local residential and amenity receptors, have been identified through site knowledge and desk study of local mapping (See 4.7.1 above).

The closest residential receptor to the Installation is a single residence along Marsh Lane, Hazel Dene, approximately 500m to the north-east of the HP Vent Stack. Table 5-1 below gives the distances from the emitters to the receptors in kilometers.

Receptor ID	Receptor	NGR Grid Reference	Existing Flue Stack 1	Existing Flue Stack 2	LP CO2 Vent 1	LP CO2 Vent 2	HP CO2 Vent Stack
R1	Hazel Dene, Marsh Lane	517330, 417311	0.800	0.623	0.644	0.646	0.529
R2	Station House, Station Road	517333, 418345	1.510	1.33	1.459	1.515	1.471
R3	Fairfield House, North Garth	514687, 418769	2.559	2.589	2.724	2.813	2.938
R4	Old Vicarage, North Garth	514428, 418197	2.436	2.511	2.62	2.699	2.844
R5	Manor Farm, North Killingholme	514515, 417653	2.145	2.255	2.336	2.406	2.561
R6	Church Lane, North Killingholme	514763, 417331	1.831	1.961	2.023	2.086	2.245
R7	Westfield Farm, North Killingholme	514708, 416785	1.879	2.044	2.062	2.104	2.265
R8	Melrose, South Killingholme	515115, 416417	1.582	1.767	1.745	1.767	1.921
R9	Town St/ Humber Road, South Killingholme	515516, 416120	1.398	1.591	1.524	1.521	1.659
R10	South Killingholme Primary School	514880, 416120	1.923	2.111	2.074	2.087	2.236
R11	East End Farm	515935, 415730	1.453	1.631	1.514	1.477	1.576
R12	Immingham	517765, 415255	2.139	2.170	2.008	1.915	1.838

Table 5-1: Distances to Receptors in km

Figure 5-19: Location of Receptors

5.9.3 Vent Plume Extents

These receptors have been reviewed against the modelled vent plumes from the HP CO_2 Vent Stack.

As shown in the results, the only case identified that extends beyond the fenceline at ground level is for a concentration of 1,500ppm CO_2 from case HP01C. This is within the normally acceptable range of CO_2 concentrations found indoors. The isopleth for 1,500ppm for 1F weather conditions is shown below:

Figure 5-20: Case HP01C 1,500ppm CO_2 extent

For the lowest concentration of interest of 5,000ppm (0.5% - LTEL), this does not touch down to ground in any of the scenarios modelled. At the plumes furthest extent for Case HP01C, the cloud centreline is about 80m above the ground and 130m in extent:

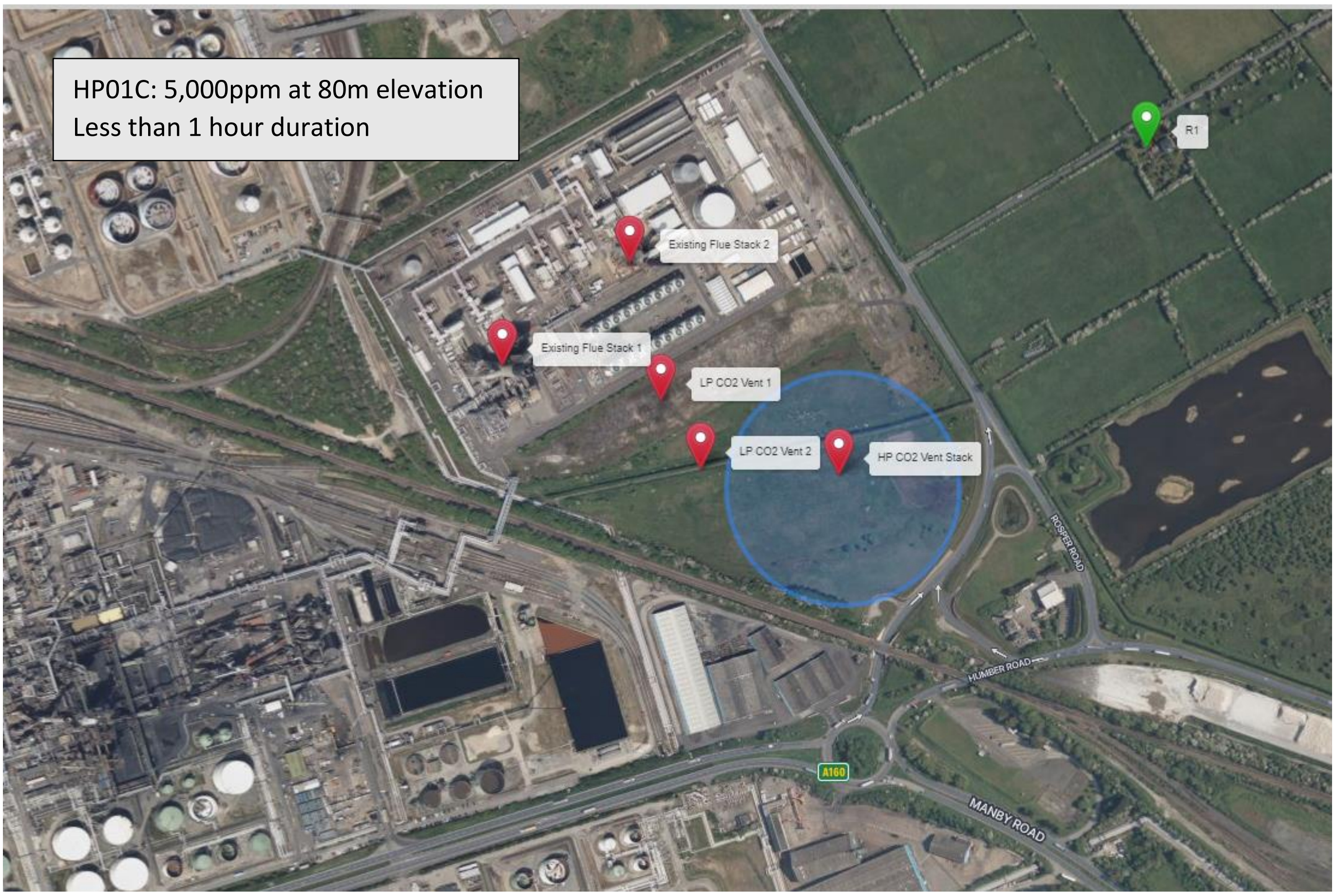


Figure 5-21: Case HP01C 5,000ppm CO_2 extent at 80m elevation

6. Conclusions

The vent dispersion modelling results from PHAST exhibit the type of slumping behaviour seen in real world releases and in test data from literature for very low concentrations (less than 2,000ppm). For the higher concentrations of interest used in the modelling (5,000 to 50,000 ppm), the plume does not touch down to ground level and does not represent a hazard to people or animals.

When considering different vent discharge conditions, there are a few limited cases with discharge rates that may result in concentrations of CO_2 at grade in excess of 1,500 ppm, but less than 2,000ppm for limited periods (less than 1 hour). For longer releases, the plume is shown to always be less than 1,000ppm at grade, which is similar to a well-ventilated building, and not much more than the background levels outdoors (~400ppm).

Although this study was not able to model all the release cases identified, due to the lack of data at this phase of the project, the cases that have been modelled cover a wide range of temperatures and flowrates and are likely to represent the full set of cases once detailed design data is available.

This assessment demonstrates that public exposure levels to CO_2 from the VPI-I PCC project are well below the levels at which the onset of symptoms and effects are reported, and the modelling indicates that even the lowest Long-Term Exposure Limit (LTEL) of 0.5% (5,000ppm) does not reach the ground for any of the cases identified or reach any of the receptors shown in Section 4.7. Overall, the dispersion modelling indicates that the gas plumes from planned or unplanned events will be of very limited extent, and at a height that will not impact people, fauna, or flora.

Attachment A – Input data

A.1 Low Pressure Releases

These cases are vented from the LP CO2 Vent above the CO2 Absorber Stack at 110m above grade and comingled with the existing residual flue gases. The vent tip is 6m diameter.

			Source Temp	Source Press	Source Flowrate	CO_2	Mass Flow	Discharge Volume Flow	Velocity	Valve Orifice		Frequency
Case	Valve	Description	°C	Bara	m^3/s	%	kg/s	m^3/s	m/s	mm	Notes	1/yr
LP01		Normal operation	44	1.01		0.27%	667.7	622.1	22.0		From Air dispersion Modelling Report (415000-00201-8150-RP-0008)	100
LP02	PV-1111A	Start-up (Full LP Recycle)	44	1.01		5.2%	333.9	311.0	11.0		50% of full production	10
LP03		Loss of Solvent in Absorber	40	1.01		5.2%	714.30	605.03	21.4		Full rate, no CO2 removal or cooling	0.1
LP04	PSV-1111 A-G	CO2 Stripping	94.5	4.5		56.0%	79.7			8T10 x 6	Blocked outlet case	0.1

A.2 High Pressure Releases

These cases are vented from the dedicated HP CO2 Vent at 40m above grade. The vent tip is 0.742mm diameter (30”).

Case	Valve	Description	Source Temp	Source Press	Source Flowrate	CO_2	Discharge Temp	Discharge Press	Mass Flow	Velocity	Valve Orifice	Notes	Frequency
			°C	Bara	m^3/s	%	°C	Bara	kg/s	m/s	mm		1/yr
HP01	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	0.0354	99.96%	52	1.03	27.78	38.7		Fully open: 50% of one compressor	10
HP01A	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	0.0177	99.96%	52	1.03	13.89	19.36		50% Open (i.e. ~25% of one compressor)	1
HP01B	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	0.0035	99.96%	52.9	1.03	2.78	3.89		10% Open (i.e. ~5% of one compressor)	1
HP01C	70-PV-1568	CO2 Compressor Discharge 10"-CO2-70-3096-F2GA-PP	132	137.5	0.0707	99.96%	50	1.03	55.56	71.76		2 x fully open from 2 compressors (2 x 50%)	0.5
HP02	70-XDV-1538	Final CO2 Cooler 70-E-1110 See HP04 which is identical	25	137.5		99.96%	-58	1.01	2.78	2.54		This is identical to HP04 below, but with smaller inventory and faster depressurising	0.5
HP03	70-XDV-1539	Final CO2 Cooler 70-E-1110 See HP05 which is identical	-43	8		99.96%			2.78			This is identical to HP05 below, but with smaller inventory and faster depressurising	0.5
HP04	70-XDV-0501	CO2 Station metering upstream of line 12-CO2-70-3098-F2GA-C (Dense Phase)	25	137.5		99.96%	-58	1.01	2.78	2.54		Initial conditions for dense phase depressurising through Vent KO Drum. Release modelled from Vent KO Drum only at 8barg and -42C with 10 000kg/h initial flow rate (vapour)	0.5

			Source Temp	Source Press	Source Flowrate	CO_2	Discharge Temp	Discharge Press	Mass Flow	Velocity	Valve Orifice		Frequency
Case	**Valve**	**Description**	°C	Bara	m³/s	%	°C	Bara	kg/s	m/s	mm	**Notes**	1/yr
HP04A	70-XDV-0501	CO2 Station metering (Liquid Phase)	25	54.2		99.96%	-58	1.01	1.16	1.06		Liquid phase depressurising through Vent KO Drum after 48 mins dense phase depressurising. Release modelled from Vent KO Drum only at 8barg and -42C with 4 196kg/h initial flow rate (vapour)	0.5
HP05A	70-XDV-0502	CO2 Station metering (Vapour Phase 1)	8	42		99.96%	-87.9	1.01	2.31	0.92		Vapour phase depressurising direct to vent after about 8 hours of liquid phase depressurising. Flow rate may be reduced to limit low temperatures in piping	0.5
HP05B	70-XDV-0502	CO2 Station metering (Vapour Phase 2)	-37	10		99.96%	-56.6	1.01	1.33	1.227		Vapour phase after about 2½ hours	0.5
HP06	70-TSV-0513	CO2 Station metering	65	170		99.96%	-58	1.01	2.778	2.54	1.5D2	Modelled as 1.5D2 PSV with 9.5mm Orifice diameter and initial flow rate of 5.9973kg/s. Release modelled from Vent KO Drum only at 8barg and -42C with max 10 000kg/h initial flow rate (vapour) assuming additional restriction orifice in line to limit flow rate Only opens for < 10mins so no STEL/LTEL	0.5
HP07	70-PSV-1501A/B	CO2 Compressor Suction Knock Out Drum 70-D-1101		7								More data available when CO2 Compressor vendor is selected	
HP08	70-PSV-1502A/B	CO2 Compressor 2nd Stage Knock Out Drum 70-D-1102		10								More data available when CO2 Compressor vendor is selected	

Case	Valve	Description	Source Temp °C	Source Press Bara	Source Flowrate m³/s	CO_2 %	Discharge Temp °C	Discharge Press Bara	Mass Flow kg/s	Velocity m/s	Valve Orifice mm	Notes	Frequency 1/yr
HP09	70-PSV-1503A/B	CO2 Compressor 3rd Stage Knock Out Drum 70-D-1103		14								More data available when CO2 Compressor vendor is selected	
HP10	70-PSV-1504A/B	CO2 Compressor 4th Stage Knock Out Drum 70-D-1104		24								More data available when CO2 Compressor vendor is selected	
HP11	70-PSV-1505A/B	CO2 Compressor 4th Stage Discharge 18"-CO1-70-3031-D0LA-PP	119	38	1.23	99.43%	117	1.01	60.04	100.84	6Q8	PSV on discharge of LP compressor section. 100% flow.	0.05
HP12	70-PSV-1506A/B	Oxygen Removal Reactor (70-RE-1101)		48								More data available when vendor is selected	
HP13	70-PSV-1507A/B	Dehydration Knock Out Drum 70-D-1105		48								More data available when vendor is selected	
HP14	70-PSV-1514A/B	CO2 Compressor HP Discharge line 10"-CO2-70-3096-F2GA-PP	155.5	165	0.076	99.96%	153.3	1.01	59.91	110.00	4L6	PSV on discharge of HP compressor section. 100% flow.	0.05
HP15	70-PSV-1511	Regeneration Heater 70-E-1112		49							1D2	More data available when vendor is selected	
HP16	70-PSV-1512A/B	Regeneration KO Drum 70-D-1111		49							1D2	More data available when vendor is selected	
HP17	70-PSV-1513A/B	Regeneration Compressor 70-C-1103		49							1D2	More data available when vendor is selected	
HP18	70-PSV-1509A/B	Desiccant Bed 70-D-1113A		49							1D2	More data available when vendor is selected	
HP19	70-PSV-1510A/B	Desiccant Bed 70-D-1113C		49							1D2	More data available when vendor is selected	

Case	Valve	Description	Source Temp	Source Press	Source Flowrate	CO_2	Discharge Temp	Discharge Press	Mass Flow	Velocity	Valve Orifice	Notes	Frequency
			°C	Bara	m^3/s	%	°C	Bara	kg/s	m/s	mm		1/yr
HP20	70-PSV-1517A/B	Desiccant Bed 70-D-1113B		49							1D2	More data available when vendor is selected	
HP21	70-TSV-1519A/B	Dry CO2 Filter 70-F-1102A/B		49							1D2	More data available when vendor is selected	
HP22	70-PSV-1520A/B	16"CO2-70-3060-D2GA-NI	89	49	0.440	99.96%	47.5	1.01	26.60	36.57	4L6	PSV on discharge of Dehydration package upstream of isolation valve and NRVs Flow rate set from PSV orifice size rather than Relief Summary	0.05
HP23	70-PSV-1521A/B	Regeneration Filter 70-F-1101A/B		49							1D2	More data available when vendor is selected	
HP24	70-PSV-1522A/B	16"-CO2-70-3060-D2GA-NI	117	73		99.96%	61.6	1.01	85.85	121.58	4P6	PSV on suction of HP Compressor downstream of isolation valve and NRVs Flow rate set from PSV orifice size rather than Relief Summary	0.05

(green shading)	The cases that were modelled