Peterhead CCS Project

Doc Title: Relief and Vent Study Report

Doc No.: **PCCS-00-PTD-HX-5880-00004**

Date of issue: **28/05/2015**

Revision: **K03**

DECC Ref No: **11.037**

Knowledge Cat: **KKD - Technical**

KEYWORDS

Goldeneye, CO_2, Carbon Capture and Storage, Relief and Vent Study Report, dispersion modelling, relief calculations, depressurisation, vent sizing, vent system.

Produced by Shell U.K. Limited

ECCN: EAR 99 Deminimus

IMPORTANT NOTICE

Information provided further to UK CCS Commercialisation Programme (the **Competition**)

The information set out herein (the **Information**) has been prepared by Shell U.K. Limited and its sub-contractors (the **Consortium**) solely for the Department for Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Table of Contents

Executive Summary

The Relief and Vent Study report encompasses the design of the relief and vent systems for the entire PCCS chain. Under normal operations, CO_2 from the power plant flue gas is captured and stored offshore in the Goldeneye store. However, there is a process requirement to be able to vent CO_2 temporarily – e.g. to allow periodic maintenance to take place. The document covers the main features of the design of the relief and vent systems on the onshore and offshore facilities of the PCCS Chain for venting of dense and gaseous phase CO_2. Relief design has also been undertaken for the 'business as usual' aspects of the project – such as for steam and fuel gas systems. Such aspects are not the main focus of this report but are considered within the appendices to this document. Venting of compounds formed within the CO_2 capture process is detailed in the Basic Design and Engineering Package (Key Knowledge Deliverable 11.003). To minimise fugitive emissions of these compounds, then depending upon where they occur in the process they are either vented back into the process or are subject to conditioning (e.g. if entrained with the flue gas) before the treated flue gas is released to atmosphere.

This document only covers controlled venting of CO_2 under normal operational conditions. Emergency venting of CO_2 is not part of the project operation philosophy, eg. there is no automatic depressurisation of equipment. Non-operational release of CO_2 and other compounds (i.e. due to accidental events) is covered separately in the Health, Safety and Environment Report (Key Knowledge Deliverable 11.120). As CO_2 is not flammable, there is little risk of a fire starting as a result of release, and therefore no flare system is required for the CO_2 system.

This report describes the designed venting locations, summarises system depressurisation requirements and includes vent dispersion studies and considerations. The primary PCCS CO_2 vent locations are:

- Onshore (Peterhead Power Station) – venting to the bottom of the absorber tower, where it is recycled in the absorption process. Some of this vented CO_2 may eventually be released to atmosphere via the existing stack;
- Onshore (Peterhead Power Station) - at the vent stack local to the compression plant;
- Offshore (Goldeneye platform) – at the existing vent stack structure, which will be retained and modified to be suitable for the required CO_2 duty; and
- Offshore (Goldeneye platform) – via below deck thermal relief valves.

The purpose of the dispersion studies is to analyse the dispersion of CO_2. Both the onshore and offshore dispersion modelling has been performed using the proprietary PHAST software. The information obtained from the dispersion studies is used to assist in the definition of vent requirements and to provide input into various safety assessment studies. Two dispersion modelling studies were carried out, one focusing on onshore depressurisation of CO_2 systems, and the other which considers the offshore CO_2 systems including sizing of the offshore vent for pipeline depressurisation. Workplace Exposure Limits (WELs) have been applied in consideration of both onshore and offshore locations in accordance with the UK Health and Safety Executive (HSE) guidelines.

For the onshore scope the results of the dispersion modelling study confirm that vents directed vertically will have a negligible impact. This is because the momentum of the vertically vented CO_2 will entrain air such that rapid mixing and dispersion will occur. Little or no slumping back to the ground is predicted to occur provided that there is some air movement – giving rise to predicted CO_2 concentration levels which are lower than the 8 hour HSE exposure limit. Operational restrictions are proposed to prevent venting of CO_2 on completely still days when the vented CO_2 could potentially slump to ground. Onshore CO_2 venting takes place via the existing 170 m stack or the new compression plant stack. Therefore, the risk to persons (on or off site), building or structures is considered to be minimal and can be controlled under normal site operations. Other proposed mitigation measures include installation of CO_2 detection at the Peterhead Power Station site and use of personal CO_2 detectors for site staff once the carbon capture plant is operational. These measures will be reviewed further and finalised during Detailed Design.

Pressure relief loads have been determined in accordance with the applicable sections of ISO 23251 (API STD 521). Venting route and vent header sizes have also been calculated and incorporated in the FEED design. Depressurising the CO_2 system will be done in a manner that prevents significant solid CO_2 formation, potentially interfering with the venting process, and excessive material cooling, potentially resulting in component failure, through controlling the depressurisation rate.

Dispersion modelling has been carried out for the offshore scope. Although the Goldeneye platform is a Normally Unmanned Installation (NUI) the modelled venting scenarios also apply the WELs provided in the HSE guidelines. As for the onshore dispersion studies, it was found that operational venting from vent tower or underdeck thermal relief have a negligible potential impact on personnel on the platform or vessels that may be in the vicinity.

1. Project Introduction

The Peterhead CCS Project aims to capture around one million tonnes of CO_2 per annum, over a period of 10 to 15 years, from an existing combined cycle gas turbine (CCGT) located at SSE's Peterhead Power Station in Aberdeenshire, Scotland. This would be the world's first commercial scale demonstration of CO_2 capture, transport and offshore geological storage from a (post combustion) gas-fired power station.

Post cessation of production, the Goldeneye gas-condensate production facility will be modified to allow the injection of dense phase CO_2 captured from the post-combustion gases of Peterhead Power Station into the depleted Goldeneye reservoir.

The CO_2 will be captured from the flue gas produced by one of the gas turbines at Peterhead Power Station (GT-13) using amine based technology provided by Cansolv (a wholly-owned subsidiary of Shell). After capture the CO_2 will be routed to a compression facility, where it will be compressed, cooled and conditioned for water and oxygen removal to meet suitable transportation and storage specifications. The resulting dense phase CO_2 stream will be transported direct offshore to the wellhead platform via a new offshore pipeline which will tie-in subsea to the existing Goldeneye pipeline.

Once at the platform the CO_2 will be injected into the Goldeneye CO_2 Store (a depleted hydrocarbon gas reservoir), more than 2 km under the seabed of the North Sea. The project layout is depicted in Figure 1-1 below:

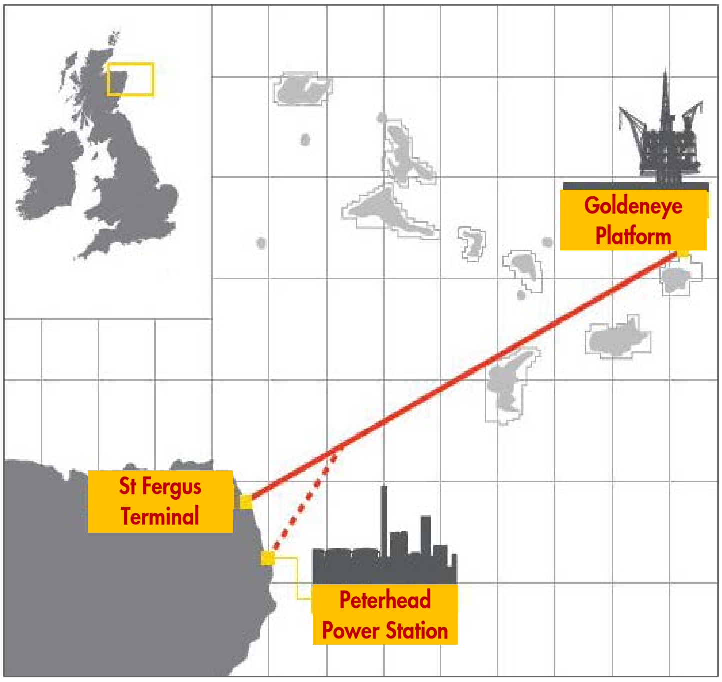


Figure 1-1: Project Location

2. Relief and Vent Study Objectives

Under normal operations, CO_2 from the power plant flue gas is captured and stored offshore in the Goldeneye store. However, there is a process requirement to be able to vent CO_2 temporarily – e.g. to allow periodic maintenance to take place.

This Relief and Vent Study Report outlines the relief and vent requirements of the CCS Chain and is comprised of this summary document plus five appendices which provide more details on specific technical aspects – such as the onshore and offshore vent design and dispersion modelling work.

The document covers the main features of the design of the relief and vent systems on the onshore and offshore facilities of the PCCS Chain with particular focus given to venting of dense and gaseous phase CO_2. Relief design has also been undertaken for the 'business as usual' aspects of the project – such as for steam and fuel gas systems. Such aspects are not the main focus of this report but are considered within the appendices to this document.

Venting of compounds formed within the CO_2 capture process is detailed in the Basic Design and Engineering Package (Key Knowledge Deliverable 11.003). To minimise fugitive emissions of these compounds, then depending upon where they occur in the process they are either vented back into the process or are subject to conditioning (e.g. if entrained with the flue gas) before the treated flue gas is released to atmosphere.

This document covers controlled venting of CO_2 under normal operational conditions. Emergency venting of CO_2 is not proposed as part of the project operation philosophy. Non-operational release of CO_2 and other compounds (i.e. due to accidental events) is covered separately in the Health, Safety and Environment Report (Key Knowledge Deliverable 11.120) [1].

The description of the design of the relief and vent systems includes the methodology for relief valve selection and sizing. Information on the vent system hydraulics is also presented. The system depressurisation requirement and how this is catered for in the presented design is also summarised.

This report also defines at which locations venting will occur and includes vent dispersion studies and considerations. The purpose of the dispersion studies is to analyse the dispersion of CO_2 from vents given a range of operating pressures and temperatures, vent sizes and vent stack heights. The information obtained from the dispersion studies is used to assist in the definition of vent requirements and to provide input into various safety assessment studies. Two dispersion modelling studies were carried out, one focusing on the depressurisation scenarios for the onshore CO_2 systems, and the other considering offshore depressurisation scenarios.

Workplace Exposure Limits (WELs) have been applied in consideration of both onshore and offshore locations in accordance with the UK Health and Safety Executive (HSE) guidelines [2]. The study considers the risks to personnel in manned areas or buildings when venting takes place and also describes the means used to protect personnel against risk or hazard.

3. Overall CO_2 System Venting Philosophy and Requirements

Under normal operations, minimal venting of the CCS system will be required. Venting is anticipated to be required associated with the following operations and/or events:

- Depressurisation of equipment to perform maintenance and routine inspections (e.g. for the compression plant);

- Production of out of specification CO_2; and
- Temporary venting of CO_2 as a result of operational upset.

In practice, it is anticipated that non-maintenance related venting of CO_2 will be minimal – particularly as operational experience is developed.

As CO_2 is not flammable, there is little risk of a fire starting as a result of release, and therefore no flare system is required for the CO_2 system. If there is a process upset or in event of an emergency, i.e. as a result of blocked CO_2 inventory, the plant/equipment can be stopped, and isolated. The only possible source of combustible material is the lube oil skid for the CO_2 compressor. This will be located away from the CO_2 compressor to ensure there is no danger of a fire impinging on the compressor and associated equipment. All relief valves required shall either discharge to atmosphere or to the absorber tower.

4. CO_2 System – Venting Locations and Design Philosophy

4.1. CO_2 System Venting Locations

The primary PCCS CO_2 vent locations are:

- Onshore (Peterhead Power Station) – venting to the bottom of the absorber tower, where it is recycled in the absorption process. Some of this vented CO_2 may eventually be released to atmosphere via the existing stack;
- Onshore (Peterhead Power Station) - at the vent stack local to the compression plant;
- Offshore (Goldeneye platform) – at the existing vent stack structure, which will be retained; and
- Offshore (Goldeneye platform) – via below deck thermal relief valves.

Gaseous phase CO_2 is vented onshore at Peterhead Power Station, except downstream of the main CO_2 compression plant where dense phase CO_2 is vented. Dense phase CO_2 is vented offshore at the Goldeneye platform.

4.2. CO_2 System Venting Design Philosophy

There are two primary means of releasing CO_2 to atmosphere in the PCCS CO_2 system design:

- via vent stacks; and
- via Pressure Safety Valves (PSVs) and thermal relief.

Where potential to be able to release large volumes of CO_2 is required, this is achieved onshore via vent stacks with the CO_2 first heated (via a KO drum or in the Onshore Gas-Gas Heat-Exchanger) to aid buoyancy and dispersion. One of the outputs from the CO_2 dispersion modelling is confirmation that the proposed stack height is acceptable for use. Direct venting is proposed offshore via the new dedicated CO_2 vent.

For the onshore CO_2 system, PSVs release CO_2 into vent headers with CO_2 ultimately released to atmosphere via either the existing 170 m stack or the new vent stack local to the compression plant.

For the offshore system, thermal relief valves are used to temporarily discharge small volumes of CO_2 via individual vents below the platform. Pressure relief loads have been determined in accordance with relevant standards [3].

The results and conclusions of the FEED vent design are attached in Appendices 1, 2 and 4. The results of the dispersion modelling which has been performed are attached in Appendices 3 and 5. Note that the dispersion modelling for the clean flue gas discharged from the 170m stack is not included here but is described in detail in Appendix 3 of the Impact Assessment [4].

5. Onshore CO_2 Relief and Vent System Design

5.1. Capture Plant Venting Design (to the Absorber)

5.1.1. General

Under normal CCS operations, flue gas from GT-13 is treated in the carbon capture plant process. Approximately 90% of the CO_2 in the flue gas is captured in the CO_2 absorption process before being compressed, conditioned and transported offshore to be injected into the Goldeneye CO_2 store. The treated flue gas leaving the top of the CO_2 absorption section will pass through a Water Wash section and Acid Wash Section before being routed via the Gas-Gas Heat Exchanger to the existing 170 m stack and to the atmosphere. This includes some 10% of the CO_2 in the flue gas which is not captured by the absorption process.

Vented CO_2 within the carbon capture plant is routed back to the Absorber. If not re-absorbed within the process, this may temporarily result in a small increase in the volume of CO_2 which is released to atmosphere via the existing stack.

5.1.2. Vent Header Sizing (Carbon Capture Plant)

In the capture plant a number of tanks, packages and vessels vent into the vent header; the operating pressure of each tank is calculated as based upon the back pressure from the Absorber based on line lengths and losses. The basis for sizing the vent header connecting each tank (located in the capture plant) to the absorber is based on determining the maximum possible load which will be vented from each tank at any given time.

In the areas where a fire is plausible a fire case was considered. The sizing case for each tank provided the cumulative total vented via the vent header to the absorber. For each of the tanks connected to the vent header the design pressure is set by the static head from the top of the tank to the vent header when the vent line becomes flooded with liquid, unless the tank is protected with a PSV in which case the design pressure is matched to the vent header pressure.

5.2. Compression Plant Venting Design

5.2.1. General

In the event that either the CO_2 Compression and Conditioning area needs depressurising or the CO_2 produced by the unit is off-spec, it shall be vented to atmosphere. It is used for relief from PSVs in the CO_2 Compression and Conditioning area. Both gaseous and dense phase CO_2 is vented from the compression plant via the new vent stack.

Gaseous CO_2 will enter the venting system (from PSVs, or the outlet of the CO_2 Dehydration Molecular Sieves), flow through the CO_2 header, and be vented to atmosphere through the local Vent Stack.

Dense-phase CO_2, could also be vented from the compression plant. Vented dense phase CO_2 is sent to the Vent KO Drum where it is gravity fed to the CO_2 Vaporiser and vaporised by medium pressure (MP) steam. The CO_2 vapour then flows back to the Vent KO Drum, where it passes to the CO_2 vent header via pressure control, and out to atmosphere through the Vent Stack.

The vaporisers will be used on an infrequent basis and this has been considered when setting the capacity of the MP steam system. The MP steam system design philosophy allows for offloading of the Thermal Reclaimer Unit (TRU) reboilers during periods of high venting of dense phase product. The TRU is not required to operate at all times.

5.2.2. Vent Header Sizing (Compression Plant Vent Stack)

The vent header is sized on the largest relief load, as there is no potential for a fire starting. In addition, the operation philosophy is that multiple relief valves would not be operated in parallel so no mixing of relief streams is anticipated.

5.3. Depressurisation Requirements

The aim of the depressurisation systems is to safely depressurise the plant, or part of the plant, and equipment in preparation for plant maintenance. The objective for the facilities is to operate in such a way to eliminate as far as possible any operational venting during normal operations. Depressurising large inventories of CO_2 creates considerable challenges, in particular due to the phase changes when dense phase CO_2 is depressurised. One of the key challenges is to depressurise a CO_2 system in a manner that prevents significant solid CO_2 formation and excessive material cooling, through controlling the depressurisation rate. Depressurisation will be carried out under operator control when required.

As CO_2 is not flammable, there is minimal risk of a fire starting as a result of release, for example within the compression section of the CCS plant, and therefore no flare system is required for the system.

5.4. Depressurisation Routes

Three main depressurisation routes are considered for the onshore CO_2 system:

1) Low pressure gaseous phase CO_2 released from PSVs local to the absorber is vented into the absorber tower where it may ultimately be vented to atmosphere from the top of the 170m stack.
2) Low pressure gaseous phase CO_2 is discharged to from all the major PSVs (excluding thermal relief) within the CO_2 compression train the local compression plant Vent Stack via a vent header. This includes CO_2 released via the depressuring line downstream of the Molecular Sieves.
3) High pressure dense phase CO_2 released downstream of the CO_2 compressor discharge is routed to a Vent KO Drum. The drum is pressurised above the CO_2 triple point using instrument air, to avoid dry ice formation, and thereby avoid blockage. MP steam is then used to vaporise the CO_2 in the vaporiser, before being vented to atmosphere via a separate route to the Vent Stack.

Depressuring lines are fitted with a flow transmitter and flow control valve, such that the rate of CO_2 flowing to the vent stack and ultimately to atmosphere can be controlled. This is standard industry practice for onshore vent stations and for the depressurising of sections of onshore pipeline for inspection, maintenance of repair.

During a CO_2 compressor trip or shutdown, CO_2 from the capture plant which is being supplied to the compressor inlet shall be automatically diverted back to the CO_2 absorber. This recycled CO_2 is a small percentage (approx. 4%) of the total flow through the Absorber and is therefore anticipated to have minimal impact upon the Absorber process.

5.5. Onshore Relief Valve Sizing

The Relief and Vent Study Report (Power Plant) and Relief and Vent Study Report (Capture Plant) attached in Appendices 1 and 2 cover the methodology and results of the FEED stage relief valve sizing for the Peterhead Power station and for the Carbon Capture Plant area respectively. Pressure relief loads have been determined in accordance with the applicable sections of ISO 23251 (API STD 521) [4]. The relief valve sizing calculation methodology used for these calculations has a checklist covering various scenarios, to ensure that the calculations consider all the potential scenarios. Examples of these scenarios include closed outlets on equipment, utility failures, burst tubes, overfilling, failure of controls, chemical reactions, hydraulic expansion, external fire, loss of electrical power, compressor trips and mal-operation.

The relief valve sizing tool is based on the formulas given in API 520 Part 1 to calculate the required relief valve sizes based on the determined flowrate and fluid properties of each scenario. Appropriate relief valve sizes were then selected based on the identified sizing case. Selected relief valve sizes are detailed in Appendices 1 and 2.

5.6. Onshore Dispersion Modelling

Dispersion Modelling for the onshore carbon capture plant was performed using PHAST v. 7.01. As described in CO_2 Vent Dispersion Report (attached as Appendix 3), the CO_2 releases considered are controlled releases from vents only under normal operational conditions.

A range of representative conditions were modelled to help confirm the proposed vent locations and operating conditions at these vents. Climactic conditions at the Peterhead Power Station site have been considered in accordance with the Design Basis information provided in Part 2 of the Basic Design and Engineering Package (Key Knowledge Deliverable 11.003) [3].

The results of the study confirm that vents directed vertically will have a negligible impact downwind. This is because the momentum of the vertically released gas will entrain air such that rapid mixing and dispersion will occur. Little or no slumping back to the ground is predicted to occur provided that there is some air movement: operational restrictions will therefore be required to prevent venting of CO_2 on completely still days when the vented CO_2 could potentially slump to ground. No horizontally oriented vents are proposed in the onshore FEED design.

The dense phase CO_2 dispersion modelling carried out during FEED covered venting directly to atmosphere. The design proposed at the end of FEED considers a much more controlled system where the liquid CO_2 is heated and boiled off. As a result, the vented CO_2 is likely to contain CO_2 in a mixture of states which would give an improved dispersion profile. The onshore venting design and associated dispersion modelling will be reviewed further and finalised during Detailed Design.

6. Offshore CO_2 and Methanol Relief and Vent system

6.1. Offshore Venting Design

The existing Goldeneye Platform Vent Tower structure will be retained and used to support a new dedicated vent to handle depressurisation of the pipeline and the depressurisation of the injection and monitoring wells to perform SSSV tests.

Vent systems will be provided for relief and venting of pipework and equipment. There will be no emergency depressurisation facilities. The following systems are provided:

1) A system is provided for depressurising the large inventory of CO_2 in the pipeline. The vent for this is located on the existing Goldeneye vent tower. Depressurising of the pipeline will take several weeks and periodic attendance on the platform is required as the vent system is normally positively isolated. A pipeline depressurising system will not be provided at the onshore facilities.
2) A system for depressurising the wells for SSSV leak-off testing is provided. This may also be used for sampling the monitoring well. This utilizes the existing vent KO drum and vent stack. This may contain small quantities of hydrocarbon, water and methanol. The vent KO drum will collect liquid. The liquids will be allowed to stabilize and then drained to an IBC via a flexible hose.
3) Individual vents discharging below the platform are provided for thermal relief. The volumes of CO_2 discharged will be very small. Nevertheless, these vents shall be located and oriented so as not to impact upon the spider deck access ways.
4) Individual vents are provided for manual depressurising of equipment and pipework sections for maintenance. These are vented below the deck level of the platform.
5) Individual local vents are provided for double-block-and-bleed isolation valves.

6.2. Offshore Depressurisation Requirements

The offshore vent system is required to be capable of performing the following duties:

- Pipeline depressurisation;
- Topsides maintenance depressurisation;
- Topsides (CO_2) thermal relief valve discharge;
- Methanol filter thermal relief valve;
- Venting wells for SSSV testing;
- Venting lubricators and other small inventories during well intervention.

6.3. Offshore Depressurisation Routes

Depressurisation routes on the Goldeneye Platform include:

1) Dense phase CO_2 is released via a new dedicated vent using the existing vent tower which requires to be modified to be suitable for venting CO_2; and
2) Dense phase CO_2 and methanol is discharged via thermal relief valves located below the platform deck.

6.4. Offshore Relief Sizing

The offshore CO_2 venting systems will be designed to handle dense phase CO_2.

The main vent stack at the Goldeneye Platform is sized to facilitate final depressurisation of the offshore pipeline, if required at the end of operations. The vent tip will be angled at 45°C facing platform north to direct the CO_2 plume away from the platform. The existing KO drum will be retained and used to aid pipeline venting and well venting for SSSV testing.

CO_2 venting from the topsides pipework is via below deck thermal relief valves. A methanol filter thermal relief valve is also provided. Calculations have been performed during FEED to size these relief valves in accordance with applicable standards.

6.5. Offshore Dispersion Modelling

Dispersion Modelling for the offshore project scope was performed using PHAST as described in the Vent Dispersion Study – Platform (Appendix 5). As for the onshore design, no emergency depressurisation is proposed offshore. CO_2 venting is controlled for operational purposes with small amounts of CO_2 vented below deck for thermal relief. Climactic conditions at Goldeneye have been considered in accordance with the Design Basis information provided in Part 2 of the Basic Design and Engineering Package (Key Knowledge Deliverable 11.003) [3]. Although the Goldeneye platform is a Normally Unmanned Installation (NUI) the modelled venting scenarios also apply the WELs provided in the HSE guidelines.

The objectives of the modelling are defined below:

- Confirm that CO_2 concentrations at the platform and at sea level are within the WELs provided in the HSE guidelines minimising the risk to personnel who require to access the platform on a temporary basis – e.g. to perform routine maintenance;
- Confirm optimal relief valve and vent locations taking constructability, operability, inspection and maintenance considerations into account.

As in the onshore dispersion studies, it was found that vertical venting (or an angled vent tip) has a negligible impact downwind. The concentration of CO_2 at the offshore platform is lower than the 0.5% concentration permitted in the HSE 8 hour long-term exposure limit. The concentration of CO_2 at sea level was also found to be lower than the 0.5% concentration permitted in the HSE 8 hour long-term exposure limit. Therefore under normal operations, it is not considered that offshore venting will present a significant risk to the safety of personnel who are required to visit the platform – for example to perform planned maintenance activities.

7. Risks to Personnel

The CO_2 dispersion modelling completed for the PCCS FEED confirms that dispersion from vertically oriented vents will have a negligible impact downwind in both onshore and offshore locations. This is because the momentum of the vertically released gas will entrain air such that rapid mixing and dispersion will occur. Little or no slumping back to the ground, platform or sea level is predicted to occur provided that there is some air movement: operational restrictions will therefore be required to prevent venting of CO_2 on completely still days when the vented CO_2 could potentially slump. No horizontally oriented vents are proposed in the FEED design.

Dispersion modelling performed for both the onshore and offshore venting system designs predicts that the worst case concentration of CO_2 which would be experienced is lower than the 0.5% concentration permitted in the HSE 8 hour long-term exposure limit. Therefore under normal operations, it is not considered that onshore or offshore venting will present a significant risk to the safety of personnel. Operational measures, such as the use of personal CO_2 detectors for site staff are also proposed to mitigate the potential hazard presented by concentrated release of CO_2.

Onshore and offshore vents have been located such that no risks to buildings or structures are anticipated during venting operations.

These measures will be reviewed further and finalised during Detailed Design.

8. Conclusion

The Relief and Vent Study report describes the proposed relief and venting systems for the entire PCCS chain, focusing primarily on the CO_2 release requirements under normal operational conditions. Emergency venting of CO_2 is not proposed under the project operational philosophy.

Vent design and CO_2 dispersion modelling has been performed and is reported in more detail in the documents included in the appendices to this report. The dispersion modelling confirms the selected vent design and have also been used to assist in the definition of vent requirements and to provide input into various safety assessment studies. Pressure relief loads have been determined in accordance with the applicable sections of ISO 23251 (API STD 521) [5]. Venting route and vent header sizes have also been calculated and incorporated in the FEED design. Depressurising the high pressure dense phase CO_2 system will be done in a manner that prevents significant solid CO_2 formation and excessive material cooling, through controlling the depressurisation rate.

The dispersion modelling has also demonstrated that release of CO_2 from vertically oriented vents will have a negligible impact downwind. This is because the momentum of the released gas will entrain air such that rapid mixing and dispersion will occur as the plume rises higher. Little or no slumping back to the ground is predicted to occur provided that there is some air movement. Operational restrictions are proposed to prevent venting of CO_2 on completely still days when the vented CO_2 could potentially slump to ground, platform deck or sea level.

The dispersion modelling has demonstrated that the risks to personnel either onshore or offshore as a result of controlled release of CO_2 is considered to be minimal and can be controlled under normal site operations.

9. References – Bibliography

1. Health, Safety and Environment Report (Key Knowledge Deliverable 11.120)
2. HSE Guidance Note EH40/2005 Workplace Exposure limits
3. Basic Design and Engineering Package (Key Knowledge Deliverable 11.003)
4. Peterhead CCS Project Onshore Environmental Statement.
5. ISO 23251 (API Standard 521). "Petroleum, petrochemical and natural gas industries - Pressure-relieving and depressuring systems"

10. Glossary of Terms

Term	Definition
API	American Petroleum Institute
CCP	Carbon Capture Plant
CCS	Carbon, Capture and Storage
CO_2	Carbon Dioxide
FEED	Front End Engineering Design
HP	High Pressure
HSE	Health & Safety Executive
IBC	Intermediate Bulk Container
ISO	International Organisation for Standardisation
KO	Knock-Out
KT	Knowledge Transfer
LP	Low Pressure
MP	Medium Pressure
PCCS	Peterhead Carbon Capture and Sequestration
PHAST	Process Hazard Analysis Software Tools
ppm	Parts per Million
PSV	Pressure Safety Valve
SSSV	Sub Surface Safety Valve
STEL	Short Term Exposure Limit
TRU	Thermal Reclaimer Unit
WEL	Workplace Exposure Limit

APPENDIX 1. Relief and Vent Study Report (Power Plant) (PCCS-01-TC-PX-7180-00001)

Peterhead CCS Project

Doc Title: Relief and Vent Study Report (Power Plant)

Doc No.:	**PCCS-01-TC-PX-7180-00001**
Date of issue:	**28/05/2015**
Revision:	**K03**
DECC Ref No:	**11.037**
Knowledge Cat:	**KKD - Technical**

KEYWORDS

Goldeneye, CO_2, Carbon Capture and Storage. Relief, Vent, Power Plant.

Produced by Shell U.K. Limited

ECCN: EAR 99 Deminimus

IMPORTANT NOTICE

Information provided further to UK CCS Commercialisation Programme (the **Competition**)

The information set out herein (the **Information**) has been prepared by Shell U.K. Limited and its sub-contractors (the **Consortium**) solely for the Department for Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Table of Contents

List of Tables

1. Introduction

The Peterhead Carbon, Capture and Storage (PCCS) project would be the world's first commercial scale demonstration of CO_2 capture, transport and offshore geological storage from a (post combustion) gas-fired power station. Carbon Capture technology will be fitted to an existing gas-fired power station at Peterhead in North East Scotland, UK, at a site with sufficient space for the construction of the post combustion CO_2 capture plant and the compression and conditioning plant. Approximately 1 million tonnes of CO_2 will be captured from the flue gas produced by the Peterhead Power Station and stored each year in a depleted Goldeneye reservoir currently operated by Shell. After capture, the CO_2 will be routed to compression, also located at the Peterhead Power Station site, where it will be compressed, cooled and conditioned for water and oxygen removal to meet a suitable transportation and storage specification. Following post-compression cooling the resulting dense phase CO_2 stream will be transported direct offshore via a new offshore pipeline which will tie-in subsea to the existing Goldeneye pipeline. The CO_2 will be permanently stored in an area centered on the depleted Goldeneye gas field.

2. Scope of Document

This document covers the methodology and results of the FEED stage relief valve sizing for the Power Station area of the Peterhead Carbon Capture project.

3. Relief Valve Sizing Methodology

Pressure relief loads have been determined in accordance with the applicable sections of ISO 23251 (API STD 521). All the calculations contained within this report have been performed and checked / approved by Chartered Chemical Engineers, satisfying the requirement of Construction Design and Management Regulations 2007 (CDM) for designers to be competent.

3.1. Relief Scenarios

The following relief scenarios have been checked and considered for all relief valves studied:

- Closed Outlets on Equipment;
- Cooling Water Failure;
- Reflux Failure;
- Steam Failure;
- Burst Tube;
- Accumulation of Non-Condensables;
- Entrance of Highly Volatile Materials;
- Overfilling of Tank or Vessel;
- Failure of Automatic or Manual Controls;
- Abnormal Heat Input;
- Abnormal Fluid Input;
- Chemical Reaction;
- Blocked-in (Hydraulic Expansion);

- Exterior Fire;
- Electrical Power Failure (local user and site wide);
- Instrument Air Failure (local user and site wide);
- Refrigerant Failure;
- Loss of Liquid Level;
- Quench Failure;
- Compressor Trips;
- Start-up / Shut-down / Part Load;
- Mal-operation;
- Other.

The relief valve sizing calculation template used for these calculations has a checklist covering these scenarios, to ensure that all of the calculations consider all the scenarios.

Some cases have been marked as not applicable, where there is an obvious case of inapplicability (e.g. on a system with no cooling water, then cooling water failure cannot initiate a relief scenario) otherwise they have been justified with a longer description as to why the scenario is considered to be applicable or not, possibly with a calculation to determine applicability.

3.2. Relief Load Determination

Where a condition has been identified to apply, then a load determination calculation has been performed. Depending on the scenario being studied, standard Technip internal tools and calculation methods have been used where these are available. Where a standard method is not available, a bespoke method has been created and approved as part of the overall sizing calculation. An example of where a bespoke calculation was required is where a Chemical Reaction scenario has been identified.

The relief load has been calculated based on the flowrate generated at the design pressure plus the allowable accumulation. The allowable accumulation under ASME VIII and Pressure Equipment Directive (97/23/EC) (PED) is 10%, and this has been used throughout the power station area. The exception to this is the relief valve downstream of the Auxiliary Boiler, which is designed to protect the boiler superheater. Therefore this valve has been sized based on an allowable accumulation of 6% based on the requirements of ASME I and IV for fired boilers.

Where flow from an upstream system has been used to determine the relief load, the flowrate has been calculated using the design pressure of the upstream system rather than normal operating pressure.

3.3. Relief Valve Sizing

The Technip internal relief valve sizing tool calculates the required relief valve size based on the determined flowrate and fluid properties of each scenario, before selecting the appropriate relief valve size based on the sizing case. The tool, which has been internally validated, calculates the relief area based on the formulas from API 520, part 1.

4. Relief Valve Inlet and Outlet Line Sizing Methodology

4.1. Inlet Line Sizing

The sizing of relief valve inlet lines has been performed using the Technip internal hydraulic line sizing spreadsheet, normally for Single Phase flow. The allowable inlet line pressure drop that has been used is 3% of the relief valve set pressure for the rated flowrate of the selected valve, as detailed in API 520/1. No other criteria have been used for the sizing of the inlet lines.

4.2. Outlet line sizing

The sizing of the relief valve outlet lines has been performed using the appropriate Technip internal hydraulic line sizing spreadsheet. Typically the appropriate tool is the Compressible Flow or Two Phase Flow version, depending on the relief scenario. The permitted back pressure that has been used is 10%, to allow the use of conventional valves, all of which is attributable to built-up back pressure, as all the Power Station relief valves are routed to atmosphere. This built-up back pressure has been calculated using the rated flow capacity of the relief valve, as detailed in API 520/1. Additionally the criterion that the velocity within the outlet line must not exceed 90% of the calculated speed of sound (Mach 1) for the fluid at relief conditions was applied.

5. Sizing Results (By Relief Valve)

5.1. Ammonia Storage PSV

Over pressure scenarios identified:

- Closed outlets on equipment;
- Overfilling of tank or vessel;
- Failure of automatic or manual controls;
- Abnormal fluid input;
- Chemical Reaction;
- Blocked-in (hydraulic expansion);
- Electrical Power Failure;
- Instrument Air Failure;
- Possible back flow from downstream unit (Ammonia Transfer and Control Unit) – To be confirmed.

Sizing scenario was **Abnormal fluid input/chemical reaction**, caused by incorrect tanker delivery of Sulphuric Acid, which will also be used on site. Sizing is limited by tanker delivery discharge flowrate.

The provisional relief valve size calculated was 4M6, which will need to be confirmed by the relief valve vendor. 2 pressure safety valves (PSV) (1 service and 1 spare) will be installed.

Inlet line size was calculated as 6" [152.4 mm] reducing to 4", with an outlet line size of 6" to an atmospheric discharge point at a safe location.

5.2. 19 barg [20 bara] Auxiliary Steam Distribution PSV

Over pressure scenarios identified:

- Closed outlets on equipment;
- Failure of automatic or manual controls.

Sizing scenario was **Closed outlets on equipment**, caused by manual valve between control valve and pressure transmitter being closed. Sizing is limited by the control valve.

The provisional relief valve size calculated was 6R10, which will need to be confirmed by the relief valve vendor. 3 PSVs (2 service and 1 spare) will be installed.

Inlet line size was calculated as 16" reducing to 10", with an outlet line size of 16" to an atmospheric discharge point at a safe location.

5.3. 27 barg [28 bara] Auxiliary Steam Distribution PSV

Over pressure scenarios identified:

- Closed outlets on equipment;
- Failure of automatic or manual controls;
- Abnormal heat input;
- Electrical power failure;
- Instrument air failure;
- Mal-operation.

Sizing scenario was **Closed outlets on equipment**, caused by a fail closed valve being closed. Sizing is limited by an estimation of the maximum boiler output.

The provisional relief valve size calculated was 4M6, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 6", with an outlet line size of 10" to an atmospheric discharge point at a safe location.

5.4. Auxiliary Steam Flash Drum PSV

Over pressure scenarios identified:

- Closed outlets on equipment;
- Failure of automatic or manual controls;
- Exterior fire;
- Electrical power failure;
- Instrument air failure.

Sizing scenario was **Closed outlets on equipment**, caused by a fail closed valve being closed. Sizing is limited by an estimation of the maximum CCP condensate pump in rate.

The provisional relief valve size calculated was 1E2, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 2", with an outlet line size of 6" to an atmospheric discharge point at a safe location.

5.5. Auxiliary Steam Deaerator PSV

Over pressure scenarios identified:

- Closed outlets on equipment;
- Entrance of highly volatile material;
- Overfilling of tank or vessel;
- Failure of automatic or manual controls;
- Abnormal heat input;
- Exterior fire.

Sizing scenario was **Entrance of highly volatile material**, caused by a control valve letting excess Aux Steam into the deaerator. Sizing is limited by the control valve.

The provisional relief valve size calculated was 8T10, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 14", with an outlet line size of 16" to an atmospheric discharge point at a safe location.

5.6. Condensate Heat Recovery Exchanger PSV

Over pressure scenarios identified:

- Burst tube;
- Exterior fire.

Sizing scenario was **Burst tube**. Sizing is limited by the estimated tube dimensions.

The provisional relief valve size calculated was 1.5G3, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 2", with an outlet line size of 8" to an atmospheric discharge point at a safe location.

5.7. Fuel Oil Storage Tank PSV

Over pressure scenarios identified:

- Liquid movement into tank;
- Liquid movement out of tank;
- Thermal expansion;
- Thermal contraction;
- External fire.

Sizing scenario was **External fire**. Sizing was calculated based on API2000 for atmospheric storage tanks. Sizing is limited by the tank dimensions.

No provisional relief valve or line size has been calculated, as vendor information will be required.

5.8. Sea Water Supply and Return Line PSVs

Over pressure scenarios identified:

- Electrical power failure.

Sizing scenario was **Electrical power failure**, causing vacuum. Sizing was limited by an estimation of the slope of the lines.

No provisional relief valve or line size has been calculated, location, sizing and number of elements are to be confirmed by the EPC contractors.

6. Relief Sizing Summary

Table 6-1: Relief Sizing Summary

Relief Valve Location	Size	Sizing Case
Ammonia storage	2 x 100% 4 M 6	Abnormal fluid input / chemical reaction
19barg Auxiliary Steam Distribution PSV	3 x 50% 6 R 10	Closed outlets on equipment
27barg Auxiliary Steam Distribution PSV	2 x 100% 4 M 6	Closed outlets on equipment
Auxiliary Steam Flash Drum	2 x 100% 1 E 2	Closed outlets on equipment
Auxiliary Steam Deaerator	2 x 100% 8 T 10	Entrance of highly volatile material
Condensate Heat Recovery Exchanger	2 x 100% 1.5 G 3	Burst tube
Fuel Oil Storage Tank	By Vendor	External fire
Sea Water Supply and Return Lines	By EPC Contractor	Electrical Power Failure

7. Confirmations Required to Finalise Relief Sizing During Detailed Design

Relief valve calculations will require review during the project's EPC phase to close out the confirmations raised during this revision of the sizing calculations.

Some common confirmation requirements have been raised for all the sizing calculations:

- Line routing and lengths;
- Relief valve discharge coefficient (K_d = 0.975) – to be confirmed with valve vendor.

Other specific confirmation requirements have been raised for each relief valve calculation as required, depending on scenarios and equipment involved:

- Ammonia Storage.
  - Confirmation that road tanker pump deadhead pressure doesn't over pressure upstream of isolation valves;
  - Confirmation that the Ammonia Transfer and Control unit cannot cause over pressure due to backflow;
  - Confirmation of pressure drop caused by PSV inlet bursting disc.
- 19 barg [20 bara] Auxiliary Steam Distribution.
  - Confirmation of the CV of control valve and bypass globe valve.
- 27 barg [28 bara] Auxiliary Steam Distribution.
  - Confirmation of maximum boiler steam generation load.
- Auxiliary Boiler Flash Drum.
  - Confirmation of piping lengths within fire zone;
  - Confirmation of CCP maximum condensate pump flowrates.
- Auxiliary Boiler Deaerator.
  - Confirmation of vessel dimensions to allow calculation of fire relief scenario;
  - Confirmed CV size of steam pressure control valves and bypass valves;
  - Confirmed size of demin water booster pump flowrate;
  - Confirm the ability of the boiler to sustain the flow of steam calculated based on the steam pressure valve CVs;
  - Confirm the flash drum control valve CV sizes.
- Condensate Heat Recovery Exchanger.
  - Confirm tube size (length and internal diameter) of the heat exchanger to confirm bust tube flowrate;
  - Confirm exchanger dimensions for fire relief valve scenario sizing calculation.
- Fuel Oil Storage Tank.
  - Confirm tank dimensions;
  - Confirm delivery tanker maximum discharge flowrate.
- Sea Water Supply and Return Lines.
  - Review number, size and location of valves following transient analysis.

8. Glossary of Terms

Term	Definition
CCP	Carbon Capture Plant
CCS	Carbon Capture and Storage
CDM	Construction Design and Management Regulations 2007
CO_2	Carbon Dioxide
CV	Valve Flow Coefficient
EPC	Engineering, procurement and construction
FEED	Front End Engineering Design
KKD	Key Knowledge Deliverable
PED	Pressure Equipment Directive (97/23/EC)
PHAST	Process Hazard Analysis Software Tools
PSV	Pressure Safety Valve

9. Glossary of Unit Conversions

Table 10-1: Unit Conversion Table

Function	Unit - Imperial to Metric conversion Factor
Length	1 Inch = 25.4 millimetres

APPENDIX 2. Relief and Vent Study Report (Capture Plant) (PCCS-02-TC-7180-00001)

Peterhead CCS Project

Doc Title: Relief and Vent Study Report (Capture Plant)

Doc No.: **PCCS-02-TC-PX-7180-00001**

Date of issue: **28/05/2015**

Revision: **K03**

DECC Ref No: **249**

Knowledge Cat: **KKD - Technical**

KEYWORDS

Goldeneye, CO_2, Carbon Capture and Storage. Relief, Vent, Capture Plant.

Produced by Shell U.K. Limited

ECCN: EAR 99 Deminimus

IMPORTANT NOTICE

Information provided further to UK CCS Commercialisation Programme (the **Competition**)

The information set out herein (the **Information**) has been prepared by Shell U.K. Limited and its sub-contractors (the **Consortium**) solely for the Department for Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Table of Contents

List of Tables

1. Introduction

The Peterhead Carbon, Capture and Storage (CCS) Project would be the world's first commercial scale demonstration of CO_2 capture, transport and offshore geological storage from a (post combustion) gas-fired power station. Carbon Capture technology will be fitted to an existing gas-fired power station at Peterhead in North East Scotland, UK, at a site with sufficient space for the construction of the post combustion CO_2 capture plant and the compression and conditioning plant. Approximately one million tonnes of CO_2 will be captured from the flue gas produced by the Peterhead Power Station and stored each year in the depleted Goldeneye reservoir currently operated by Shell. After capture, the CO_2 will be routed to compression, also located at the Peterhead Power Station site, where it will be compressed, cooled and conditioned for water and oxygen removal to meet a suitable transportation and storage specification. Following post-compression cooling the resulting dense phase CO_2 stream will be transported direct offshore via a new offshore pipeline which will tie-in subsea to the existing Goldeneye pipeline. The CO_2 will be permanently stored in an area centered on the depleted Goldeneye gas field.

2. Scope of Document

This document covers the methodology and results of the Front End Engineering Design (FEED) stage relief valve sizing for the Carbon Capture Plant area of the Peterhead Carbon Capture project.

3. Relief Valve Sizing Methodology

Pressure relief loads have been determined in accordance with the applicable sections of ISO 23251 (API STD 521) (1). All the calculations contained within this report have been performed and checked / approved by Chartered Chemical Engineers, satisfying the requirement of Construction Design and Management Regulations 2007 (CDM) for Designers to be competent.

3.1. Relief Scenarios

The following relief scenarios have been checked and considered for all relief valves studied:

- Closed Outlets on Equipment;
- Cooling Water Failure;
- Reflux Failure;
- Steam Failure;
- Burst Tube;
- Accumulation of Non-Condensables;
- Entrance of Highly Volatile Materials;
- Overfilling of Tank or Vessel;
- Failure of Automatic or Manual Controls;
- Abnormal Heat Input;
- Abnormal Fluid Input;
- Chemical Reaction;

- Blocked-in (Hydraulic Expansion);
- Exterior Fire;
- Electrical Power Failure (local user and site wide);
- Instrument Air Failure (local user and site wide);
- Refrigerant Failure;
- Loss of Liquid Level;
- Quench Failure;
- Compressor Trips;
- Start-up/Shut-down/Part Load;
- Mal-operation;
- Other.

The relief valve sizing calculation template used for these calculations has a checklist covering these scenarios, to ensure that all of the calculations consider all the scenarios.

Some cases have been marked as not applicable, where there is an obvious case of inapplicability (e.g. on a system with no cooling water, then cooling water failure cannot initiate a relief scenario) otherwise they have been justified with a longer description as to why the scenario is considered to be applicable or not, possibly with a calculation to determine applicability.

3.2. Relief Load Determination

Where a condition has been identified to apply, then a load determination calculation has been performed. Depending on the scenario being studied, standard Technip internal tools and calculation methods have been used where these are available. Where a standard method is not available, a bespoke method has been created and approved as part of the overall sizing calculation. An example of where a bespoke calculation was required is where a Chemical Reaction scenario has been identified.

The relief load has been calculated based on the flowrate generated at the design pressure plus the allowable accumulation. The allowable accumulation under Pressure Equipment Directive (97/23/EC) (PED) is 10%, and this has been used throughout the Carbon Capture Plant (CCP) area.

Where flow from an upstream system has been used to determine the relief load, the flowrate has been calculated using the design pressure of the upstream system rather than normal operating pressure.

3.3. Relief Valve Sizing

The Technip internal relief valve sizing tool calculates the required relief valve size based on the determined flowrate and fluid properties of each scenario, before selecting the appropriate relief valve size based on the sizing case. The tool, which has been internally validated, calculates the relief area based on the formulas from API 520 part 1 (2).

4. Relief Valve Inlet and Outlet Line Sizing Methodology

4.1. Inlet Line Sizing

The sizing of relief valve inlet lines has been performed using the Technip internal hydraulic line sizing spreadsheet, normally for Single Phase flow. The allowable inlet line pressure drop that has been used is 3% of the relief valve set pressure for the rated flowrate of the selected valve, as detailed in API 520/1 (2). No other criteria have been used for the sizing of the inlet lines.

4.2. Outlet Line Sizing

The sizing of the relief valve outlet lines has been performed using the appropriate Technip internal hydraulic line sizing spreadsheet. Typically the appropriate tool is the Compressible Flow or Two Phase Flow version, depending on the relief scenario. The permitted back pressure that has been used is 10%, to allow the use of conventional valves, all of which is attributable to built-up back pressure, for relief valves routed to atmosphere. This built-up back pressure has been calculated using the rated flow capacity of the relief valve, as detailed in API 520/1 (2). Additionally the criterion that the velocity within the outlet line must not exceed 90% of the calculated speed of sound velocity (mach) for the fluid at relief conditions was applied.

5. Sizing Results (By Relief Valve)

5.1. Thermal Reclaimer No. 2 Condenser Thermal Safety Valve (TSV)

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief (1).

Inlet line size was calculated as 2" [50.8 mm] reducing to 1", with an outlet line size of 2" discharging back into the cooling water return line.

5.2. CO_2 Stripper Overhead Condensers TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1.5F2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed on each exchanger. Sparing not required on thermal relief (1).

Inlet line size was calculated as 2" reducing to 1.5", with an outlet line size of 2" discharging back into the cooling water return line.

5.3. Wash Water Cooler TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1.5G3, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief (1).

Inlet line size was calculated as 2" reducing to 1", with an outlet line size of 3" discharging back into the cooling water return line.

5.4. Lean Amine Cooler TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1E2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief.

Inlet line size was calculated as 2" reducing to 1", with an outlet line size of 2" discharging back into the cooling water return line.

5.5. Thermal Reclaimer No.3 Condenser TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief.

Inlet line size was calculated as 2" reducing to 1", with an outlet line size of 2" discharging back into the cooling water return line.

5.6. Thermal Reclaimer No.1 Condenser TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief.

Inlet line size was calculated as 2" reducing to 1", with an outlet line size of 2" discharging back into the cooling water return line.

5.7. Ion Exchanger Amine Cooler TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief.

Inlet line size was calculated as 2" reducing to 1", with an outlet line size of 2" discharging back into the cooling water return line.

5.8. Direct Contact Cooler (DCC) Water Coolers TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1.5F2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed on each exchanger. Sparing not required on thermal relief.

Inlet line size was calculated as 1.5", with an outlet line size of 2" discharging back into the cooling water return line.

5.9. Ion Exchanger Demin Water Heater PSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 1 PSV will be installed. Sparing not required on thermal relief.

Inlet line size was calculated as 2" reducing to 1", with an outlet line size of 2" discharging back into the demin water return line.

5.10. Condensate Coolers TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of valve on cooling water return.

The provisional relief valve size calculated was 1.5F2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed on each exchanger. Sparing not required on thermal relief.

Inlet line size was calculated as 2" reducing to 1.5", with an outlet line size of 2" discharging back into the cooling water return line.

5.11. Thermal Reclaimer No. 1 Column PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Cooling Water failure;
- Burst Tube;
- Failure of automatic or manual controls;
- Electrical Power Failure;
- Abnormal heat input;
- Exterior fire;
- Start-up/shutdown/part-load.

Sizing scenario was **Burst tube**. The reboiler is located inside the thermal reclaimer no.1 column, therefore an MP steam leak would occur in this scenario.

The provisional relief valve size calculated was 3L4, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 4" reducing to 3", with an outlet line size of 6" discharging to Degraded Amine Vessel.

5.12. Thermal Reclaimer No. 2 Column PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Cooling Water failure;
- Burst Tube;
- Entrance of highly volatile material;
- Exterior fire;
- Start-up/shutdown/part-load.

Sizing scenario was **burst tube.** The reboiler is located inside the thermal reclaimer no.2 column, therefore an MP steam leak would occur in this scenario.

The provisional relief valve size calculated was 3L4, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 4" reducing to 3", with an outlet line size of 8" discharging to Degraded Amine Vessel.

5.13. Thermal Reclaimer No. 3 Column PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Cooling Water failure;
- Burst Tube;
- Entrance of highly volatile material;
- Exterior fire;
- Start-up/shutdown/part-load.

Sizing scenario was **burst tube**. The reboiler is located inside the thermal reclaimer no.3 column, therefore an MP steam leak would occur in this scenario.

The provisional relief valve size calculated was 3L4, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 4" reducing to 3", with an outlet line size of 8" discharging to Degraded Amine Vessel.

5.14. CO_2 Stripper Column PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Cooling Water failure;
- Overfilling.

Sizing scenario was **Closed outlet on equipment**. This is caused by blocked vapour outlet, e.g. V-2001 blocked outlet.

The provisional relief valve size calculated was 8T10, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 12" reducing to 8", with an outlet line size of 16" discharging to CO_2 Absorber.

5.15. 1st Stage Suction Knock-Out (KO) Drum PSV

No over pressure scenarios identified.

Therefore a nominal relief valve size has been specified. This will be 1D2, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 1", with an outlet line size of 2" discharging to atmosphere via a vent stack.

5.16. Hydrogen Injection to CO_2 Compressor Package (Vendor PSV)

A Hydrogen gas distribution panel shall be provided. These are designed to safely control and dispense gases. Purging and relief routes (integrated PSV) are provided. The arrangement for this panel shall be finalised during Engineering, Procurement and Construction (EPC).

5.17. Oxygen Removal Reactor PSV

Over pressure scenario identified:

- Abnormal Heat Input.

Sizing scenario was **Abnormal heat Input.** This arises from temperature control failure on E-3202 (electric heater), leading to higher temperature of CO_2 gas feeding R-3001 during reactor startup sequence.

The provisional relief valve size calculated was 1.5G3, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 2" reducing to 1.5", with an outlet line size of 6" discharging to an atmospheric discharge point at a safe location (alongside vent stack SPI-4803).

5.18. Reactor Outlet Cooler PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Burst Tube;
- Blocked-in (hydraulic expansion).

Sizing scenario was **Burst Tube.** Sizing is limited by the estimated tube dimensions.

The provisional relief valve size calculated was 2J3, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 4" reducing to 2", with an outlet line size of 6" discharging to atmosphere via vent stack. A further safeguard is provided in the form of a local pot to collect and safely vent CO_2 from closed loop cooling water system. Refer to section 5.26 for further details.

5.19. Regeneration Gas Discharge Cooler PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Burst Tube;
- Blocked-in (hydraulic expansion).

Sizing scenario was **Burst Tube.** Sizing is limited by the estimated tube dimensions.

The provisional relief valve size calculated was 3K4, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 4" reducing to 2", with an outlet line size of 6" discharging to an atmospheric discharge point at a safe location (alongside vent stack). A further safeguard is provided in the form of a local pot to collect and safely vent CO_2 from closed loop cooling water system. Refer to section 5.26 for further details.

5.20. Molecular Sieves PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Failure of Automatic or Manual Control;
- Abnormal Heat Input.

Sizing scenario was **Abnormal Heat Input**. Sizing limited by the amount of heat input from the regeneration heater.

The provisional relief valve size calculated was 1.5G3, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 2" reducing to 1.5", with an outlet line size of 6" discharging to an atmospheric discharge point at a safe location (alongside vent stack).

5.21. Regeneration Gas Discharge Separator PSV

No over pressure scenarios identified.

Therefore a nominal relief valve size has been specified. The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 1.5" reducing to 1", with an outlet line size of 3" discharging to atmosphere via vent stack.

5.22. Regeneration Gas Compressor PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Failure of Automatic Control;
- Instrument Air Failure.

Sizing scenario was **Closed Outlet On Equipment,** i.e. blocked discharge on the regeneration gas compressor.

The provisional relief valve size calculated was 2H3, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 3" reducing to 2", with an outlet line size of 8" discharging to vent stack (atmosphere).

5.23. Dense phase pipework TSV

Over pressure scenario identified:

- Blocked-in (hydraulic expansion).

Sizing scenario was **Blocked-in (hydraulic expansion),** caused by closure of block valve on pipework.

The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 1 TSV will be installed. Sparing not required on thermal relief (1).

Inlet line size was calculated as 2" reducing to 1". No outlet piping provided (TSV to be located in a safe location).

5.24. Instrument Air Buffer Vessel PSV

No over pressure scenarios identified.

Therefore a nominal relief valve size has been specified. The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 1.5" reducing to 1", with an outlet line size of 3" discharging to atmosphere at safe location.

5.25. LP Condensate Drum PSV

No over pressure scenarios identified.

Therefore a nominal relief valve size has been specified. The provisional relief valve size calculated was 1D2, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 1.5" reducing to 1", with an outlet line size of 3" discharging to atmosphere at safe location.

5.26. Cooling Water Expansion Vessel PSV

Over pressure scenarios identified:

- Closed Outlet on equipment;
- Burst Tube;
- Blocked-in Expansion;
- Overfilling.

Sizing scenario was **Burst Tube**, i.e. CO_2 leak into closed loop cooling water system.

The provisional relief valve size calculated was 3L4, which will need to be confirmed by the relief valve vendor. 2 PSVs (1 service and 1 spare) will be installed.

Inlet line size was calculated as 6" reducing to 3", with an outlet line size of 6" discharging to a local pot, which knocks out any water, and safely releases CO_2 to atmosphere at safe location.

6. Relief Sizing Summary

Table 6-1: Relief Sizing Summary

Relief Valve Location	Size	Sizing Case
Thermal Reclaimer No.2 Condenser	1 x 100% DN 25 x DN 50 (D orifice)	Blocked in (hydraulic expansion)
CO_2 Stripper Overhead condenser	1 x 100% DN 40 x DN 50 (F orifice)	Blocked in (hydraulic expansion)
Wash Water Cooler	1 x 100% DN 40 x DN 80 (G orifice)	Blocked in (hydraulic expansion)
Lean Amine Cooler	1 x 100% DN 25 x DN 50 (E orifice)	Blocked in (hydraulic expansion)
Thermal Reclaimer No.3 Condenser	1 x 100% DN 25 x DN 50 (D orifice)	Blocked in (hydraulic expansion)
Thermal Reclaimer No.1 Condenser	1 x 100% DN 25 x DN 50 (D orifice)	Blocked in (hydraulic expansion)
Ion Exchanger Amine Cooler	1 x 100% DN 25 x DN 50 (D orifice)	Blocked in (hydraulic expansion)
DCC Water Coolers	1 x 100% DN 40 x DN 50 (F orifice)	Blocked in (hydraulic expansion)
Ion Exchanger Demin Water Heater	1 x 100% DN 25 x DN 50 (D orifice)	Blocked in (hydraulic expansion)
Condensate Coolers	1 x 100% DN 40 x DN 50 (F orifice)	Blocked in (hydraulic expansion)
Thermal Reclaimer No 1 Column	2 x 100% DN 80 x DN 100 (L orifice)	Burst Tube

Thermal Reclaimer No 2 Column	2 x 100% DN 80 x DN 100 (L orifice)	Burst Tube
Thermal Reclaimer No 3 Column	2 x 100% DN 80 x DN 100 (K orifice)	Burst Tube
CO_2 Stripper Column	2 x 100% DN 200 x DN 250 (T orifice)	Closed Outlet on Equipment
1st Stage Suction KO Drum	2 x 100% DN 25 x DN 50 (D orifice)	None
Oxygen Removal Reactor	2 x 100% DN 40 x DN 80 (G orifice)	Abnormal heat load
Reactor Outlet cooler	2 x 100% DN 50 x DN 80 (J orifice)	Burst Tube
Regeneration gas discharge Cooler	2 x 100% DN 80 x DN 100 (K orifice)	Burst Tube
Molecular Sieves	2 x 100% DN 40 x DN 80 (G orifice)	Abnormal heat input
Regeneration gas discharge separator	2 x 100% DN 25 x DN 50 (D orifice)	None
Regeneration gas compressor	2 x 100% DN 50 x DN 80 (H orifice)	Closed Outlet on Equipment
Instrument Air Buffer Vessel	2 x 100% DN 25 x DN 50 (D orifice)	None
LP Condensate drum	2 x 100% DN 25 x DN 50 (D orifice)	None
Cooling Water Expansion Vessel	2 x 100% DN 80 x DN 100 (L orifice)	Burst Tube

Dense phase pipework	1 x 100% DN 25 x DN 50 (D orifice)	Blocked in (hydraulic expansion)
Lean and Fresh Amine Tank (T-2001, T-2002)	-	To be confirmed by tank vendor during EPC.
Filter Coalescer (S-33201)	-	To be confirmed during EPC, once vessel dimensions known.

7. Confirmations Required To Finalise Relief Sizing during EPC

Relief valve calculations will require review during the project's EPC phase to close out the confirmations raised during this revision of the sizing calculations.

Some common confirmation requirements have been raised for all the sizing calculations:

- Line routing and lengths;
- Relief valve discharge coefficient (K_d = 0.975) – to be confirmed with valve vendor.

Other specific confirmation requirements have been raised for each relief valve calculation as required, depending on scenarios and equipment involved:

- 1st stage suction KO drum
    - Confirmation of CO_2 compressor settle out pressure;
    - Inclusion of Safety Integrity Level (SIL) rated block valve for CO_2 compressor;
    - Compressor design regarding valve arrangement at discharge of the CO_2 compressor package.
- Molecular Sieves
    - Confirmation of vessel size depending upon vendor selection;
    - Confirmation of CO_2 compressor settle out pressure;
    - Inclusion of SIL rated block valve for CO_2 compressor;
- Oxygen Removal Reactor
    - Confirmation of vessel size depending upon vendor selection;
    - Confirmation of CO_2 compressor settle out pressure.;
    - If a combined hydrogen flow measurement and control package are selected in EPC (refer to section 5.16), the maximum flowrate shall need confirmation.
- Regeneration Gas Separator
    - Inclusion of SIL rated block valve for CO_2 compressor.
- Regeneration Gas Compressor
    - Selected compressor performance curves;
    - Regeneration flow will be determined during EPC based on selected molecular sieve vendor.
- Wash water cooler/CO_2 Stripper Overhead Condenser/Lean Amine Cooler

  - Confirmation of discharge to sewer.
- Regeneration Gas Compressor
  - Selected compressor performance curves;
  - Regeneration flow will be determined during EPC based on selected molecular sieve vendor.
- DCC Water Cooler
  - No. of coolers / relief valves;
  - Confirmation of discharge to sewer.
- Thermal reclaimer condenser No. 3
  - Confirmation of downstream pressure.
- Thermal reclaimer column No. 1
  - Confirmation of all physical properties related to all cases to be provided by LICENSOR during EPC;
  - Combination correction factor during EPC;
  - LICENSOR to confirm during EPC, that downstream liquid cannot ignite due to static electricity. If this is confirmed as a hazard, the vents from the TRU need to be segregated and purged (e.g. with CO_2);
  - Ratio of clean to dirty heat transfer coefficients during EPC;
  - Confirm rated flowrate of thermal reclaimer No. 1 feed pump at relief discharge pressure during EPC.
- Thermal reclaimer column No. 2 / Thermal reclaimer column No. 3
  - Confirmation of all physical properties related to all cases to be provided by LICENSOR during EPC;
  - Combination correction factor during EPC.
- CO_2 Stripper
  - Confirmation of relieving temperature of 204°C by LICENSOR.

8. Depressurisation

The aim here is to safely depressurise the plant, or part of the plant, and equipment in preparation for plant maintenance.

The objective for the facilities is to operate in such a way to eliminate as far as possible continuous operational venting during normal operations.

Depressurising large inventories of CO_2 creates considerable challenges, in particular due to the phase changes when supercritical CO_2 is depressurised. One of the key challenges is to depressurise a CO_2 system (containing supercritical or liquid phase) in a manner that prevents significant solid CO_2 formation and excessive material cooling, through controlling the depressurisation rate.

The provision of blowdown measures prevents escalation of abnormal conditions, i.e.:

- Reduction of the magnitude/duration of a hazardous event by disposing of harmful inventory in a controlled manner, routing gases to safe location;
- Reduction of the size/duration of harmful plume affecting personnel inside and outside of CCC Plant;

- Prevention of CO_2 escalation due to rupture caused by loss of metal strength due to low temperatures (i.e. as low as -79°C) or brittle fracture;
- Ensures all sections are fully depressurised, reducing risk to responder crews who will be placed at risk if equipment remains pressurised.

As CO_2 is not flammable, there is little risk of a fire starting within the compression section of the CCS plant, hence no emergency depressurisation is required. If there is a process upset or emergency, the plant/equipment can be stopped, and isolated, i.e. blocked inventory. Depressurisation, if required, can be carried out under operator control.

Potential CO_2 compressor vendors recommend immediate depressurisation of the compressor if the machine stops, i.e. no start up from settle out conditions. This mode of operation shall be confirmed during EPC in conjunction with selected CO_2 compressor vendor.

The only possible source of combustible material is the lube oil skid for the CO_2 compressor. This will be located away from the CO_2 compressor to ensure there is no danger of a fire impinging on the compressor and associated equipment.

The Capture Plant shall not be connected to any flare system. All relief valves required shall either relieve to atmosphere (safe location) or to the absorber tower.

There are generally non-combustible materials within the capture section of the CCS plant. However, should amine be heated above its flash point, there is a fire risk, hence fire case shall need to be considered for the TRU area, pending advice from LICENSOR on risks for amine discharging and purging arrangements on header (to be confirmed during EPC).

8.1. Venting/Depressuring Routes

The compression & conditioning section of the plant may be vented via a number of locations along the compression train:

- Depressuring line downstream of CO_2 dehydration molecular sieves. To reduce/empty inventory of CO_2 in the oxygen removal and dehydration systems, and is sent to the vent stack;
- Depressurising line downstream of stages 5-6 of CO_2 compressor. This route is used to reduce/empty dense phase CO_2 inventory from pipework. This is used in the event of off-spec CO_2 e.g. high water, oxygen content, or high downstream pressure, and is sent to atmosphere via the vent KO drum and the vent stack;
- Both CO_2 compressor sections also include blowdown valves to empty inventory of CO_2, required for CO_2 compressor start-up. Potential CO_2 compressor vendors have included a separate route for blowdown from both the low pressure (LP) and high pressure (HP) sections of the CO_2 compressor. The blowdown routes shall be combined and routed to the vent stack. The provision of blowdown and PSV valves and their arrangement will need to be confirmed during EPC as part of final CO_2 compressor vendor selection. The depressuring loads shall need to be advised by vendor also during EPC. The depressuring loads/equipment volumes associated with the CO_2 compressor package, are expected to be less than that estimated for depressuring the oxygen removal and dehydration systems.

Downstream of the molecular sieve beds, a depressuring line is fitted with a flow transmitter and flow control valve, such that the rate of CO_2 depressuring can be controlled through to the vent stack to atmosphere. This configuration is typical for onshore vent stations for depressurising sections of onshore pipeline for inspection, maintenance of repair.

8.2. Dense Phase CO_2 Venting

The depressuring route (for off-spec CO_2) downstream of the high pressure section of the CO_2 compression train is fitted with a safety on/off valve and a restriction orifice downstream, connected to the vent stack.

In the event of off-spec CO_2 (detected downstream of CO_2 compressor discharge):

1) Low pressure CO_2 shall be vented from the top of the absorber, upon detection of high oxygen/water levels in the system. During this period, the oxygen removal reactor is capable of operating at turndown of up to 30% (advised by vendor). Therefore 70% of the CO_2 flow shall preferentially be diverted to the atmosphere, via the stripper overheads valve and the absorber.

2) A depressurisation/venting route is provided downstream of the CO_2 compressor discharge, via the depressurising valve to the vent stack. Here CO_2 will be in 'dense phase'. Venting shall be achieved by routing the dense phase CO_2 to the Vent KO Drum, This vessel shall be pressurised (using instrument air) to approximately 8 bara, which avoids dry ice production by keeping the pressure above the triple point (5.18 bara). The CO_2 shall be 2-phase at 8 bara, hence a source of heat (MP steam) is required to vaporise the liquid in the vessel, and vent the CO_2 gas to atmosphere via a separate route to the stack. A separate vapouriser shall be used to provide the heating duty. The route to vent shall be fitted with a back pressure controller to hold the pressure in the vessel at 8 bara, thereby safely venting to atmosphere without dry ice formation.

The Vent KO Drum, shall be sized to accommodate 30% of the CO_2 throughput from the CO_2 compressor train. The CO_2 vaporiser shall be sized for a vaporisation rate of 40%. This shall be an inverted kettle type exchanger to ensure MP steam condensate does not flood the tubes.

During a CO_2 compressor trip or shutdown, the split range control system on the CO_2 stripper, shall divert the CO_2 to back to the CO_2 absorber.

All major PSVs (excluding thermal relief) within the CO_2 compression train shall discharge to the vent stack. This also applies for the depressuring line from downstream of Molecular Sieves.

8.3. Vent Header Sizing (Vent Stack)

The vent header is sized on the largest relief load, as there is no potential for a fire starting, and multiple relief valves lifting. Mixing with other relief streams shall therefore be minimised / eliminated in this respect.

The sizing basis for the vent header is based upon the largest vent load, which arises from PSV blocked discharge scenario for the CO_2 compressor. This load is estimated to be the full flow through the CO_2 Compressor, i.e. 138 t/h.

The basis used for estimating the peak depressuring load is based on 1 hour depressuring time. This is selected as the intent is to depressure in a controlled manner and there is no requirement for emergency depressurisation (no fire case) on this facility. The peak flowrate calculated to depressure this section is 38.9 t/h.

Table 8-1: Vent System Loads

Area	Peak Load estimated (t/h)
Oxygen Removal & Dehydration	38.9 (Note 1)
Off-spec CO_2	41.6 (Note 2)
CO_2 Compressor Package	(Note 3)
CO_2 Compressor Package	138t/h (Note 4)

Notes

1. Load calculated

2. Load to be confirmed by selected CO_2 compressor vendor during EPC.

3. Based on 30% flowrate through CO_2 compression train (see section 8.2).

4. PSV load for blocked discharge from CO_2 compressor shall be confirmed during EPC, to assess impact on vent header sizing.

The governing case for sizing the vent header for the largest load is deemed to be from PSV blocked discharge scenario for the CO_2 compressor. This load is estimated to be the full flow through the CO_2 Compressor, i.e. 138t/h. The main vent header size is calculated to be 350 mm increasing to 400 mm. The vent header sizes & noise levels shall be confirmed by the EPC contractor upon final selection of CO_2 compressor vendor and known equipment volumes (depressurisation loads) within.

To accommodate potential liquid carryover via relief valve discharge from either the reactor outlet cooler), or regeneration gas discharge cooler, a water trap shall be fitted in the vent header, to ensure liquid can be trapped and freely drained to safe location.

8.4. Vent Header Sizing (CCP)

The basis for sizing the vent header connecting each tank (located in the capture plant) to the Absorber (C-2001) is based on determining the maximum possible load venting from each tank at any given time. In the capture plant a number of tanks, packages and vessels vent into the vent header. The operating pressure of each tank is calculated as based upon the back pressure from the Absorber based on line lengths and losses. The following cases have been considered for sizing the load to the to/from each tank; net pump in, net pump out, thermal inbreathing (API-STD 2000), thermal out-breathing (API-STD 2000) and in the areas where a fire is plausible a fire case was considered (API-521) (1). The sizing case for each tank provided the cumulative total vented via the vent header to the absorber. The line size of each branch connected to the header is stated in the calculation and at the absorber the line size is 450mm. As the design pressure of the CO_2 absorber is 1.085 bara the vent header needs to be capable of entering the absorber when it is at design pressure therefore the design pressure of the vent header is 1.15 bara. For each of the tanks connected to the vent header the design pressure is set by the static head from the top tan line of the tank to the vent header when the vent line becomes flooded with liquid, unless the tank is protected with a PSV where the design pressure will match the vent header 1.15 bara.

Refer to for further details regarding sizing of vent header.

8.5. Minimum Metal Temperature for CO_2 compression section

The minimum metal temperatures have been estimated based on the following scenario:

Where the compressor is assumed to be operating at minimum temperature and the gas is allowed to cool to -5°C (at constant volume) before depressurisation.

The calculation recommended the Minimum Metal Temperature (MMT), based upon depressurisation to atmospheric pressure (see Appendix B):

- Stage 1 suction: -7°C
- Stage 4 suction: -29°C
- Stage 4 discharge and onwards: -79°C

Equipment and pipework have been specified with a minimum design temperature of -5°C (ambient), and also an alternative design temperatures any of the above.

No credit has been taken for the thermal inertia of the compressors and coolers, giving a conservative minimum temperature. In practice the CO_2 compressor vendors do not expect to see low temperatures in practice due to the thermal inertia and heat content of the compressor casings.

8.6. Dispersion Modelling

A separate report has been issued detailing the dispersion characteristics and results of the CO_2 vent dispersion modelling. Within this are the dispersion graphs for 4 different cases:

- Case A: (15,000ppm CO_2, 1.15 bara, 24°C);
- Case B: (15,000ppm CO_2, 73 bara, 31°C);
- Case C: (15,000ppm CO_2, 37.25 bara, 23°C);
- Case D: (15,000ppm CO_2, 121 bara, 25°C).

Representative wind/weather combinations were used to closely mimic Peterhead site conditions.

The results confirm that vents directed vertically will have a negligible impact downwind, as the momentum of the CO_2 gas release, will entrain air such that rapid mixing and dispersion will occur as the plume rises higher, and little or no slumping back to the ground is predicted to occur.

The dispersion distances range over 100m.

Upon finalisation of all equipment volumes to be safely vented, i.e. CO_2 compressor & Filter coalescer, further dispersion studies are required during detail design by EPC contractor.

9. Venting Risks to Personnel

An Occupied Building Risk Assessment has been produced that reviews the availability of occupied buildings to fufil their requirement in the event of major accident events, and to identify any improvements that are required to ensure that they are adequately safeguarded.

In the event of dense phase CO_2 release, a significant and rapid drop in temperature occurs that might lead to cold temperature embrittlement and even failure of some equipment items. Thereafter, the main hazard associated with CO_2 is as an asphyxiant/toxic gas which may ingress into occupied buildings.

Warehouse Building / Control room building

The CO_2 Vent Dispersion Report endorses that leakages directed vertically will have a negligible impact downwind. This is because the momentum of the released gas will entrain air such that rapid mixing and dispersion will occur as the plume rises higher and little or no slumping back to the ground is predicted to occur. When the leakage is directed horizontally, the dispersion distances can be over 100 m to the 15,000 ppm level. (STEL limit of 15,000 ppm is the allowable short term exposure limit for 15 minute) However the shortest distance between Compression plant areas to this building is about 170 m and hence the asphyxiant effect due to release of dense phase may not result in any significant ingress of CO_2 gas into this building.

The risks to persons within the Control Room/Building are low. Design recommendations to be considered are listed in the Occupied Building Risk Assessment.

10. Reference Documents

1) API STD 521 (ISO 23251)
2) API RP 520 Part 1

11. Glossary of Terms

Term	Definition
CCC	Capture, Compression and Conditioning
CCP	Carbon Capture Plant
CCS	Carbon, Capture and Storage
CDM	Construction Design and Management Regulations 2007
CO_2	Carbon Ddioxide
DCC	Direct Contact Cooler
DN	Nominal Diameter
EPC	Engineering, Pprocurement and Cconstruction
FEED	Front End Engineering Design
HP	High Ppressure
KKD	Key Knowledge Deliverable
KO	Knock-Out
LICENSOR	Cansolv
LP	Low Pressure
MMT	Minimum Metal Temperature
MP	Medium Pressure
PED	Pressure Equipment Directive (97/23/EC)
PSV	Pressure Relief Valve
SIL	Safety Integrity Level
STEL	Short Term Exposure Limit
TRU	Thermal Reclaimer Unit
TSV	Thermal Safety Valve
XDV	Depressuring Valve

12. Glossary of Unit Conversions

Table 12-1: Unit Conversion Table

Function	Unit - Imperial to Metric conversion Factor
Length	1 Inch = 25.4 millimetres

APPENDIX 3. CO_2 Vent Dispersion Report (PCCS-00-TC-HX-0580-00001)

Peterhead CCS Project

Doc Title: CO_2 Vent Dispersion Report

Doc No.	**PCCS-00-TC-HX-0580-00001**
Date of issue:	**28/05/2015**
Revision:	**K03**
DECC Ref No:	**11.037**
Knowledge Cat:	**KKD - Technical**

KEYWORDS

Goldeneye, CO_2, Carbon Capture and Storage, CO_2, Vent.

Produced by Shell U.K. Limited

ECCN: EAR 99 Deminimus

IMPORTANT NOTICE

Information provided further to UK CCS Commercialisation Programme (the **Competition**)

The information set out herein (the **Information**) has been prepared by Shell U.K. Limited and its sub-contractors (the **Consortium**) solely for the Department for Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Table of Contents

List of Tables

1. General

1.1. Introduction

The Peterhead Carbon Capture and Storage (PCCS) project would be the world's first commercial scale demonstration of CO_2 capture, transport and offshore geological storage from a (post combustion) gas-fired power station. Carbon Capture technology will be fitted to an existing gas-fired power station at Peterhead in North-East Scotland, UK, at a site with sufficient space for the construction of the post combustion CO_2 capture plant and the compression and conditioning plant. Approximately one million tonnes of CO_2 per year will be captured from the flue gas produced by the Peterhead Power Station and stored in a depleted Goldeneye reservoir currently operated by Shell. After capture, the CO_2 will be routed through a compression cycle, also located at the Peterhead Power Station site. It will be compressed, cooled and conditioned for water and oxygen removal to meet a suitable transportation and storage specification. Following post-compression cooling the resulting dense phase CO_2 stream will be transported directly offshore via a new offshore pipeline, which will be tied-in approximately 20 km offshore at a subsea location to the existing Goldeneye pipeline. The CO_2 will be permanently stored subsurface; located in the existing Goldeneye gas field.

This document has been produced to provide the details of the CO_2 vent dispersion modelling performed for the CCS facilities at Peterhead Power Station.

1.2. Purpose

The purpose of this document is to describe the dispersion of CO_2 from vents given a range of operating pressures and temperatures, vent sizes and height of vent stack. The information set out in this document may be used by the design team to assist in the definition of vent requirement and may also be used to provide input into other safety assessment studies and the overall design process as required.

The primary focus of this report is on CO_2 release scenarios in the carbon compression unit.

2. Dispersion Modelling

Modelling was performed using PHAST (v. 7.01) software. The releases considered are releases from Depressuring Valves (XDV). The precise location of the XDVs and the operating conditions at these points had not been confirmed at the time of production of this document. Hence a range of representative conditions has been modelled.

2.1. Main Assumptions

The following input parameters were used for the dispersion modelling:

- Hole sizes of 20 mm, 50 mm and 100 mm and a typical height elevation of 10 m in order to reduce ground effect problems;
- Typical mass inventories of 100 kg, 500 kg and 1000 kg;
- Atmospheric conditions of F2 (i.e. Pasquill stability F (Stable conditions), 2 m/s wind speeds), D5 (i.e. Pasquill stability D (Neutral conditions), 5 m/s wind speeds), D8 (i.e. Pasquill stability D (Neutral conditions), 8 m/s wind speeds) at 8°C and 60% humidity.

- Short Term Exposure Limit (STEL) limits of 15,000 ppm CO_2 concentration was used for the dispersion calculation. 15,000 ppm is the allowable short term exposure limit (15 minute reference period) of CO_2.

2.2. Release Conditions

Release conditions used are presented in Table 2-1 below:

Table 2-1: Release Conditions

Cases	Fluid	Origin/Destination	Pressure (bara)	Temperature (°C)
A	Wet treated CO_2	CO_2 Stripper overheads (downstream control valve)	1.15	24
B	Treated CO_2 gas	-	73	31
C	Dry treated CO_2 gas	Dehydration package	37.25	23
D	Dry CO_2 product	To pipeline	121	25

3. Results

The results obtained from PHAST which details downwind dispersion distances for both vertical and horizontal release directions are presented in Summary Tables below.

Dispersion graphs for all cases considered are presented in Appendix A.

Table 3-1: Summary Results - Case A (15,000 ppm CO_2, 1.15 bar (a), 24°C)

Hole Size (mm)	Wind speeds	Release Rate kg/s	1,000 kg			500 kg			100 kg		
			Release Duration (s)	Vert. Release Direction	Hor. Release Direction	Release Duration (s)	Vert. Release Direction	Hor. Release Direction	Release Duration (s)	Vert. Release Direction	Hor. Release Direction
				Distance to 15,000 ppm (m)	Distance to 15,000 ppm (m)		Distance to 15,000 ppm (m)	Distance to 15,000 ppm (m)		Distance to 15,000 ppm (m)	Distance to 15,000 ppm (m)
20	2F	0.045	3600	0.014	3.927	3600	0.014	3.927	2201.01	0.014	3.927
	5D			0.016	3.783		0.016	3.783		0.016	3.783
	8D			0.016	3.626		0.016	3.626		0.016	3.626
50	2F	0.284	3521.77	0.035	9.044	1760.89	0.035	9.044	352.18	0.035	9.044
	5D			0.040	8.402		0.040	8.402		0.040	8.402
	8D			0.040	7.870		0.040	7.870		0.040	7.870
100	2F	1.136	880.44	0.070	16.729	440.22	0.070	16.729	88.04	0.070	16.729
	5D			0.080	15.156		0.080	15.156		0.080	15.156
	8D			0.080	13.981		0.080	13.981		0.080	13.981

Table 3-2: Summary Results - Case B (15,000ppm CO_2, 73 bar (a), 31°C)

Hole Size (mm)	**Wind speeds**	**Release Rate** (kg/s)	**1,000 kg**			**500 kg**			**100 kg**		
			Release Duration (s)	Vert. Release Direction Distance to 15,000 ppm (m)	Hor. Release Direction Distance to 15,000 ppm (m)	Release Duration (s)	Vert. Release Direction Distance to 15,000 ppm (m)	Hor. Release Direction Distance to 15,000 ppm (m)	Release Duration (s)	Vert. Release Direction Distance to 15,000 ppm (m)	Hor. Release Direction Distance to 15,000 ppm (m)
20	2F	9.057	110.42	0.096	34.684	55.21	0.096	34.684	11.04	0.096	34.684
	5D			0.111	31.360		0.111	31.360		0.111	31.360
	8D			0.111	28.959		0.111	28.959		0.111	28.959
50	2F	56.604	17.67	0.241	78.973	8.83	0.241	78.973	1.77	0.241	80.064
	5D			0.277	68.442		0.277	68.442		0.277	68.442
	8D			0.277	62.363		0.277	62.363		0.277	62.363
100	2F	226.417	4.42	0.485	160.909	2.21	0.485	137.374	0.44	0.485	103.731
	5D			0.554	162.072		0.554	141.264		0.554	100.731
	8D			0.554	139.407		0.554	141.330		0.554	96.578

Table 3-3: Summary Results - Case C (15,000ppm CO_2, 37.25 bar (a), 23°C)

Hole Size (mm)	**Wind speeds**	**Release Rate** (kg/s)	**1,000 kg** Release Duration (s)	Vert. Release Direction Distance to 15,000 ppm (m)	Hor. Release Direction Distance to 15,000 ppm (m)	**500 kg** Release Duration (s)	Vert. Release Direction Distance to 15,000 ppm (m)	Hor. Release Direction Distance to 15,000 ppm (m)	**100 kg** Release Duration (s)	Vert. Release Direction Distance to 15,000 ppm (m)	Hor. Release Direction Distance to 15,000 ppm (m)
20	2F	3.270	305.82	0.051	19.400	152.91	0.051	19.400	30.58	0.051	19.400
	5D			0.059	18.103		0.059	18.103		0.059	18.103
	8D			0.059	17.014		0.059	17.014		0.059	17.014
50	2F	20.437	48.93	0.129	46.463	24.47	0.129	46.463	4.89	0.129	46.463
	5D			0.148	41.425		0.148	41.425		0.148	41.425
	8D			0.148	38.175		0.148	38.175		0.148	38.175
100	2F	81.747	12.23	0.258	91.176	6.12	0.258	91.176	1.22	0.258	88.200
	5D			0.296	76.296		0.296	76.296		0.296	76.296
	8D			0.296	69.366		0.296	69.366		0.296	69.366

Table 3-4: Summary Results - Case D (15,000ppm CO_2, 121 bar(a), 25°C)

Hole Size (mm)	Wind speeds	Release Rate (kg/s)	1,000 kg			500 kg			100 kg		
			Release Duration (s)	Vert. Release Direction	Hor. Release Direction	Release Duration (s)	Vert. Release Direction	Hor. Release Direction	Release Duration (s)	Vert. Release Direction	Hor. Release Direction
				Distance to 15,000 ppm (m)	Distance to 15,000 ppm (m)		Distance to 15,000 ppm (m)	Distance to 15,000 ppm (m)		Distance to 15,000 ppm (m)	Distance to 15,000 ppm (m)
20	2F	3.270	305.82	0.051	19.400	152.91	0.051	19.400	30.58	0.051	19.400
	5D			0.059	18.103		0.059	18.103		0.059	18.103
	8D			0.059	17.014		0.059	17.014		0.059	17.014
50	2F	20.437	48.93	0.129	46.463	24.47	0.129	46.463	4.89	0.129	46.463
	5D			0.148	41.425		0.148	41.425		0.148	41.425
	8D			0.148	38.175		0.148	38.175		0.148	38.175
100	2F	81.747	12.23	0.258	91.176	6.12	0.258	91.176	1.22	0.258	88.200
	5D			0.296	76.296		0.296	76.296		0.296	76.296
	8D			0.296	69.366		0.296	69.366		0.296	69.366

4. Discussion

This study has investigated the dispersion characteristics of vented CO_2 gas as a result of being released from a number of different base case process conditions.

The purpose of the study has been to provide designers of such vent systems with sufficient information to enable them to select the most appropriate height and orientation of the vent.

Representative wind/weather combinations have also been used and these are broadly in line with the conditions used in other studies at the Peterhead location.

The dispersion calculations are dependent upon not only the process conditions but also the volume of gas to be vented in total, which will have an impact on the deviation of any steady state conditions predicted. The designer of the vent systems will need to take all such factors into account.

The results of the study confirm that vents directed vertically will have a negligible impact downwind. This is because the momentum of the released gas will entrain air such that rapid mixing and dispersion will occur as the plume rises higher and little or no slumping back to the ground is predicted to occur.

When the vent is oriented vertically, the dispersion distances can be large (over 100 m to the 15,000 ppm level). Consequently, if a horizontal vent discharge were to be used, the height above grade would need to be selected to minimise the threat to persons at distance.

It is anticipated that further dispersion studies will be required during detailed design as the final vent design is defined.

5. Glossary of Terms

Term	Definition
°C	Degrees Celsius
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
kg	Kilograms
KKD	Key Knowledge Deliverable
m	Metres
mm	Millimetres
PHAST	Process Hazard Analysis Software Tools
ppm	Part Per Million
s	Seconds
STEL	Short Term Exposure Limit
WEL	Workplace Exposure Limits
XDV	Depressuring Valve

APPENDIX 1. Dispersion Graphs

A1.1. Case A Dispersion Graphs

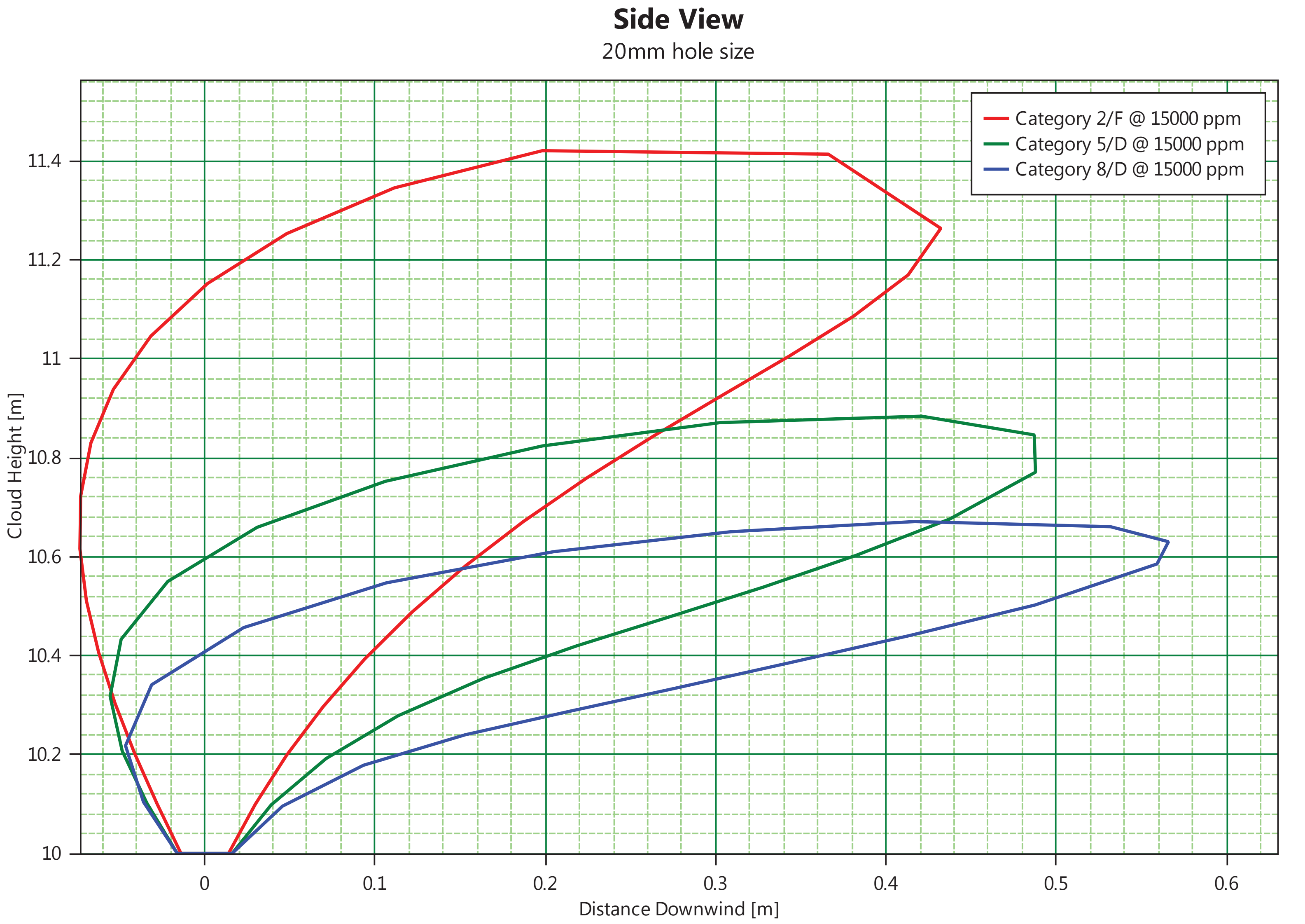
Case A - Vertical release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1

Case A - Horizontal release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1

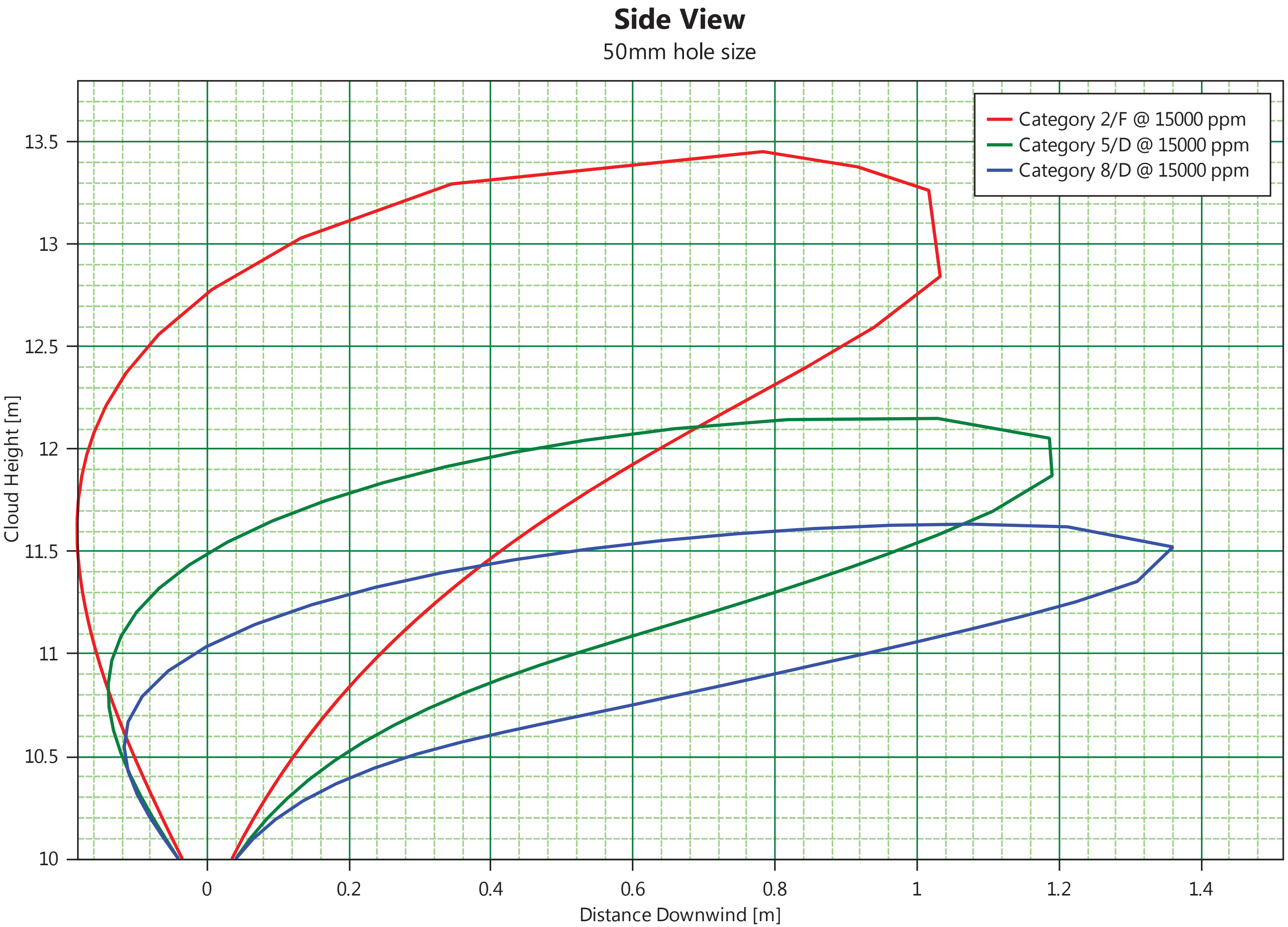
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.0750713 s
Time (Category 2/F)	0.185104 s
Time (Category 5/D)	0.102945 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

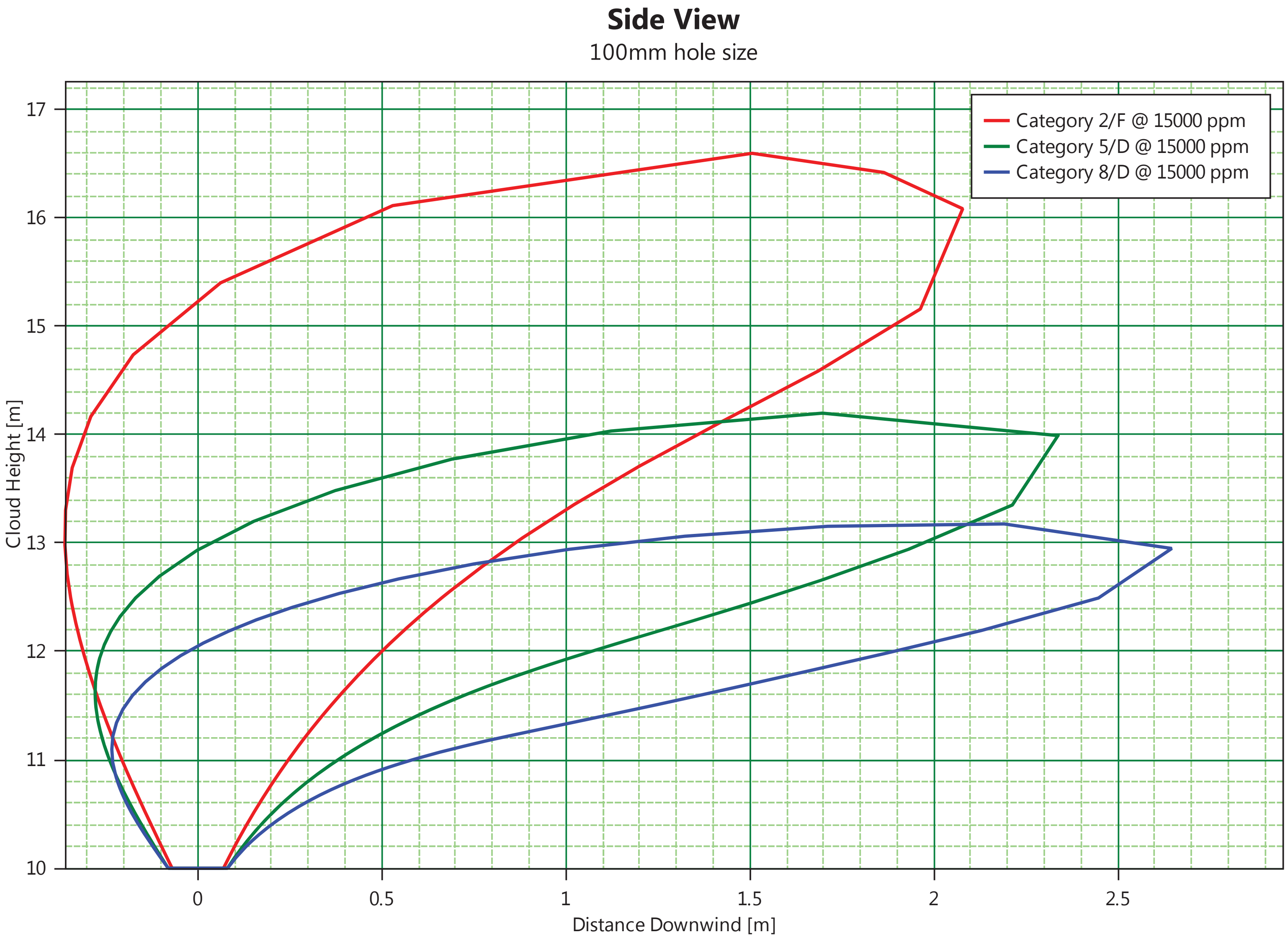
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.178667 s
Time (Category 2/F)	0.435017 s
Time (Category 5/D)	0.247169 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

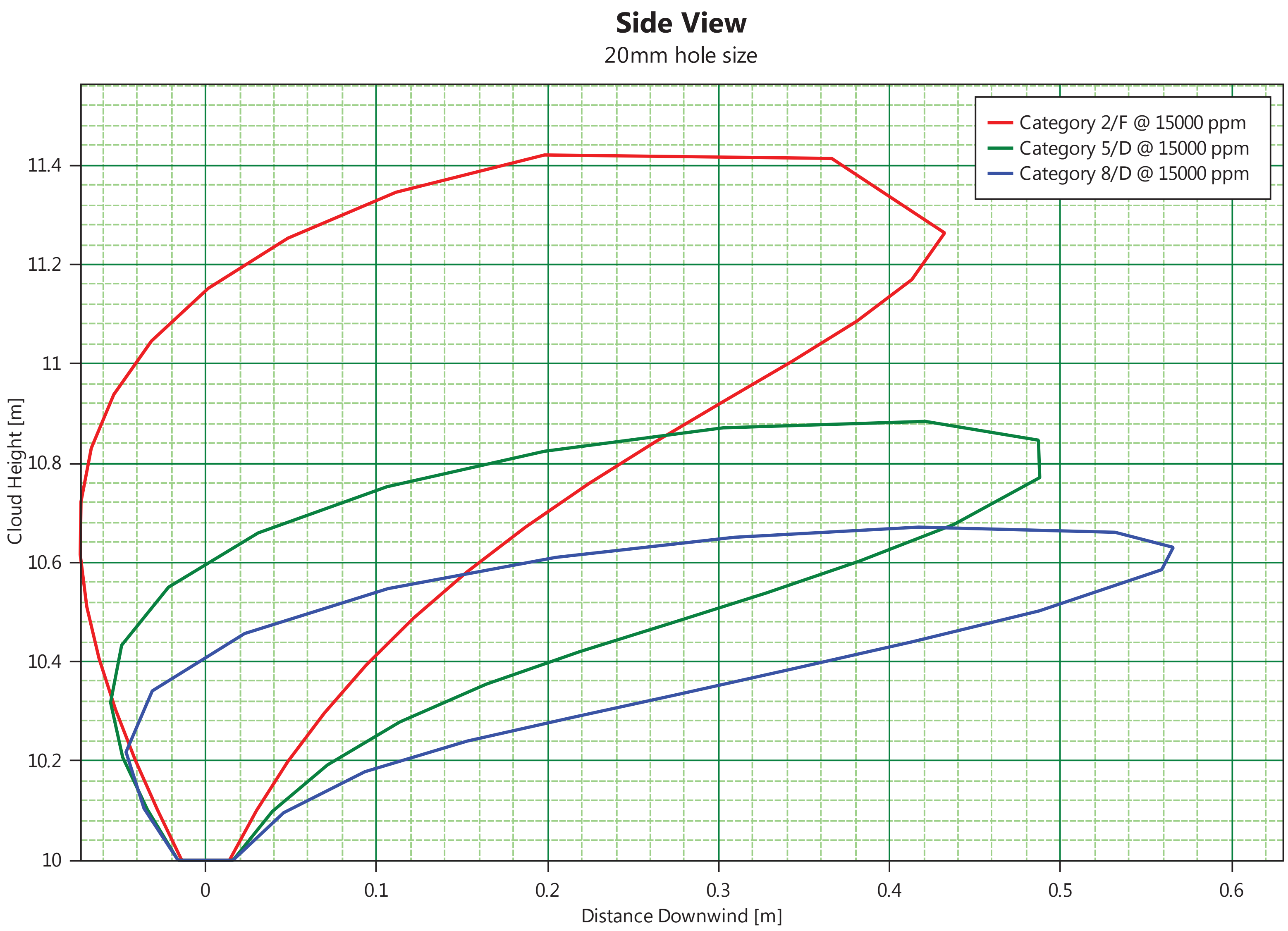
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.341612 s
Time (Category 2/F)	0.811923 s
Time (Category 5/D)	0.475888 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

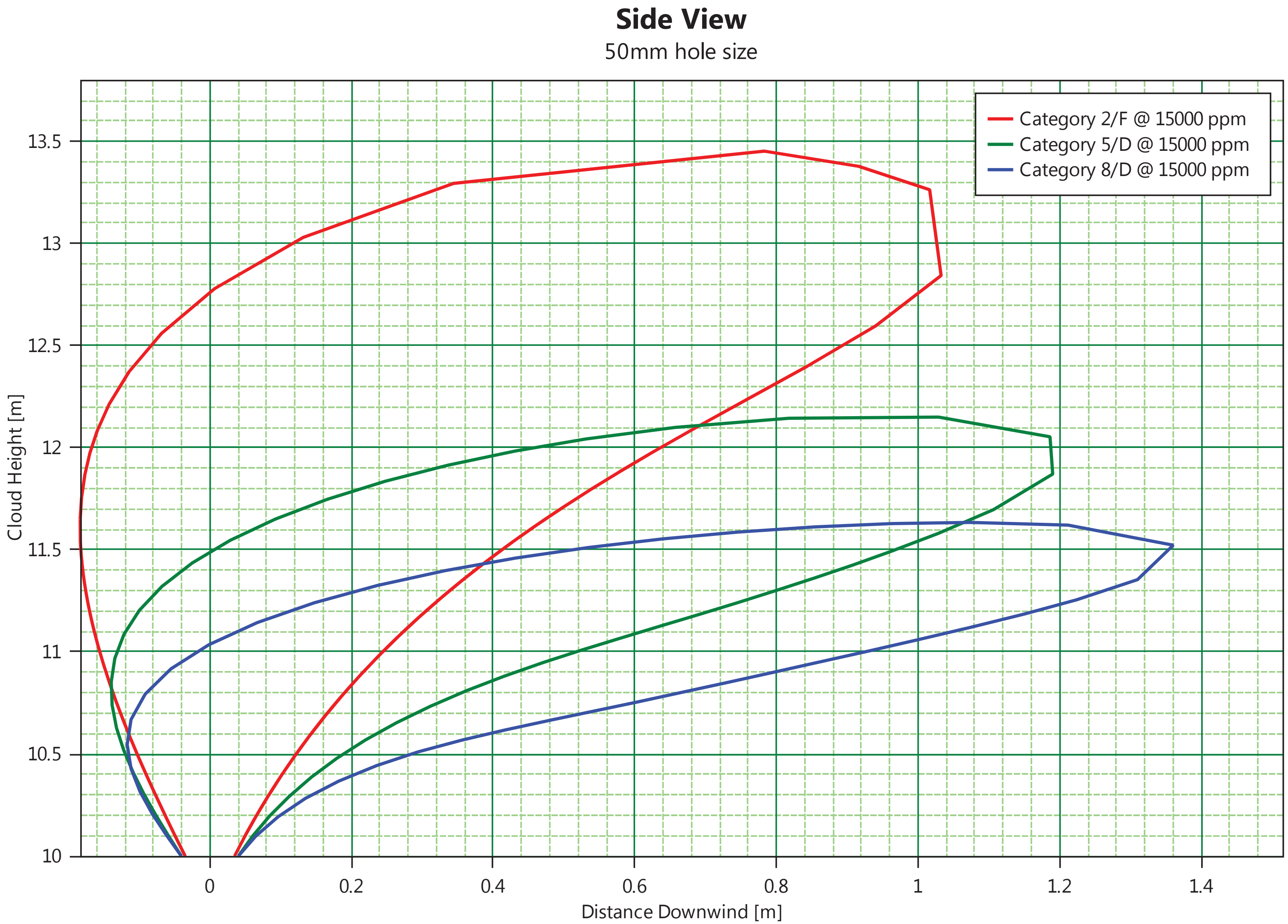
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.0750713 s
Time (Category 2/F)	0.185104 s
Time (Category 5/D)	0.102945 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

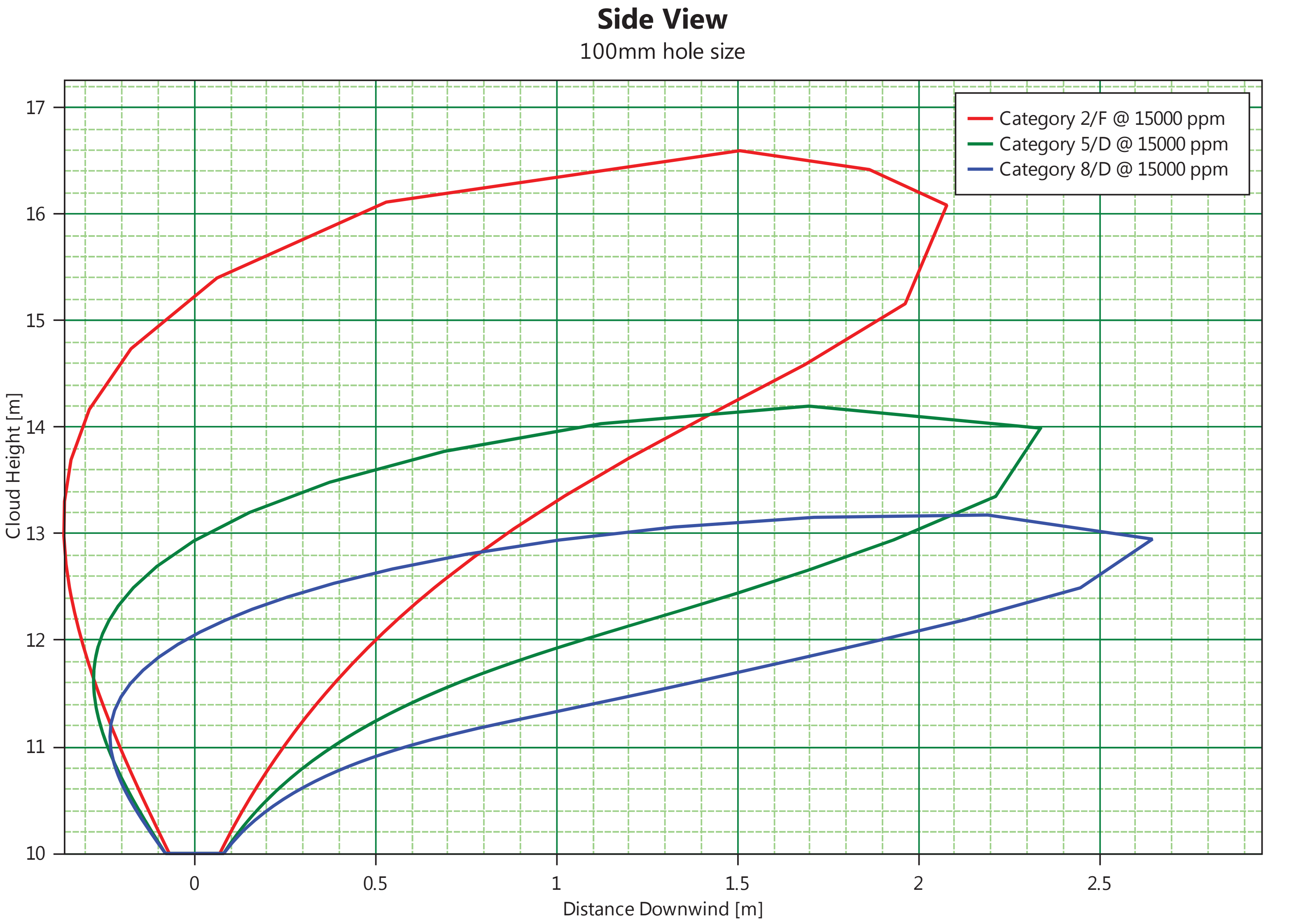
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.178667 s
Time (Category 2/F)	0.435017 s
Time (Category 5/D)	0.247169 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

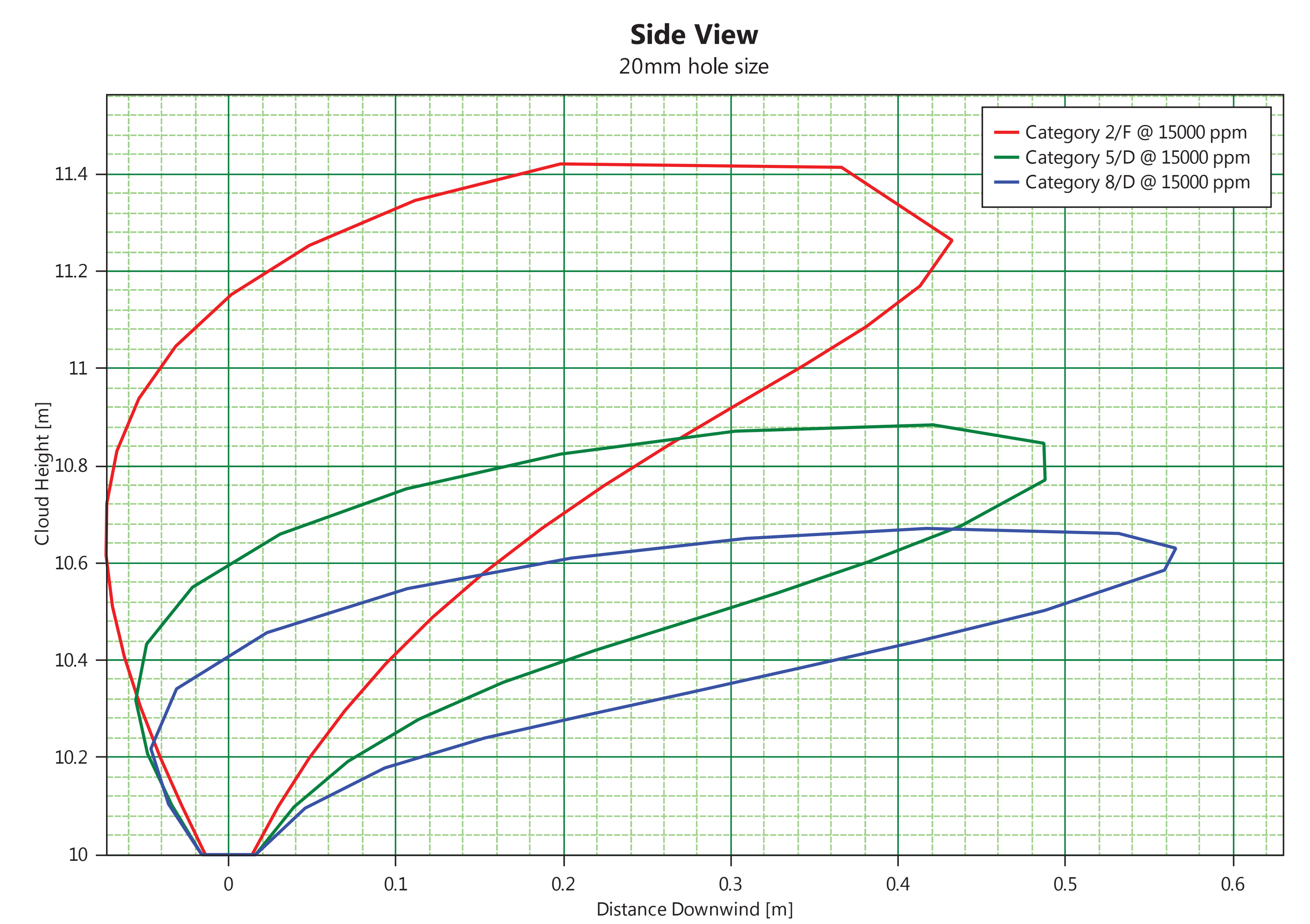
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.341612 s
Time (Category 2/F)	0.811923 s
Time (Category 5/D)	0.475888 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

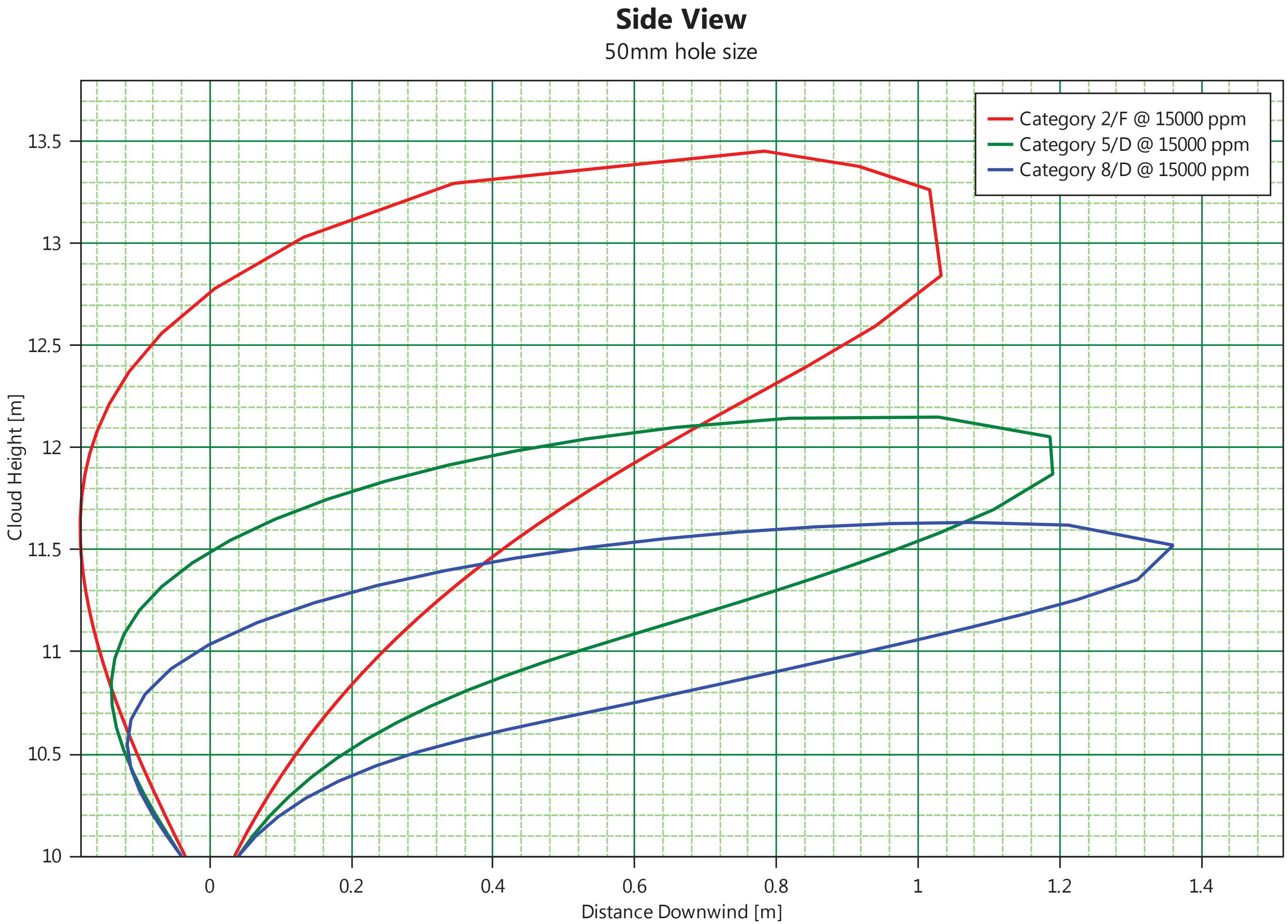
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.0750713 s
Time (Category 2/F)	0.185104 s
Time (Category 5/D)	0.102945 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.178667 s
Time (Category 2/F)	0.435017 s
Time (Category 5/D)	0.247169 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



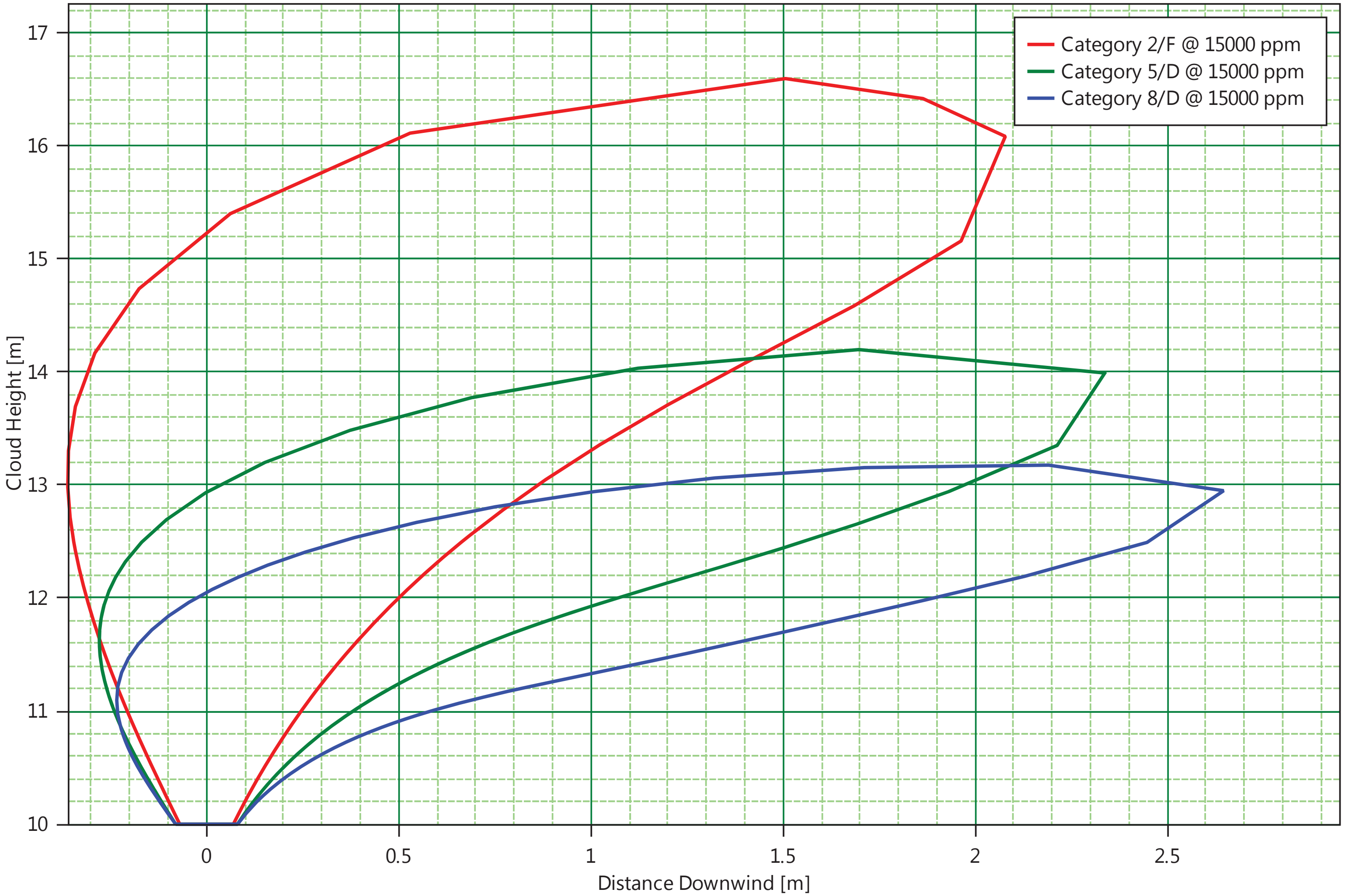
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.341612 s
Time (Category 2/F)	0.811923 s
Time (Category 5/D)	0.475888 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

100mm hole size



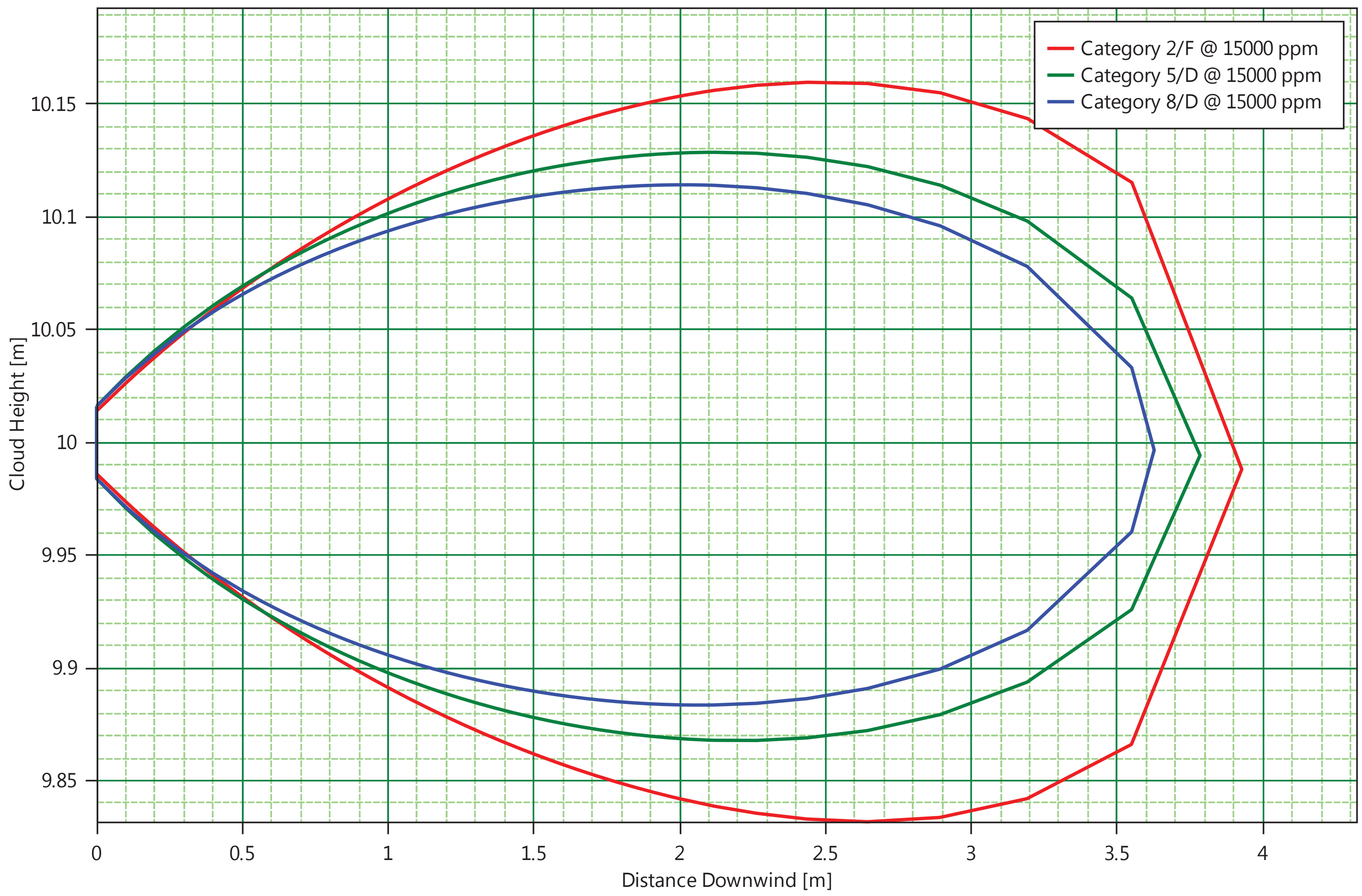
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.236044 s
Time (Category 2/F)	0.473691 s
Time (Category 5/D)	0.318108 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

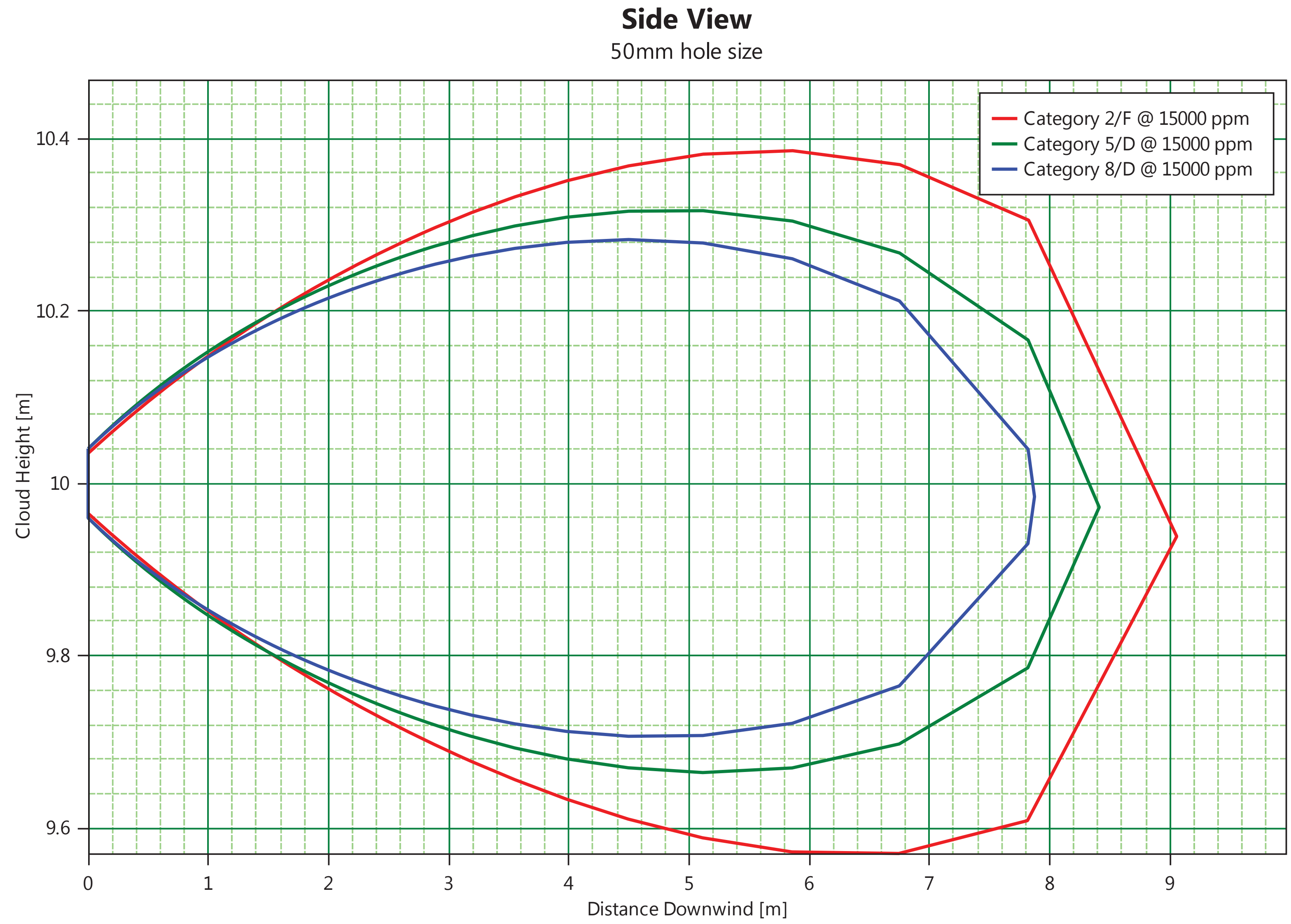
20mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

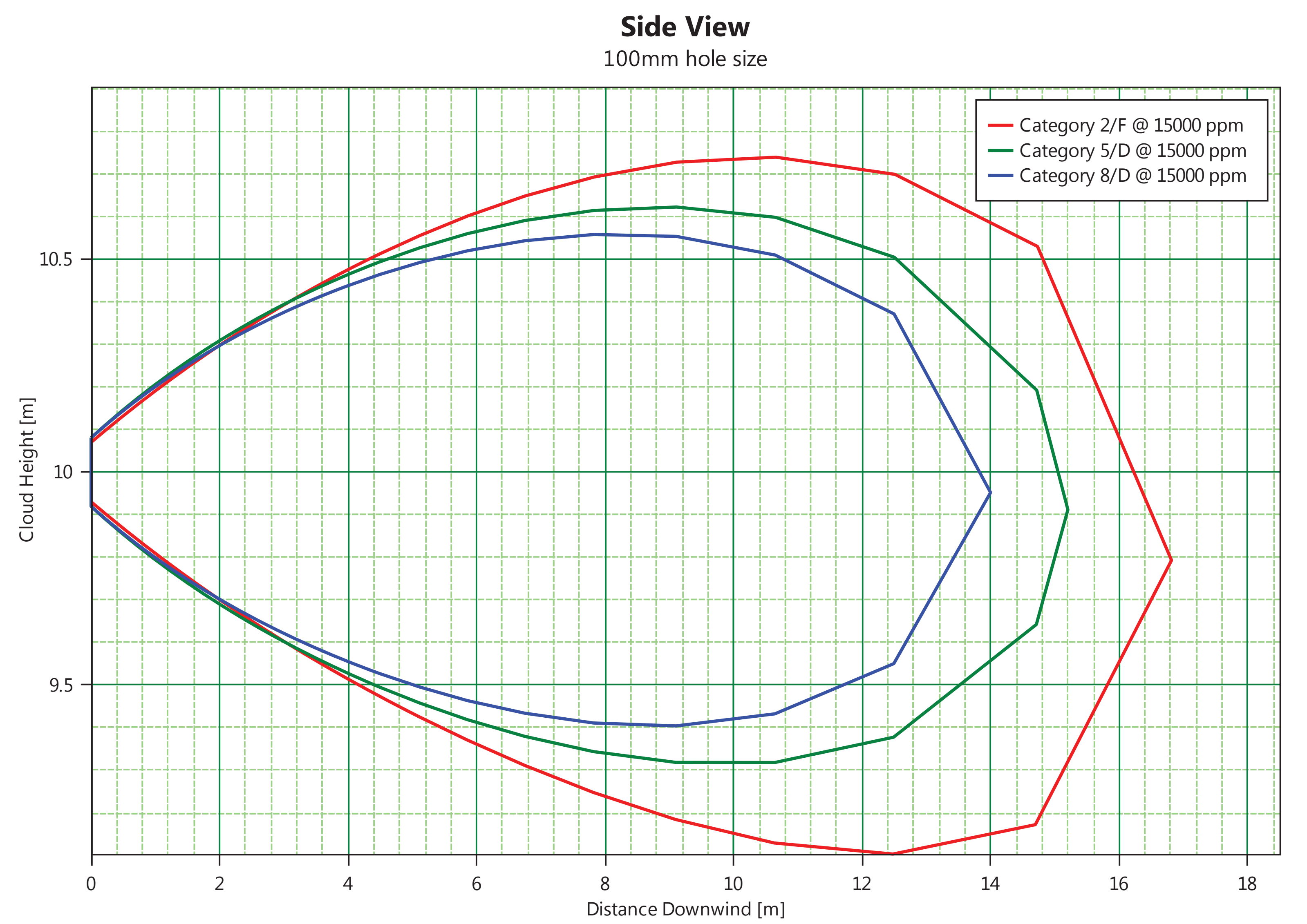
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.499891 s
Time (Category 2/F)	1.0669 s
Time (Category 5/D)	0.689356 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.870303 s
Time (Category 2/F)	1.93758 s
Time (Category 5/D)	1.21809 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.236044 s
Time (Category 2/F)	0.473691 s
Time (Category 5/D)	0.318108 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

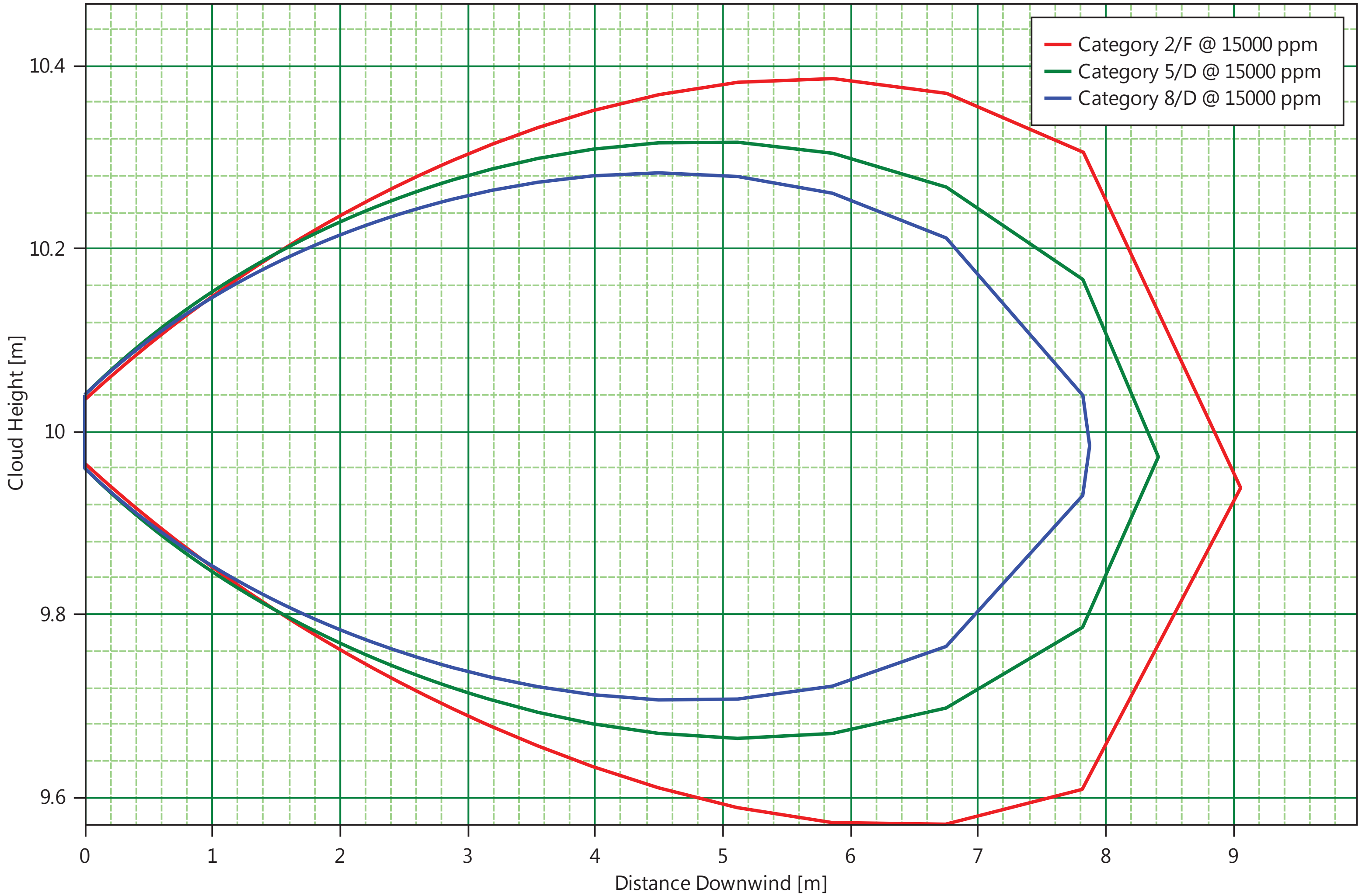
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.499891 s
Time (Category 2/F)	1.0669 s
Time (Category 5/D)	0.689356 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

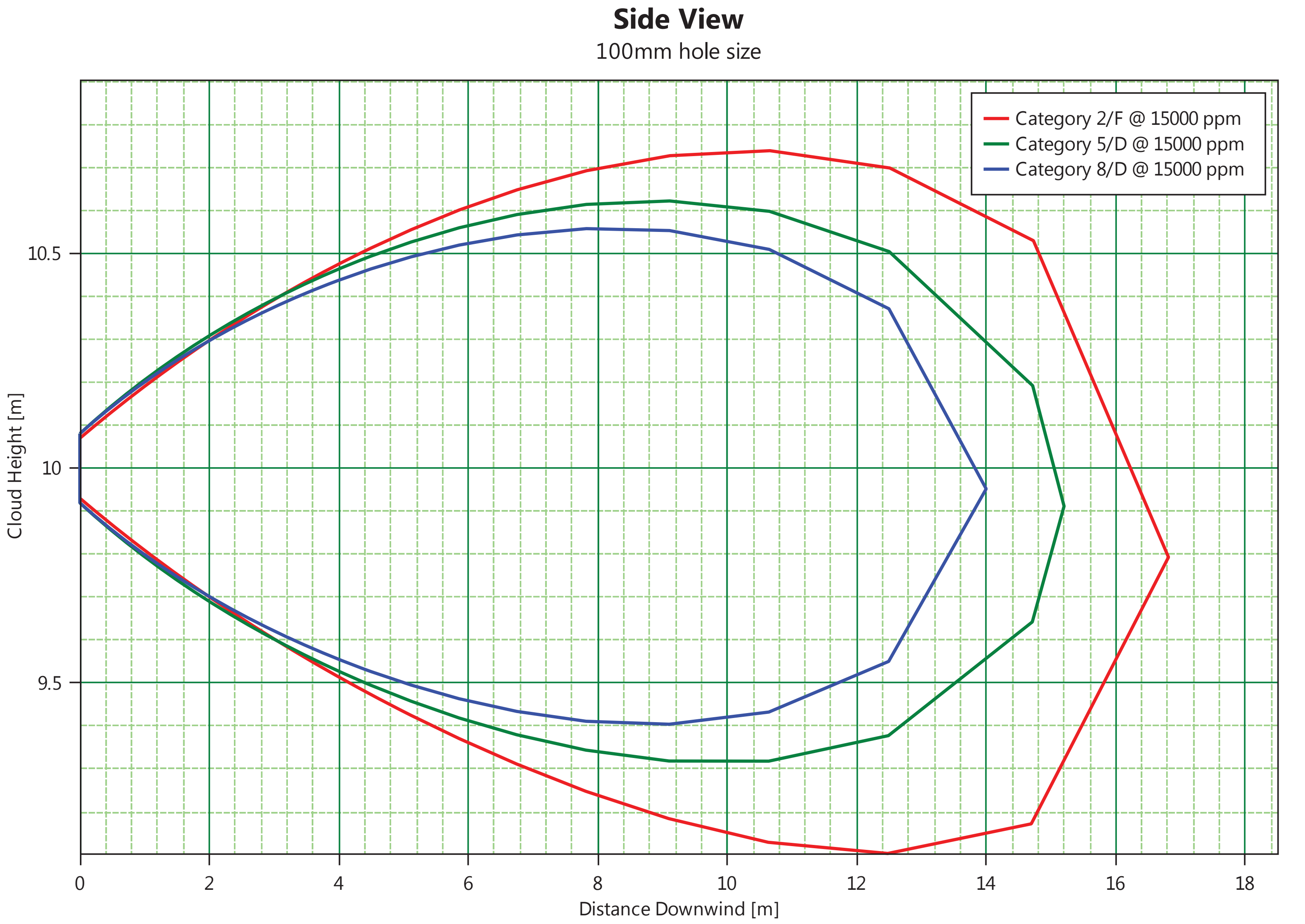
50mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

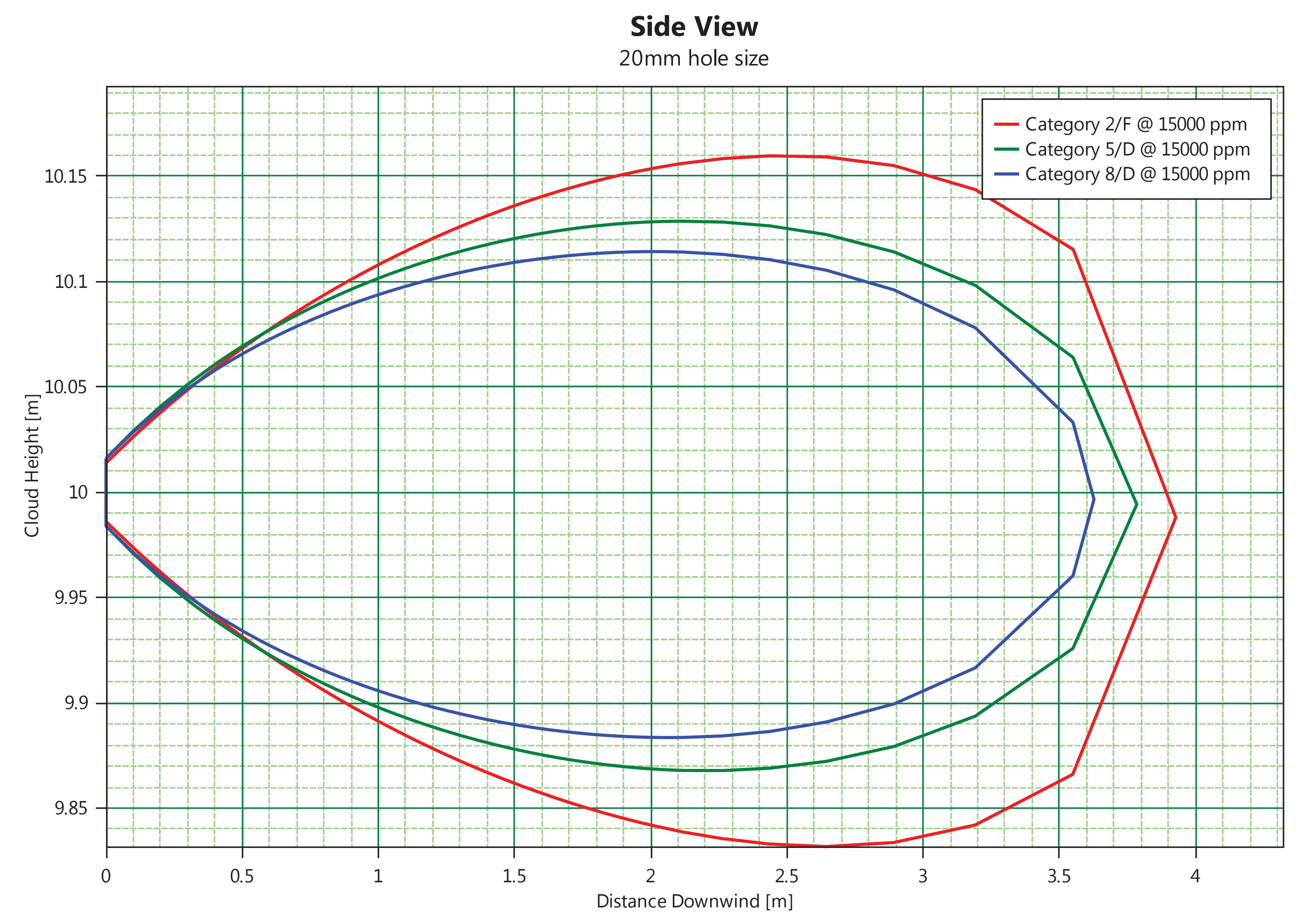
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.870303 s
Time (Category 2/F)	1.93758 s
Time (Category 5/D)	1.21809 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.236044 s
Time (Category 2/F)	0.473691 s
Time (Category 5/D)	0.318108 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

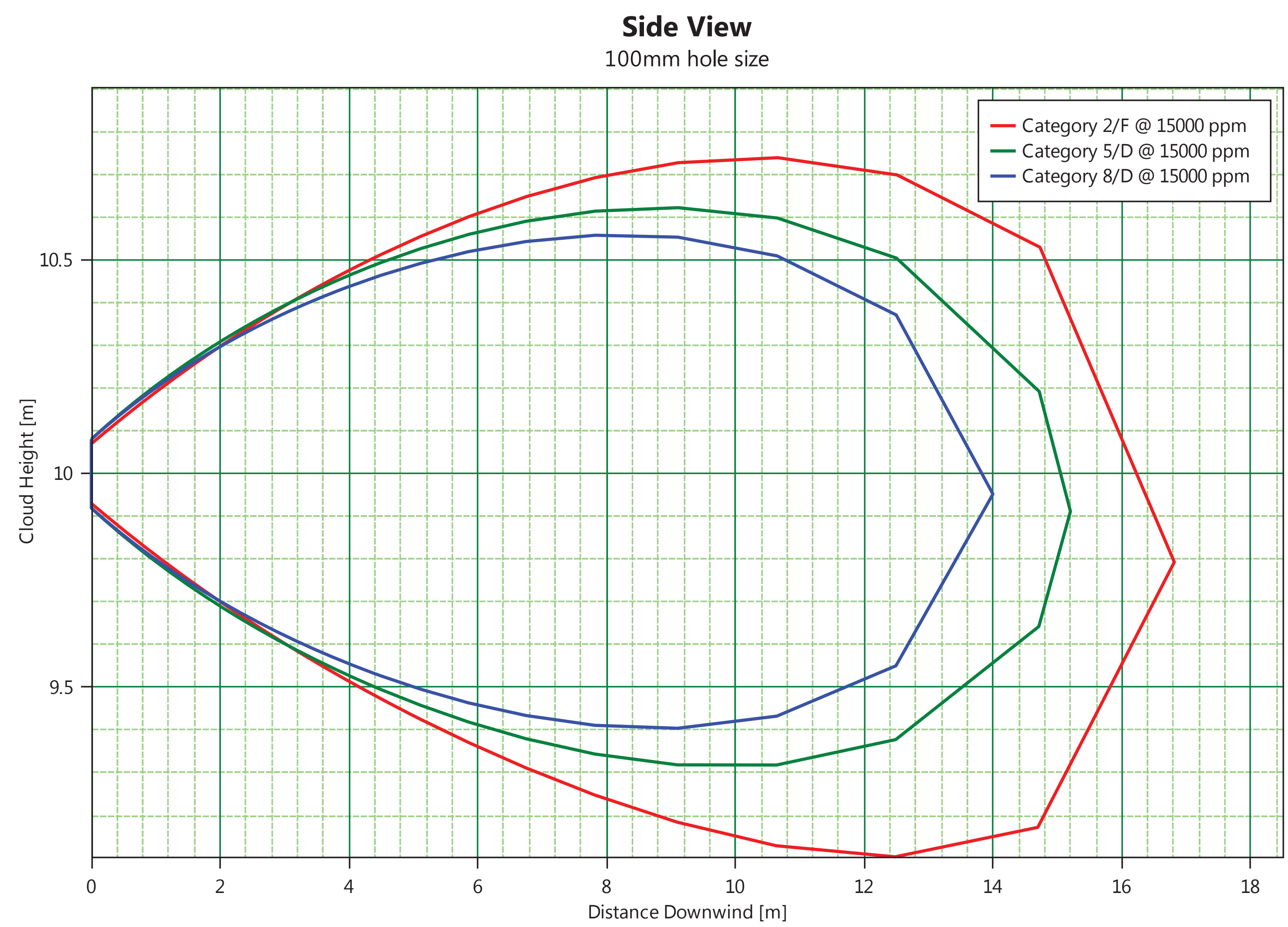
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.499891 s
Time (Category 2/F)	1.0669 s
Time (Category 5/D)	0.689356 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.870303 s
Time (Category 2/F)	1.93758 s
Time (Category 5/D)	1.21809 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

A1.2. Case B Dispersion Graphs

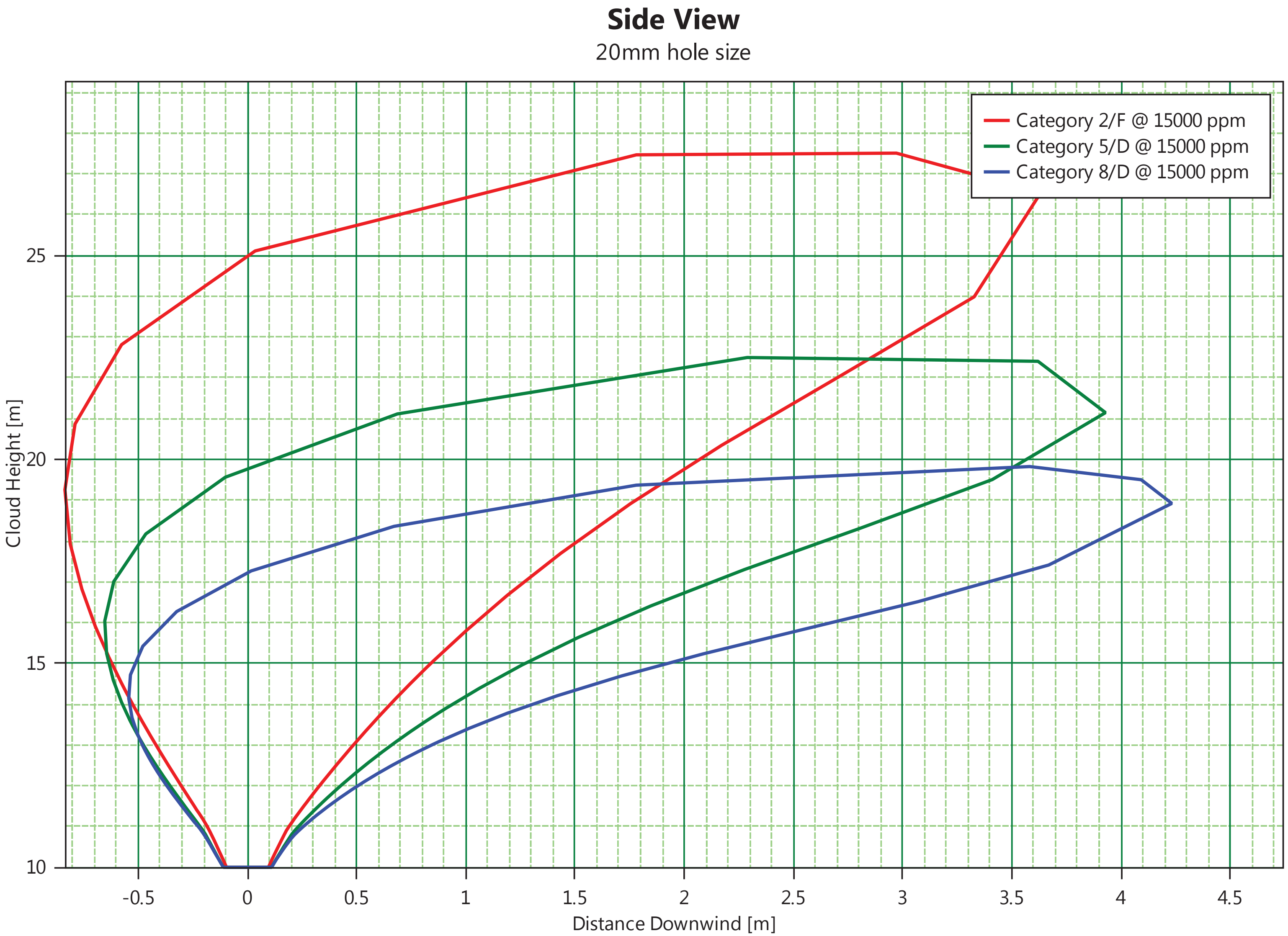
Case B - Vertical release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1

Case B - Horizontal release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, maximum concentration footprint	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, maximum concentration footprint	1

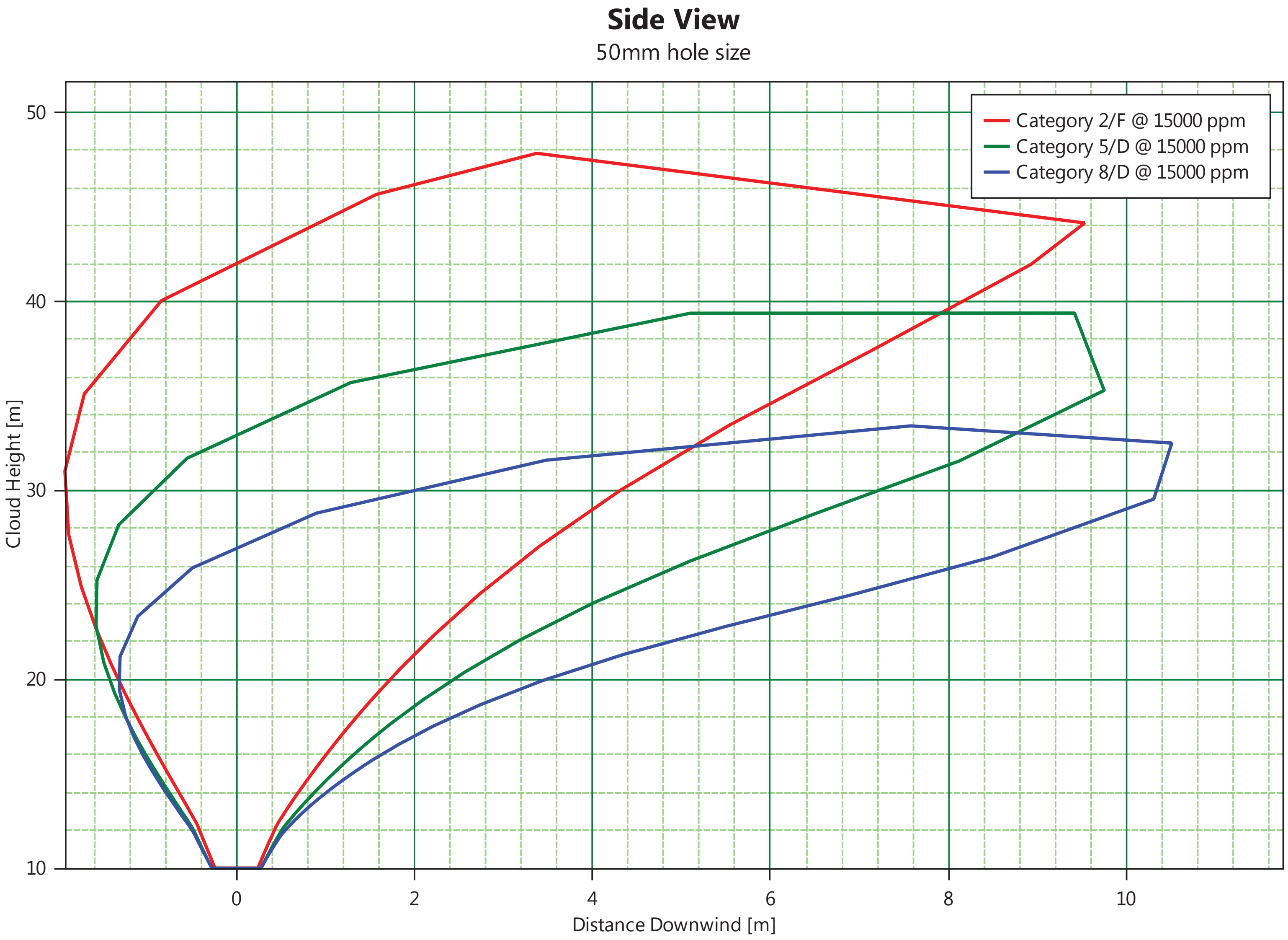
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.493439 s
Time (Category 2/F)	1.02842 s
Time (Category 5/D)	0.679787 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

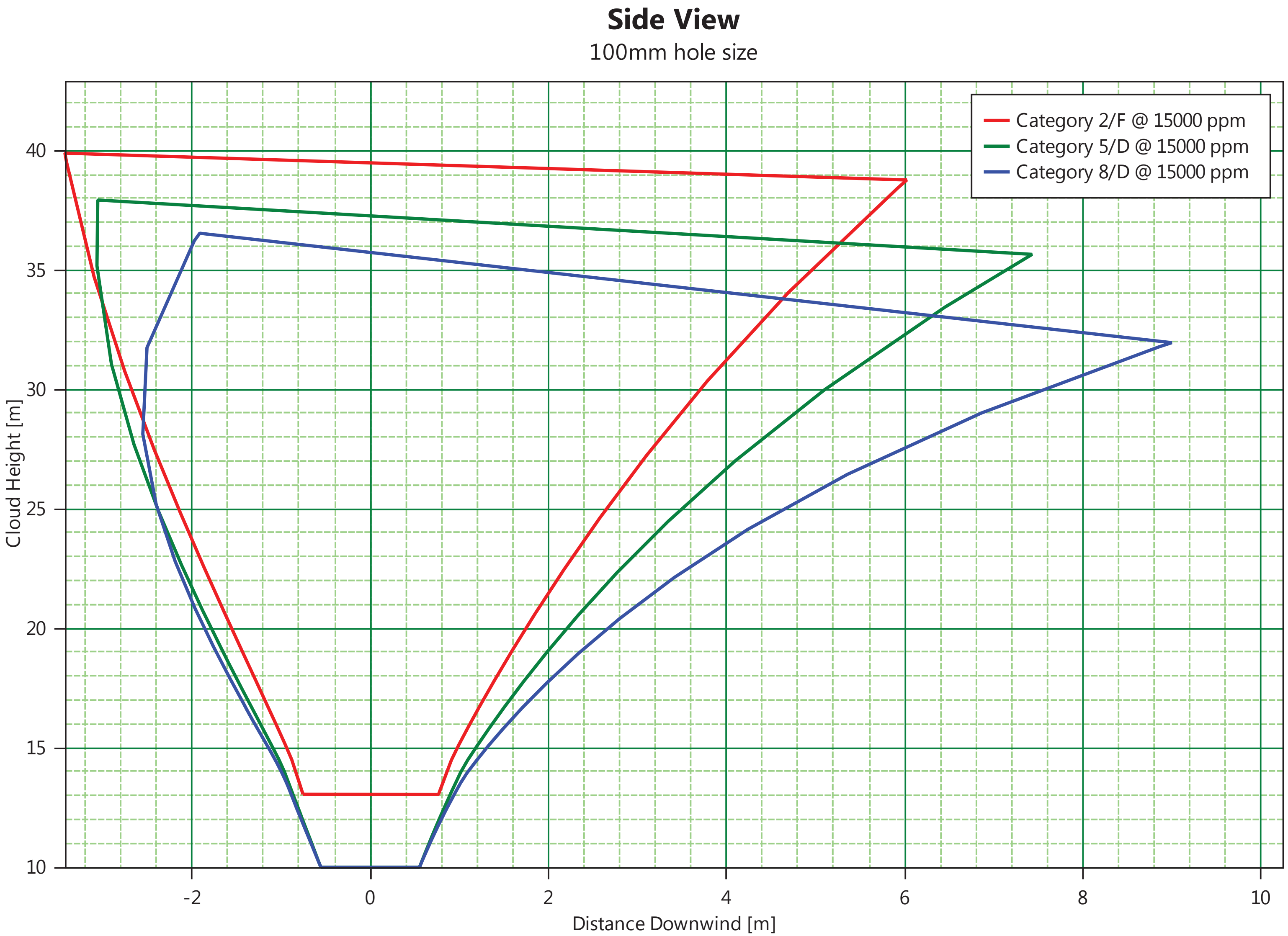
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.15759 s
Time (Category 2/F)	1.76667 s
Time (Category 5/D)	1.60068 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

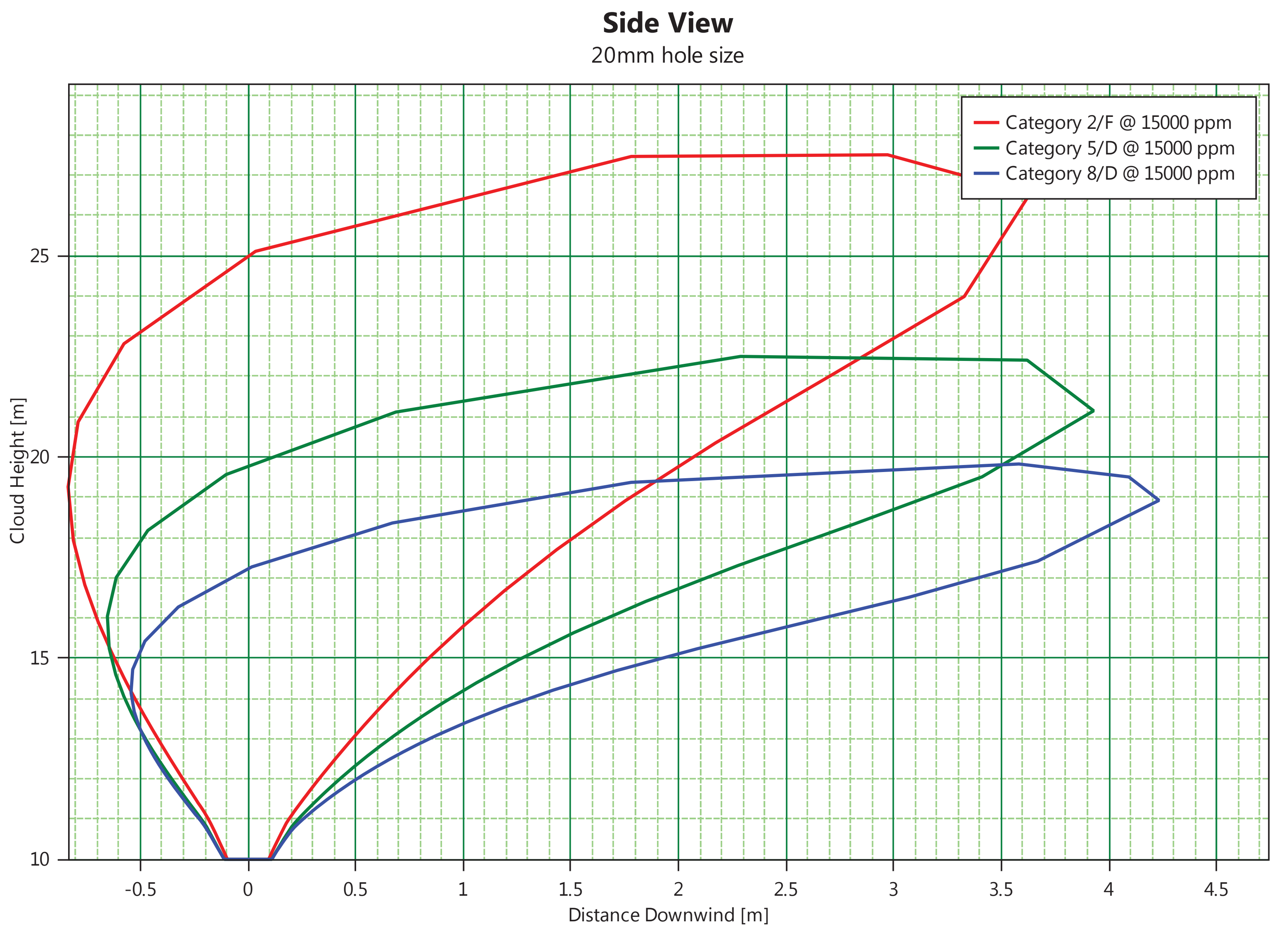
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.441395 s
Time (Category 2/F)	0.455046 s
Time (Category 5/D)	0.440272 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

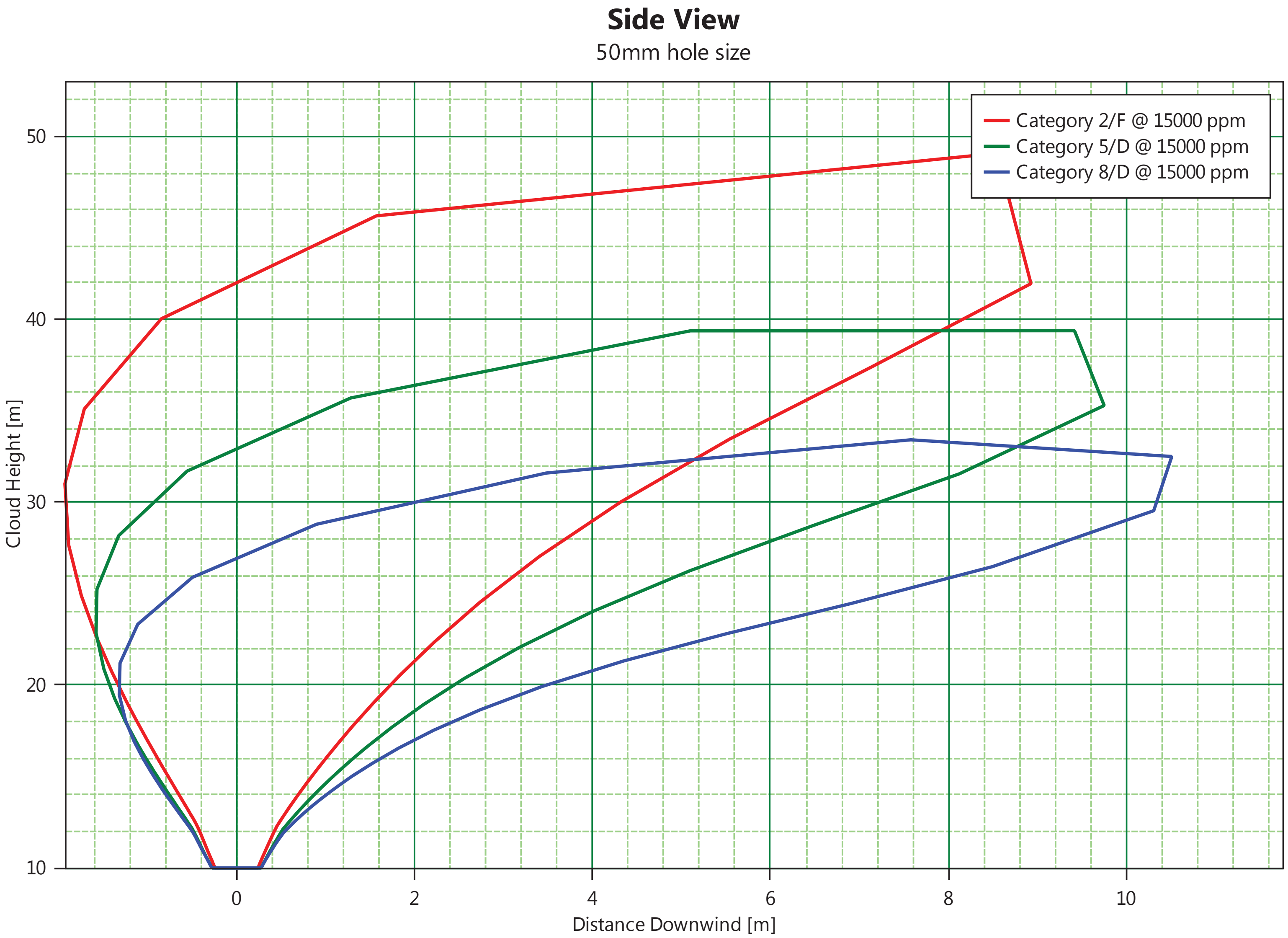
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.493439 s
Time (Category 2/F)	1.02842 s
Time (Category 5/D)	0.679787 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

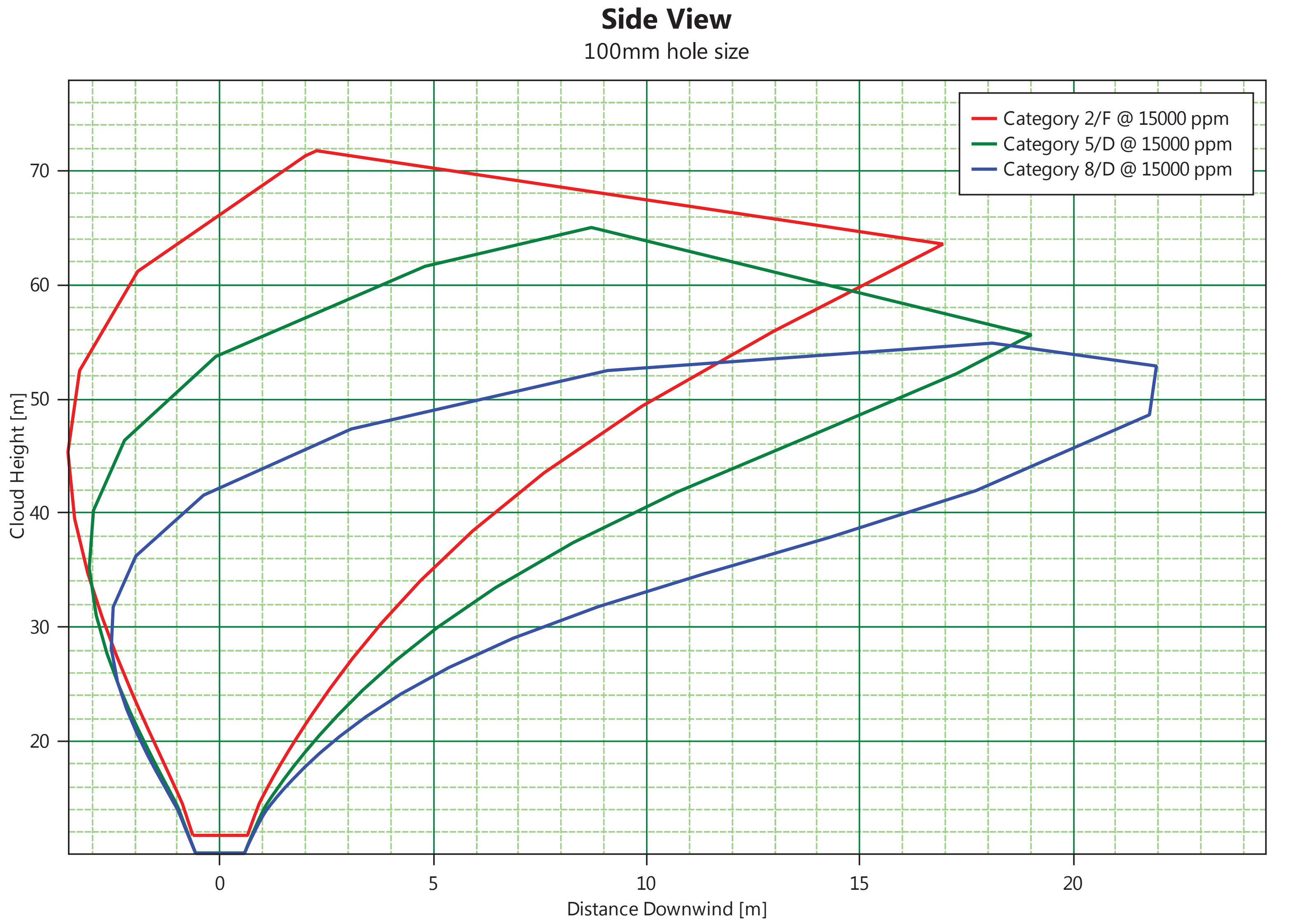
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.15759 s
Time (Category 2/F)	2.24413 s
Time (Category 5/D)	1.60068 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

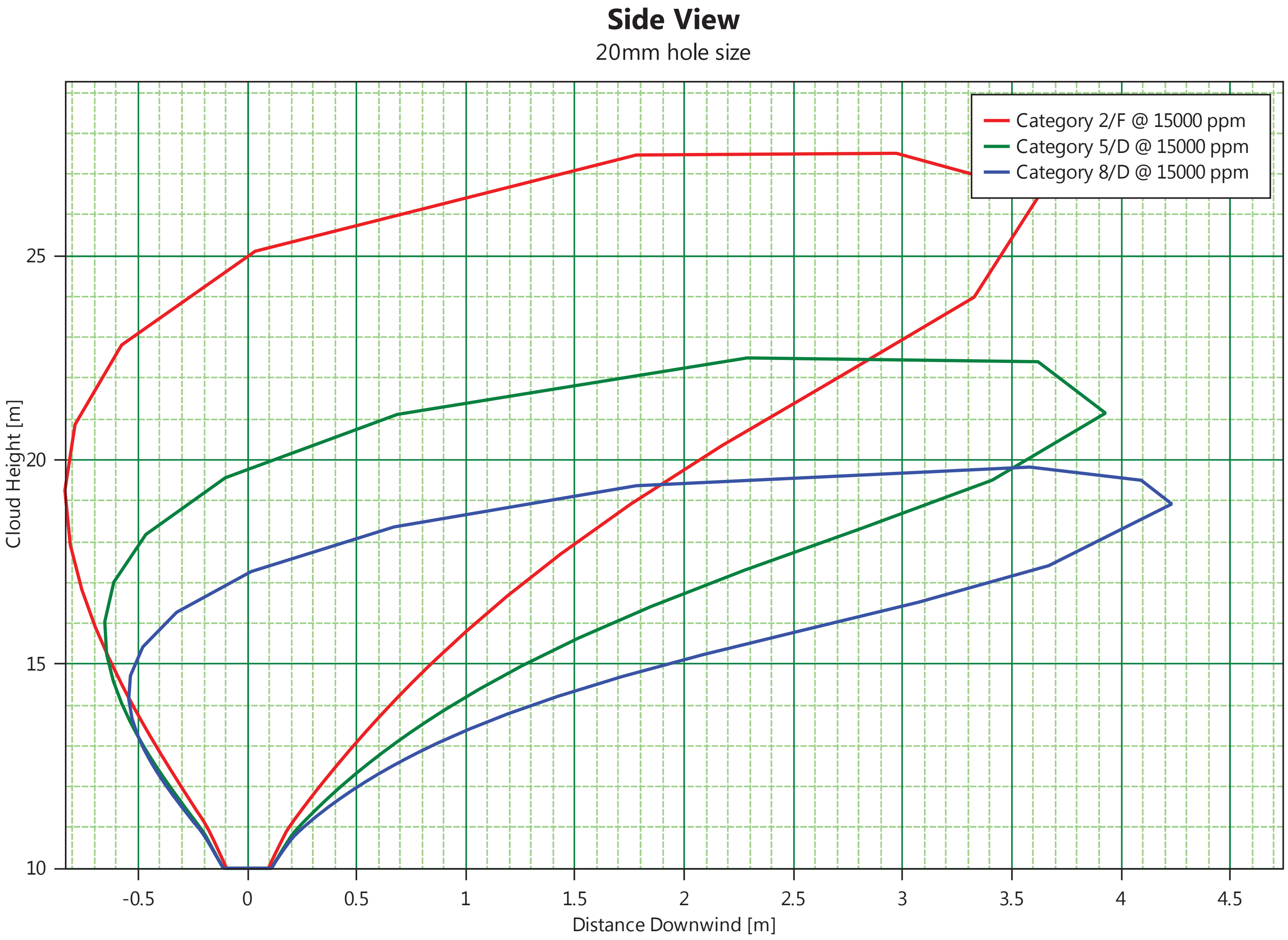
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	2.20894 s
Time (Category 2/F)	2.21538 s
Time (Category 5/D)	2.20909 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

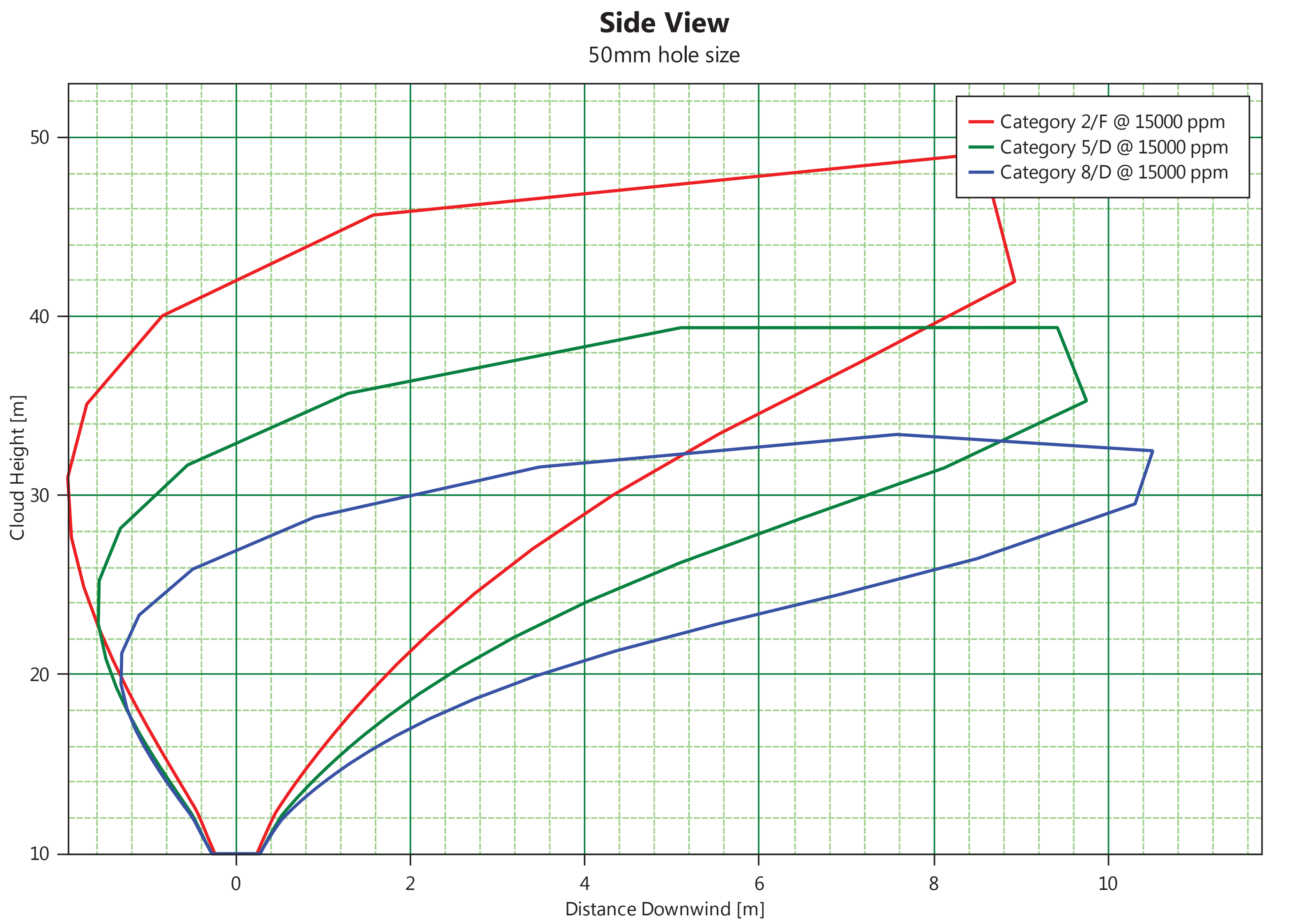
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.493439 s
Time (Category 2/F)	1.02842 s
Time (Category 5/D)	0.679787 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

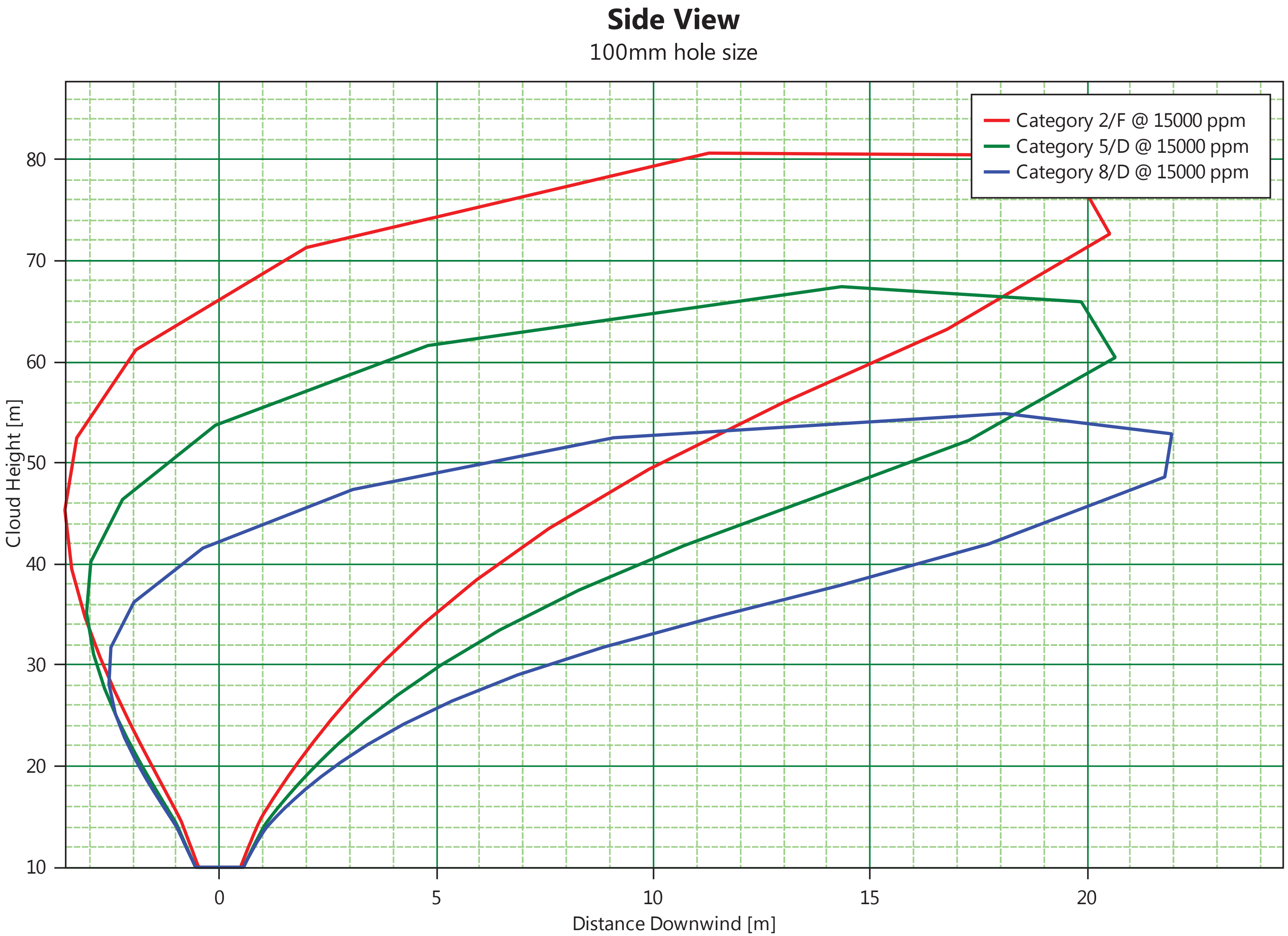
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	Toxic (0 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.15759 s
Time (Category 2/F)	2.24413 s
Time (Category 5/D)	1.60068 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	2.20955 s
Time (Category 2/F)	4.00049 s
Time (Category 5/D)	3.06233 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



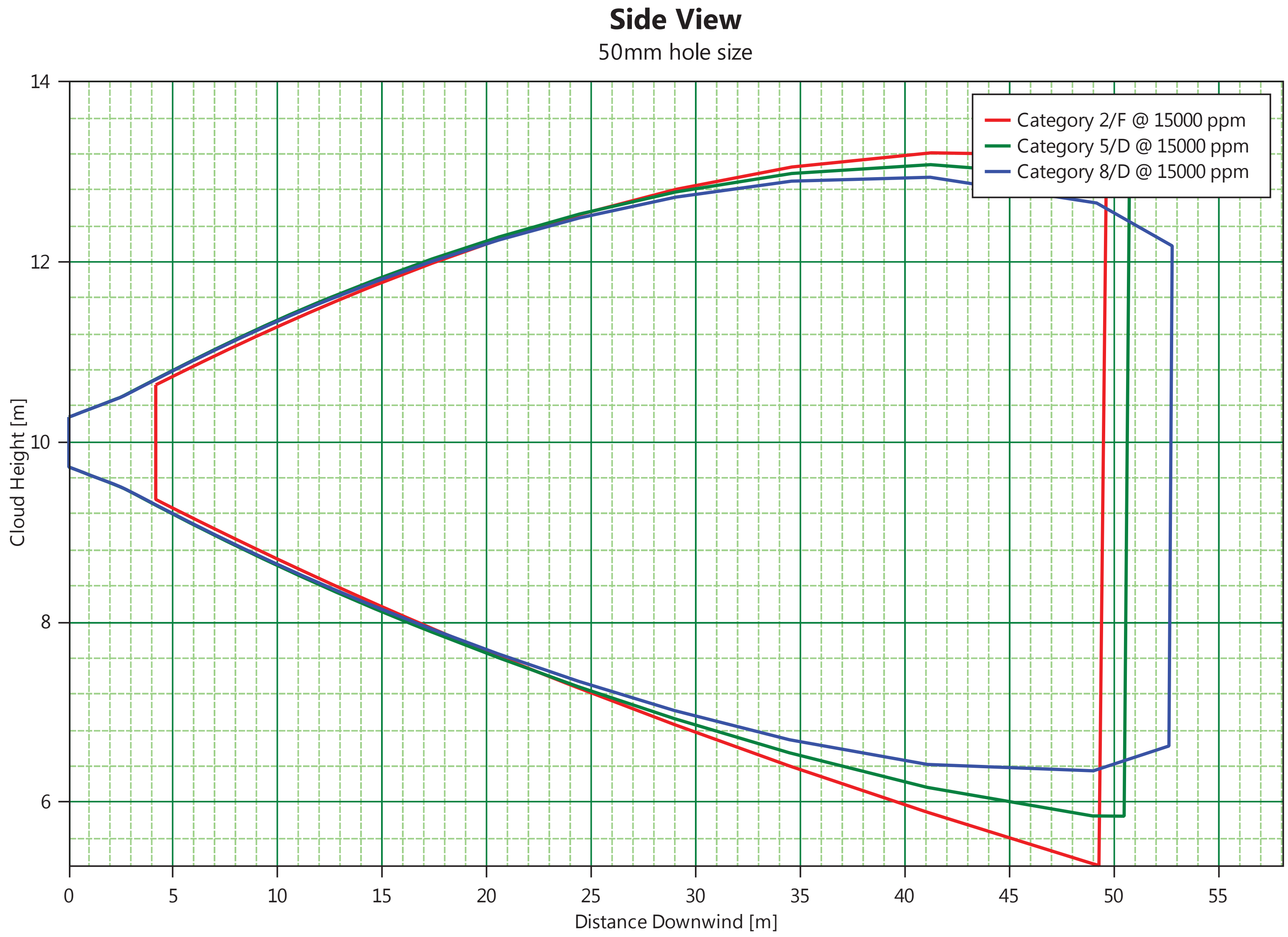
C/L Conc.
Conc. vs Time
Footprint
Side View
Cross Section
Max. Concentration
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	1.16774 s
Time (Category 2/F)	2.17299 s
Time (Category 5/D)	1.52544 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

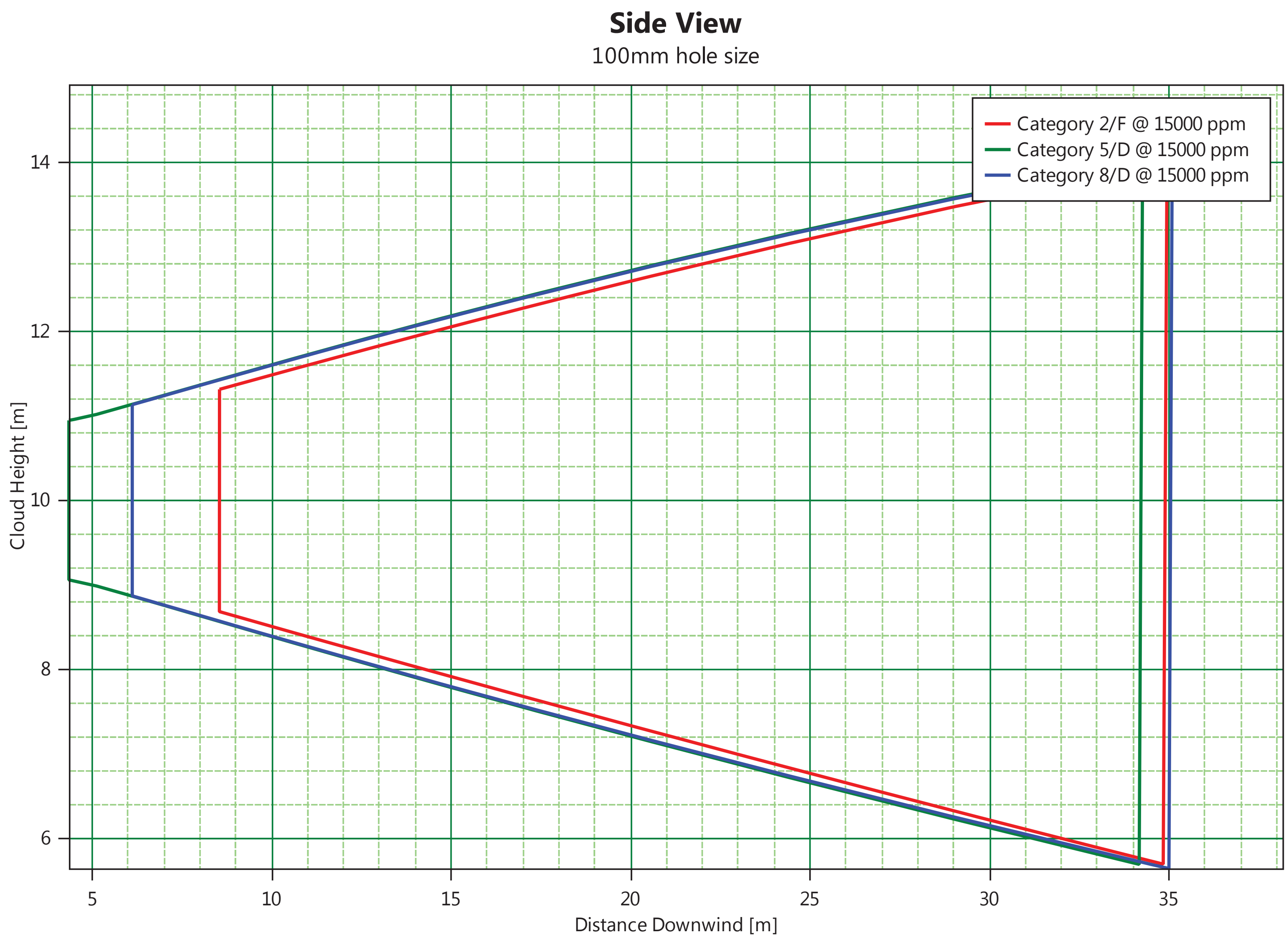
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.76389 s
Time (Category 2/F)	1.79027 s
Time (Category 5/D)	1.75017 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.472545 s
Time (Category 2/F)	0.490807 s
Time (Category 5/D)	0.461797 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

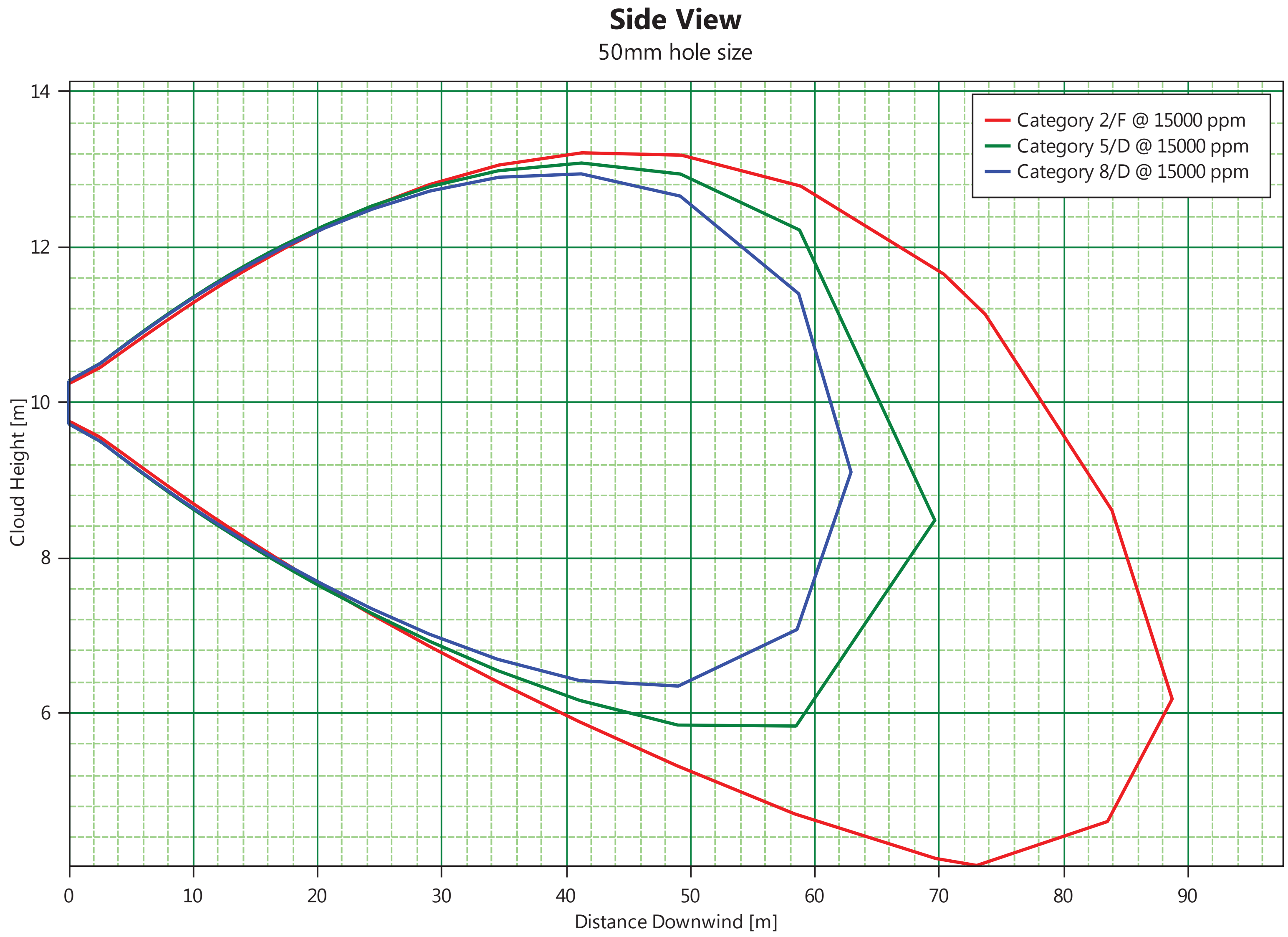
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	1.16774 s
Time (Category 2/F)	2.17299 s
Time (Category 5/D)	1.52544 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

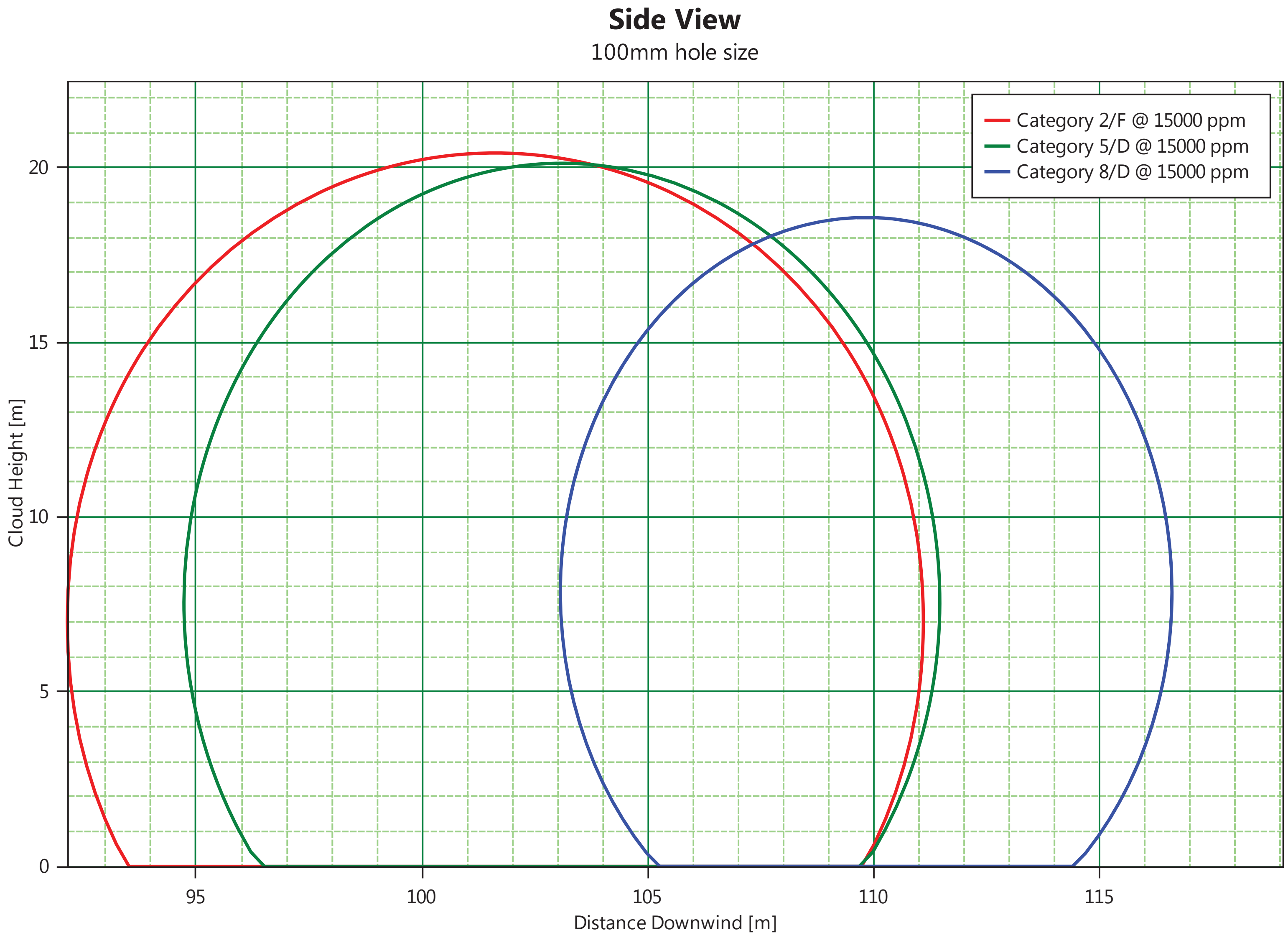
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	2.43309 s
Time (Category 2/F)	5.69007 s
Time (Category 5/D)	3.23383 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	5.02928 s
Time (Category 2/F)	4.85502 s
Time (Category 5/D)	4.80304 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



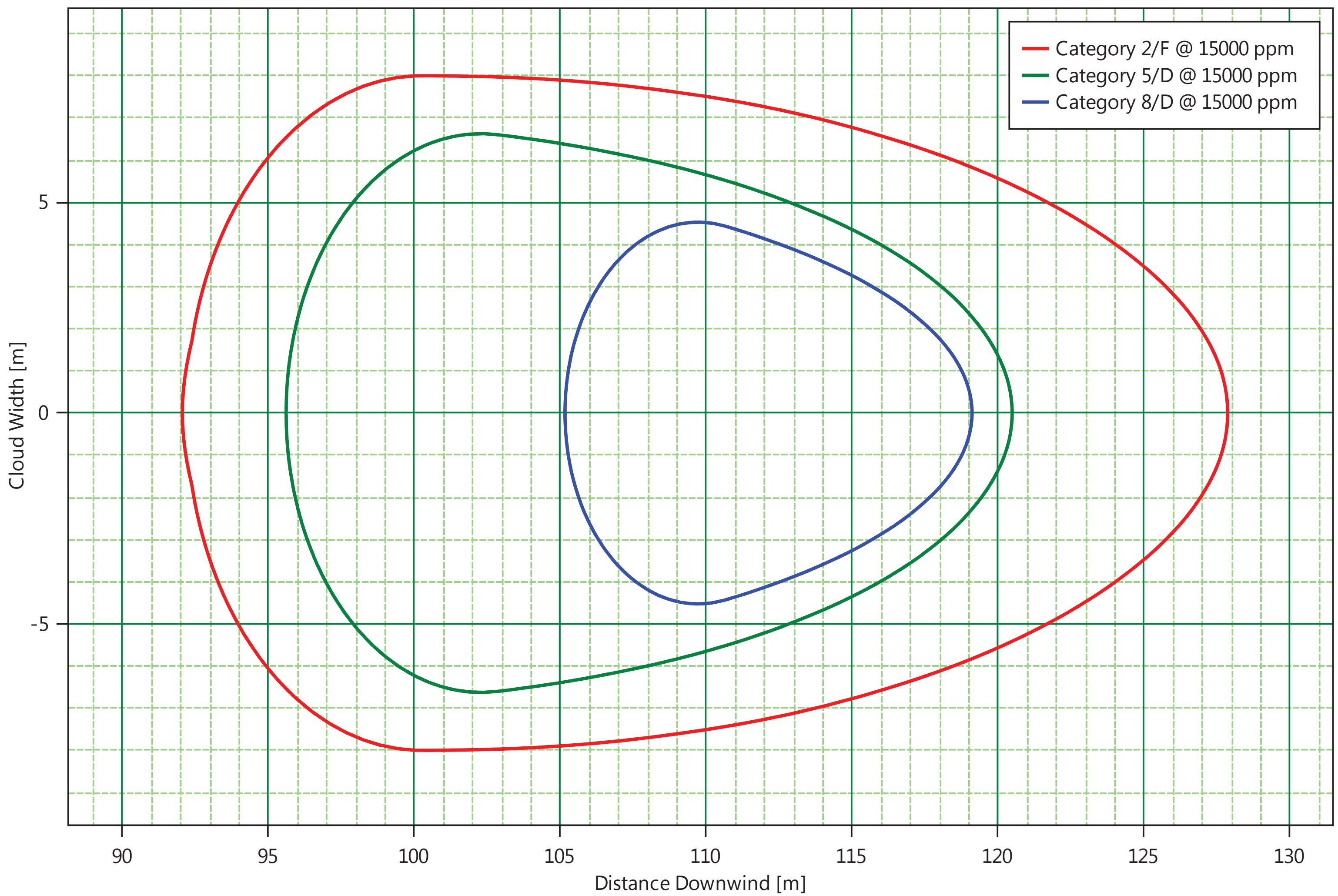
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Height of Interest	0 m
Material	CARBON DIOXIDE
Program	Phast 7.01
Scenario	100mm hole size
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Maximum Concentration Footprint

100mm hole size



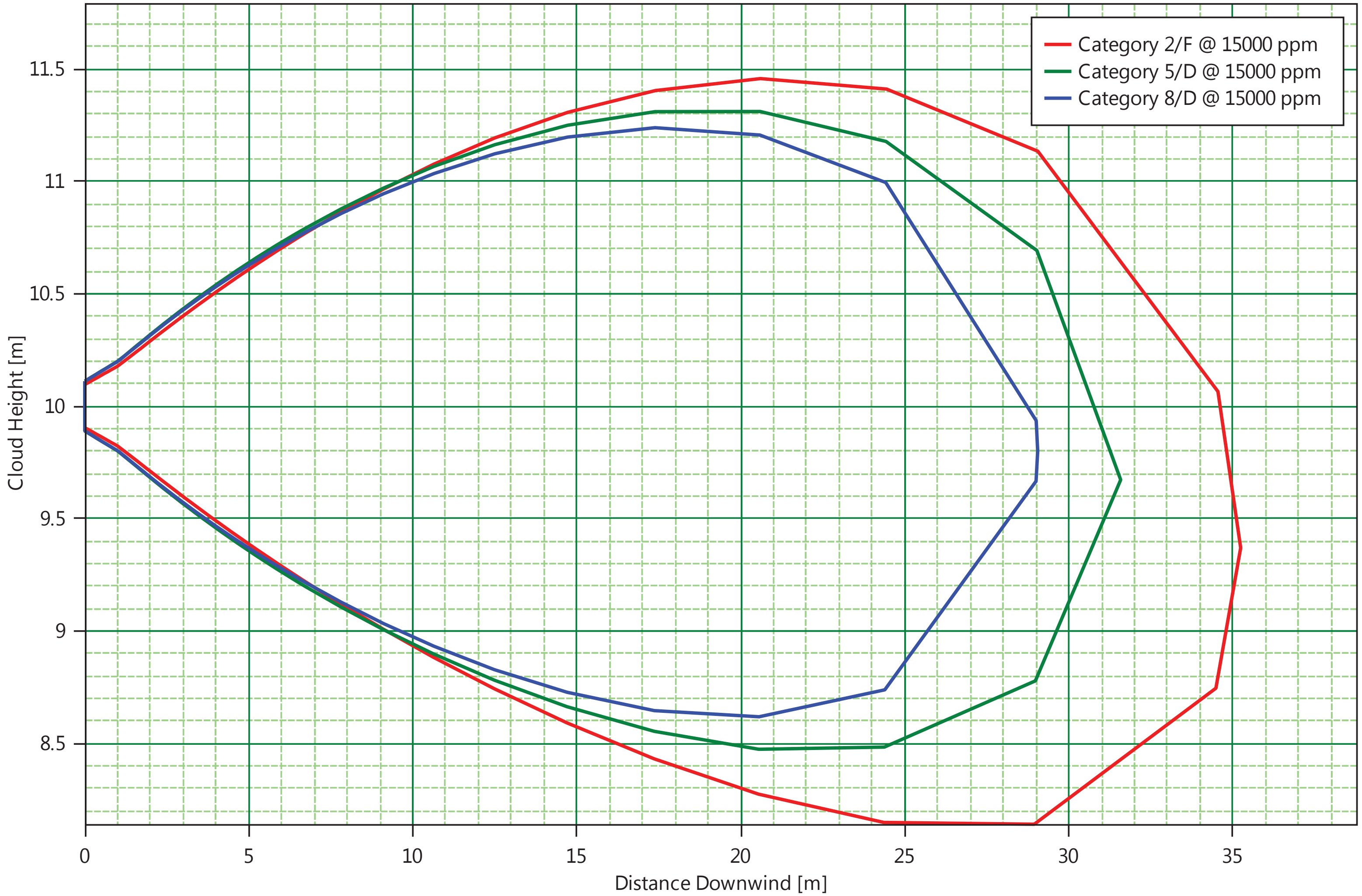
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	1.16774 s
Time (Category 2/F)	2.17299 s
Time (Category 5/D)	1.52544 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

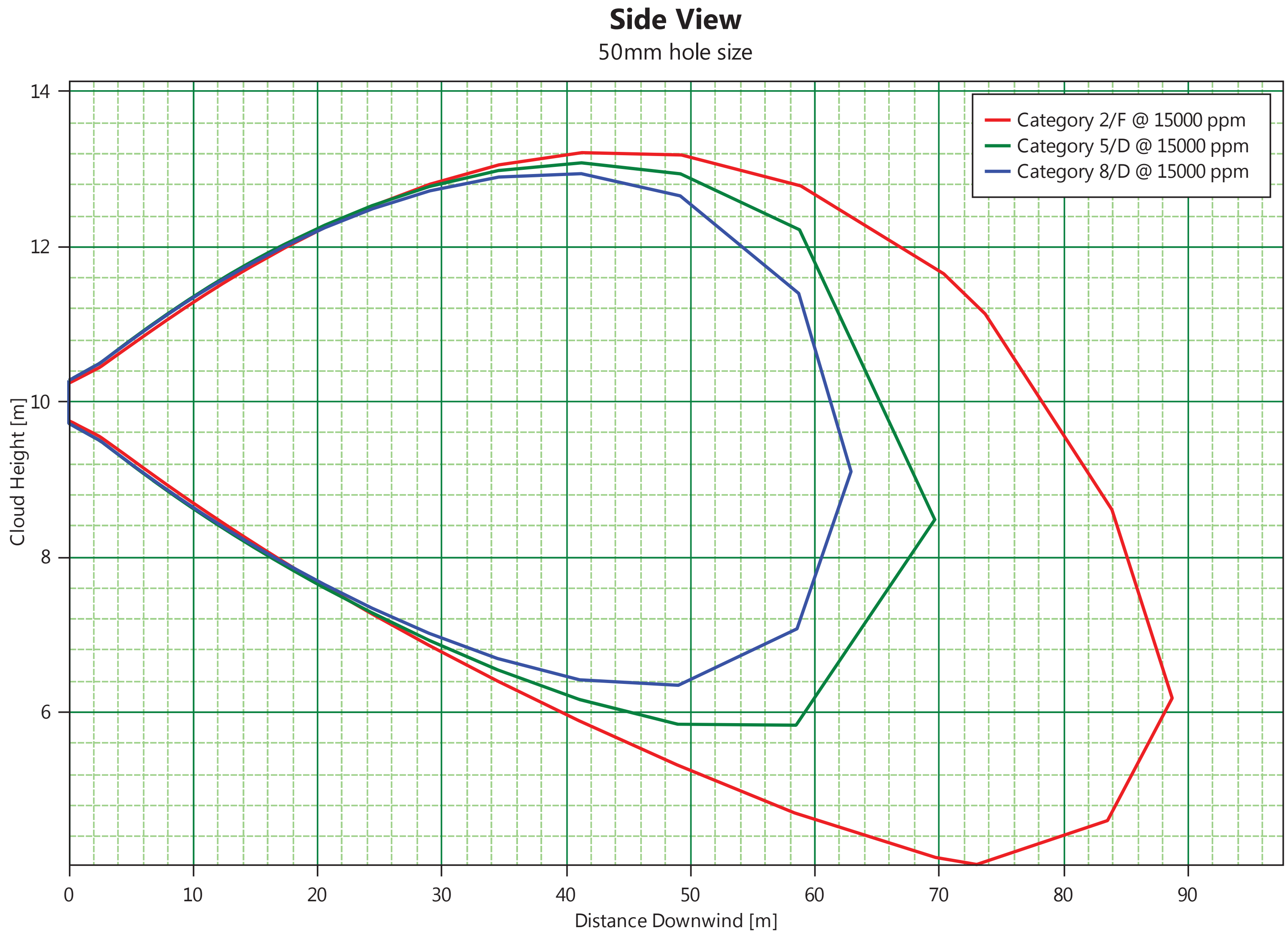
20mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

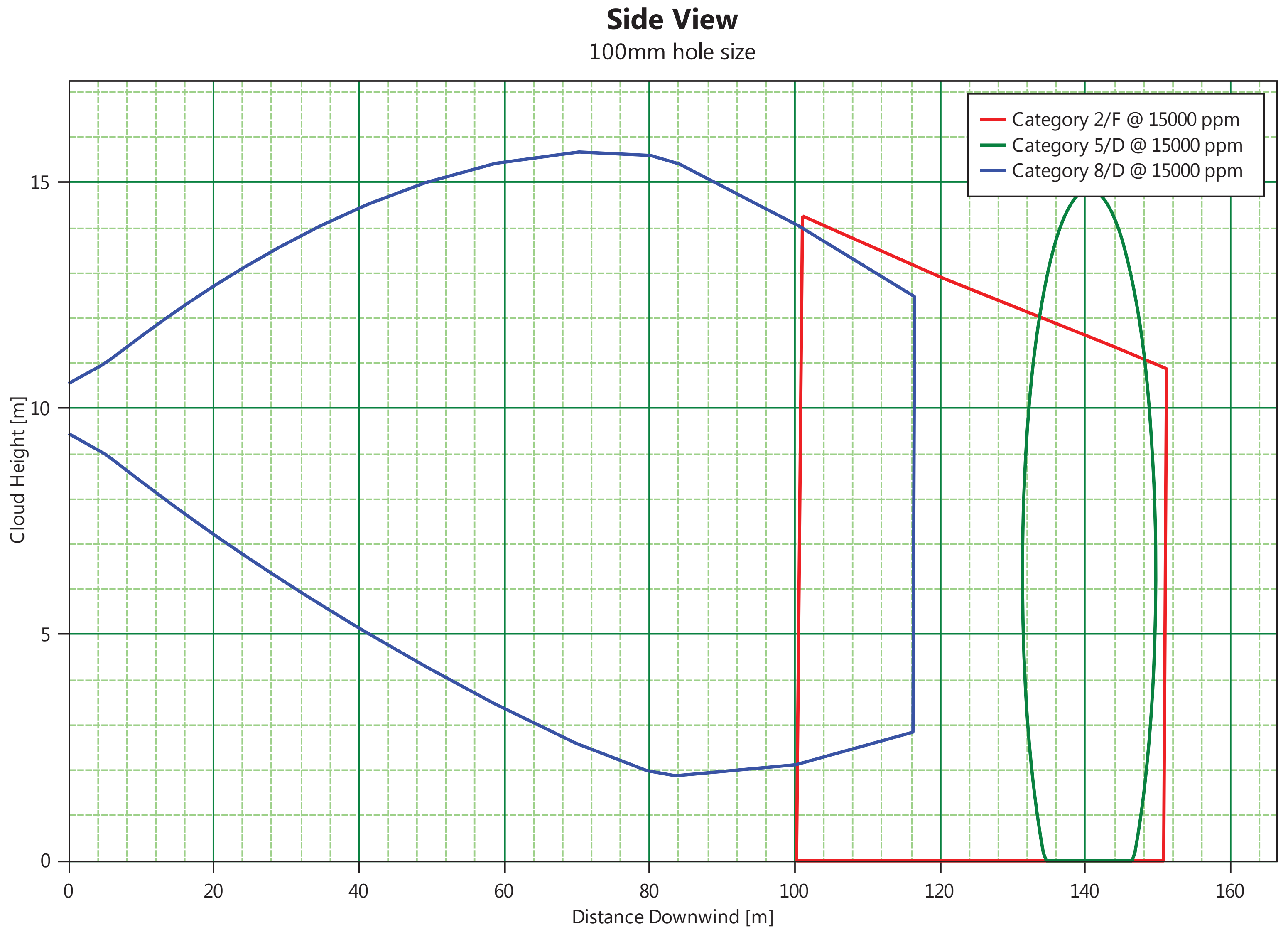
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	Toxic (0 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	2.43309 s
Time (Category 2/F)	5.69007 s
Time (Category 5/D)	3.23383 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

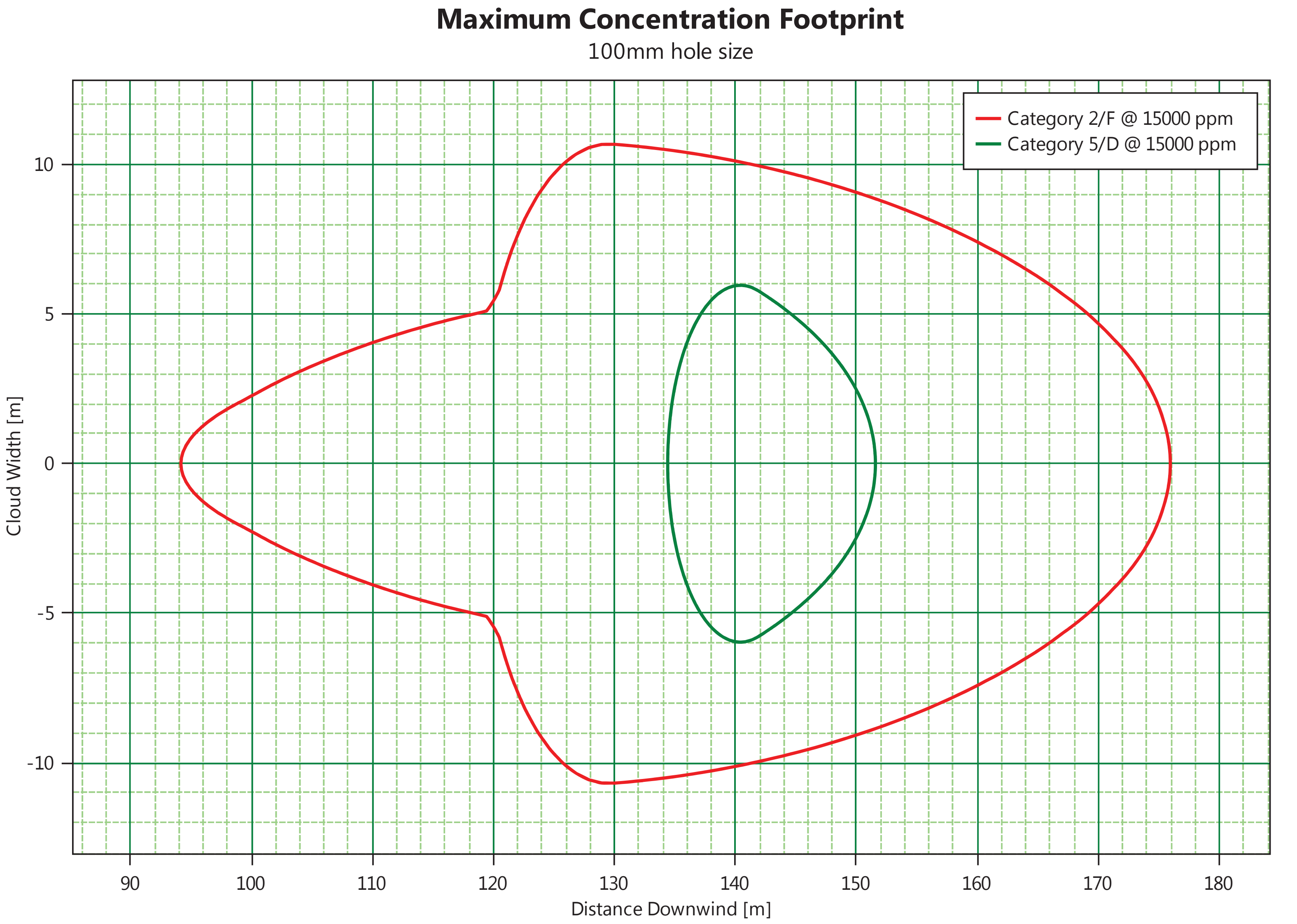
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	4.38507 s
Time (Category 2/F)	8.14205 s
Time (Category 5/D)	8.73535 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Height of Interest	0 m
Material	CARBON DIOXIDE
Program	Phast 7.01
Scenario	100mm hole size
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

A1.3. Case C Dispersion Graphs

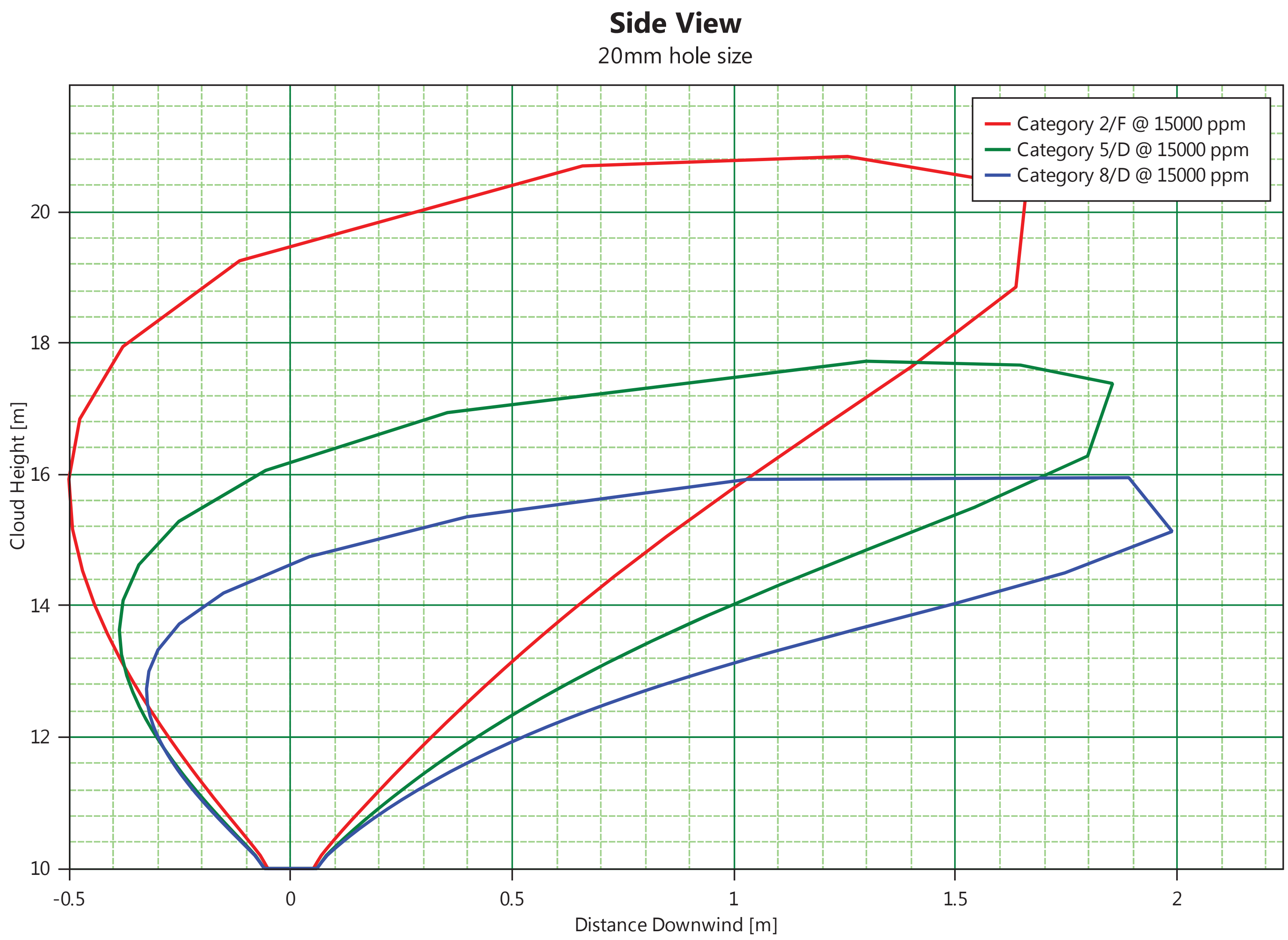
Case C - Vertical release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1

Case C - Horizontal release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1

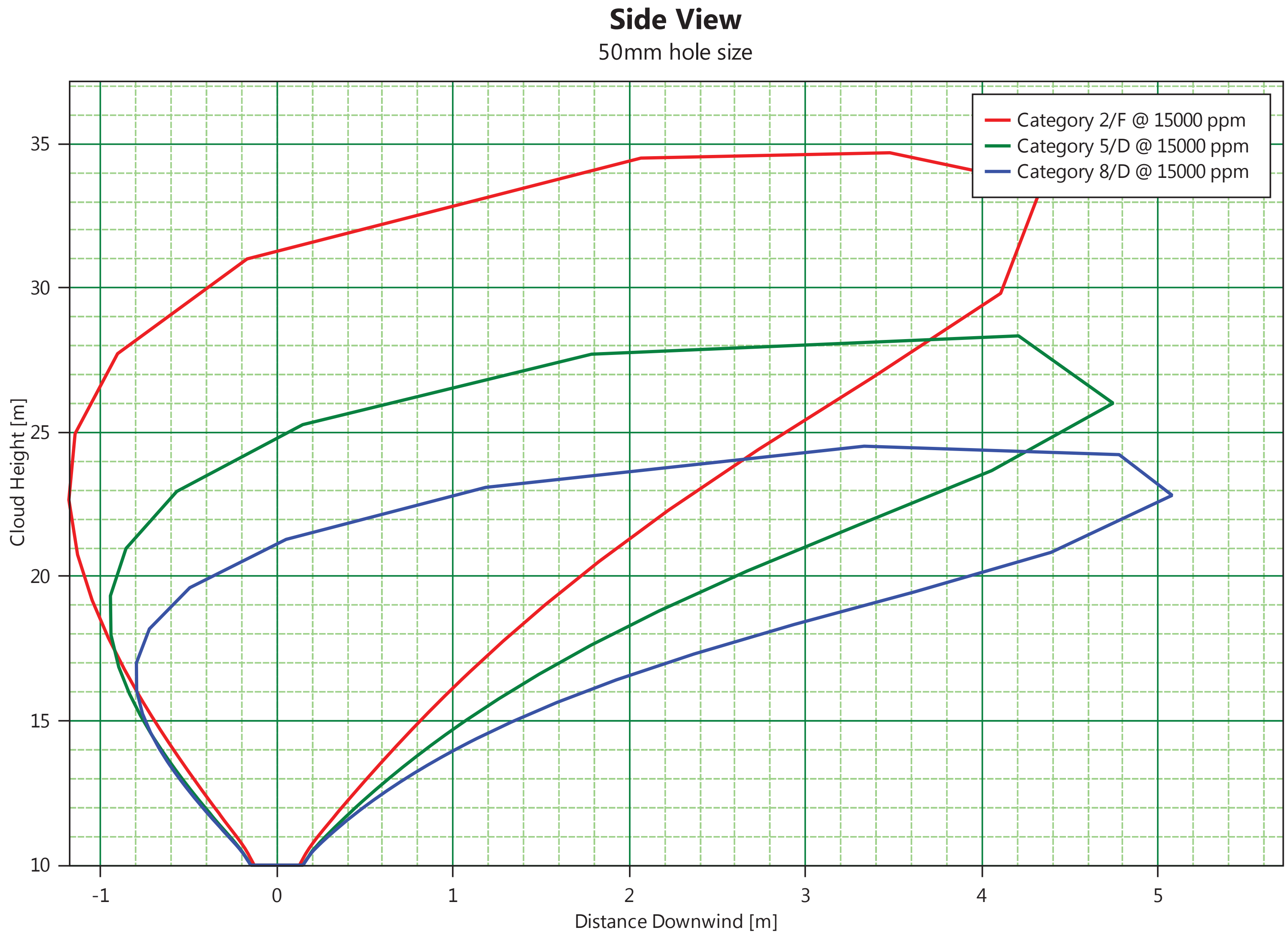
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.234935 s
Time (Category 2/F)	0.493007 s
Time (Category 5/D)	0.320413 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

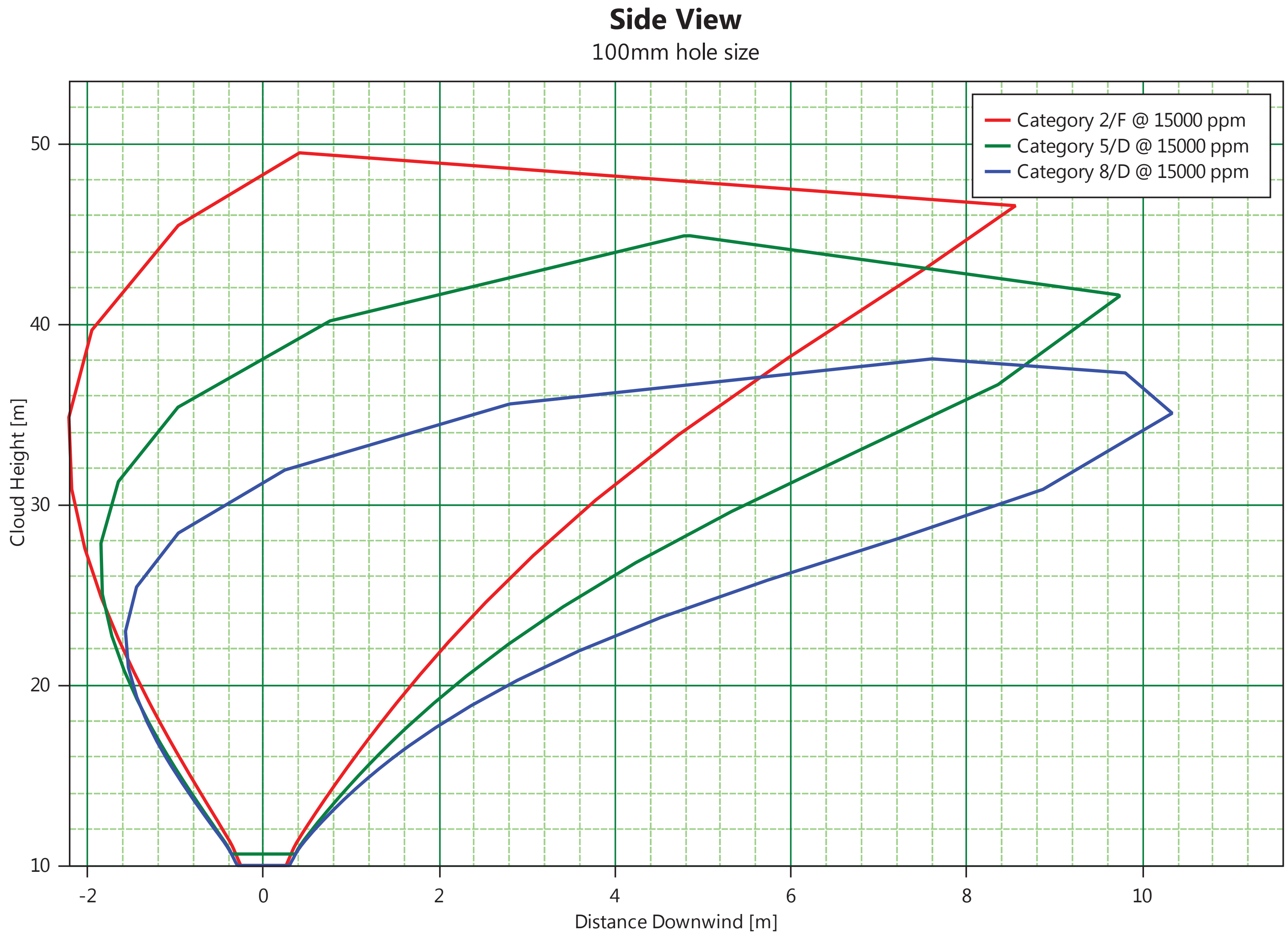
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.553861 s
Time (Category 2/F)	1.08331 s
Time (Category 5/D)	0.757041 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

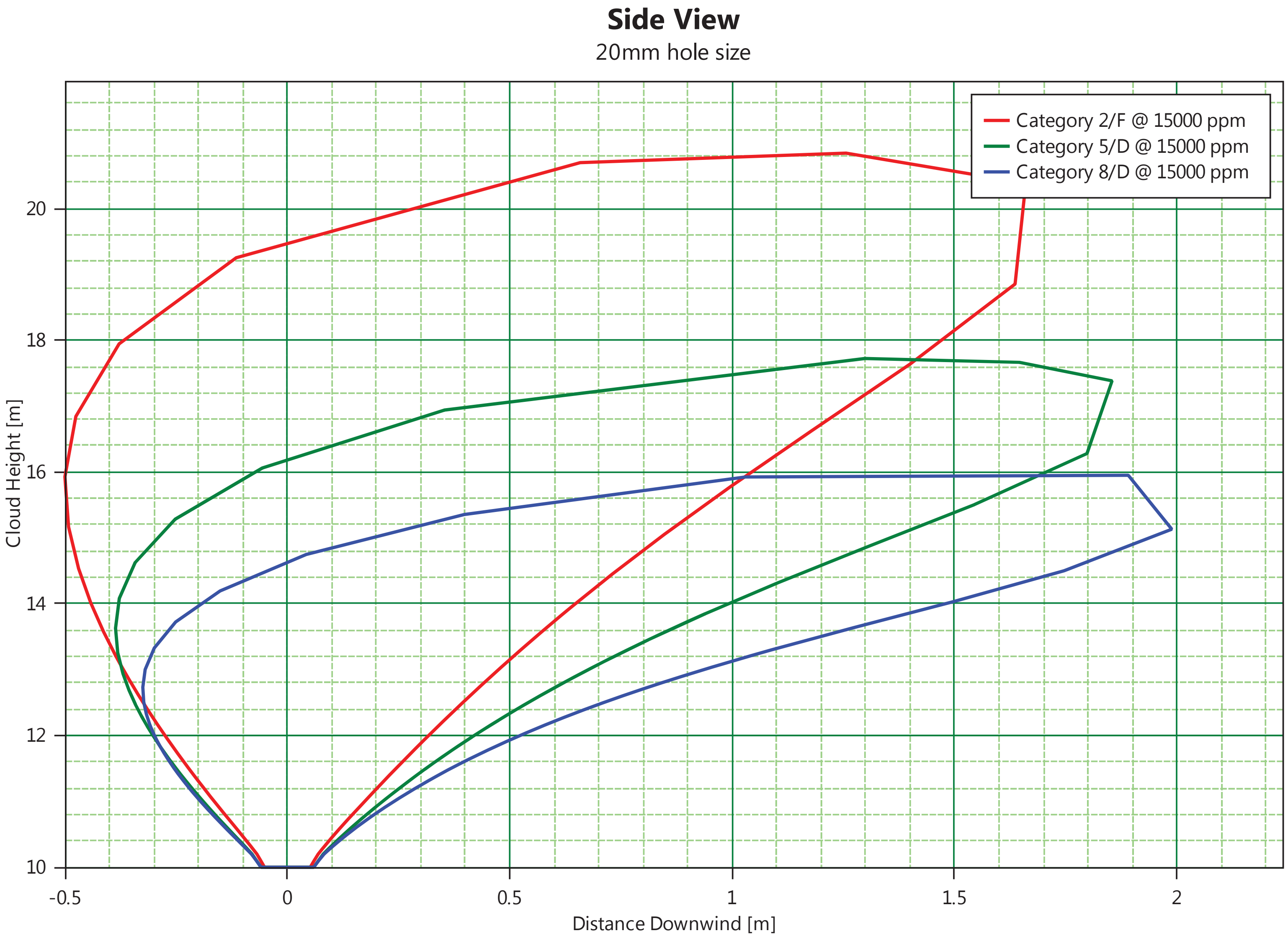
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	1.05302 s
Time (Category 2/F)	1.2159 s
Time (Category 5/D)	1.22509 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

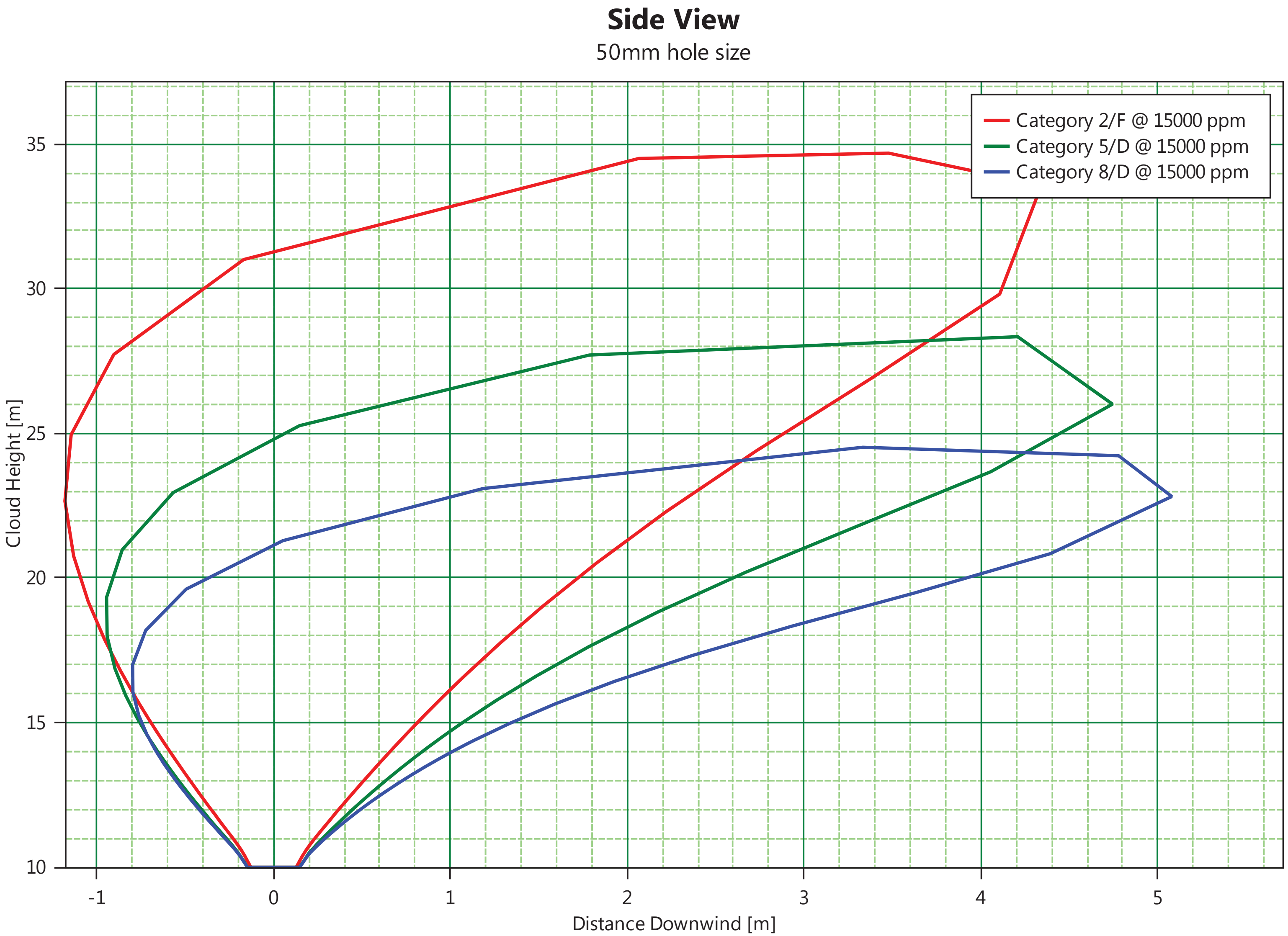
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.234935 s
Time (Category 2/F)	0.493007 s
Time (Category 5/D)	0.320413 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

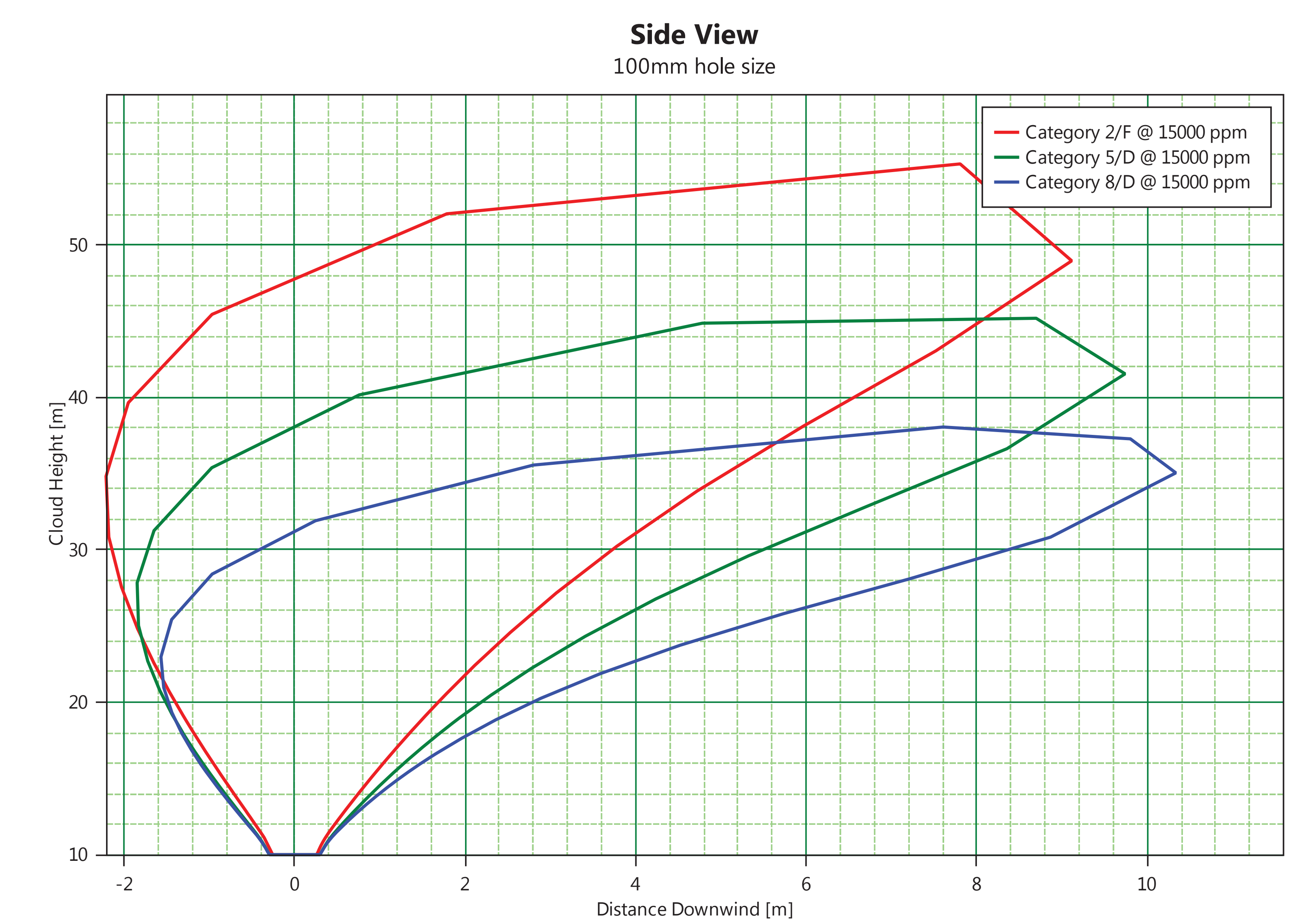
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.553861 s
Time (Category 2/F)	1.08331 s
Time (Category 5/D)	0.757041 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	1.05302 s
Time (Category 2/F)	1.93943 s
Time (Category 5/D)	1.43995 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



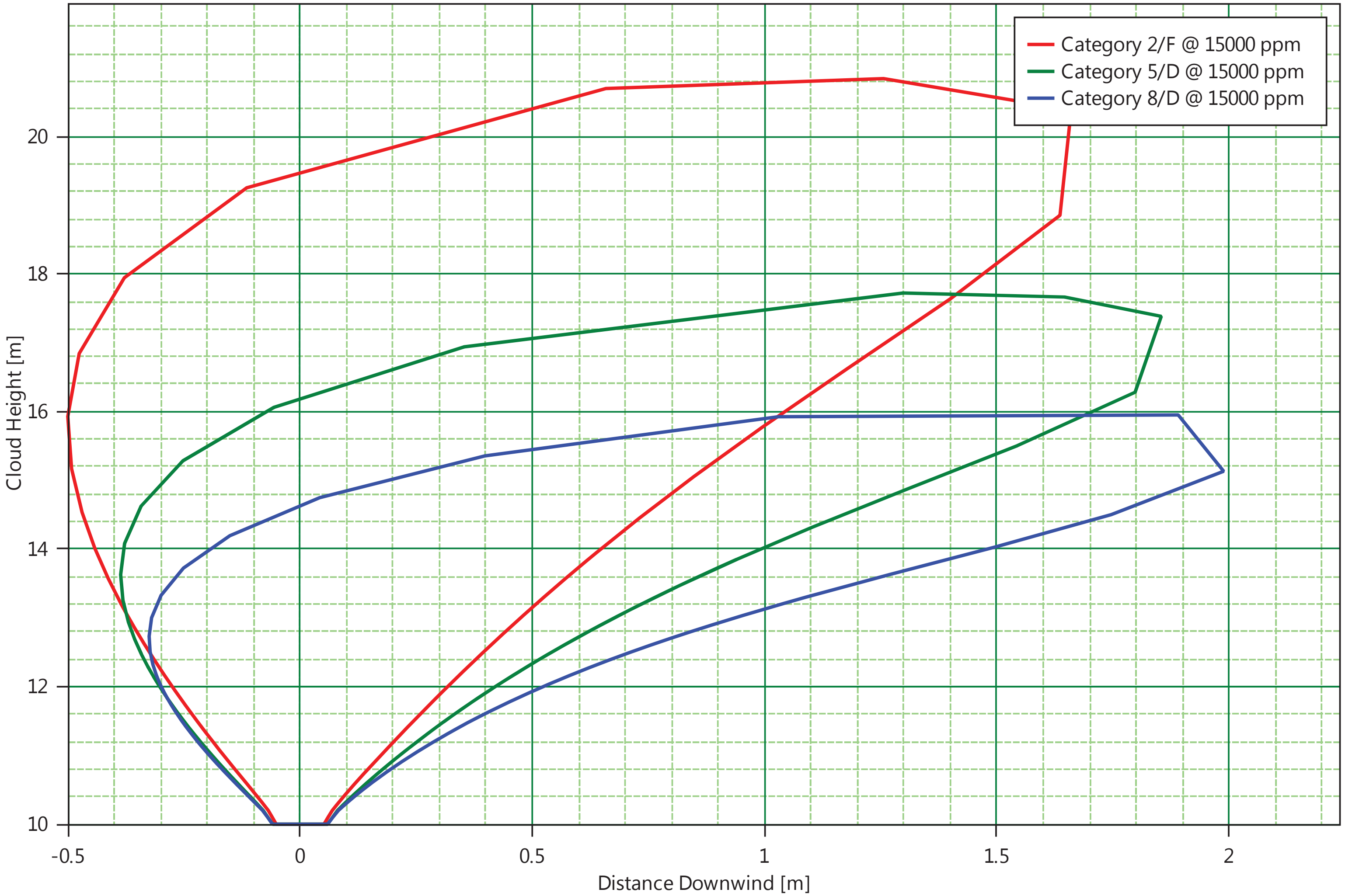
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.234935 s
Time (Category 2/F)	0.493007 s
Time (Category 5/D)	0.320413 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

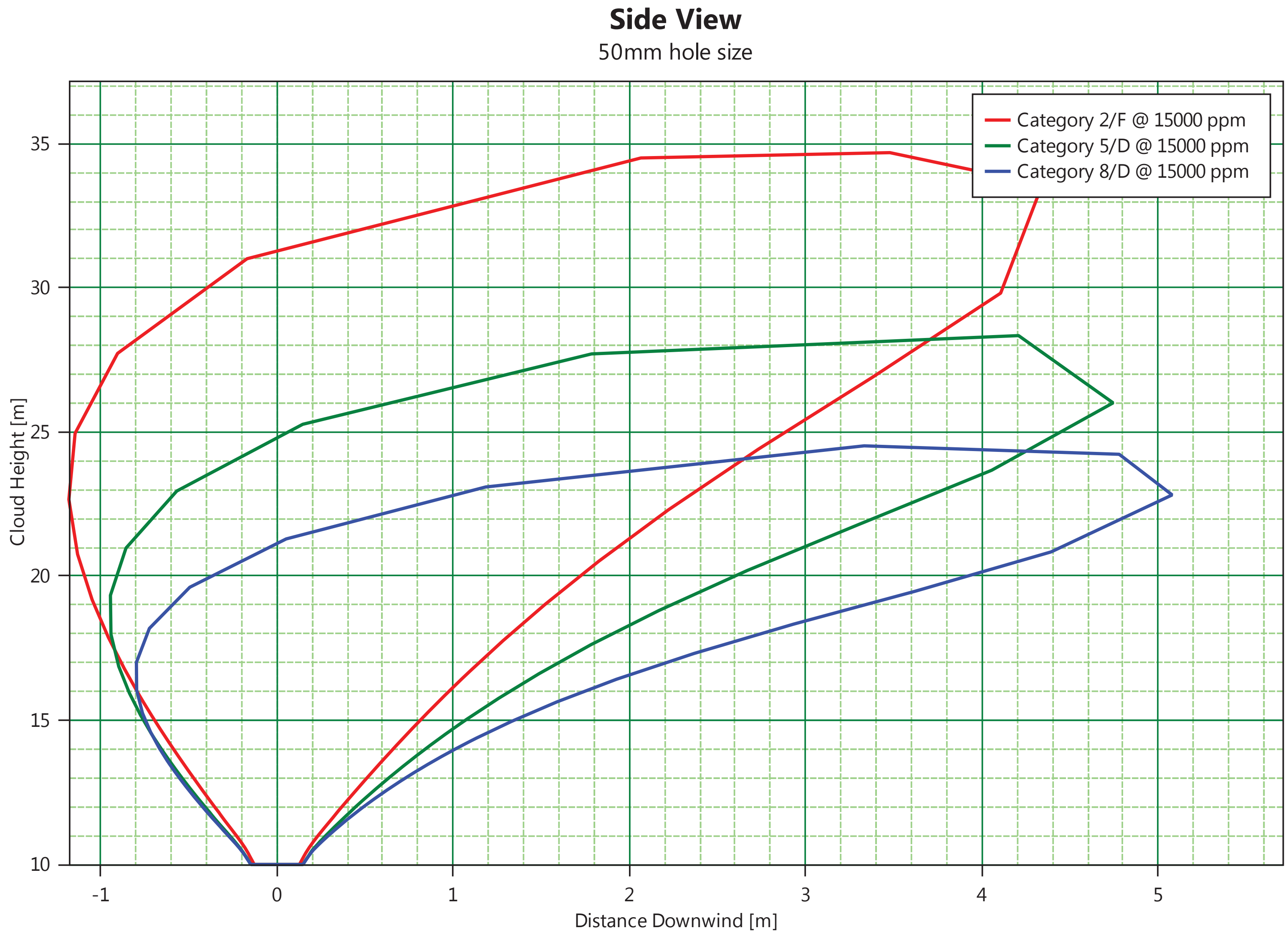
20mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

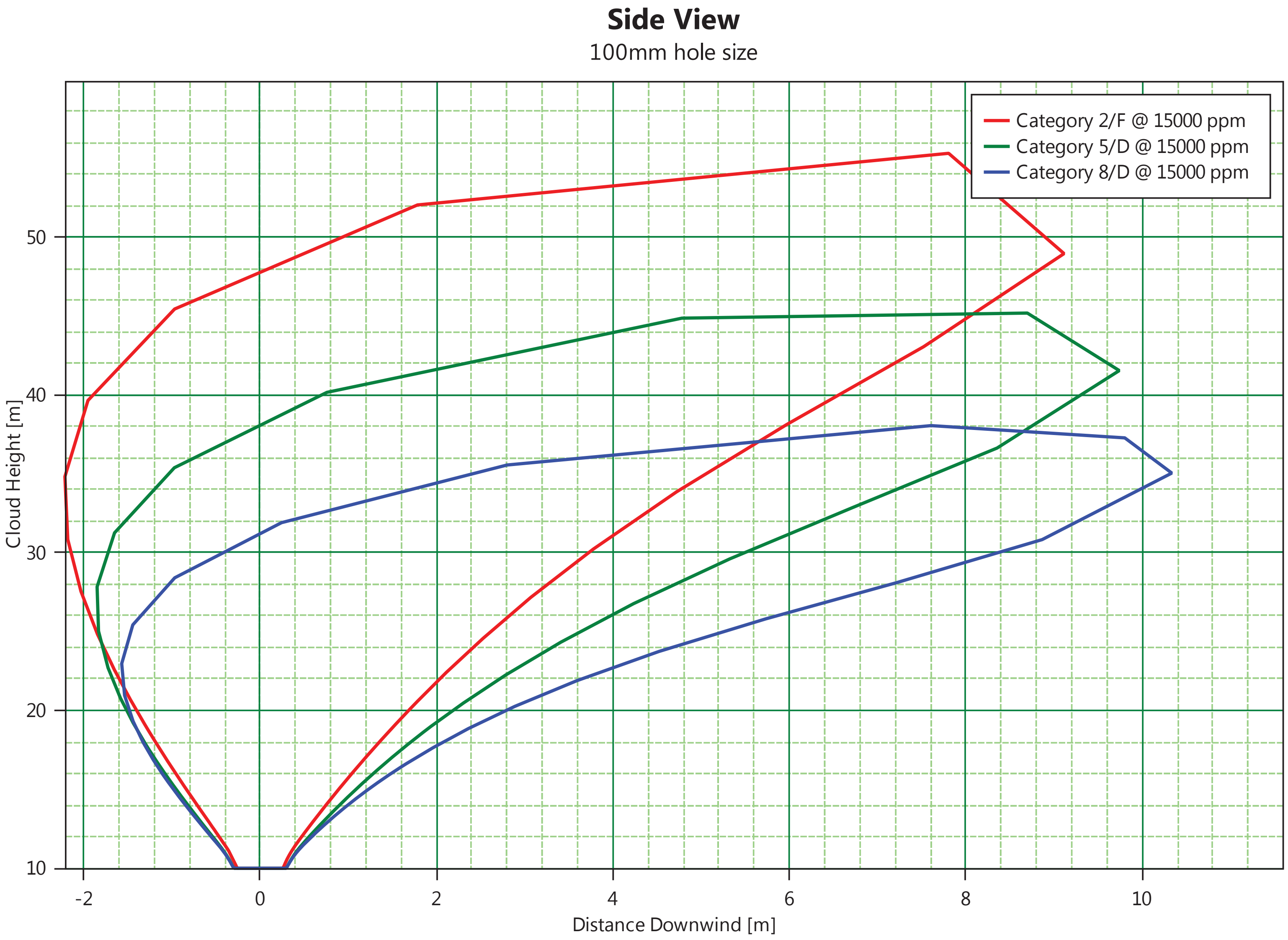
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO_2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.553861 s
Time (Category 2/F)	1.08331 s
Time (Category 5/D)	0.757041 s
Weather	Multiple Weather
Workspace	CO_2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

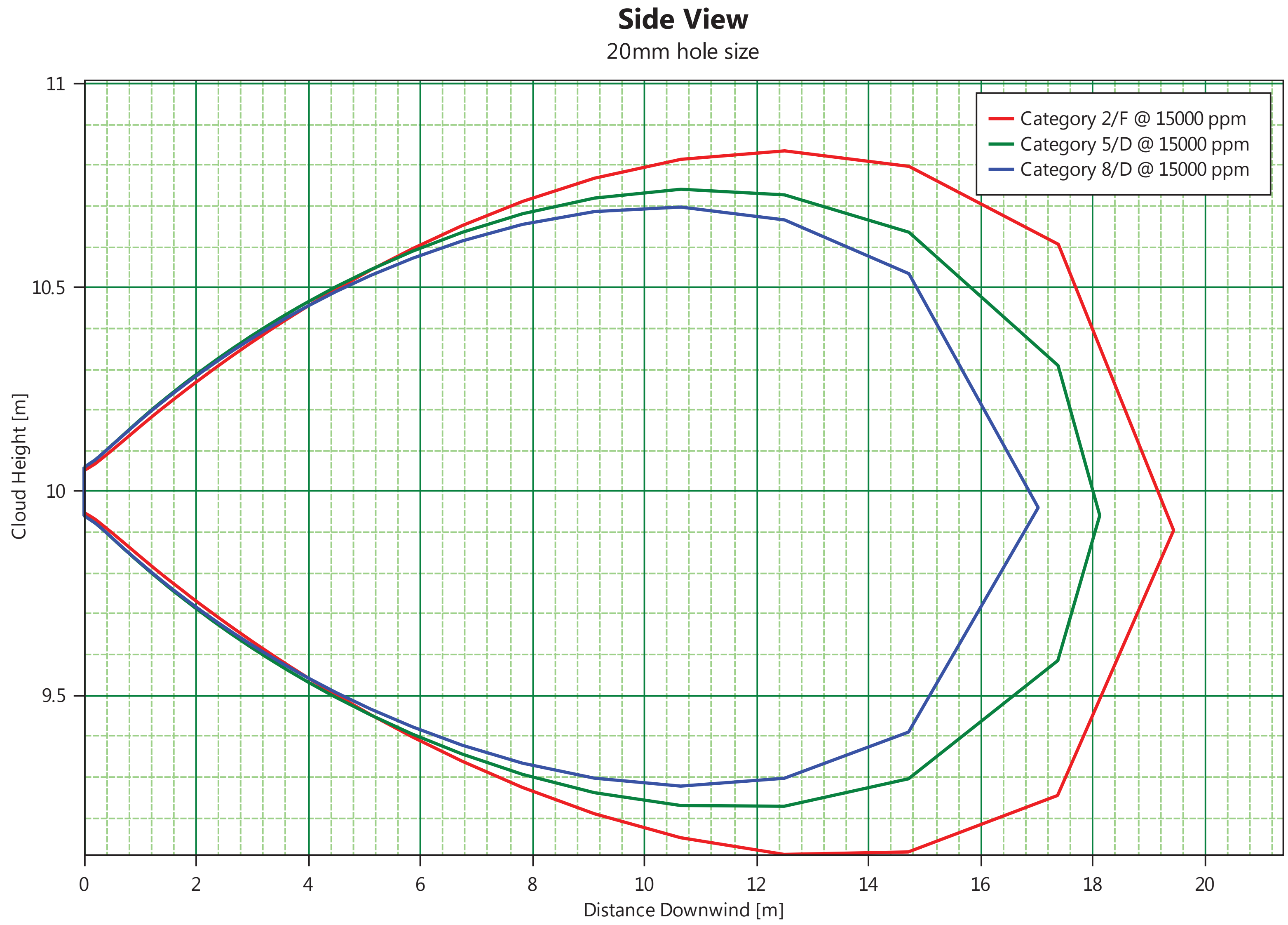
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	1.05302 s
Time (Category 2/F)	1.93943 s
Time (Category 5/D)	1.43995 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

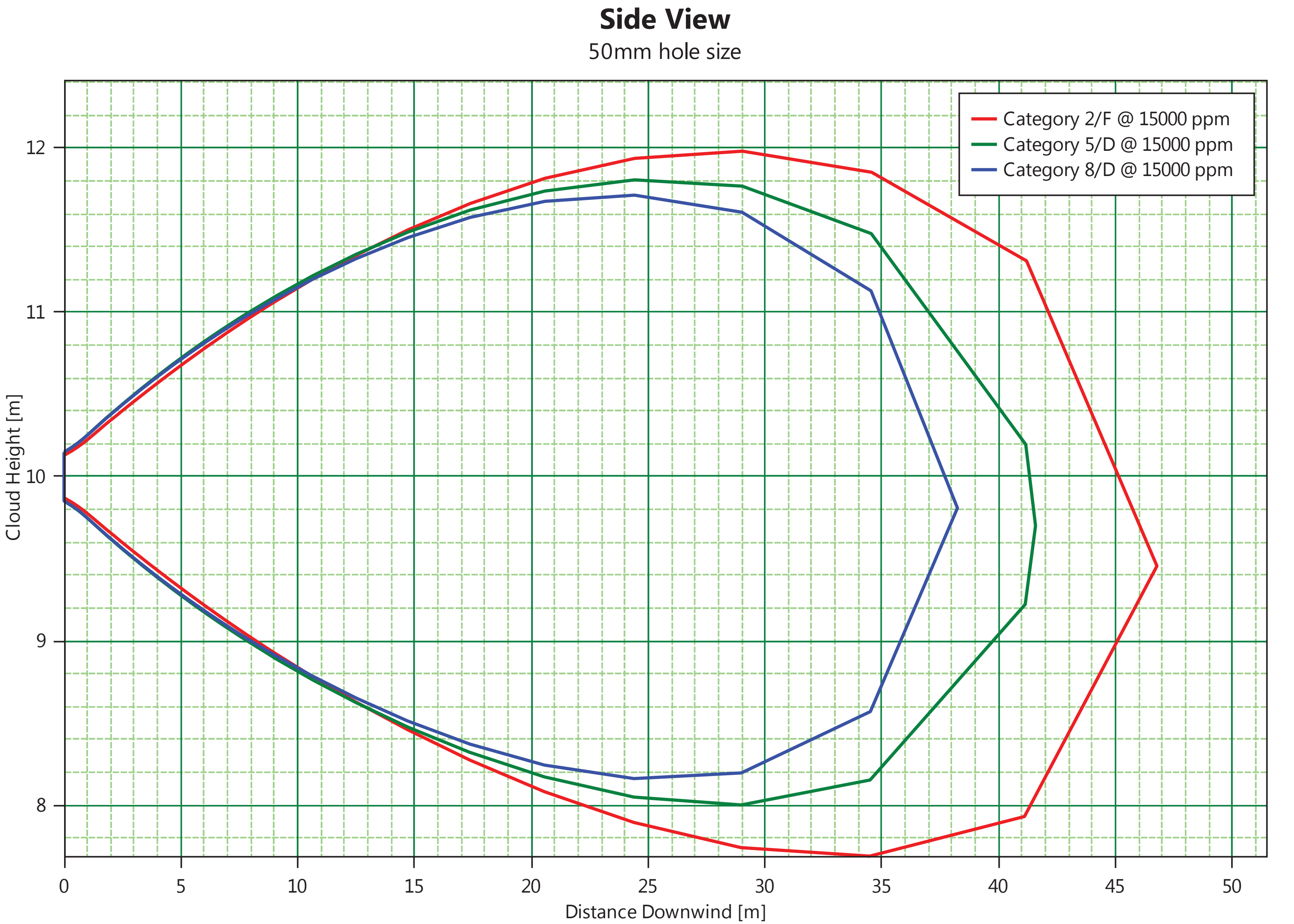
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.582264 s
Time (Category 2/F)	0.936974 s
Time (Category 5/D)	0.723117 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

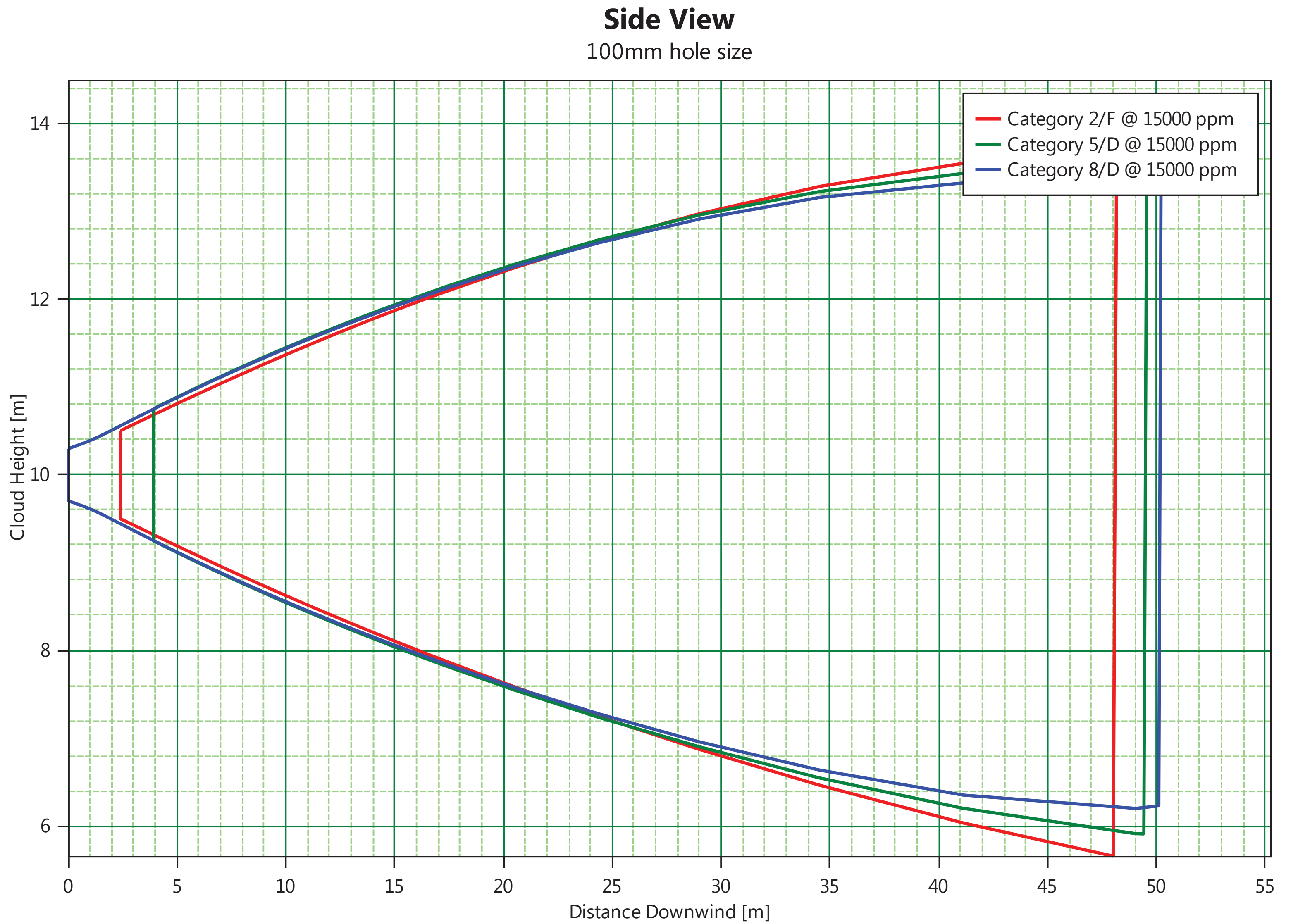
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.26777 s
Time (Category 2/F)	2.23878 s
Time (Category 5/D)	1.61338 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	1.21339 s
Time (Category 2/F)	1.23159 s
Time (Category 5/D)	1.23909 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

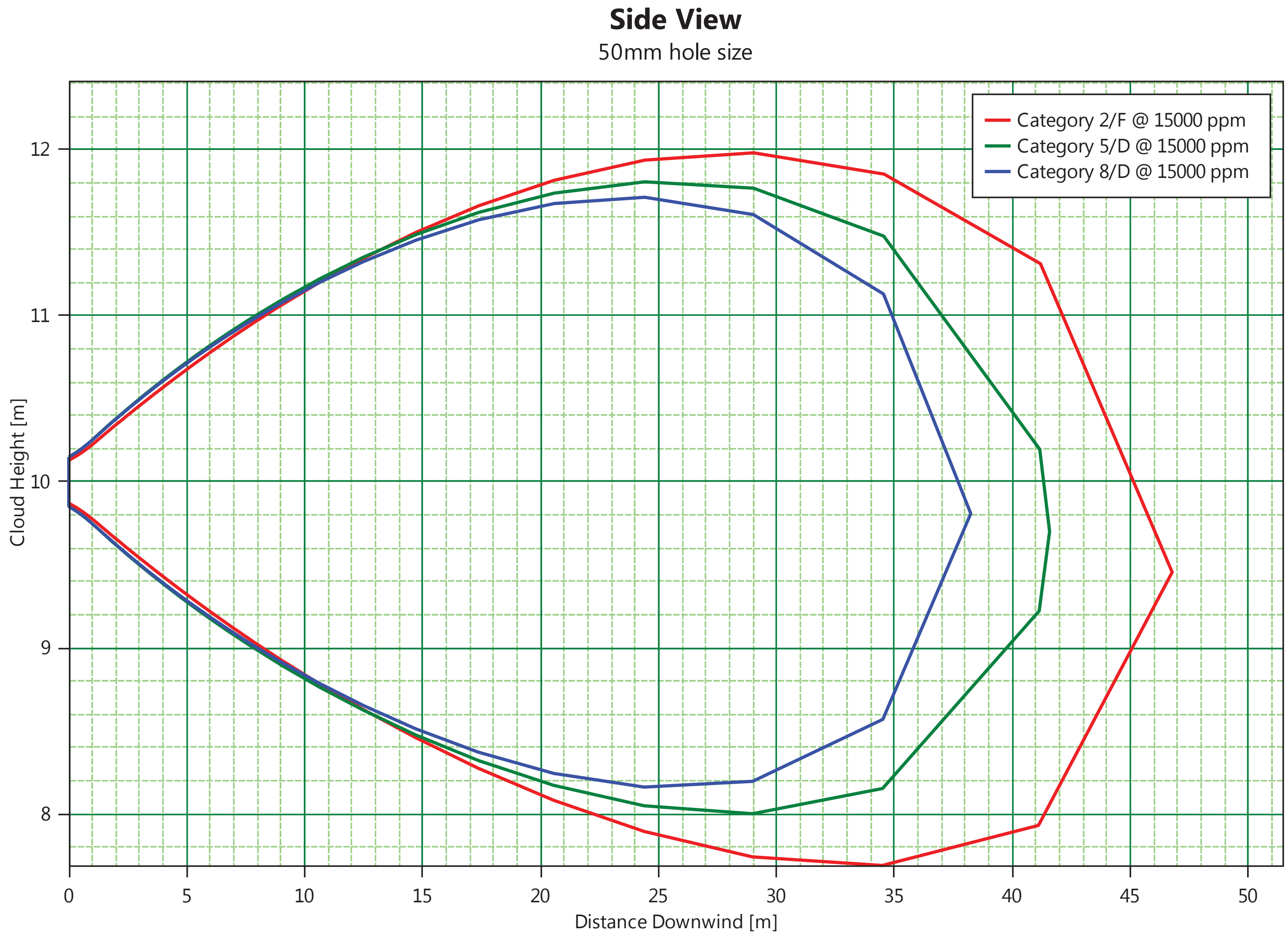
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.582264 s
Time (Category 2/F)	0.936974 s
Time (Category 5/D)	0.723117 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.26777 s
Time (Category 2/F)	2.23878 s
Time (Category 5/D)	1.61338 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

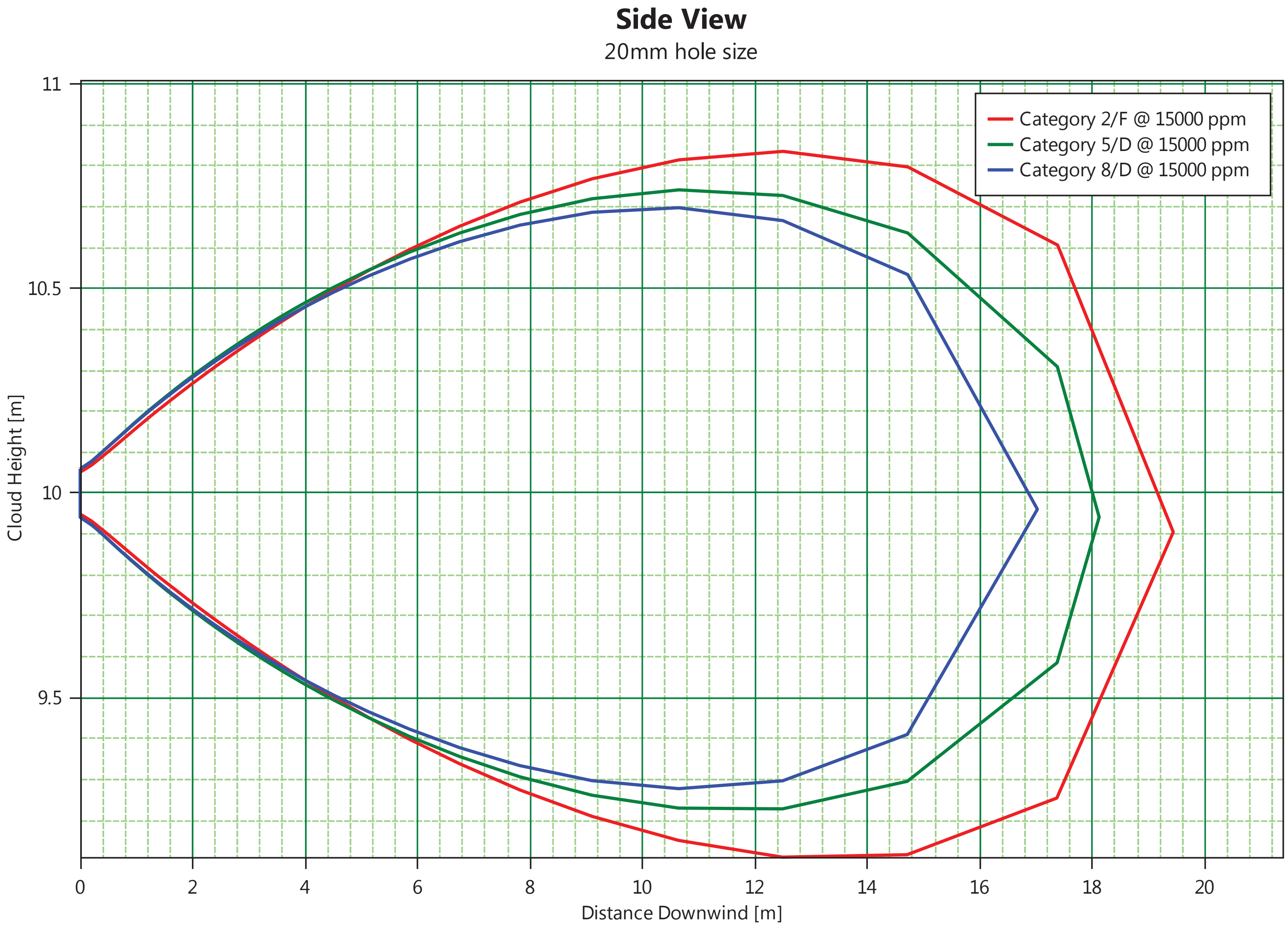
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	2.24355 s
Time (Category 2/F)	4.63354 s
Time (Category 5/D)	2.90702 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

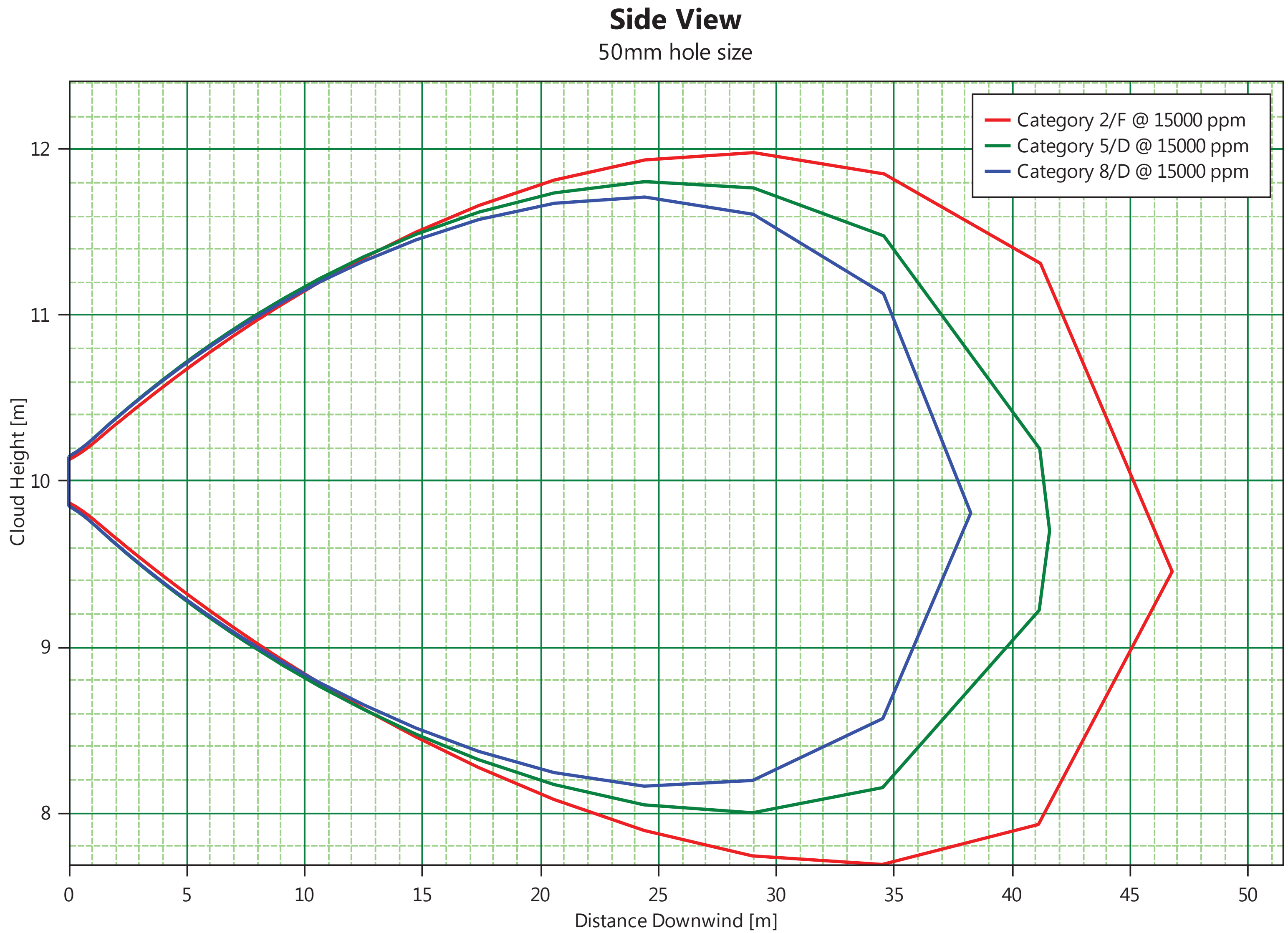
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.582264 s
Time (Category 2/F)	0.936974 s
Time (Category 5/D)	0.723117 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.26777 s
Time (Category 2/F)	2.23878 s
Time (Category 5/D)	1.61338 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



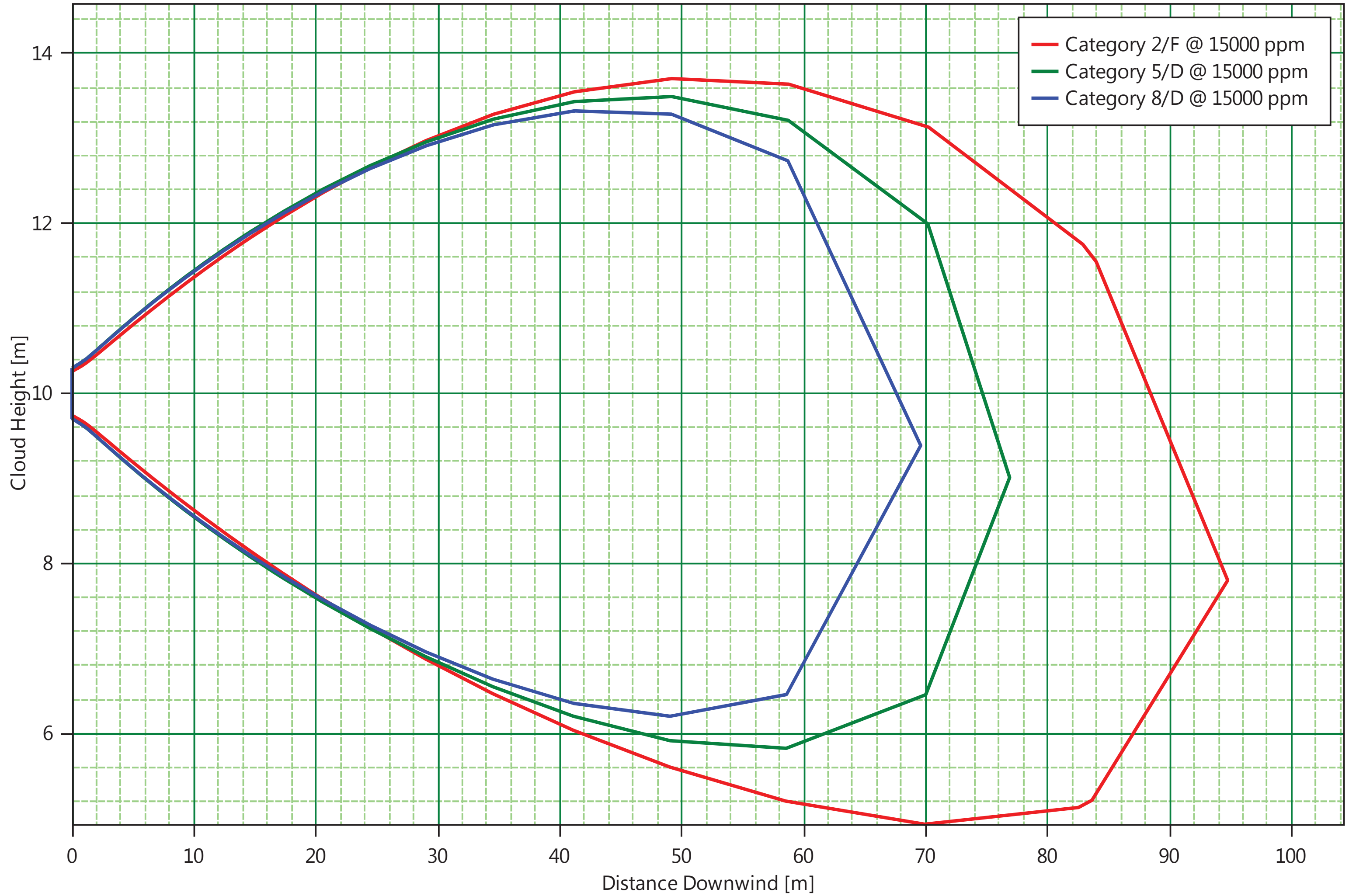
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	2.24355 s
Time (Category 2/F)	4.63354 s
Time (Category 5/D)	2.90702 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

100mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

A1.4. Case D Dispersion Graphs

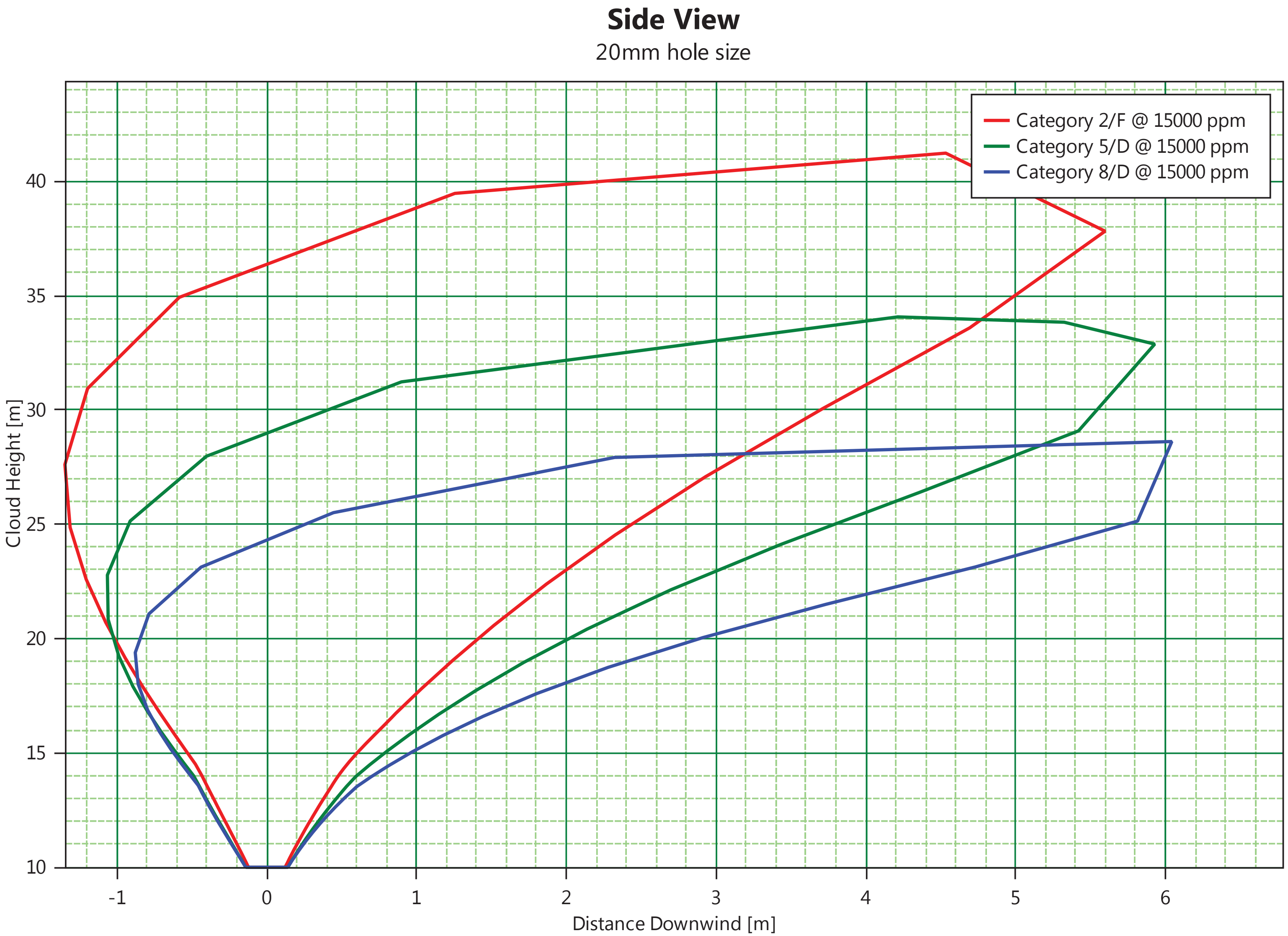
Case D - Vertical release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1

Case D - Horizontal release direction

Description	No. of Pages
100 kg CO_2, 20 mm hole size, side view	1
100 kg CO_2, 50 mm hole size, side view	1
100 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 20 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, side view	1
500 kg CO_2, 50 mm hole size, maximum concentration footprint	1
500 kg CO_2, 100 mm hole size, side view	1
500 kg CO_2, 100 mm hole size, maximum concentration footprint	1
1000 kg CO_2, 20 mm hole size, side view	1
1000 kg CO_2, 50 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, side view	1
1000 kg CO_2, 100 mm hole size, maximum concentration footprint	1

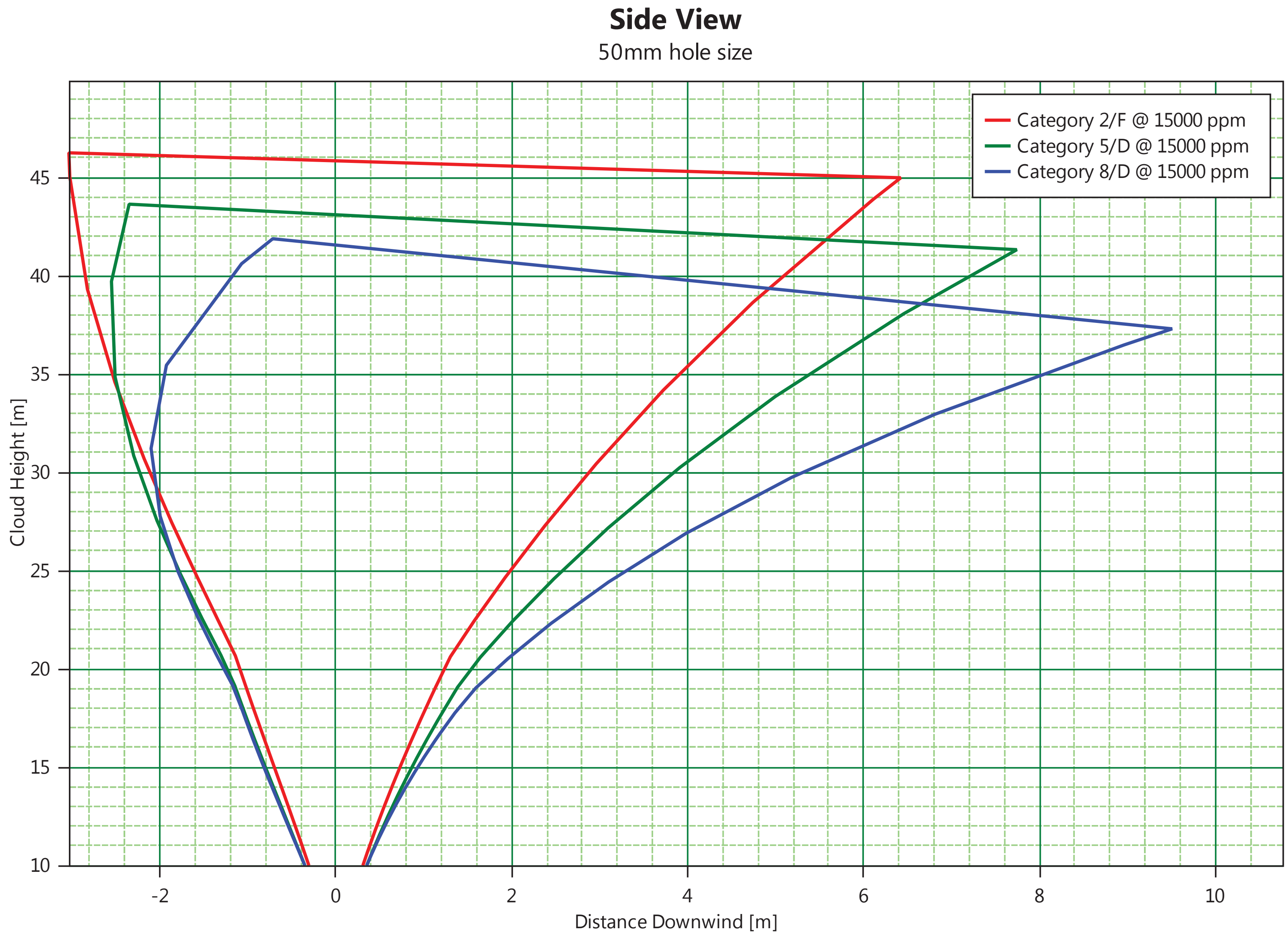
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.680943 s
Time (Category 2/F)	1.29493 s
Time (Category 5/D)	0.929307 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

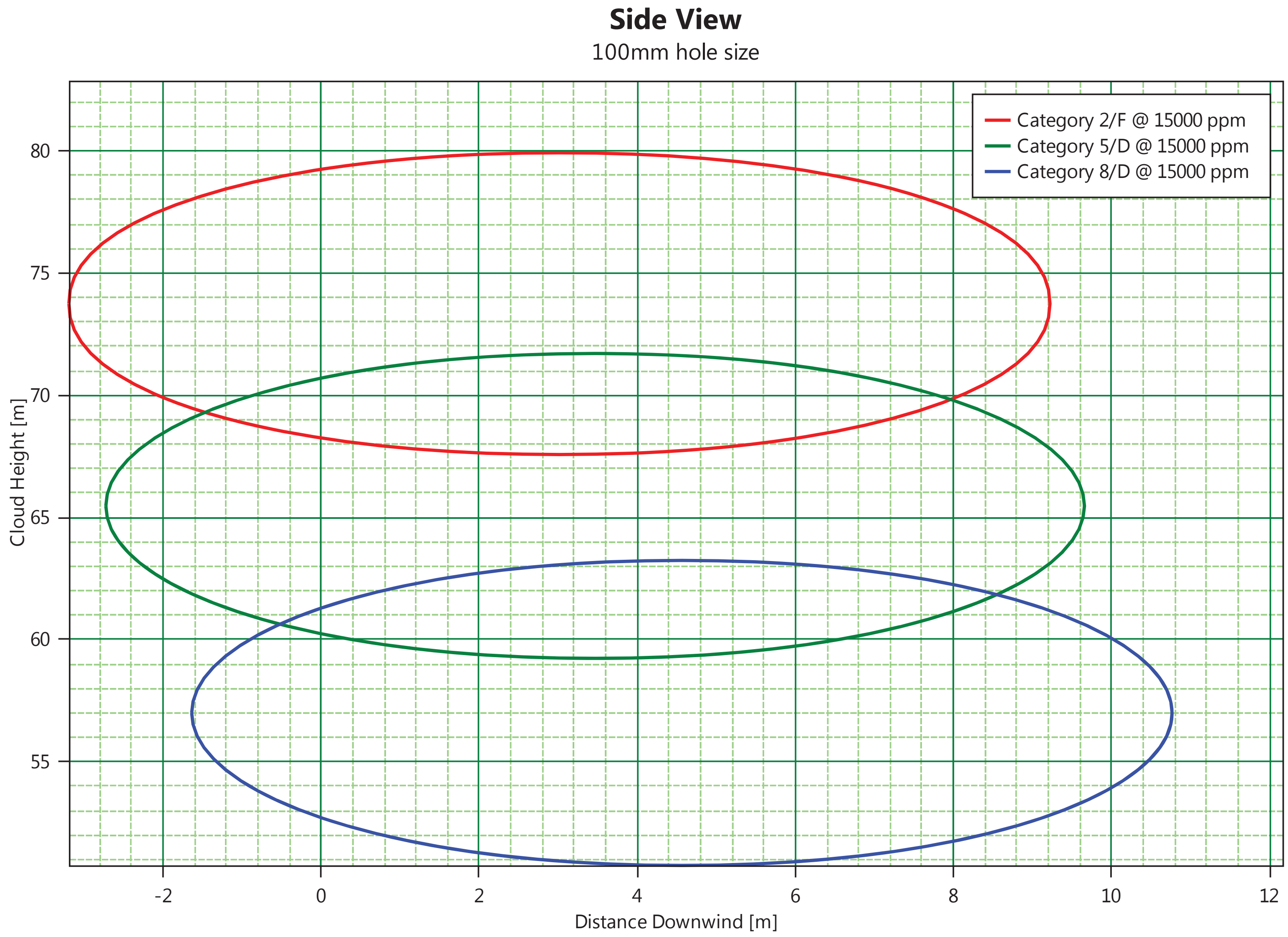
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.505091 s
Time (Category 2/F)	0.507583 s
Time (Category 5/D)	0.499208 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.579764 s
Time (Category 2/F)	0.780248 s
Time (Category 5/D)	0.676923 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

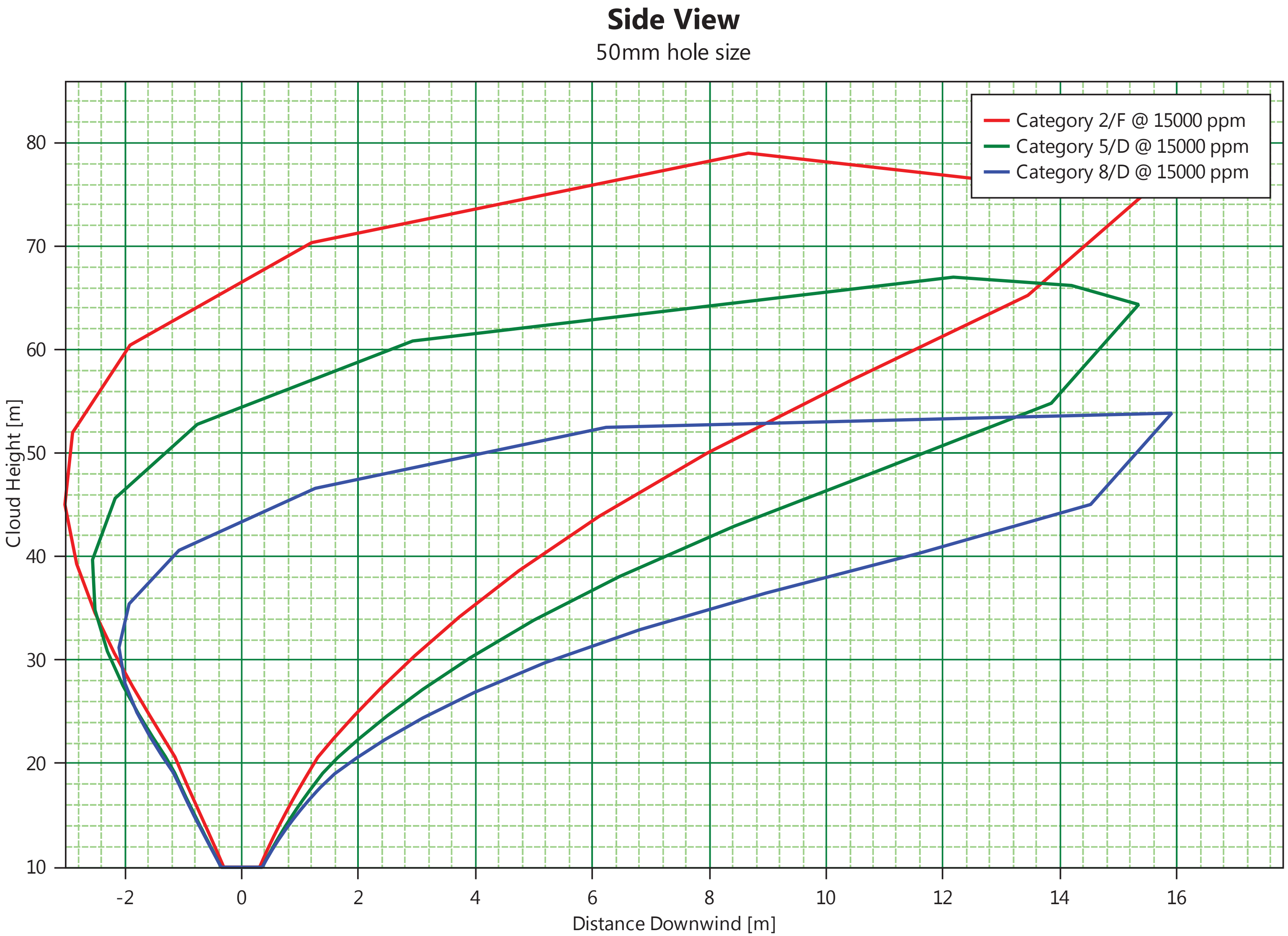
Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.680943 s
Time (Category 2/F)	1.29493 s
Time (Category 5/D)	0.929307 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

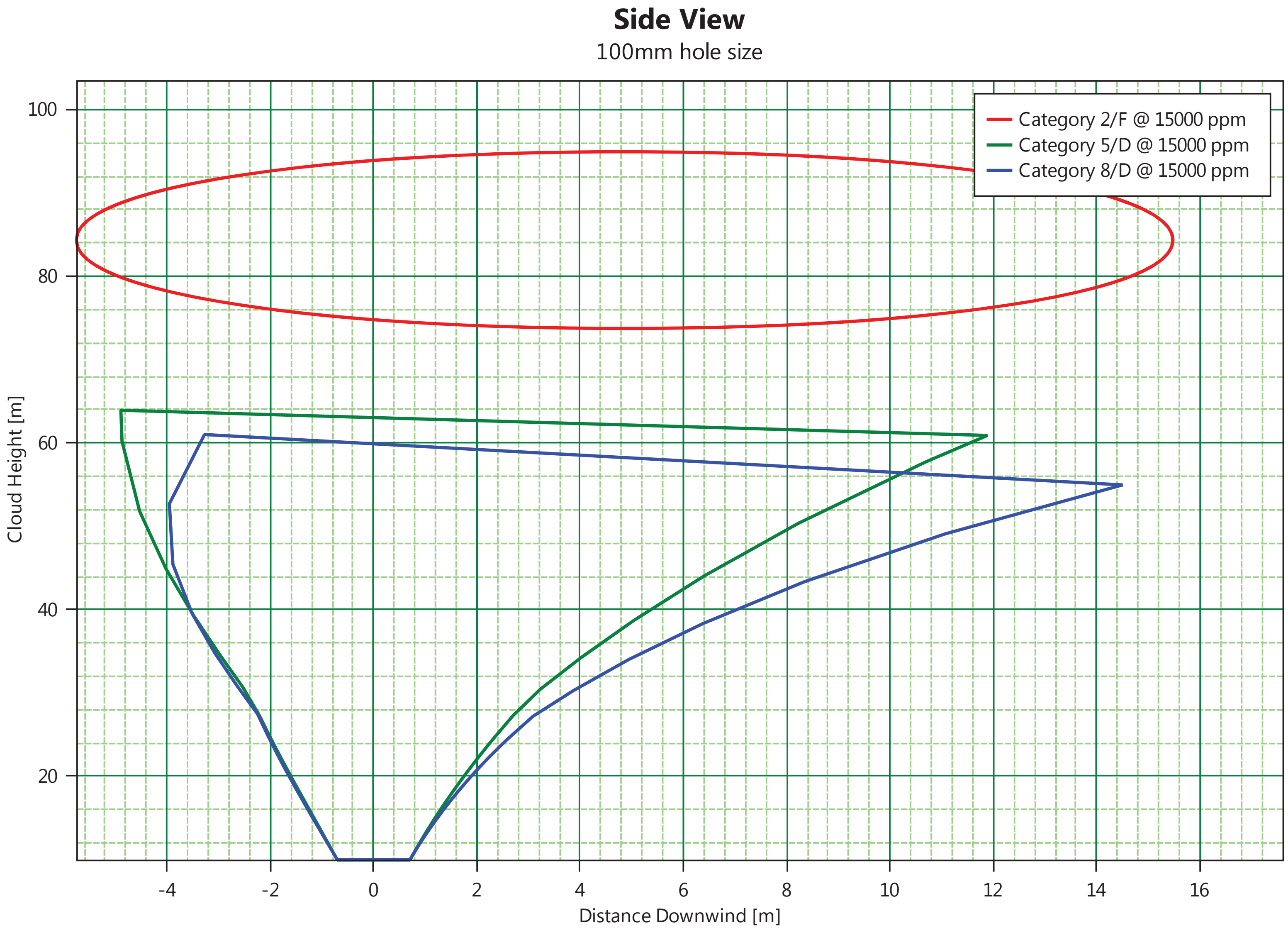
Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.59582 s
Time (Category 2/F)	2.53985 s
Time (Category 5/D)	2.18726 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.626686 s
Time (Category 2/F)	1.3095 s
Time (Category 5/D)	0.627844 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



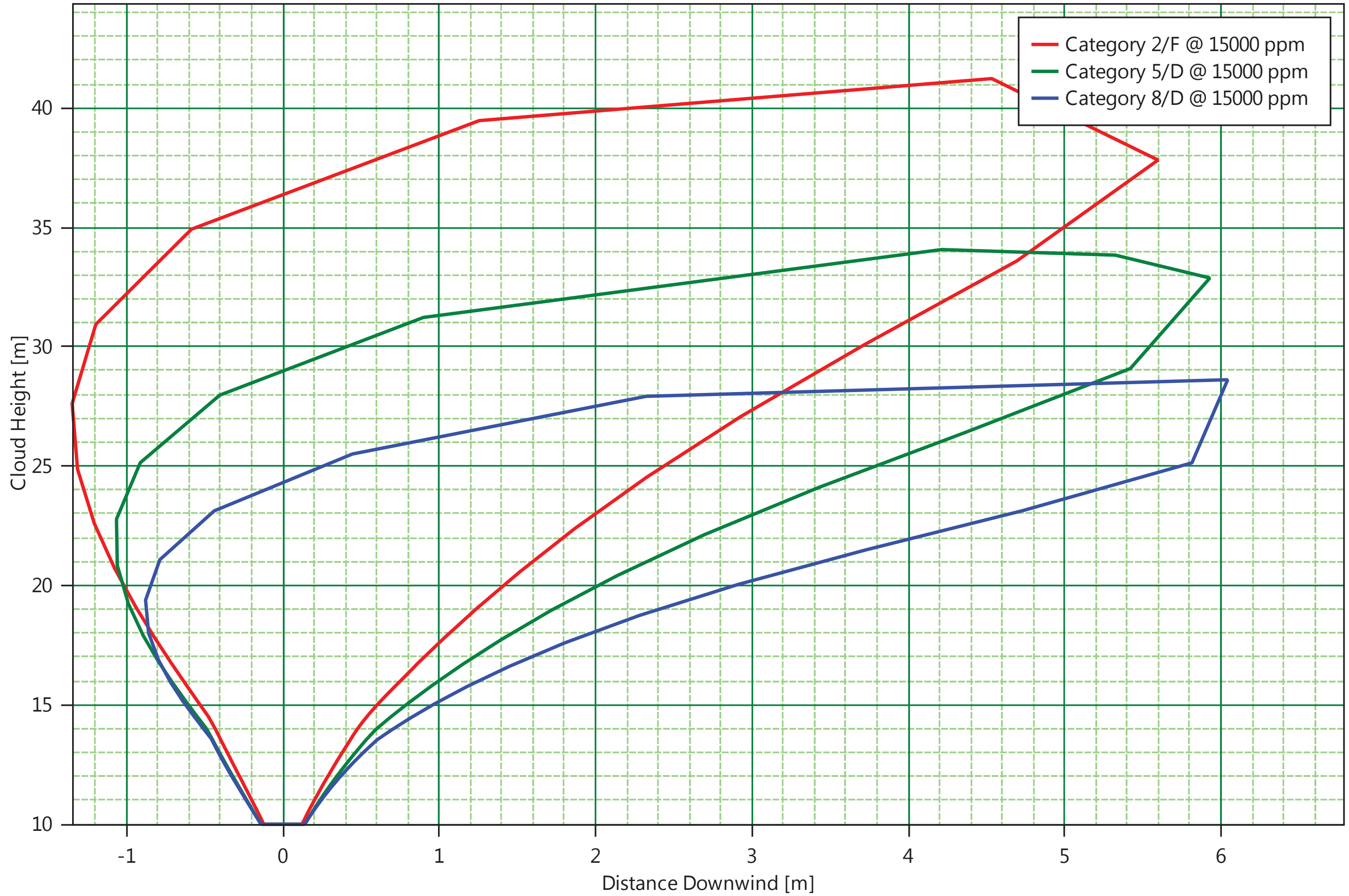
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	0.680943 s
Time (Category 2/F)	1.29493 s
Time (Category 5/D)	0.929307 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

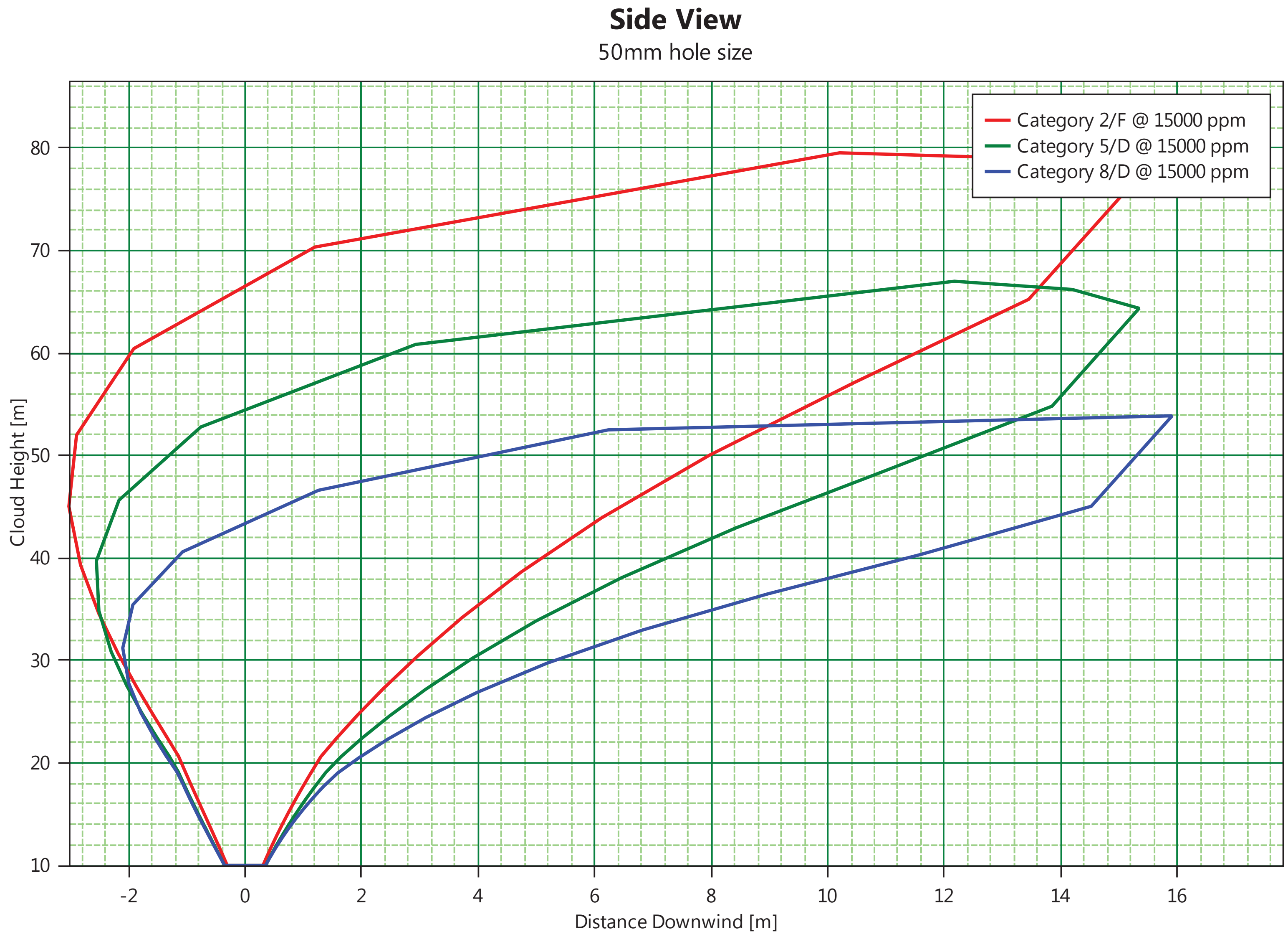
20mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	1.59582 s
Time (Category 2/F)	2.79299 s
Time (Category 5/D)	2.18726 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



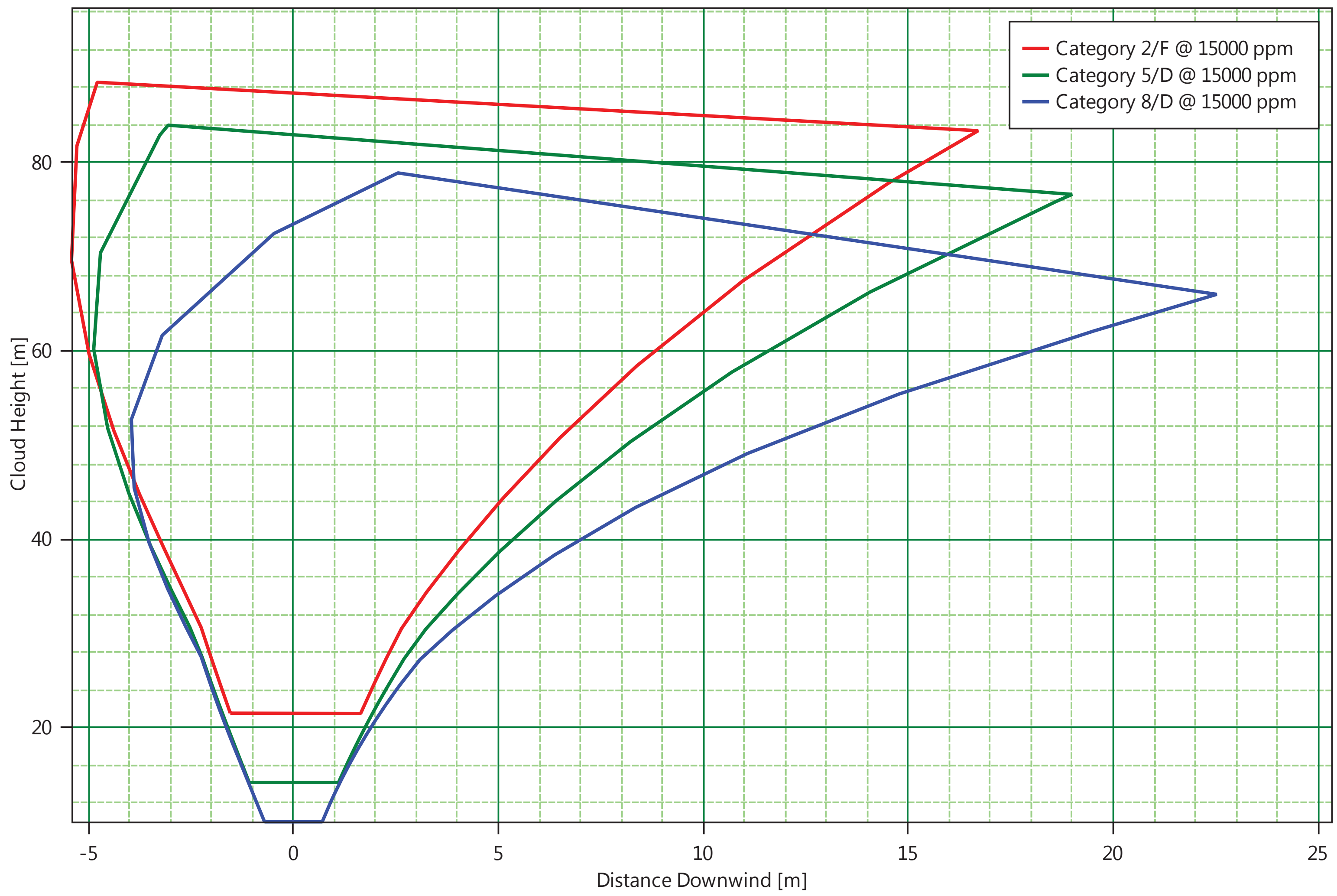
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	24784
Audit Date/Time	12/08/2014 08:51:17
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	1.2538 s
Time (Category 2/F)	1.31302 s
Time (Category 5/D)	1.28226 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

100mm hole size



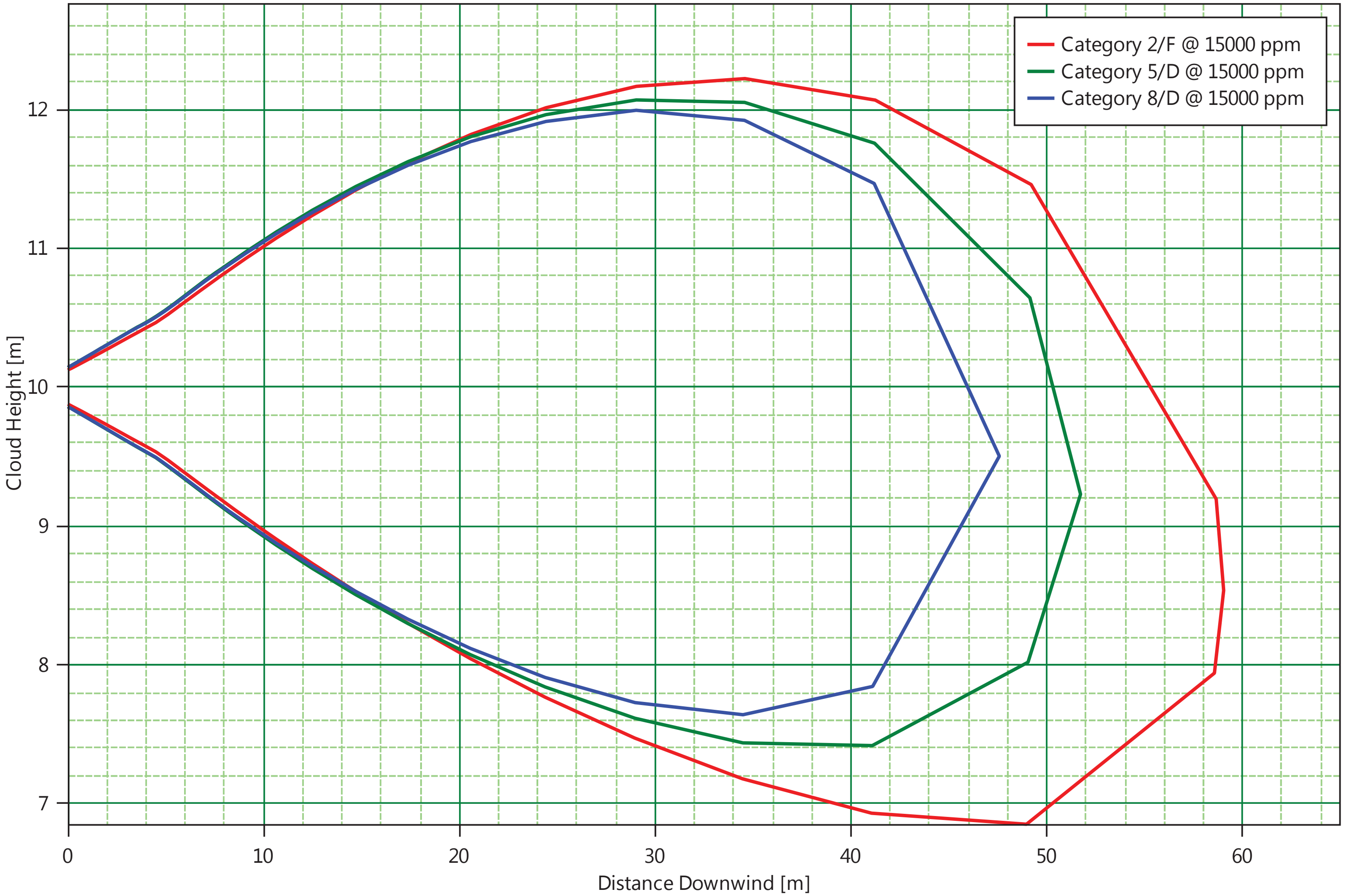
C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	1.50137 s
Time (Category 2/F)	2.70401 s
Time (Category 5/D)	1.90701 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

Side View

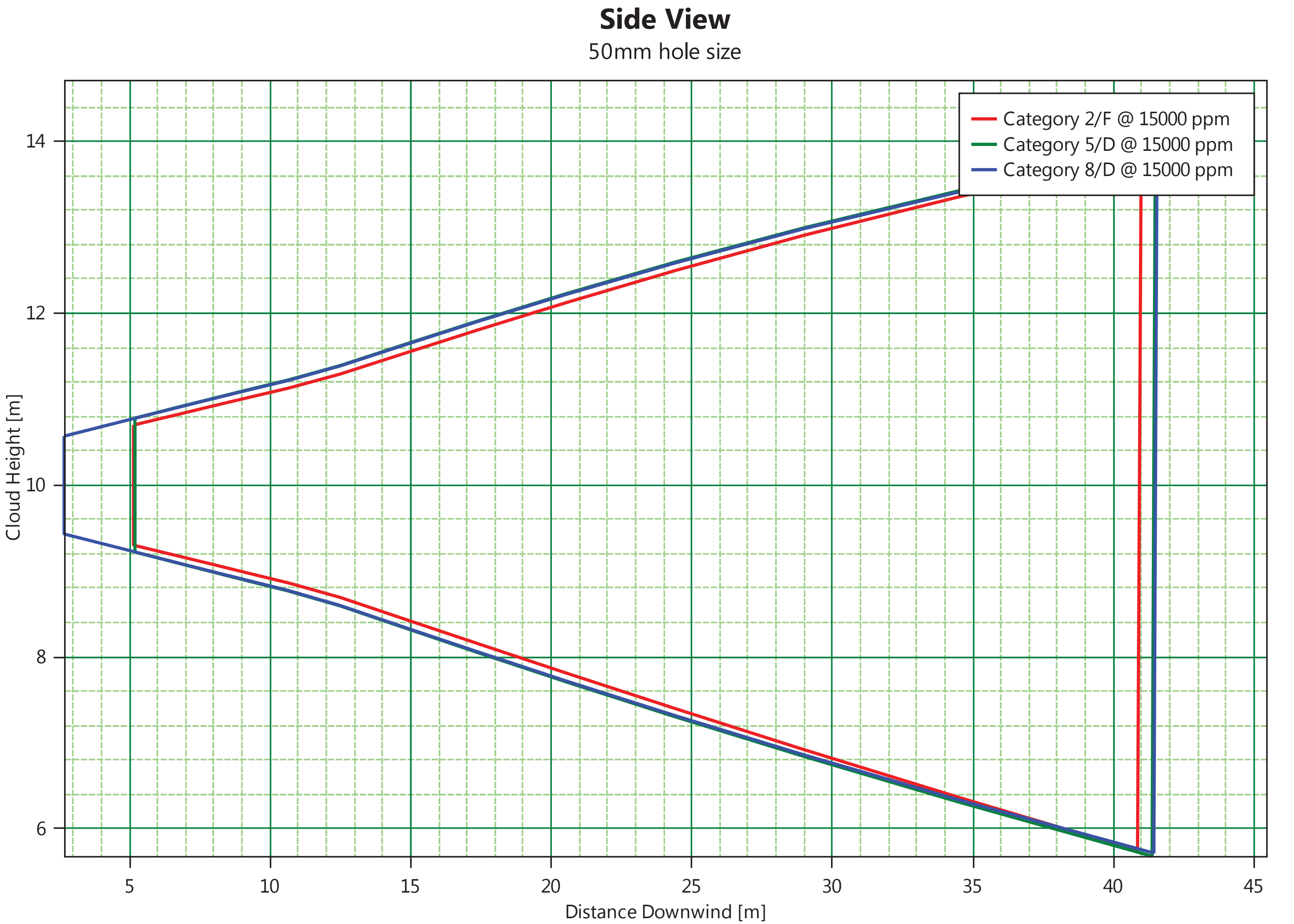
20mm hole size



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

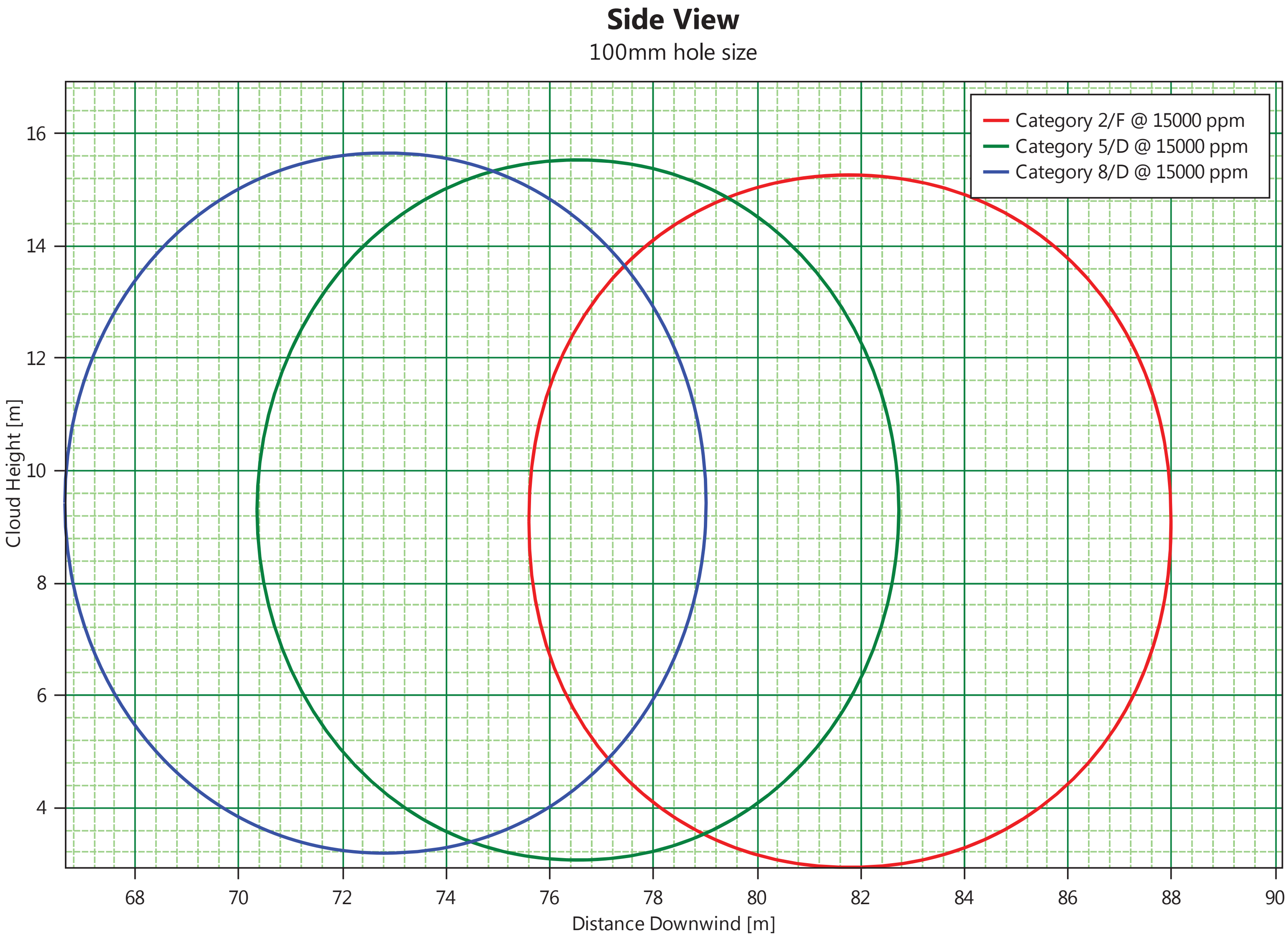
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	0.516014 s
Time (Category 2/F)	0.526051 s
Time (Category 5/D)	0.526234 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

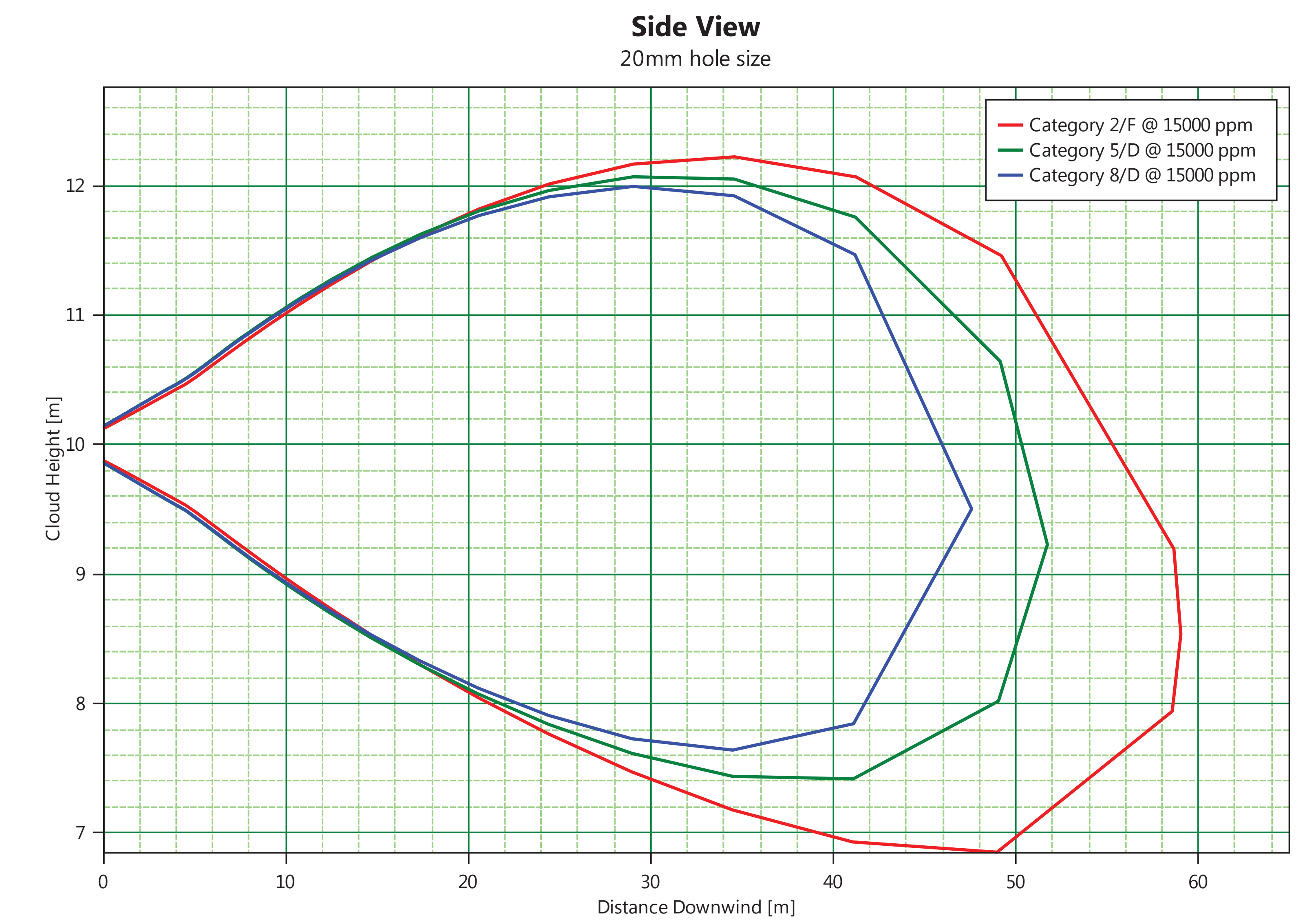
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	100kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	0.906773 s
Time (Category 2/F)	1.16682 s
Time (Category 5/D)	1.01019 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

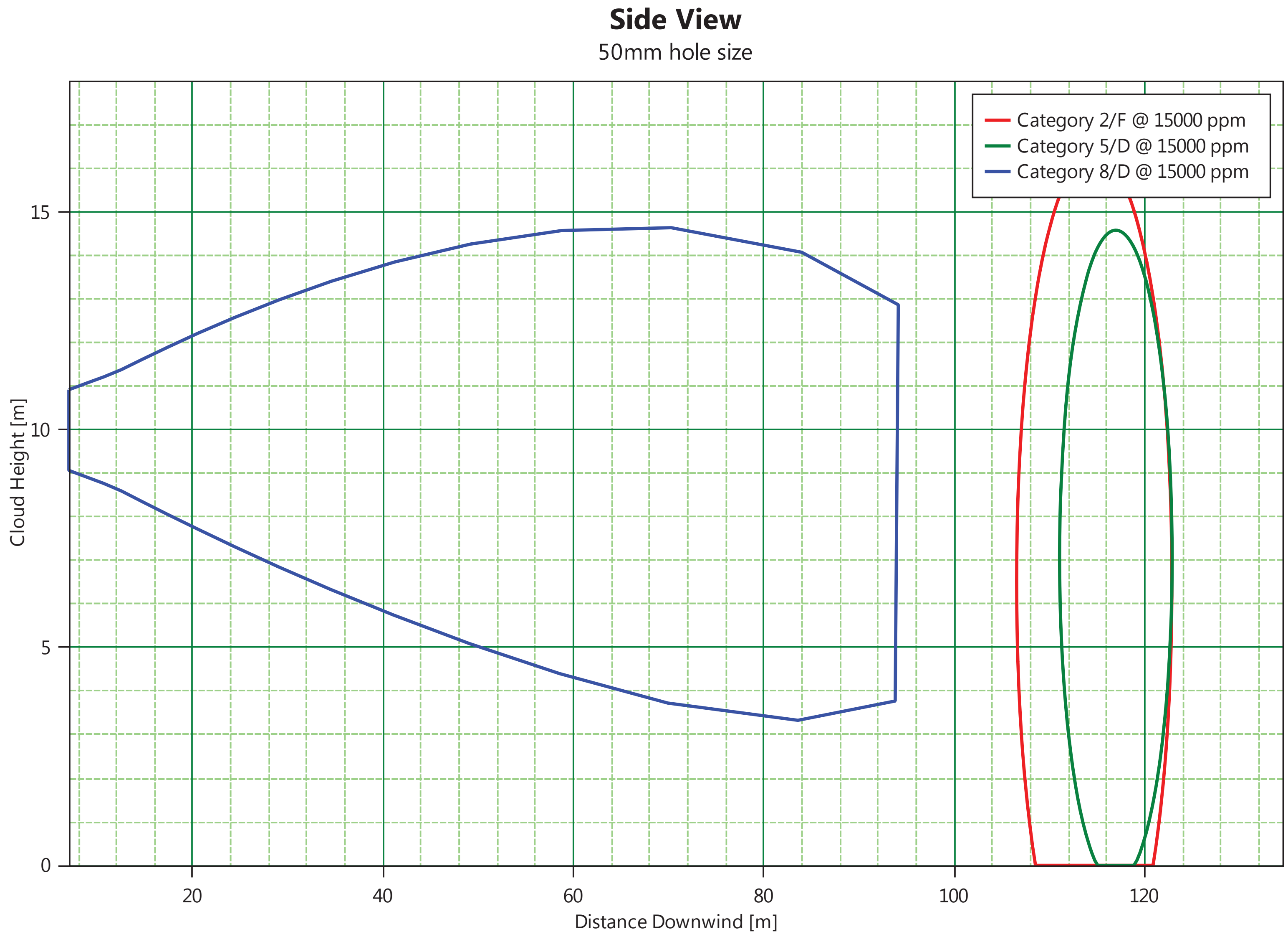
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	1.50137 s
Time (Category 2/F)	2.70401 s
Time (Category 5/D)	1.90701 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	2.56691 s
Time (Category 2/F)	5.31764 s
Time (Category 5/D)	5.32563 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

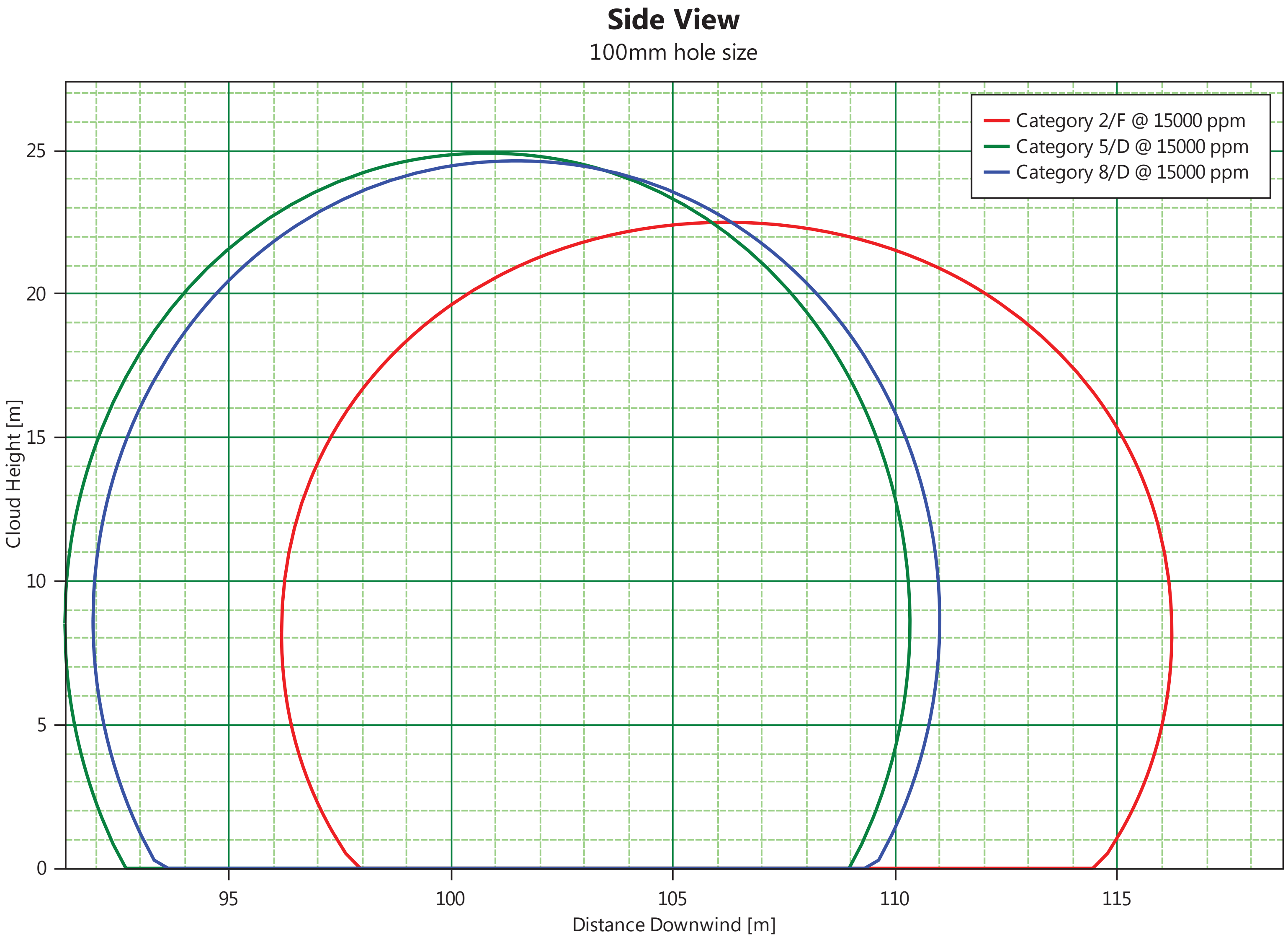
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Height of Interest	0 m
Material	CARBON DIOXIDE
Program	Phast 7.01
Scenario	50mm hole size
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

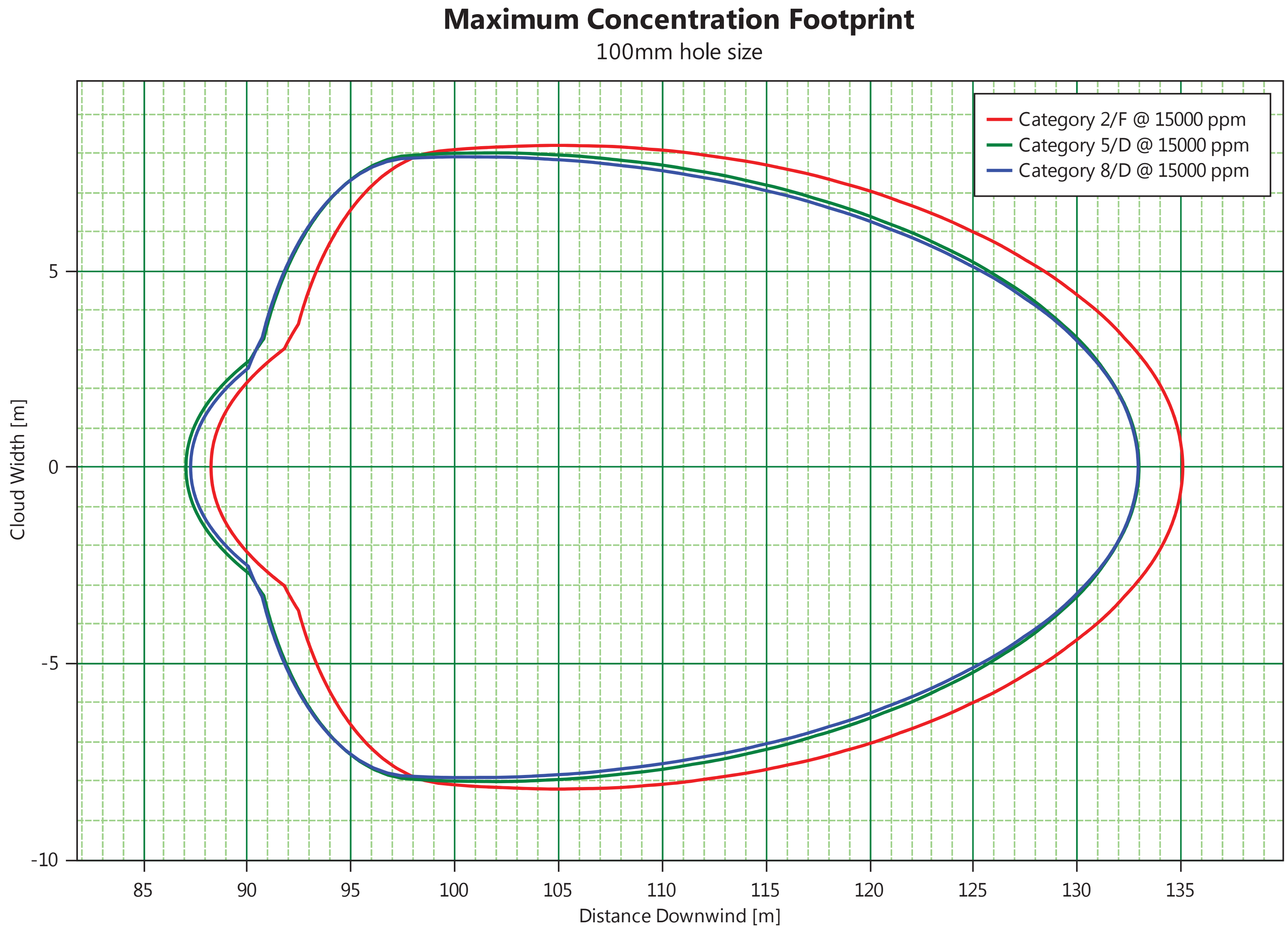
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	1.87489 s
Time (Category 2/F)	2.06437 s
Time (Category 5/D)	1.88078 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	500kg CO2
Height of Interest	0 m
Material	CARBON DIOXIDE
Program	Phast 7.01
Scenario	100mm hole size
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

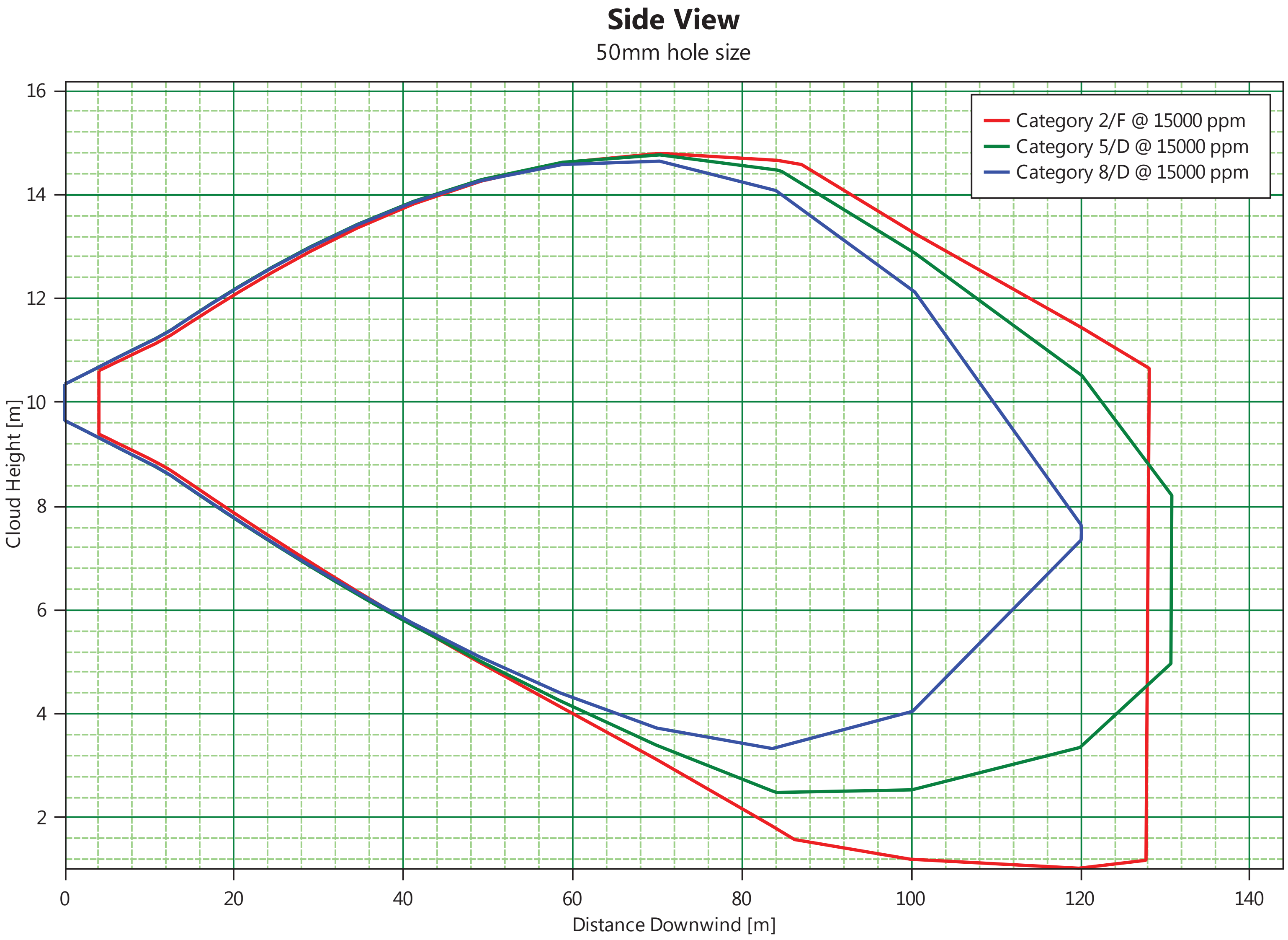
Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	20mm hole size
Time (Category 8/D)	1.50137 s
Time (Category 2/F)	2.70401 s
Time (Category 5/D)	1.90701 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm

C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

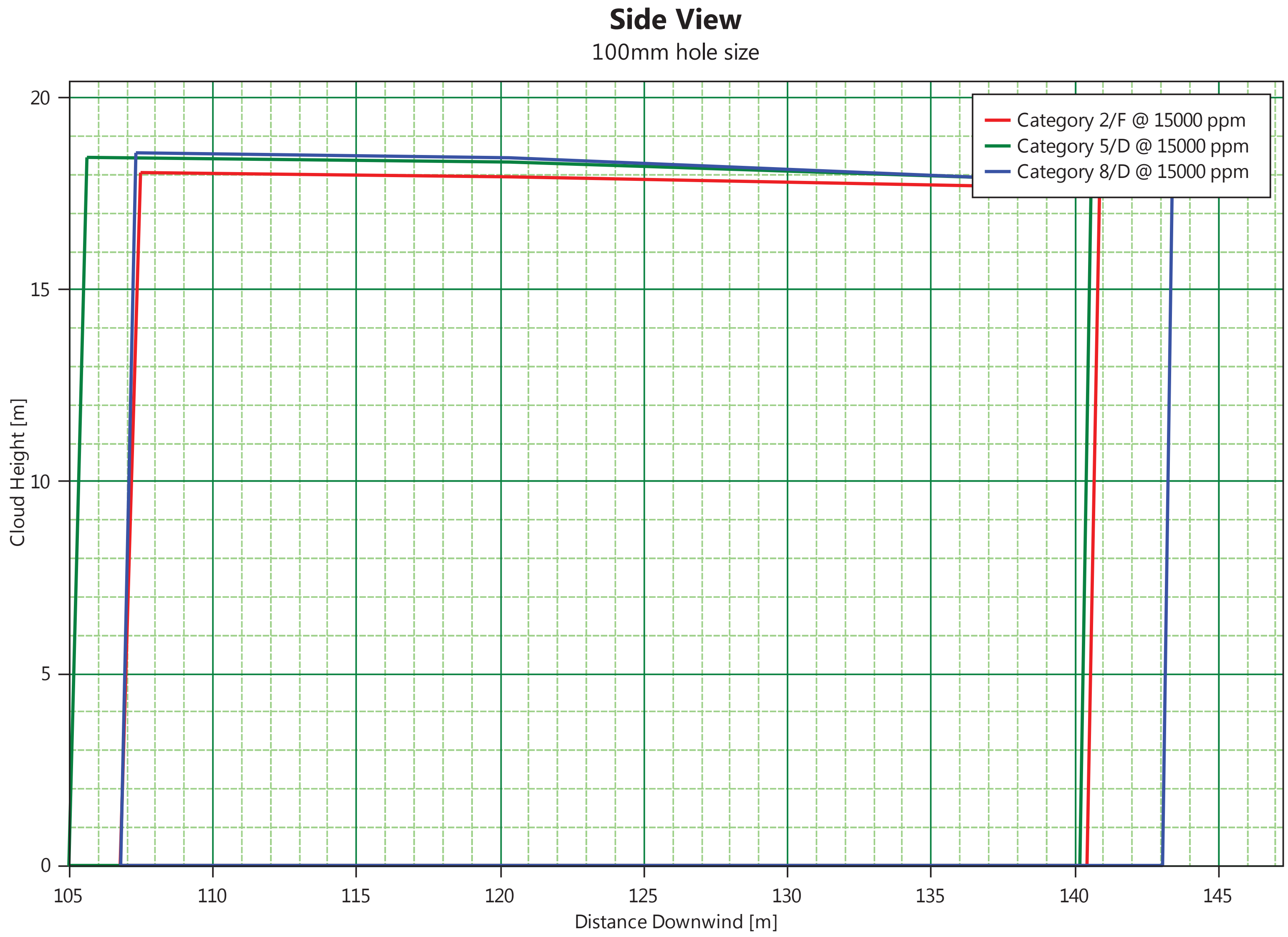
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	50mm hole size
Time (Category 8/D)	4.04198 s
Time (Category 2/F)	5.09288 s
Time (Category 5/D)	5.06108 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

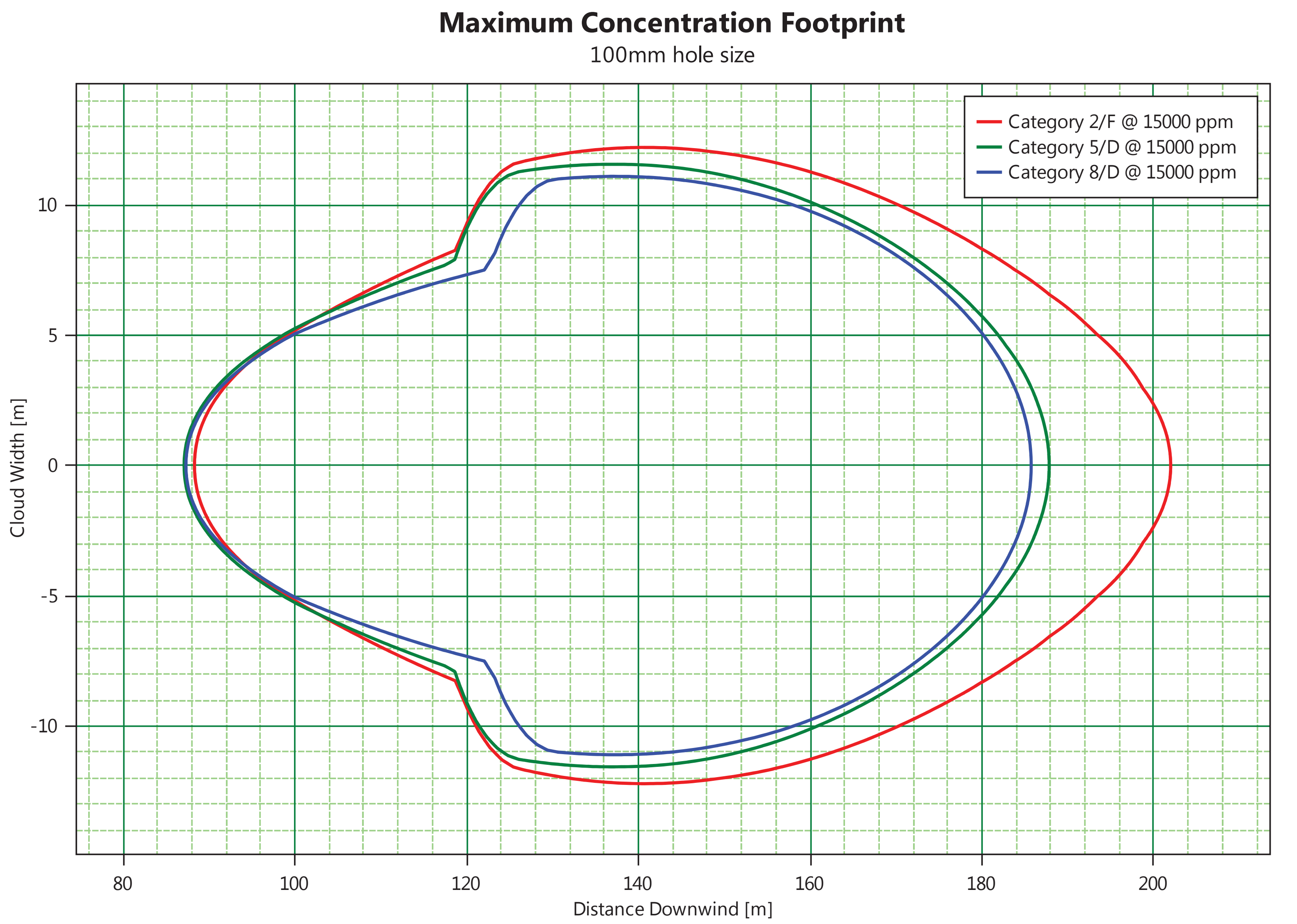
Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Material	CARBON DIOXIDE
Offset Distance	0 m
Program	Phast 7.01
Scenario	100mm hole size
Time (Category 8/D)	3.02119 s
Time (Category 2/F)	3.06794 s
Time (Category 5/D)	2.99255 s
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

Audit Number	20826
Audit Date/Time	12/08/2014 10:01:39
Averaging Time	User-defined (3600 s)
Equipment	1,000kg CO2
Height of Interest	0 m
Material	CARBON DIOXIDE
Program	Phast 7.01
Scenario	100mm hole size
Weather	Multiple Weather
Workspace	CO2 Dispersion Calculations - 15000ppm



C/L Conc. | Conc. vs Time | Footprint | Side View | Cross Section | Max. Concentration

Dispersion

APPENDIX 4. PCCS Goldeneye Relief and Blowdown Report (PCCS-04-PTD-PX-7741-00001)

Peterhead CCS Project

Doc Title: PCCS Goldeneye Relief and Blowdown Report

Doc No.: **PCCS-04-PTD-PX-7741-00001**
Date of issue: **28/05/2015**
Revision: **K03**
DECC Ref No: **11.037**
Knowledge Cat: **KKD - Technical**

KEYWORDS
Goldeneye, CO_2, Carbon Capture and Storage, Blowdown, Venting, Dispersion.

Produced by Shell U.K. Limited
ECCN: EAR 99 Deminimus

IMPORTANT NOTICE

Information provided further to UK CCS Commercialisation Programme (the **Competition**)

The information set out herein (the **Information**) has been prepared by Shell U.K. Limited and its sub-contractors (the **Consortium**) solely for the Department for Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Table of Contents

Table of Figures

List of Tables

1. Introduction

1.1. Summary

This document describes the design of the relief, vent and depressuring systems that will be provided on the Goldeneye Platform for the Peterhead Carbon Capture and Storage (PCCS) Project.

The scope of this document covers the following main aspects:

1. Injection of the CO_2 into the depleted Goldeneye gas/condensate field.
2. Receipt and handling of pipeline inspection pigs
3. Provide methanol for SSSV equalisation and other down-hole requirements. The methanol is delivered by pipeline from St Fergus using existing facilities converted for the new duty.

1.2. Document Objectives

The objective of the work is to produce a report describing the relief and vent system design and highlighting any areas of further design development required in the detailed design phase of the project. This would include:

1. Determination of the facilities required to dispose of relieved and vented fluids in a safe and reliable manner.
2. Release dispersion modelling.
3. Relief calculations.
4. Vent sizing calculations.
5. Depressurisation calculations.

2. Process Description

This section provides a brief description of the process flow of CO_2 from the Goldeneye pipeline into injection well(s) on the Goldeneye platform.

2.1. CO_2 Physical Properties & Operating Range

The CO_2 transportation and injection facilities will be designed to operate in the supercritical dense phase. Normally the pipeline will be operated under back-pressure control. The Goldeneye topsides will normally operate between 91 bara and 116 bara.

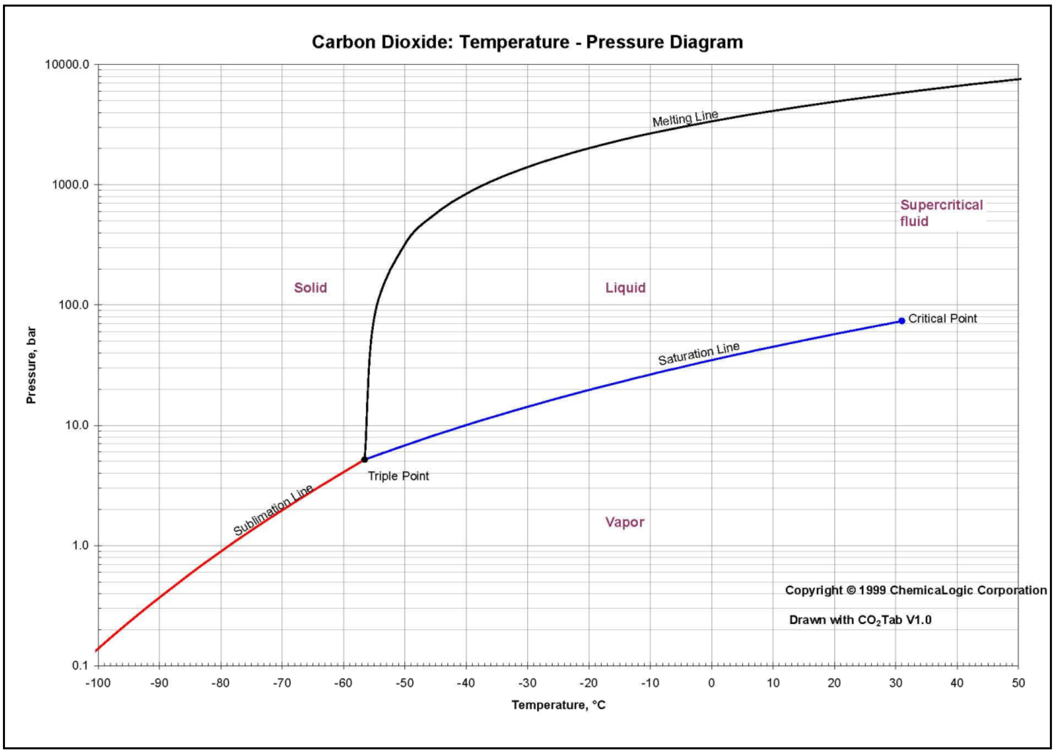


Figure 2-1: Phase Envelope of Pure CO_2

2.2. Goldeneye Platform Surface Facilities

The maximum CO_2 injection manifold operating pressure is expected to be 116 bara; this is based on a maximum pipeline inlet pressure of 121 bara, (the pipeline design pressure is 133 bara). The minimum anticipated CO_2 arrival operating pressure is expected to be ≥91 bara. The operating temperature of the CO_2 is expected to range between 3 - 10ºC (winter and summer sea temperatures minus circa 1ºC temperature drop from isentropic expansion of the fluid as it moves from the elevation of the sea floor up the riser).

The CO_2 will normally flow from the inlet riser Emergency Shut-Down Valve (ESDV) to the CO_2 reception facilities bypassing the pig receiver. The CO_2 will be routed via new 316 stainless steel topsides pipework via a flow meter. The carbon steel pipeline can be isolated from the stainless steel pipework by a shutdown valve and check valve to prevent backflow. Pipeline pressure will be controlled by a back-pressure control to maintain the pipeline in the supercritical dense phase. Upstream of the back pressure control valves the gas is passed through filters where fine debris transported from the pipeline is removed. The filtered CO_2 then flows to the injection manifold where it flows to the injection well. It is currently planned to recomplete 3 existing wells as CO_2 injectors with a 4^{th} well being maintained as a monitoring well.

Flow into each of the wells will be monitored by meters installed on each individual flowline. In the initial years injection will be into a single well. Later on, when reservoir pressure has increased, flow into two wells will be required.

3. Overpressure Protection Requirement

This section reviews the requirement for overpressure protection for the offshore facilities.

3.1. Relief Cases

In order to establish the requirement for over-pressure protection of the surface facilities, various relief cases have been reviewed. Table 3-1 summarises all the relief cases reviewed for the surface facilities (including the pig receiver) of the Goldeneye platform.

Table 3-1: Offshore Relief Cases

Relief Case	Reasoning
Blocked Outlet	1. Upstream pipeline has a lower design pressure (133 bara) than surface facilities (214 bara), hence no HP/LP interface for overpressure of topsides from pipeline. No relief case. 2. The Methanol injection system is assigned a design pressure of 241 bara. A HP/LP interface exists between the injection flowline (214 bara) and the methanol pipeline. Methanol injection is restricted to the API 5000# wellhead only. Simultaneous injection of methanol and CO_2 is prevented by interlocks in the Emergency Shutdown (ESD) system. These prevent methanol injection if the Wing Valve is not closed and the Upper Master Gate Valve not fully open. The maximum closed-in tubing head pressure (CITHP) is 214 bara. The LP side of this interface is protected by pressure relief valves required for thermal relief. However, these would only be required in the case of the failure of the ESD interlocks. If this failed, the maximum overpressure of 13% would be within code for occasional excursions.
Inadvertent Valve Opening	The CITHP of the injection wells will be lower than the design pressure of the topsides.
Backflow	Facilities rated for maximum wellhead shut in pressure so backflow overpressure of the topsides from wells not possible. Light gas from the reservoir can migrate into the tubing of wells that have not been subject to CO_2 injection or water filled. This can lead to well CITHPs up to 214 bara. In theory this pressure could propagate back to the pipeline that has an Maximum Allowable Operating Pressure (MAOP) of 133 bara. A high pressure trip is installed on each flowline that will isolate the well if the flowline pressure exceeds 133 bara. A further trip is provided downstream of the riser ESD valve. The pipeline is therefore protected from reverse flow by 1.o.o.2 high-pressure trips. Check valves are also provided to limit reverse flow. These are not class 1 check valves. No relief required.
Fire	Although diesel and methanol are stored on the platform, all the decks over which process piping are routed are grated. This eliminates the risk pool fire. The monitoring well could contain hydrocarbons but will normally be isolated from the process. There will be facilities to bleed off limited amounts of pressurised hydrocarbons/hydrocarbon CO_2 mixtures from the well for lubricator venting during well work-over and for SSSV testing.

Relief Case	Reasoning
	No fire relief or emergency blowdown required.
Utility Failure	Systems designed to fail safe on loss of power or hydraulics. Wells and surface facilities are designed to withstand transient low temperatures occurring during shutdown. No relief required.
Heat Exchanger Failure	No heat exchangers. No relief required
Thermal Relief	Required to avoid overpressure due to the high thermal expansion coefficient of dense phase CO_2 and methanol. Provision for thermal relief required for all inventories that can be isolated by remotely actuated valves (See Section 3.2). Sections that are isolated by non-actuated valves rely on procedure to prevent thermal overpressure.
Vacuum	N/A
Other	Operations with dense phase CO_2 can produce dry ice when systems are depressurised below 5.18 bara. Dry-ice has a density of 1.5 times that of dense phase CO_2 and there is a risk of overpressure should high pressure CO_2 be introduced into a system containing dry ice. Avoidance of this risk will be by operating procedure.

3.2. Thermal Relief Philosophy

Thermal relief valves are installed on all equipment and pipework that can be isolated automatically whilst containing dense phase CO_2. Piping between manual non-actuated double-block-and-bleed valves are not provided with relief valves on the basis that when the isolation is in place the pipework will be promptly depressurised and purged with nitrogen to dilute the CO_2.

The pig trap valve isolation will be left pressurised with nitrogen.

Thermal relief valve are fitted with an upstream bursting disc with a bursting pressure equal to the PSV set-point (SP) – 3 bar i.e. 211 bara. A pressure transmitter with an alarm (SP=2 bara) is installed between the bursting disc and the PSV to detect leakage or failure of the disc. The discharge of these thermal relief valves will be routed to a suitable location under the Goldeneye Platform so that the lines are self-draining and of sufficient size and configured with an uncomplicated routing to eliminate the possibility of blockage by solid CO_2.

Thermal relief valves will not be spared unless justified by availability considerations.

For small trapped inventories, e.g. valve cavities, thermal relief valves may be discharged locally provided the discharge is not in an enclosed space.

3.3. Pipeline Thermal Overpressure Protection

The Peterhead to Goldeneye CO_2 Pipeline contains 3 valves that may be closed in an emergency blocking in inventories of CO_2 that may lead to overpressure. These valves are:

1. The onshore ESD valve that will be located at the beach at Peterhead. The Sub Sea Isolation Valve (SSIV) and by-pass that is located in a subsea skid 150 m from the platform
2. The Riser ESD valve that is located at EL +22900 on the platform.

Closure of these valves must not lead to a situation where the MAOP of the pipeline is exceeded due to thermal expansion of the CO_2.

Figure 3-2 shows that the CO_2 pipeline riser (MAOP=214 bara) will not exceed the Maximum Allowable Incidental Pressure MAIP=235.3 bara over the range of sea temperatures expected (4-12ºC). The rest of the pipeline has an MAOP of 133 bara. The MAIP (146.2 bara) can theoretically be exceeded by thermal expansion of CO_2.

The design of the pipeline overpressure system is outside the scope of this document.

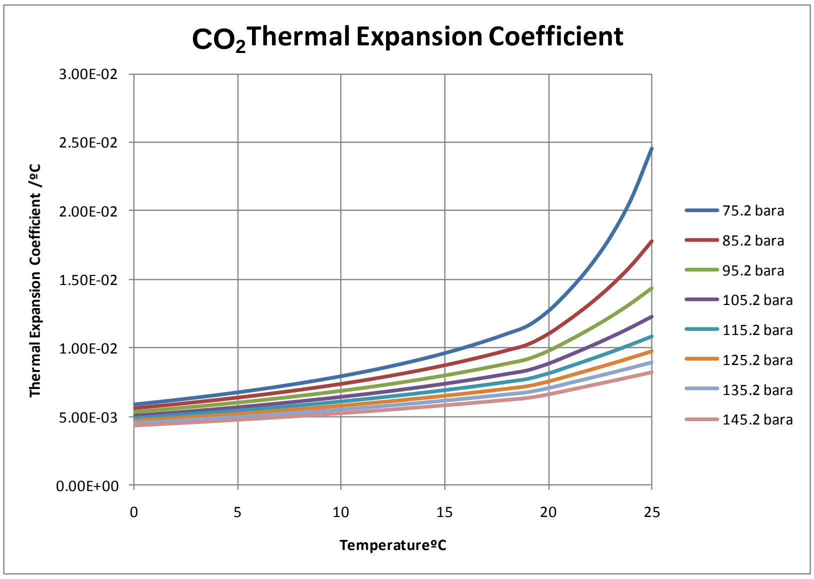


Figure 3-1: Thermal Expansion Coefficient of CO_2

A similar issue exists for the methanol pipeline from St Fergus. An increase in temperature of 1ºC at 220 bara for methanol increases the pressure by 11.7 bar. Overpressure protection of the methanol pipeline is outside the scope of this document.

3.4. Topsides Thermal Relief

Shell standards require that the standard thermal relief valve size for piping systems shall be (25 mm x 25 mm) or (20 mm x 25 mm) [(1"x1") or (¾"x1")], flanged, with a minimum orifice area of 0.71 cm^2 (0.110 in^2).

The topsides equipment handling dense phase CO_2 has a design pressure of 214 bara. The relieving pressure of the thermal relief valves will be 235.3 bara. To evaluate the relieving temperature, an inventory of CO_2 blocked in at a pressure corresponding to the MAOP of the pipeline is assumed. The MAOP of the pipeline is 133 bara. Referenced to Lowest Astronomical Tide (LAT), this corresponds to a pressure of 130 bara topsides. In practice, onshore compressor control and shutdown systems will prevent pressures reaching 130 bara. However, there will be a topsides trip set to this level to cater for the remote but possible case of high CITHP resulting from light hydrocarbon presence in a tubing string. Figure 3-2 shows the isochoric curve for CO_2 trapped at 130 bara and 4ºC. This reaches the relief pressure plus 10% accumulation of the thermal relief valves at 16ºC.

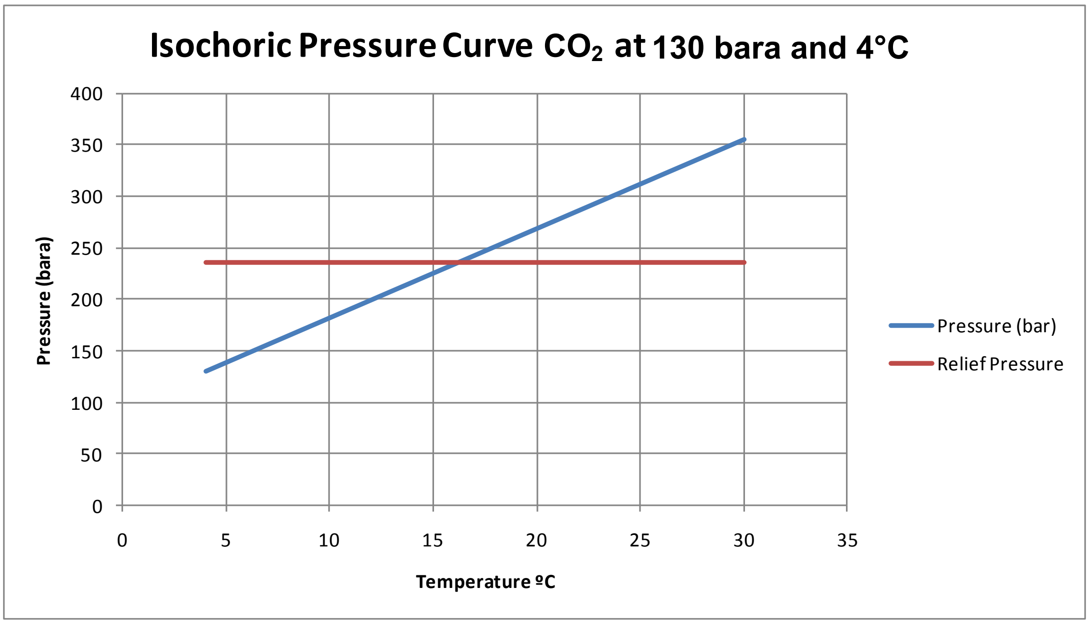


Figure 3-2: Isochoric Pressure Curve for CO_2 (ρ=971.4 kg/m³)

The mass flux through a nozzle calculated using the Homogeneous Equilibrium Model is 187,754 kg/m²/s. This gives a maximum relief rate for a standard D orifice thermal relief valve assuming a discharge coefficient, K_D, =0.90 (to account for bursting disc), as:

$$W_{max} = (K_D)(G_{max})(A)$$
$$W_{max} = (187{,}754)(71.10^{-6})(0.9)$$
$$W_{max} = 12\ kg/s$$

This rate should be used for assessing the dispersion from a relief valve vent as it is conservative with respect to atmospheric relief.

Heat transfer to the topsides pipework and vessels will come from:

a. Forced convective heat from the wind

   The maximum heat transfer coefficient from the wind is estimated to be ~67 W/m²/K. This equates to a heat transfer rate of ~ 570 W/m² at maximum ambient air temperature.

b. Solar radiation

   Maximum solar radiation at this location is ~720 W/m².

This gives a maximum heat transfer rate, Q_{max}, for the purpose of thermal relief calculations of 1.3 kW/m².

The thermal relief rate, $W_{thermal}$, from a system with effective heat transfer surface area, S (m²), is therefore:

$$W_{thermal} = (S)(\alpha_v)(Q_{max})/C_p$$

α_v = 4.10⁻³ /K, the thermal expansion coefficient of CO_2 at 16°C and 235.3 bara

C_p= 2.04 kJ/kg/K, the specific heat of CO_2 at 16°C and 235.3 bara

$$W_{thermal} = (S)(2.5)(10^{-3}) \text{ kg/s}$$

One standard thermal relief valve is therefore sufficiently sized to accommodate the thermal relief from a system with an effective surface area of $(12)/(2.5 \times 10^{-3}) \sim 4800$ m^2.

The maximum effective heat transfer surface area for a shut in section based on 30 m of 20" pipe is ~50 m^2. Hence the expected maximum relief rate per valve will be ~0.1 kg/s.

It is therefore concluded that the standard 1D1 or ¾D1 will be sufficient for all envisaged trapped volumes. For the purpose of vent location, fail-open of one valve shall be assumed for 'worst case' dispersion calculations.

The cubic coefficient of thermal expansion of methanol is 1.1×10^{-3}/ºC at 12ºC and 265 bara (system relief conditions). The specific heat, C_p, of methanol is 2.4 kJ/kg/K.

$$W_{thermal} = (S)(1.3)(1.1x10^{-3})/2.4 \text{ kg/s}$$
$$W_{thermal} = (S)6x10^{-4} \text{ kg/s}$$

Surface area of methanol filter is ~ 1 m^2 giving a relief rate of ~6×10^{-4} kg/s or 7.3×10^{-7} m^3/s.

Capacity of a D orifice thermal relief valve for methanol is 1.16×10^{-2} m^3/s. The thermal relief valve discharges below deck. A thermal relief incident would involve very small releases of methanol to sea.

3.5. Relief Valve Inlet Lines and Tail Pipes

Thermal relief valve inlet and discharge lines shall be 2" NB minimum for physical robustness. For the CO_2 thermal relief valves, discharge pipework shall be full rated to accommodate the potential for solid CO_2 /ice blockage. The relief valve pipework shall be adequately supported for reaction forces.

PSV inlet lines are required to be sized for a pressure drop less than 3% of the relief valve set pressure for the rated capacity of the relief valve. This is required to prevent severe chatter of the relief valve. For PSVs set at 214 bara this equates to $\Delta P < 6.4$ bar. As indicated above, the standard thermal PSV will be significantly oversized for the expected relief load so that the rated capacity of 13.3 kg/s is vastly in excess of the thermal relief requirement.

A preliminary sizing of the inlet line gives 2" Schedule 160 with an ID of 42.8 mm. This would give a velocity of 9.2 m/s and a pressure drop of 0.37 bar/m. Allowing for pressure loss through the bursting disc upstream of the PSV, a 2" inlet line should be acceptable provided its equivalent length is kept below 10 m to 15 m. This sizing should be confirmed in detailed design when pipe routes and bursting disc characteristics are accurately known.

The discharge pipe will be fully rated to protect against potential blockage. The maximum allowable back pressure is 10% of the PSV set pressure or 22.3 bara. For this, the actual relief rate is used to size the line. This is 0.1 kg/s and gives low pressure drops in a 2" schedule discharge pipe. The selection of line size is therefore confirmed at 2" however consideration may be given to increase this if the routing is sufficiently convoluted to increase the risk of pipe blockage.

4. Vent design

This section describes the design of the vent systems. The offshore vent system is required for the following duties in Carbon Capture and Storage (CCS) operation:

1. Pipeline depressurisation.
   This will be CO_2.
2. Topsides maintenance depressurisation.
   This will be CO_2.
3. Topsides (CO_2) thermal relief valve discharge.
   This will be CO_2.
4. Methanol filter thermal relief valve.
   Methanol.
5. Venting wells for SSSV testing.
   This may contain hydrocarbons, methanol and water as well as CO_2.
6. Venting lubricators and other small inventories during well intervention.
   This may contain hydrocarbons as well as CO_2.

The existing offshore vent system is 150# rated and is not suitable for handling the disposal of dense phase CO_2 because the system is 150# and designed to operate at near atmospheric pressure. Discharge of significant quantities of supercritical dense phase CO_2 into a system below 5.2 bara will result in solid CO_2 formation and blockage.

The liquid KO drum will be retained for venting wells for SSSV testing.

4.1. Pipeline Depressurisation Vent

The pipeline depressurisation vent is required to depressurise the offshore section of the Goldeneye Pipeline from the beach isolation valves to the pig bypass valves on the Goldeneye topsides. Depressurisation of the Goldeneye pipeline will take a long time – the pipeline is still at 26 bara after three weeks. The depressurisation system must be designed to operate when Goldeneye Platform in an attended and unattended state.

The vent is designed with the following features:

1 A new 6" [152 mm] NB vent will be constructed from the 12"NB pig receiver bypass.

2 A 6" actuated ball valve is provided as a fail-closed ESD valve that also serves as the downstream block valve on double-block-and-bleed isolation from the vent.

3 Low pressure trip, SP=36 bara will close the depressuring valve and Riser Valve. This corresponds to a temperature of 1ºC for liquid CO_2. This trip will be by-passed when the CO_2 in the pipeline is completely gaseous. Reliance will be placed on low temperature trips during the final gas phase blowdown phase of pipeline depressuring. This trip will need to be reset locally.

4 Two thermowells are located downstream of the ESD valve to detect the temperature of the vented gas. The first of these is a Temperature Indicating Control Alarm (TICA) that will alarm via the Distributed Control System (DCS). The set point of this alarm is preliminarily set at -5ºC to alert the operators to the potential for low temperatures in the pipeline during depressurisation. The device will also initiate a closure of the depressuring control valve if temperatures drop below -5ºC. This will automatically reset and allow depressurisation to

continue when the gas has warmed up. The second of these is a low temperature ESD trip with a preliminary set-point of -15ºC. This will require a visit to the platform to reset the trip locally. The trip is set below the minimum pipeline design temperature but above -20ºC which is the pipeline riser materials specification lower design temperature.

The temperature alarm and trips are part of the layers of protection of the instrumented system to protect the pipeline from low temperatures during depressuring.

The set points given above are indicative only and should be confirmed during post Front End Engineering Design (FEED) follow-up work and validated by dynamic simulation.

5 Downstream of the trips a depressuring valve is installed. Pipeline depressuring will be achieved under sequenced pressure control.

6 Downstream of the depressuring valve a removable spool piece is installed. In normal service, this is removed and the ends of the vent pipework are provided with blind flanges and tell-tale valves. This ensures that the vent is positively isolated under normal operating conditions and it also allows the vent pipework to be drained of water prior to the commencement of venting.

7 A Pressure transmitter is installed on the pipework downstream of the removable spool piece. This has a DCS indicating alarm on it that is only active during pipeline depressuring mode and the depressuring valve is open. The alarm will annunciate if the pressure is less than 11 bara to indicate proximity to the CO_2 triple point.

8 The vent pipework is fully rated and runs up the existing stack to a location at EL+52057. The vent pipework should normally aim to operate well above the pressure at which solid CO_2 forms i.e. 5.18 bara, until the pipeline is full of gas to the right of the two-phase region in the Mollier Chart in Figure 4-1. Continued operation with the pressure in the riser below 5.18 bara can result in the build-up of solid CO_2 in the riser. The density of solid CO_2 is approximately 50% greater than that of dense phase CO_2 at pipework design pressure. If trapped, the fluid could therefore overpressure the pipework. However, the Restriction Orifice (RO) at the vent tip has sufficient capacity to relieve the excess pressure.

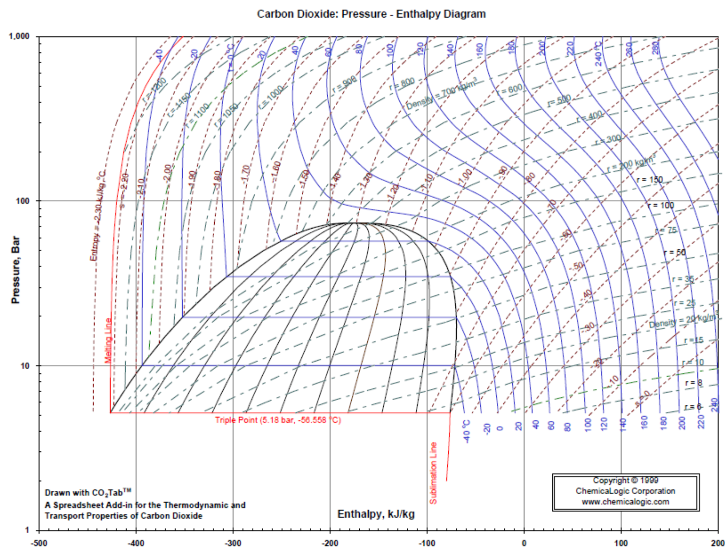


Figure 4-1: Mollier Diagram for CO_2

The vent tip will be angled at 45ºC facing platform north to direct the CO_2 plume away from the platform. The tip will have an orifice to restrict the flow. This orifice can be constructed from a drilled blind flange. This allows the operation of the vent pipework above the triple-point pressure of CO_2 until the pipeline is full of gas with an enthalpy greater than that of solid CO_2 at its sublimation line. The design ensures supersonic flow at the vent tip thereby maximising the jet momentum and associated air mixing to minimise the size of the plume under a wide range of ambient conditions.

The vent tip orifice has been sized at 25 mm assuming a pressure of 33 bara upstream of the tip of assuming a minimum flow of 8 kg/s. This is estimated as the minimum boil off rate of CO_2 during depressuring. This is a preliminary value to be confirmed by further detailed dynamic simulation.

4.1.1. Vent Tip Thrust

Table 4-1 gives a preliminary estimate for the jet thrust at the tip. The table gives the estimated vent tip thrust as ~7 kN for a 25 mm orifice. The tip is at 45° so there is a horizontal component to the force. The tip will be oriented to platform north to discharge the contents over the sea. There will also be a dynamic component with the depressuring stopping and starting many times over a period of weeks that the pipeline will require to be depressurised.

Table 4-1: Summary of Vent Tip Thrust Estimate

Force	Result	Method
AP (N)	1639	Static pressure term from API RP520 Pt II 4.4.1.1
T (N)	4994	Momentum term from API RP520 Pt II 4.4.1.1
F(N)	6632	Reaction force on tip API RP520 Pt II 4.4.1.1

4.2. Relief Valve and Topsides Vents

There are a number of blocked-in inventories topsides that require provision of relief valves and maintenance depressuring facilities. The largest of these inventories will be the filters that will contain approximately 0.7 tonnes of CO_2 each[1]. It is proposed that these will be provided with vent/thermal relief valve arrangements that discharge below deck. This will ensure that the vent pipework is kept free of water. All material for the topsides will be fabricated from 1500# stainless steel. 316 stainless steel retains its toughness at low temperatures resulting from the Joule-Thompson (JT) expansion of CO_2. All thermal relief valves will have a bursting disc installed and an alarm. The bursting disc will reduce fatigue on the PSVs making them less likely to fail open. An alarm will alert operations to a thermal relief incident. Inventories between non-actuated valves are not provided with relief valves. Valves that are normally closed during operation such as the 20" pig valves will be left pressurised with nitrogen. Maintenance isolation valves are equipped with facilities to vent and inject nitrogen.

4.3. Well Lubricator Vent

Small volumes of gas from the wellhead such as from the lubricators used during well work-overs will be vented from the well-bay via the existing vent KO drum.

[1] This is based on preliminary vendor information that sized the units at 2x100% units, 0.73 m id by 1.61 m.

4.4. Well Vent for Testing SSSV

Each well SSSV must be proof-tested at regular intervals. Venting associated with SSSV testing will be achieved using a new well depressuring manifold arrangement via the existing vent KO drum.

CO_2 injection into the well to be tested will be stopped and the well isolated from the injection manifold by closing the wing valve. The well will be allowed to settle out over a period of time.

The well will be vented above the SSSV under pressure control to avoid exposure to low temperatures. The Pressure Control Valve (PCV) is safety critical and will be sized to:

i. Limit the exposure of components in the well system below minimum design
ii. Limit the flow below the capacity of the vent system
iii. Limit the low below ρv^2 limits for 2" Schedule 160 pipework downstream of the PCV

The well depressuring procedure has yet to be fully developed but is expected to require the reduction of well pressure to 36 bara where the pressure is controlled until liquid CO_2 in the well has boiled off and the well is full of gas at a temperature above 0ºC. The set point of the pressure controller is then reduced to 24 bara so the well is full of gas at 24 bara. The well is then isolated so that pressure build up can be used to confirm SSSV integrity. Apart from the 3 injector wells, there will be a monitor well full of hydrocarbons for a long period of time. This well (GYA03) will be used to monitor the migration of CO_2 in the reservoir. This is important for confirming lateral containment. The current plan calls for converting the well to CO_2 injection once the subsurface CO_2 plume arrives at the well. The SSSV in this well needs to be tested during both the monitoring and injection phase. During the monitoring phase, estimated at 4-6 years in duration, the well will contain hydrocarbon.

5. Pipeline, Topsides and Wells Depressuring

This section describes the routine depressurisation of the pipeline, topsides and wells. There will be no provision for emergency depressurisation subject to approval by the Shell Technical Authority as required by Shell Standards.

5.1. Pipeline Depressuring

Depressuring of the Goldeneye pipeline involves the safe disposal of an inventory of 20,000 tonnes of CO_2. As much as possible of this will be disposed of via the wells. However, access to the injection wells cannot be guaranteed so disposal of the entire inventory to atmosphere must be considered. This will happen at least once in the lifetime of the project immediately prior to decommissioning of the pipeline.

The depressuring procedure requires a step-wise pressure reduction to evacuate the pipeline inventory. Each step is performed under pressure control with the pressure effectively controlling the temperature of the fluids in the pipeline by virtue of the vapour pressure curve of carbon dioxide.

Results of the Dynamic simulation performed for the Longannet Project are presented to illustrate the principal features of the depressuring process. The simulations include modelling of heat transfer from the environment. The depressuring procedure that is modelled has been simplified by assuming that the process is performed continuously rather than in the discrete steps identified above. The main conclusions of this work are summarised below:

1. Following shutdown the contents of the pipeline will cool. The pressure of the contents will drop. After 84 hours the pipeline fluid temperature is in equilibrium with sea temperature. This was assumed to be 5ºC for these simulations.

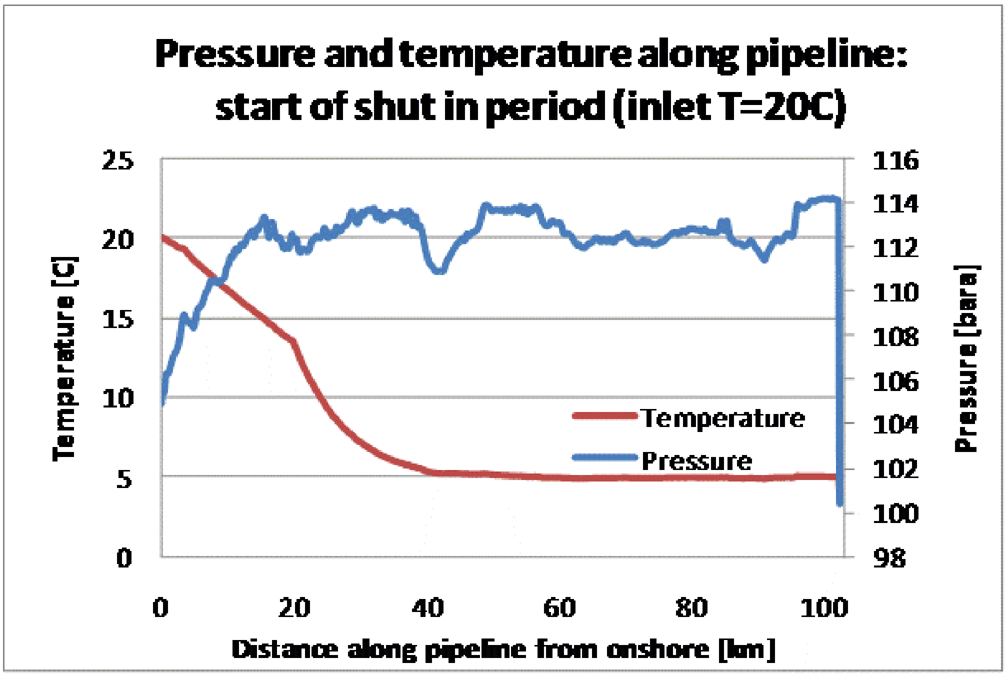


Figure 5-1: Pressure and Temperature Profiles at the Start of Shut in Period

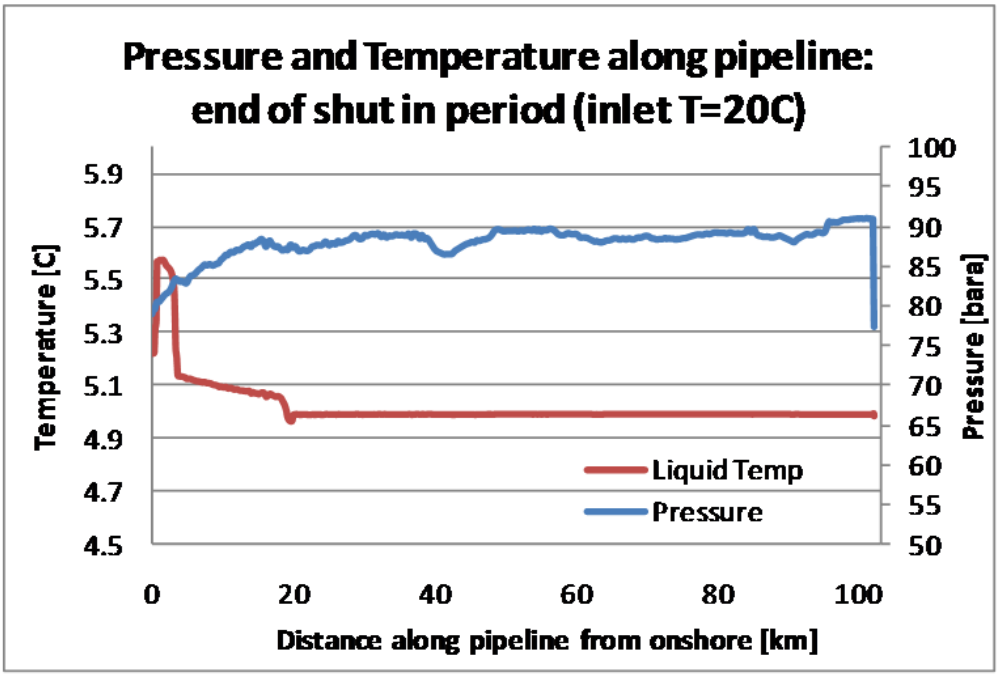


Figure 5-2: Pressure and Temperature Profiles after 84 Hours

2. After 84 hours of shut-in, the pressure at the top of the riser has reduced from 100 bara initially to 77 bara.
3. Depressuring of the pipeline is started through a blowdown valve that is modelled as a 50 mm orifice, 25% open. This gives an initial flow of 45 kg/s through the vent system.

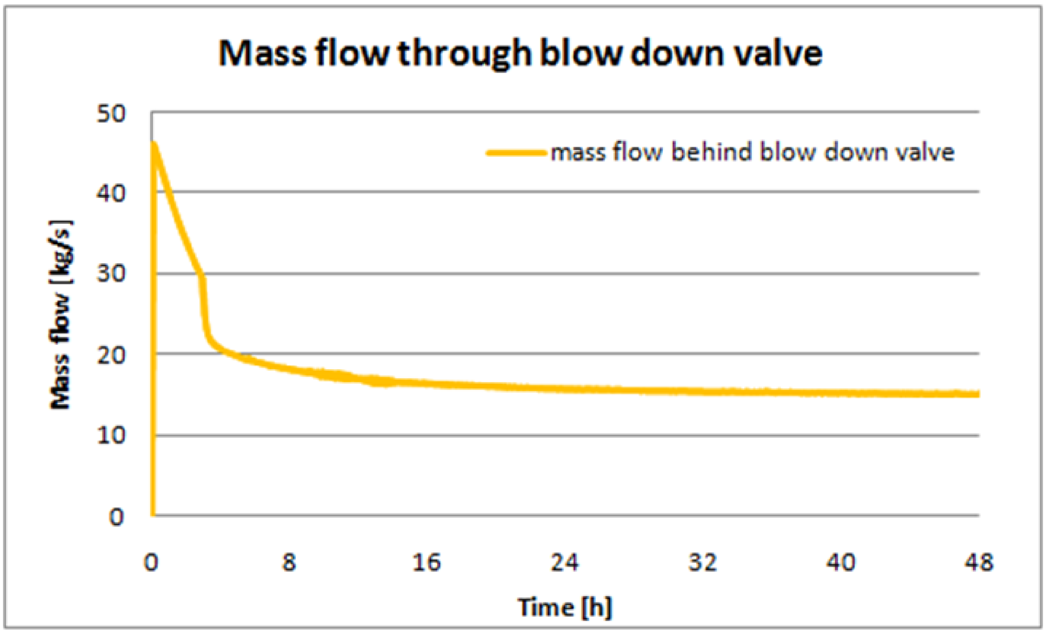


Figure 5-3: Mass Flow through Blowdown Valve in first 48 hours

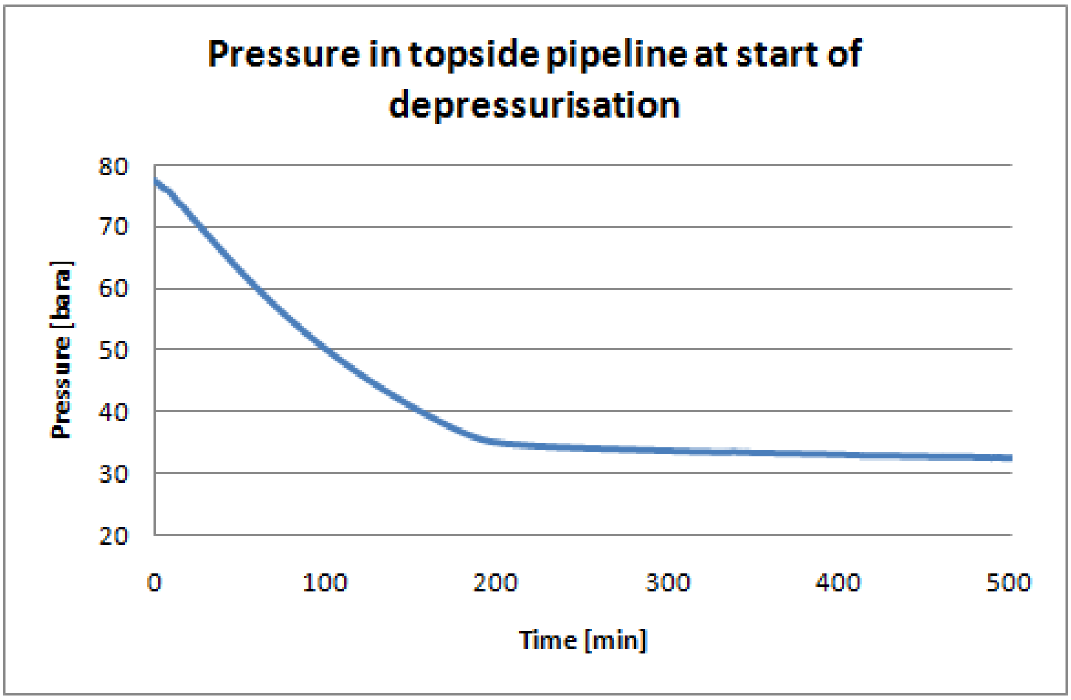


Figure 5-4: Topsides Pressure Profile in the first 500 minutes of Blowdown

Figure 5-4 shows that the mixture hits the phase boundary after about 3 hours when the pressure is ~32 bara corresponding to a fluid temperature of ~3°C.

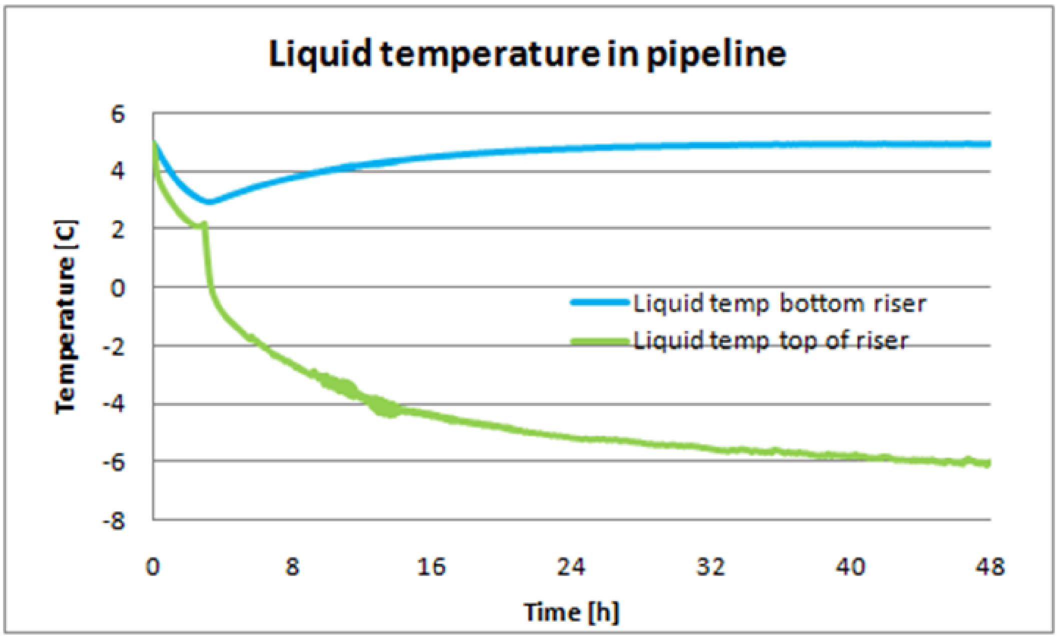


Figure 5-5: Temperatures at the Bottom and Top of Goldeneye Pipeline Riser

4. During the first phase of the depressurisation in which the CO_2 in the subsea pipeline is evaporating, the coldest temperatures are seen in the riser and at the subsea section just before the riser. The lowest temperature observed is -8°C.

5. For the first 130 hours a mixture of liquid and gas is received at the pipeline outlet. During the period 3 to 130 hours, liquid is produced up the riser driven by the expansion of gas in the higher elevation sections of pipeline closer to shore. After 130 hours, only vapour phase CO_2 is produced topsides upstream of the blowdown valve. This is illustrated in Figure 5-6.

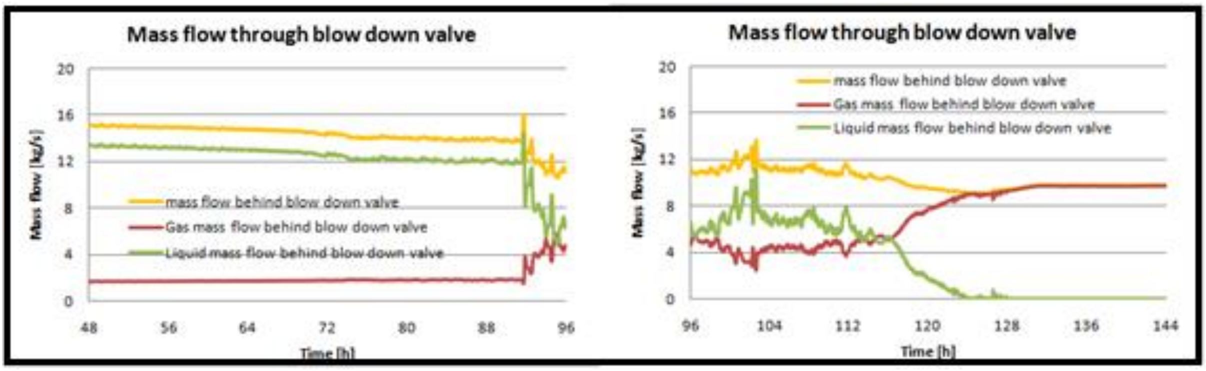


Figure 5-6: Transition from Mainly Liquid Flow to Mainly Gas Flow

6. In this 'equilibrium' the heat inflow from the ambient is large enough to compensate for the heat loss due to the evaporation process and the temperatures in the pipeline stay above 0°C
7. When CO_2 in the onshore pipeline section starts to evaporate, temperatures start to drop below 0°C and the vent rate starts to drop.
8. Heat transfer into the buried section of the pipeline that runs from the terminal to 19.4 km offshore is insufficient to evaporate liquid CO_2 without chilling to -20ºC. This is below the minimum pipeline design temperature of -10°C. The lowest temperatures are seen where liquid CO_2 collects in low spots of the buried section.
9. The temperature in the onshore pipeline section can be controlled by controlling the depressuring rate. i.e.

$$\boldsymbol{w_b \leq \frac{UA(T_{amb} - \theta(p))}{\lambda_{vap}(p)}} \qquad 1$$

Where:

W_b is the depressuring rate in kg/s

A is the surface area of affected pipe in m^2.

U is the overall heat transfer coefficient in the buried section of line ($W/m^2/K$)

T_{amb} is the ambient temperature in ºC

$\theta(p)$ is the temperature of the CO_2 in ºC.

$\lambda_{vap}(p)$ is the latent heat of evaporation in J/kg of liquid CO_2 at pressure, p, bara.

In practice, w_b, will represent an average boil-off rate of CO_2 down the length of the pipeline. U, T_{amb} and to some extent p will vary down the length of the pipeline causing local variations in temperature which cannot be directly controlled by adjustment of depressuring rate. The approach to adopt is therefore to reduce the pressure in a stepwise fashion. At each step the flowrate is monitored until is stops before lowering the pressure further.

5.2. Pig Trap Depressuring

The base case for FEED is to convert the existing carbon steel pig trap for receiving intelligent pigs. The material around the pig trap is specified as carbon steel however this is subject to confirmation that this is compliant with the relevant design codes with respect to the prevention of brittle failure. This work is not complete at end of FEED so the design of the venting system is provisional[2]. The current design assumes that the consequences of pig trap failure can be mitigated by remote control of the depressuring process with trips on low temperature and low pressure to isolate the vent. This will require personnel to be located in the Temporary Refuge to mitigate the consequences of a failure of the pig trap due to brittle fracture.

Introduction of dense phase CO_2 into a vessel containing solid CO_2 can lead to exposure of the vessel to high pressures when the vessel is exposed to temperatures below the minimum design temperature of the vessel. This effect is summarised in Figure 5-7.

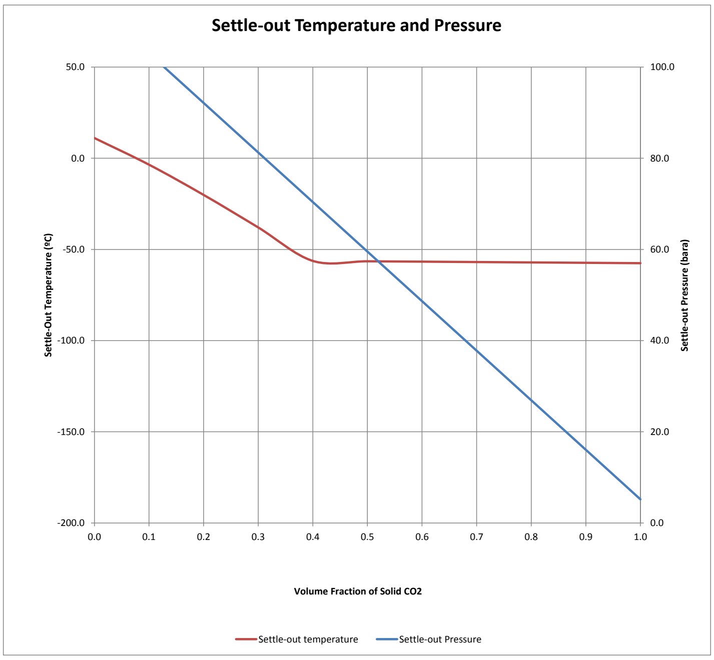


Figure 5-7: Settle-out Temperature and Pressure for Solid and Dense Phase CO_2 mixtures

It is mandatory that measures are taken to prevent pig trap re-pressurisation following exposure to low temperatures.

---

2 Description: Material selection of pig receiver

Action to close: Stress and fracture mechanics to confirm that pig trap can be used to minimum temperatures expected during dense phase CO_2 service.

Action by: Project

5.3. Topsides Depressuring

Manual depressuring vents are provided to vent pipework. The discharge of the vents is below deck with discharge away from locations where personnel may operate and structural members that can be chilled.

Apart from the pig trap and 20" [508 mm] valves, the rest of the topsides pipework is made of 316 stainless steel and can be depressurised without risk of brittle fracture.

Care must be taken to ensure that pipework and vessels are not re-pressurised whilst containing solid CO_2 as this could lead to lifting of thermal relief valves on warming. Pipework depressuring should be achieved in a staged manner avoiding production of solid CO_2 below pressures of 5.18 bara. This will increase the rate of depressurisation as heat transfer to liquid CO_2 is much more efficient than to solid CO_2.

5.4. Further Work

The procedures outlined in this report should be used as a basis for developing detailed operating procedures for pipeline depressuring during detailed design. Dynamic simulations have identified an issue with low temperatures in the buried section of line if depressuring is uncontrolled. The pipeline depressuring process is a lengthy process so further analysis will be needed to establish the most time-efficient strategy for pipeline depressuring that will not compromise pipeline integrity.

6. Vent Dispersion Calculations

Vent dispersion calculations have been performed for a number of venting scenarios. The calculations were performed using the steady state PHAST model by the MMI consultancy. The results should be treated as preliminary and re-run in detailed design to confirm the acceptability of the vent design.

6.1. Dispersion Cases

The following cases have been simulated:

Table 6-1: Vent Dispersion Cases

Case	Description	Wind Speed (m/s)	Vent Nozzle ID Size (mm)	Nozzle Angle to vertical (º)	Nozzle EL above LAT (mm)	Released Inventory (Tonnes)	Flow Rate (Kg/s)	Enthalpy set at P bara and TºC Note [3]	Pressure upstream of nozzle (Bara)	Temperature upstream of nozzle (ºC)
A	Pipeline Blowdown Max nozzle pressure	Min 5 **Note [1]**	33 Note 5	45º	+50000	20000	126	P=133, T=4	133	4
B	Pipeline Blowdown 10 bar nozzle pressure	Min 5 **Note [1]**	33 Note 5	45º	+50000	20000	10	P=133, T=4	10	-40
C	Thermal Relief with under deck discharge Note [4]	Min 5	42.8 **Note [2]**	180º	+20000 (about 1m below bottom of steel)	0.1	0.125	P=235.3, T=16	1.1	-50
D	One failed thermal relief valve Note [4]	Min 5	42.8 **Note [2]**	180º	+20000 (about 1m below bottom of steel)	10	10.5	P=133, T=4	~8	-45

Notes

1. Cases simulated for wind with direction of nozzle jet flow due to software limitations. The plume profile will be assumed to representative for all directions. The minimum wind speed is 1 m/s, the lowest value that can be used in the PHAST software.
2. Assumed 2" Schedule 160 pipe
3. Temperature and pressure which define fluid enthalpy
4. The influence of under-deck structures on dispersion is ignored
5. The results in this table are based on a 33mm nozzle assumed for the Longannet Project. PCCS will have a 25 mm, so the dispersion results are conservative.

6.2. Dispersion Results

The limiting case simulation results are reproduced in Figure 6-1, Figure 6-2, Figure 6-3 and Figure 6-4 below. The dispersion profiles are shown for

a) Time Weighted Exposure Limit (TWA) 0.5%v/v,
b) Short Term Exposure Limit (<10 minutes) (STEL) 3% v/v
c) Immediately Dangerous to Life and Health (IDLH) 4% v/v

6.3. Discussion of Dispersion Results

The results for Case A are a maximum flow rate case (Figure 6-1). Pipeline depressurisation vent rates will normally be kept well below this value. The lethal portion of the plume is maintained well above the platform and even at low wind speeds, the long term exposure level would pass over the platform. The model cannot predict levels as low as 0.25% which is the level that would initiate CO_2 detection alarms on the platform and it is conceivable that these may be initiated in certain weather conditions. There will be issues with helicopter movements but these are readily resolved by stopping depressuring during the approach and departure of aircraft.

Pipeline depressuring will involve long periods of time (i.e. weeks) with a flowrate typical of Case B (Figure 6-2). The cloud is well elevated from the platform so should not be an issue.

Figure 6-3 shows the plume expected from a thermal relief valve lifting. This again shows a hazardous zone within a few meters of the vent discharge. The more conservative case of a PSV failing open is shown in Figure 6-4. Here the IDLH limit does extend within 7 m sea level which may give concerns if there are marine activities close to the platform. However, there will be a limited inventory and the affected area be reduced. However, the dynamic effects of this case merit further investigation by dynamic simulation during detailed design to provide a basis for safe operating practices under deck.

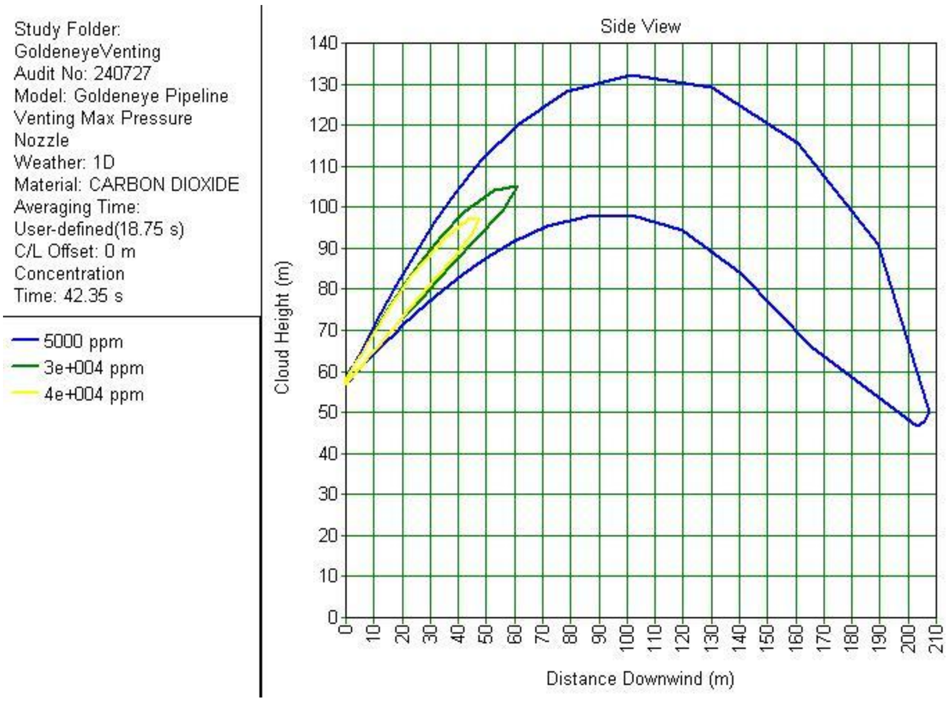


Figure 6-1: Case A – Pipeline depressurisation at maximum nozzle pressure. Wind speed of 1 m/s (stability class D).

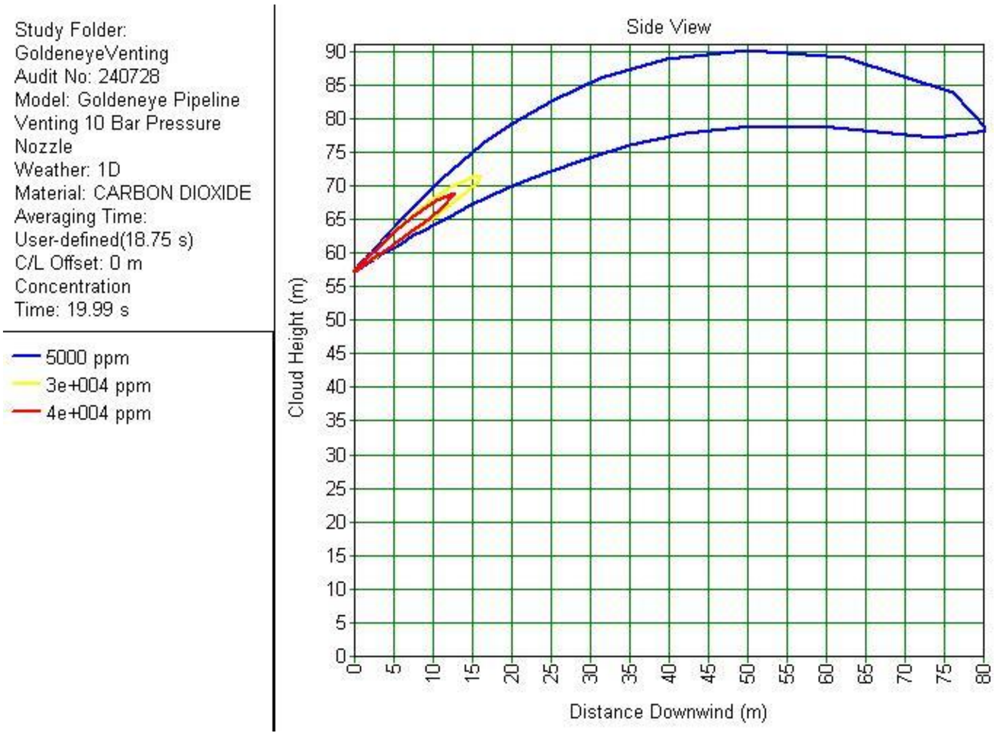


Figure 6-2: Case B – Pipeline depressurisation at nozzle pressure of 10 bara. Wind speed of 1 m/s (stability class D).

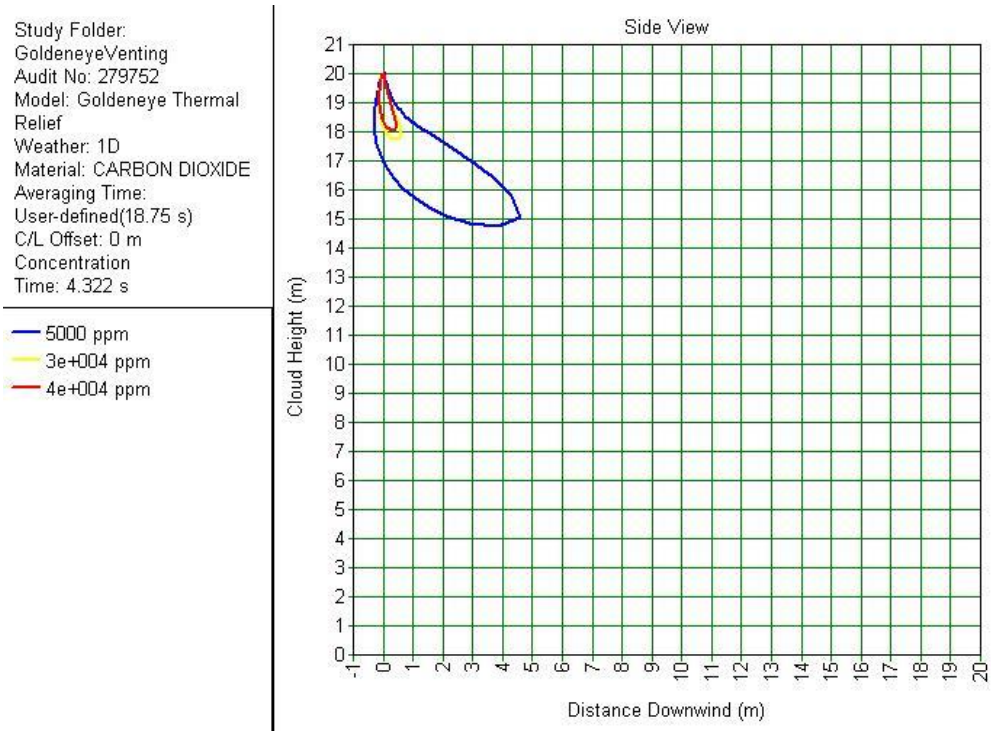


Figure 6-3: Case C – Thermal relief with under deck discharge. Wind speed of 1 m/s (stability class D).

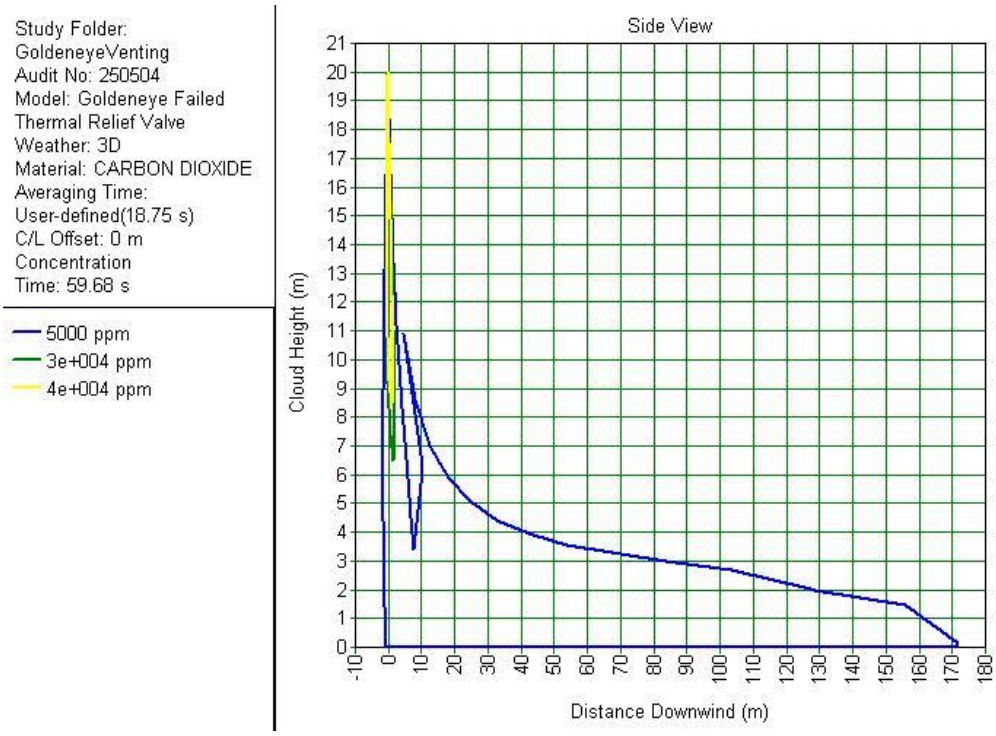


Figure 6-4: **Case D – One thermal relief valve. Wind speed of 3 m/s (stability class D).**

7. Glossary of Terms

Term	Definition
CCS	Carbon Capture and Storage
CITHP	Closed-in Tubing Head Pressure
CO_2	Carbon Dioxide
DCS	Distributed Control System
DECC	Department of Energy and Climate Change
DN	Nominal Diameter
ESD	Emergency Shutdown (system)
ESDV	Emergency Shut-Down Valve
FEED	Front End Engineering Design
HP	High pressure
ID	Inside Diameter
IDLH	Immediately Dangerous to Life and Health
JT	Joule-Thompson
KO	Knock-Out
NB	Nominal Bore
LAT	Lowest Astronomical Tide
LP	Low Pressure
MAIP	Maximum Allowable Incidental Pressure
MAOP	Maximum Allowable Operating Pressure
NB	Nominal Bore
PCCS	Peterhead Carbon Capture and Storage
PCV	Pressure Control Valve
PHAST	Process Hazard Analysis Software Tools
PSV	Pressure Safety Valve
RO	Restriction Orifice
SP	Set Point
SSIV	Sub Sea Isolation Valve
SSSV	Sub Surface Safety Valve
STEL	Short Term Exposure Limit
TICA	Temperature Indicating Control Alarm (instrumentation)
TWA	Time Weighted Average
KKD	Key Knowledge Deliverable
DEP	Design Engineering Practice

8. Glossary of Unit Conversions

Table 9-1: Unit Conversion Table

Function	Unit - Imperial to SI Metric conversion
Length	1 Foot = 0.3048 metres 1 Inch = 25.4 millimetres
Nominal Diameter (DN)	DN(mm)=(25)(NB inches)
Pressure	1 psia = 0.0689 bara
Temperature	ºF=(1.8)(ºC)+32 ºR=(1.8)(K) (absolute scale)
Weight	1lb Pound = 0.45kg Kilogram

APPENDIX 5. Vent Dispersion Study – Platform (PCCS-04-PTD-HX-0580-00003)

Peterhead CCS Project

Doc Title: Vent Dispersion Study – Platform

Doc No.: **PCCS-04-PTD-HX-0580-00003**
Date of issue: **28/05/2015**
Revision: **K03**
DECC Ref No: **11.037**
Knowledge Cat: **KKD - Technical**

KEYWORDS
Peterhead, Goldeneye, CO_2, Carbon Capture and Storage (CCS), HSE, Vent, Dispersion.

Produced by Shell U.K. Limited
ECCN: EAR 99 Deminimus

IMPORTANT NOTICE

Information provided further to UK CCS Commercialisation Programme (the **Competition**)

The information set out herein (the **Information**) has been prepared by Shell U.K. Limited and its sub-contractors (the **Consortium**) solely for the Department for Energy and Climate Change in connection with the Competition. The Information does not amount to advice on CCS technology or any CCS engineering, commercial, financial, regulatory, legal or other solutions on which any reliance should be placed. Accordingly, no member of the Consortium makes (and the UK Government does not make) any representation, warranty or undertaking, express or implied as to the accuracy, adequacy or completeness of any of the Information and no reliance may be placed on the Information. In so far as permitted by law, no member of the Consortium or any company in the same group as any member of the Consortium or their respective officers, employees or agents accepts (and the UK Government does not accept) any responsibility or liability of any kind, whether for negligence or any other reason, for any damage or loss arising from any use of or any reliance placed on the Information or any subsequent communication of the Information. Each person to whom the Information is made available must make their own independent assessment of the Information after making such investigation and taking professional technical, engineering, commercial, regulatory, financial, legal or other advice, as they deem necessary.

Table of Contents

Table of figures

1. Introduction

1.1. Overview

A series of PHAST based calculations were carried out in support of the PCCS Project by MMI. This report is included in Appendix 1. The properties used for the modelling are the same as what is required for the PCCS project and are therefore used for basing the design on. These cover a number of venting scenarios and use 0.5% as the primary concentration of interest to ensure that this level of concentration does not reach sea level. 0.5% is the concentration limit during operations to which personnel on platform may be subjected. This value is based on H&SE's (Health and Safety Executive) 8 hour time-weighted average occupational exposure limit.

1.2. Objectives

This report confirms the following:

- Height of vent required for pipeline depressurisation to ensure that 0.5% concentration of CO_2 does not reach the sea level.
- Confirm optimal vent location taking constructability and inspection/maintenance into account.
- Confirm that thermal relief discharge emissions do not reach sea level for 0.5% concentration of CO_2.
- Possibility of thermal relief vents being detected by CO_2 gas detectors.

1.3. Project Background

The offshore platform scope requires modification to the existing process equipment to replace the minimal hydrocarbon processing equipment and pipework with CO_2 compatible equipment for receipt of dense phase CO_2 from the pipeline through delivery to the injection wells.

In 2009, the Scottish Power Consortium UKCCS Project ("Longannet Project") involved similar design modifications to the Goldeneye Platform as will be required for PCCS. Where appropriate the Goldeneye component of these Longannet design documents are used as a starting point for the PCCS Project.

2. Dispersion from Vent Tower during Pipeline Blowdown

The methodology, assumptions and model inputs used are included in the Carbon Dioxide Dispersion Calculations for Onshore and Offshore Venting Report. This report is included in Appendix 1.

Recommendation 3: The assumptions in MMI Venting Report such as those on depressurisation flow rates shall be confirmed when this is confirmed by the subsea scope of work.

2.1. Dispersion Models

The dispersion modelling shows that 5,000 ppm levels can reach up to 210 meters. In the worst case the 5,000 ppm levels dip to a level that is slightly below the release point, however, they are not shown to reach sea levels. The worst case illustration is extracted from the Carbon Dioxide Dispersion Calculations for Onshore and Offshore Venting Report and is included in Figure 2-1.

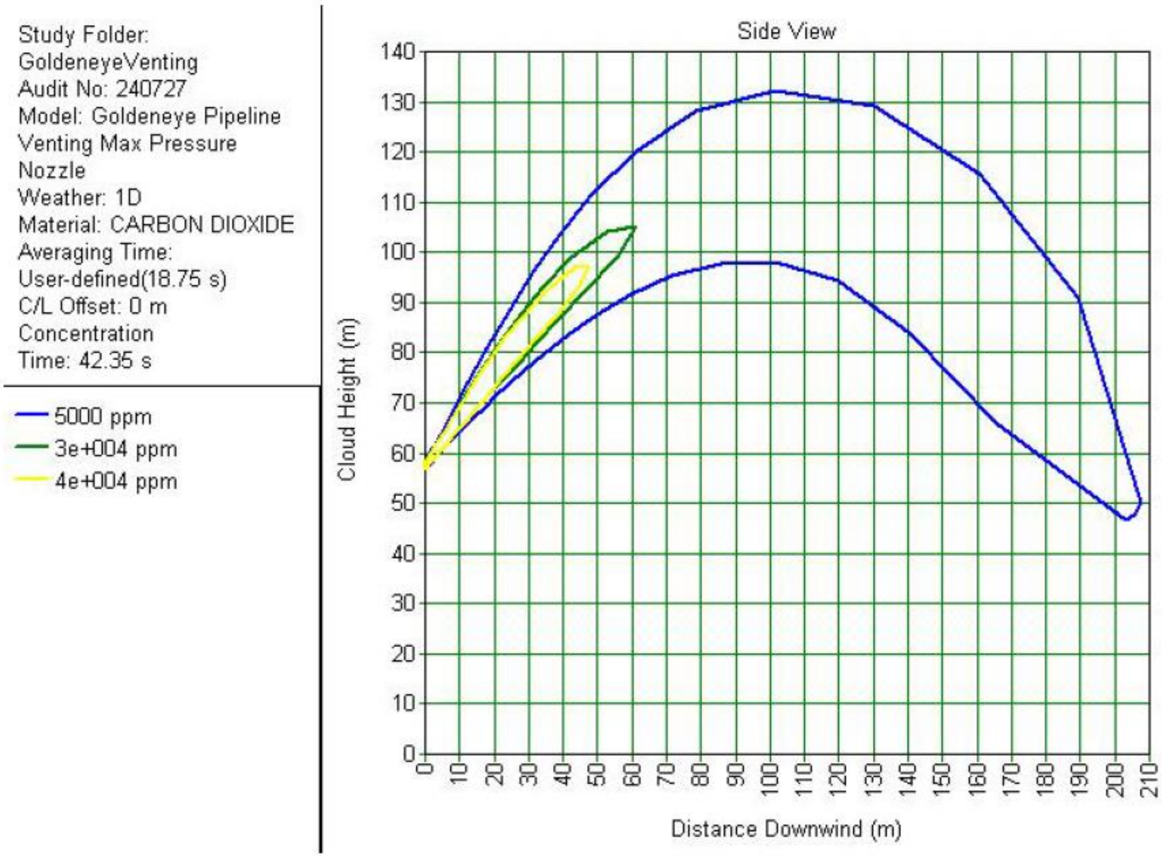


Figure 2-1: [Figure Case A in MMI Report] – Pipeline Depressurisation (offshore) at Maximum Nozzle Pressure. Wind speed of 1 m/s (stability class D).

2.2. Compromise with Accessibility

A compromise between successful dispersion of the CO_2 during pipeline blowdown and accessibility/constructability of the vent is required. The higher the vent the better the dispersion, although the modelling shows that this can be lowered and still have adequate dispersion. The lower the vent stack the easier it will be to construct and to inspect/maintain.

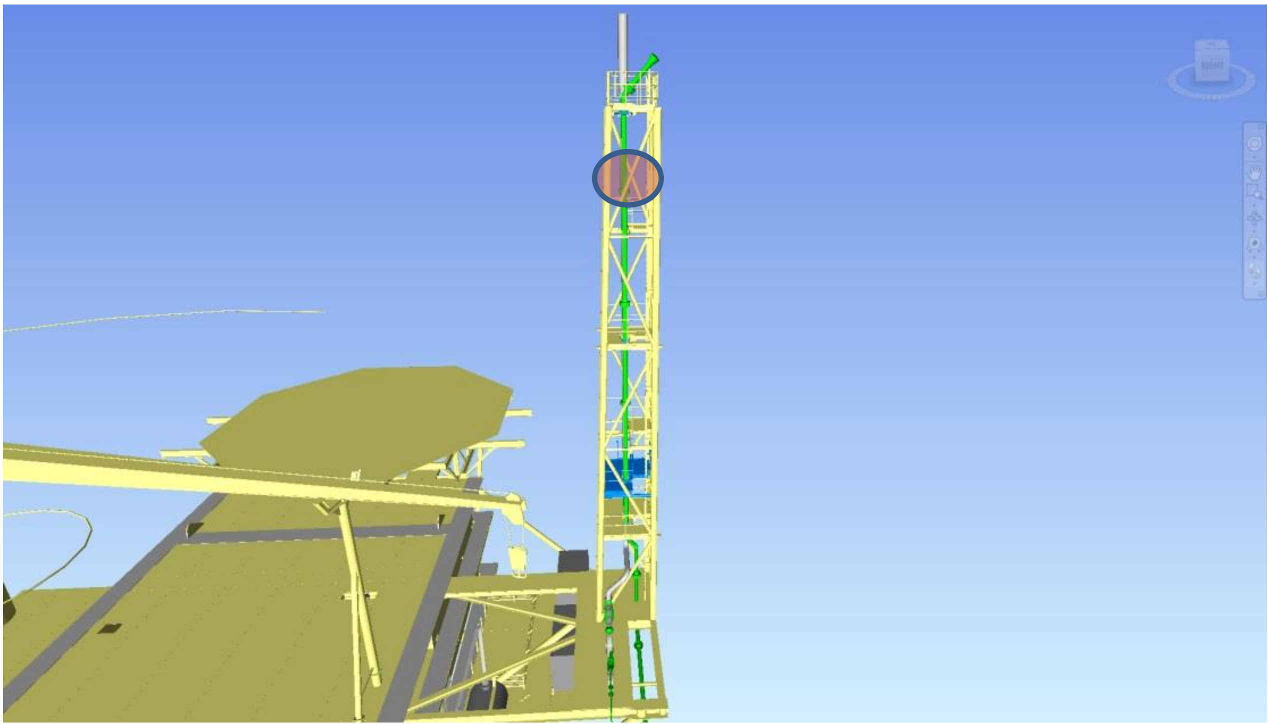


Figure 2-2: Current Vent Stack Configuration with Maximum Height

All scenarios will require the tower steel to maintain integrity during blowdown. The vent tip shall therefore be configured so that it does not impact the steel vent tower structure. To protect the structural steel from low temperatures during blowdown and to provide momentum away from the platform the vent tip shall be angled at 45° with the tip located outside the main stack structure.

Recommendation 1: As there are constructability and maintenance issues identified for the current location of vent tip, it is recommended that the vent tip should be lowered to the vent tower platform below the current location (this is circled in red in Figure 2-2). This lowers the point of discharge by approximately 7 m. This is still acceptable given the worst case dispersion illustrated in Figure 2-1.

Recommendation 2: As the depressurisation temperatures can reach very low temperatures the final vent tip location shall be reviewed to determine if there is any impact upon the surrounding vent stack steel structure.

The angling of vent tip also helps disperse the CO_2 away from the platform during still weather conditions. It is feasible that if the vent is oriented upwards the CO_2 cloud can slump back to the platform during some weather conditions. This is mitigated with the angled vent.

3. Dispersion from Thermal Relief Vents

As per the Fire, Gas and Smoke Detection Systems Design and Engineering Practice (DEP), CO_2 detectors shall be set at 5,000 ppm for alarm level 1 and 30,000 ppm for alarm level 2. The following illustrations are taken from the report included in Appendix 1. A check shall made against the modelling performed to determine the credibility of confirmed gas detection occurring. Figure 3-1 and Figure 3-2 are extracted from the Carbon Dioxide Dispersion Calculations for Onshore and Offshore Venting Report.

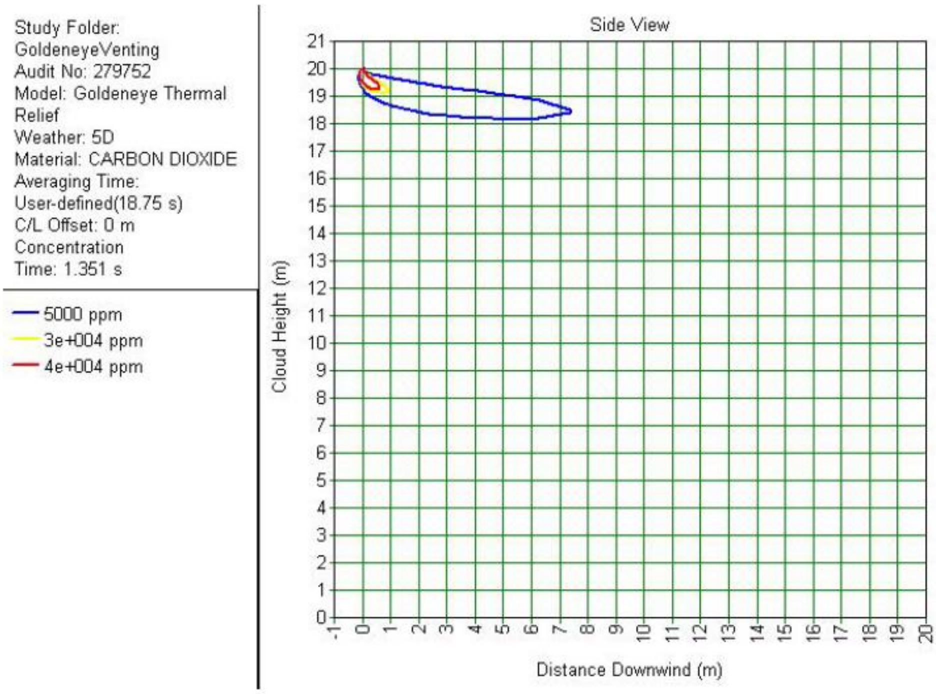


Figure 3-1: [Figure Case C in MMI Report] – Thermal relief with under deck discharge. Wind speed of 5 m/s (stability class D).

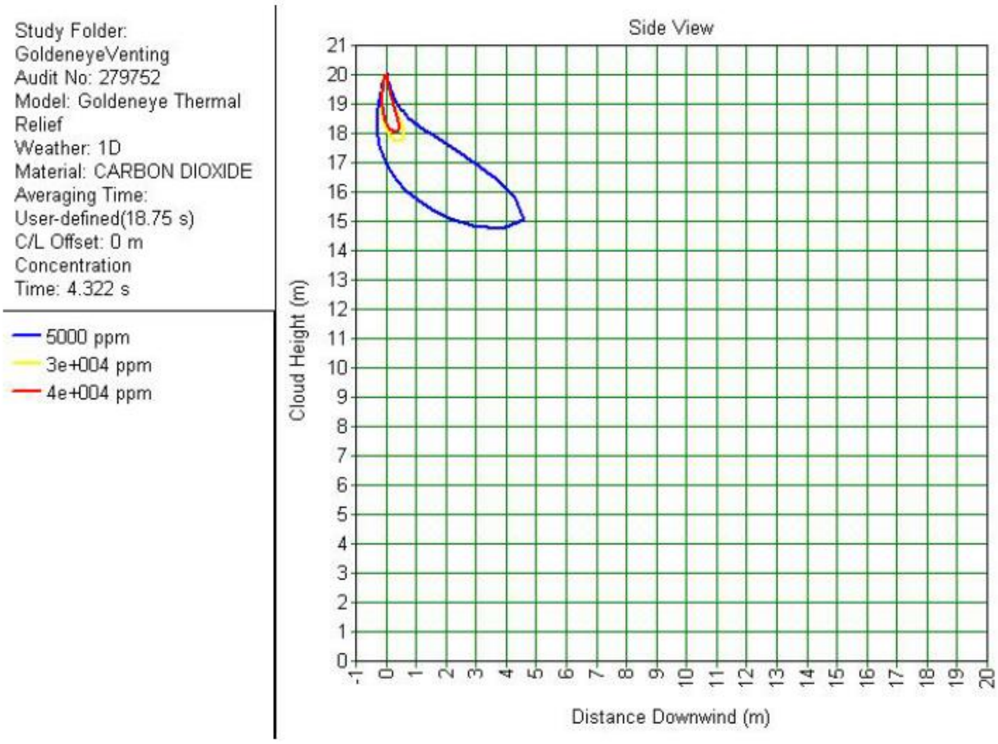


Figure 3-2: [Figure Case C in MMI Report] – Thermal relief with under deck discharge. Wind speed of 1 m/s (stability class D).

All modelling performed shows that emitted vapours are projected downwards and do not rise in either weather condition modelled. As all of the lowest sited detectors are on the cellar deck it would not be expected that emissions from the thermal relief valves which discharge below the cellar deck would give rise to gas detection. Additionally, the discharge from the thermal relief valves are expected to be short releases and not continuous. The discharge shall stop once the pressure build-up has been relieved.

If directed towards the spider deck walkways the release from the thermal release vents may impair the route back the stairs. These vents are therefore oriented at 45 degrees so that releases are away from direct impact of the walkways.

4. Conclusion and Recommendations

4.1. Conclusion

The modelling presented here indicates that:

- For the offshore pipeline depressurisation case the CO_2 concentration level of 0.5% does not reach sea level for the wind speeds considered.
- The same is true for under-deck thermal relief cases. Under deck vents shall be angled at 45 degrees away from the spider deck walkways. This is included in the PDMS model.
- It is not anticipated that thermal relief emissions will set off the gas detectors.
- The vent shall be angled at 45 degrees and assurances shall be provided that a release will not impact the surrounding structure.

4.2. Recommendations

The following recommendation was made in the report:

- **Recommendation 1:** As there are constructability and maintenance issues identified for the current location of vent tip, it is recommended that the vent tip should be lowered to the vent tower platform below the current location (this is circled in red in Figure 2-2). This lowers the point of discharge by approximately 7 m. This is still acceptable given the worst case dispersion illustrated in Figure 2-1.
- **Recommendation 2:** As the depressurisation temperatures can reach very low temperatures the final vent tip location shall be reviewed to determine if there is any impact upon the surrounding vent stack steel structure.
- **Recommendation 3:** The assumptions in MMI Venting Report such as those on depressurisation flow rates shall be confirmed when this is confirmed by the subsea scope of work

These shall be included in the HSE Action tracker for management and closure.

5. Glossary of Terms

Term	Definition
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
DEP	Design Engineering Practice
H&SE	Health and Safety Executive
HSE	Health Safety and Environment
ISO	International Standardisation Organisation
KKD	Key Knowledge Deliverable
KT	Knowledge Transfer
PCCS	Peterhead Carbon Capture and Sequestration
PDMS	Plant Design Management System
PHAST	Process Hazard Analysis Software Tools
ppm	Parts per Million
UK	United Kingdom
UKCCS	United Kingdom Carbon Capture and Storage

APPENDIX 1. MMI Modelling (Carbon dioxide dispersion for Venting at UK CCS Project)

Carbon dioxide dispersion calculations for onshore and offshore venting at UK CCS Project

Prepared for
Shell

MMI ENGINEERING LTD
a geosyntec company

Report No.	MMU186-R-03
Issue	Issue 1
Date of Issue	17th December 2010

Document History & Approval				
Issue & Date	**Prepared**	**Reviewed**	**Approved**	**Comments**
Issue 1 17/12/10	*C. Dixon*	*R. Emery*	*C. Dixon*	

Project Contacts		
MMI Engineering	Contact	C. Dixon
	Address	Wilderspool Park Greenall's Avenue Warrington Cheshire WA4 6HL
	Email	cdixon@mmiengineering.com
	Telephone	+44 (0) 1925 230655
	Fax	+44 (0) 1925 658702
SHELL	Contact	J. Mulhall
	Address	Seafield House, Floor 4B, Hill of Rubislaw, Anderson Drive, Aberdeen, AB15 6BL
	Email	jim.mulhall@shell.com
	Telephone	
	Fax	

Executive Summary

Shell is a partner in an UK based carbon capture and storage (CCS) project which will involve an on-shore component at St. Fergus and an off-shore component on the Goldeneye platform. As part of this project, MMI Engineering has carried out a number of dispersion calculations for operational venting scenarios at both the on-shore (St. Fergus) and off-shore (Goldeneye) facilities

The primary concentration level of interest for venting is taken to be 0.5% by volume (5000 ppm) which is the Threshold Limit Value given in the project Basis of Design.

For the onshore cases considered, the 5000ppm isosurfaces do not fall below the release height of 4m.

For the offshore cases, only the scenario of a failed under-deck relief valve produces a CO_2 concentration at sea level of above 5000 ppm.

Acronyms & Abbreviations

CO_2	Carbon Dioxide
CCS	Carbon Capture and Storage
TLV	Threshold Limit Value
ppm	Parts Per Million, volume basis

Table of Contents

1.0 INTRODUCTION

MMI Engineering has been requested by Shell to carry out carbon dioxide gas dispersion calculations in support of a CCS project in which Shell is a partner. The overall aim of this project is to capture carbon dioxide at the Longannet coal-fired power station and sequester it under the sea bed using Shell's Goldeneye platform. This will involve transporting the carbon dioxide by pipeline from Longannet to the St Fergus gas terminal and from there to the Goldeneye platform. Shell has a responsibility for specific aspects of the overall project:

- The Goldeneye platform at which the carbon dioxide will be injected
- A pipeline from the St. Fergus gas terminal to the Goldeneye platform (the sea line)
- A 1350m pipeline on the St. Fergus site (the tie-in line).

A number of scenarios have been developed by Shell to assess these items each of which falls into one of the following categories:

- On-shore (St. Fergus): accidental release from sea line
- On-shore (St. Fergus): accidental release from tie-in line
- On-shore (St. Fergus): venting
- Off-shore (Goldeneye): accidental release sub-sea
- Off-shore (Goldeneye): accidental release on platform with SSIV
- Off-shore (Goldeneye): venting.

This report considers only dispersion from venting. Shell has specified that for venting the primary carbon dioxide concentration level of interest is 0.5% by volume based on the project Basis for Design that states: 'The current threshold limit value (TLV) or maximum level that is considered safe for healthy adults for an eight-hour work day is 0.5% (5,000 ppm)'

The report is laid out as follows. The general methodology is first discussed in section 2.0, the results are presented in section 3.0 and the conclusions are given in section 4.0.

2.0 CALCULATION METHODOLOGY

Version 6.6 of DNV's PHAST code has been used to obtain all of the data presented in this report.

PHAST calculates release rate, external flashing and dispersion, but allows a scenario to be set up in only a limited number of ways; applicable to the work here are "Leak" which is a straightforward vessel release (i.e. a hole in a vessel), and "Line Rupture" in which a length of pipe is included in the calculation.

The cases to be simulated were specified in reference 2 in terms of a line diameter, mass flow rate, exit pressure and reference upstream conditions (130 bara and 4°C) used to specify the fluid enthalpy (with the assumption of an isenthalptic flash to the exit). In some cases this leads to two phase vapour/liquid flow at the orifice. It is assumed that the mass flow rates and exit conditions have been calculated in a process modelling tool such as Hysys or similar and these values are taken to be correct.

In order to allow calculations to be carried out, this information must be placed into the framework of the allowable methods of setting up scenarios in PHAST as listed above. In order to allow this, the following process was followed. The "vessel" in PHAST was set to the upstream conditions used to describe the enthalpy (i.e. to 130bara and 4°C) and a length of pipe added to give the correct flow rate. This will not guarantee that the exit conditions are identical to those specified, but it is found that they are similar.

It is important that the following parameters in Phast are in good agreement with the specified data in reference 2 to give greater confidence in the Phast output models:

- Mass flow rate.
- Exit pressure. This will have an effect on the flashing process (for example predicting the jet velocity after flashing) which then affects the gas dispersion.
- Exit density. If pressure is approximately correct, this is equivalent to getting the liquid fraction right. Again this will affect the flashing process and subsequent dispersion.

If each of these is a reasonable match to those specified, then the gas dispersion will be a good representation of that which would occur with the specified conditions, assuming that these are correct. The mass flow rate and exit pressure have been specified in the scope. The exit density which these conditions correspond to, assuming isenthalpic flash from the specified upstream conditions, has been calculated. This has been compared to the exit density in the PHAST calculations to ensure that they are similar and is shown later.

The level of accuracy to which these parameters must be specified is clearly related to how onerous the release transpires to be. Of the current scenarios the under-deck failed thermal relief valve is the most onerous case and the above process happens to be most successful in that case.

The general details of the gas dispersion model used within PHAST will not be given here, only those details specific to the release and dispersion for liquid CO_2. The set up of cases has been carried out in line with the appropriate DNV Software advice as set out in references 5 and 6.

This PHAST set up has been employed in calculations carried out for Shell by MMI Engineering as part of an ongoing validation project and compared against a limited set of liquid release experiments and the results appear good. This work will be reported to Shell in early 2011.

Limitations of PHAST are that:

- Geometry cannot be included in the calculations.
- The minimum wind speed which PHAST can employ is 1m/s, though in some cases a wind speed as low as this will produce non-physical results so that some judgement must be employed.
- The wind must be aligned with the horizontal component of a non-vertical release and cannot be opposed to a release.

3.0 RESULTS

3.1 Offshore Venting Releases

A number of carbon dioxide gas dispersion calculations have been carried out to allow venting operations on the Goldeneye platform to be assessed. The scenarios were specified in the scope document [2].

Case A: Pipeline Depressuring at Maximum Nozzle Pressure (offshore)

The case was specified as:

- Nozzle diameter of 33mm
- Mass flow of 126 kg/s
- Nozzle exit pressure of 133bara.
- Nozzle at +57231mm above LAT.
- Wind speeds of 5m/s and minimum achievable in PHAST code

This release was specified in PHAST as a "Leak" from a vessel at 130bar and 4°C with the discharge coefficient set to give the correct flow rate. This discharge coefficient was found to be close to unity.

Contours are shown in Figure 1 to Figure 4 for wind speeds of 5, 3, 1.5m/s and 1m/s. Note that 1m/s is the minimum wind speed which PHAST will allow the user to run without issuing a warning, though in many cases it is lower than it is advisable to employ in integral models. It is included here to show that it is unlikely that the 5000ppm contour reaches sea level even at this wind speed.

Case B: Pipeline Depressuring at 10 bar Nozzle Pressure (offshore)

The case was specified as:

- Nozzle diameter of 33mm
- Mass flow of 10 kg/s
- Nozzle exit pressure of 10bara.
- Nozzle at +57231mm above LAT.
- Wind speeds of 5m/s and minimum achievable in PHAST code.

This release was specified in PHAST as a "Line Rupture" with a line length of 223m found to give the correct flow rate. It should be noted that this may not be a good match to the physical length of line as this may contain bends and/or other elements which are not included within the simple PHAST representation.

Contours are shown in Figure 5 and Figure 6 for wind speeds of 5 and 1m/s. Again, 1m/s is the minimum wind speed which PHAST will allow the user to run without issuing a warning. Once again it is included here to show that it is unlikely that the 5000ppm contour reaches sea level even at this wind speed.

Case C: Thermal Relief with Under-deck Discharge

The case was specified as:

- Nozzle diameter of 42.8mm
- Mass flow of 0.125 kg/s
- Nozzle exit pressure of 1.1bara.
- Nozzle at +20000mm above LAT.
- Wind speeds of 5m/s and minimum achievable in PHAST code.

Based on the nozzle pressure and enthalpy given in [2] is seems likely that there may be a two-phase gas/solid mixture in the vent line for this case. PHAST will not allow a gas/solid mixture upstream of the release so that this case has been simulated as a pure vapour release with the appropriate mass flow rate and a temperature of -56°C. It is expected that a better representation of the release can be achieved with more time to set up the case if necessary, though the present results are such that this may not be required.

Contours are shown in Figure 7 and Figure 8 for wind speeds of 5 and 1m/s. Again, 1m/s is the minimum wind speed which PHAST will allow the user to run without issuing a warning. Once again it is included here to show that it is unlikely that the 5000ppm contour reaches sea level even at this wind speed.

Case D: One Failed Thermal Relief Valve (underdeck discharge)

The case was specified as:

- Nozzle diameter of 42.8mm
- Mass flow of 10.5 kg/s
- Nozzle exit pressure of 10bar.
- Nozzle at +20000mm above LAT.
- Wind speeds of 5m/s and minimum achievable in PHAST code.

This release was specified in PHAST as a “Line Rupture” with a line length of 820m found to give the correct flow rate. Once again, it should be noted that this may not be a good match to the physical length of line as this may contain bends and/or other elements which are not included within the simple PHAST representation. It is simply chosen to give the best match to the flow rate and exit pressure.

Contours are shown in Figure 9 and Figure 10 for wind speeds of 5 and 3m/s. In neither case do the 30,000 or 40,000 contours reach sea level, and it is not expected that either would reach sea level at lower wind speeds as the release is still in a jet phase and relatively insensitive to wind speed.

However in both cases the 5000ppm contour does reach sea level. With a wind speed of 5m/s the sea-level plume extends for a distance in excess of 100m. It should be noted that for the 3m/s wind speed the 5000ppm contour has non-physical shape at around 10m so that this result should be treated with some caution. However the trend of the plume extending further down-wind with decreasing wind speed is as expected.

3.2 Onshore Venting

Two release rates were specified for the on-shore venting cases. These correspond to:

- Thermal relief on the onshore pig launcher
- Failed thermal relief valve on the onshore pig launcher.

The thermal relief on onshore pig launcher is case E in reference 3. The case was specified as:

- Nozzle diameter of 42.8mm
- Mass flow of 0.125 kg/s
- Nozzle exit pressure of 1.1bar.

This is identical to the offshore thermal relief case which is described in section 3.1. The release is located 4m above ground level and vertically oriented. Contours are shown in Figure 11 and Figure 12 for wind speeds of 5 and 1m/s. 1m/s is the minimum wind speed which PHAST will allow the user to run without issuing a warning.

The single failed thermal relief valve on onshore pig launcher is case F in reference 3. The case was specified as:

- Nozzle diameter of 42.8mm
- Mass flow of 10.5 kg/s
- Nozzle exit pressure of 10bar.

This is identical to the offshore thermal relief case which is described in section 3.1. The release is located 4m above ground level and vertically oriented. Contours are shown in Figure 13 and Figure 14 for wind speeds of 5 and 1m/s.

In neither of the onshore venting scenarios does the resulting 0.5% CO_2 plume drop below the height of the release location.

3.3 PHAST Flow rates and Exit Conditions

In order to check that release conditions used in the PHAST cases using the “Line Rupture” model were a good representation of those specified in the scope [2] the mass flow rate and exit conditions were compared. The mass flow rate is straightforward. PHAST outputs orifice pressure which can be compared to those specified in the scope.

Density is slightly more involved. For the conditions specified in the scope the exit liquid fraction was found from the enthalpy at the specified reference state (133bara and 4°C) and the liquid and vapour enthalpies at the exit pressure. Then from a knowledge of the liquid and vapour density at the exit pressure the density can be found. Material properties were taken from the NIST Chemistry Webbook[4]. PHAST outputs orifice velocity and using this in combination with orifice (or pipe) diameter and mass flow rate the density can be found.

The comparison between specified values and those used in the PHAST calculations are shown in Table 1.The values extracted from the PHAST are shown in parentheses. The agreement is reasonably good, particularly for case D which is the most onerous case.

Case	Flow rate Specified (PHAST) kg/s	Exit pressure Specified (PHAST) bara	Exit density Specified (PHAST) kg/m^3
A	126 (126.5)		
B	10 (10.03)	10 (13.54)	87.6 (140)
C	0.125 (0.125)		
D	10.5 (10.48)	8 (8.51)	64.8 (74.8)

Table 1: Flow rates and exit conditions used in PHAST calculations

4.0 CONCLUSIONS

A series PHAST based calculations have been carried out in support of the Shell UK CCS Project. These cover a number of venting scenarios and use 0.5% as the primary concentration of interest as it is the Threshold Limit Value specified in the project Basis of Design. Hazard distances have been presented for CO_2.

The calculations presented here indicate that:

- For the offshore pipeline depressurisation case the CO_2 concentration level of 0.5% does not reach sea level for the wind speeds considered.
- The same is true for under-deck thermal relief cases.
- For a failed under-deck thermal relief valve the 0.5% concentration level does reach sea level and can extend for a downwind distance in excess of 100m.
- For the onshore venting scenarios which have been considered, the gas plume at a concentration of 0.5% does not drop below the release height of 4m.

5.0 REFERENCES

1. "CO2 Dispersion Study for UK Based CCS Project", C Dixon, MMI Proposal MMU09-109, Issue2, 14/08/2009
2. "Revised Input for Vent Simulation", e-mail from Ian Veltman (Shell) to Chris Dixon (MMI) on 26 October 2010.
3. "Goldeneye Vent Cases rev 11-11-10.docx", supplied by e-mail to C Dixon from I Veltman, 12/11/2010.
4. NIST Chemistry Webbook, http://webbook.nist.gov/chemistry/fluid/
5. PHAST Version 6.6 release Notes, DNV Software
6. DNV Document "CO_2 modelling of discharge and dispersion in Phast Risk and SAFETI-NL; old method in 6.53.1/6.54 versions versus improved method in 6.6"

6.0 FIGURES

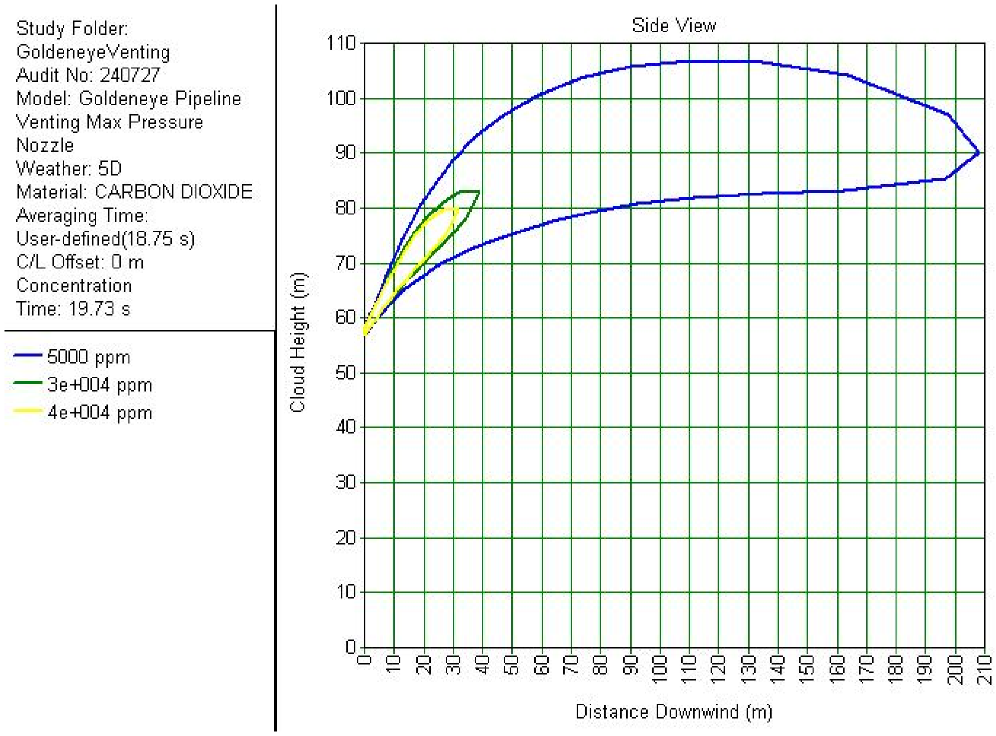


Figure 1: Case A – Pipeline depressurisation (offshore) at maximum nozzle pressure. Wind speed of 5m/s (stability class D).

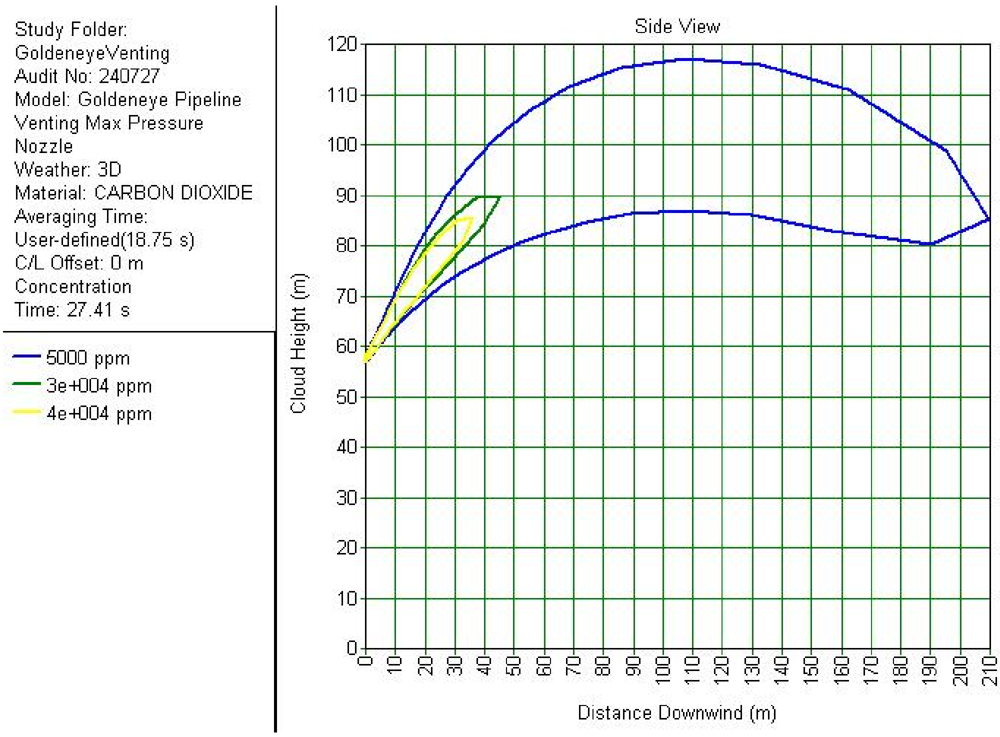


Figure 2: Pipeline depressurisation (offshore) at maximum nozzle pressure. Wind speed of 3m/s (stability class D).

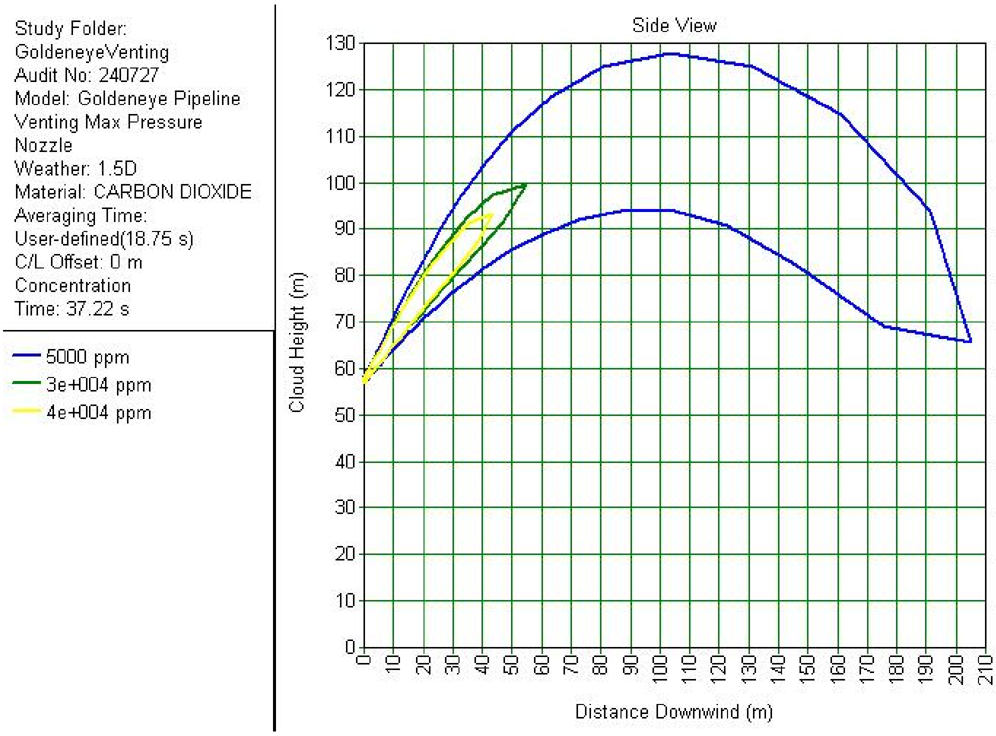


Figure 3: Case A – Pipeline depressurisation (offshore) at maximum nozzle pressure. Wind speed of 1.5m/s (stability class D).

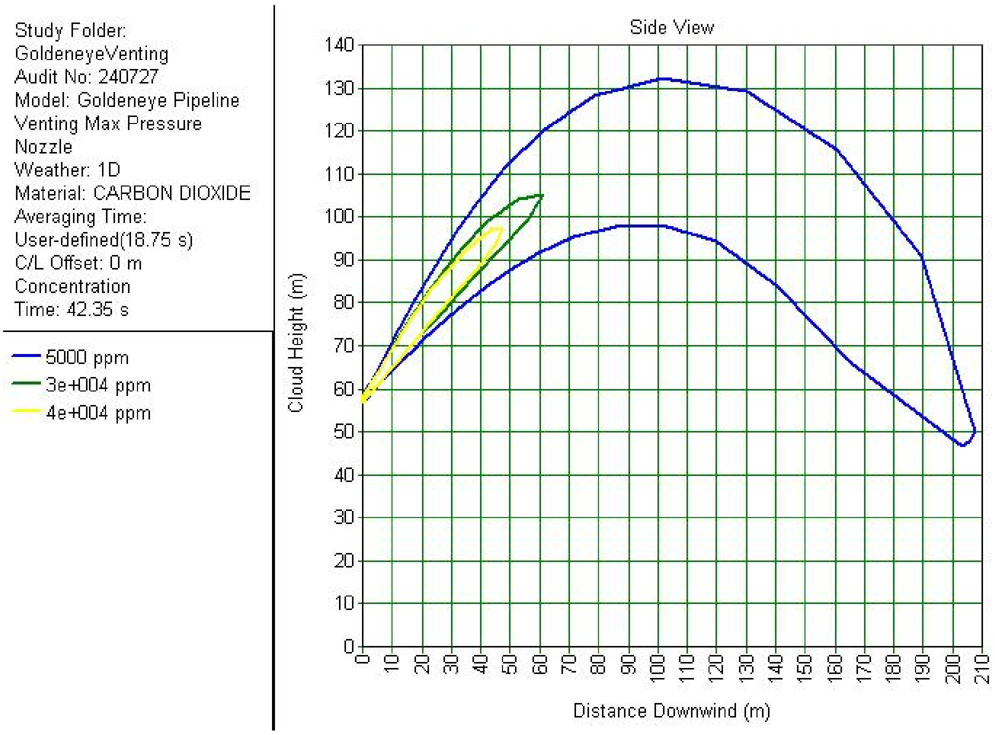


Figure 4: Case A – Pipeline depressurisation (offshore) at maximum nozzle pressure. Wind speed of 1m/s (stability class D).

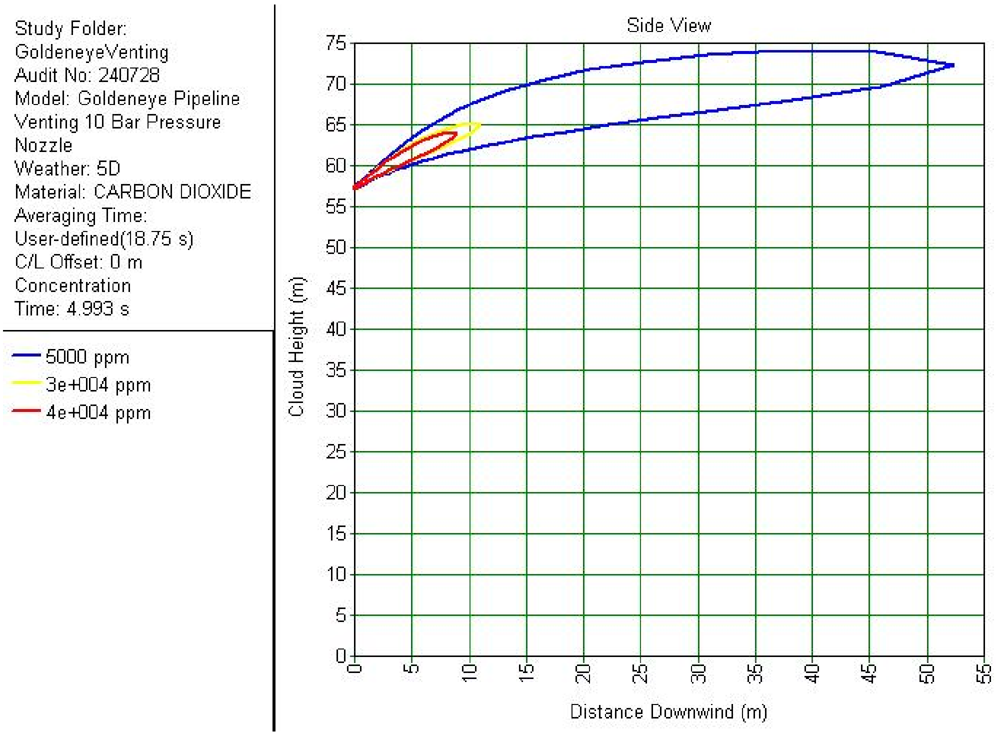


Figure 5: Case B – Pipeline depressurisation (offshore) at nozzle pressure of 10bara. Wind speed of 5m/s (stability class D).

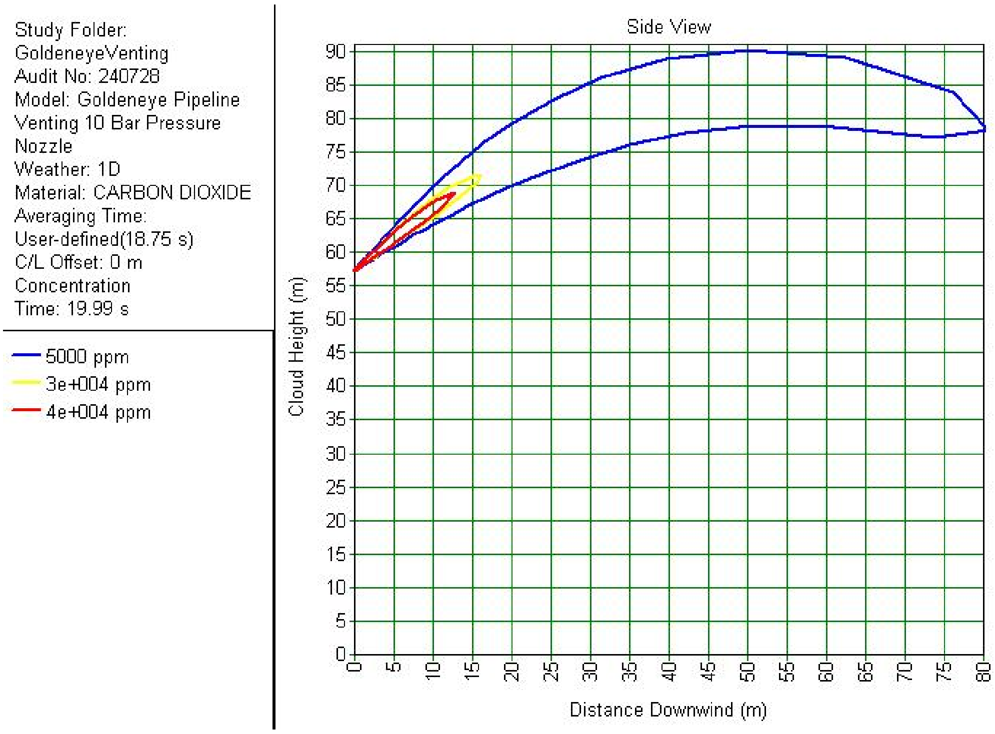


Figure 6: Case B – Pipeline depressurisation (offshore) **at nozzle pressure of 10bara. Wind speed of 1m/s (stability class D).**

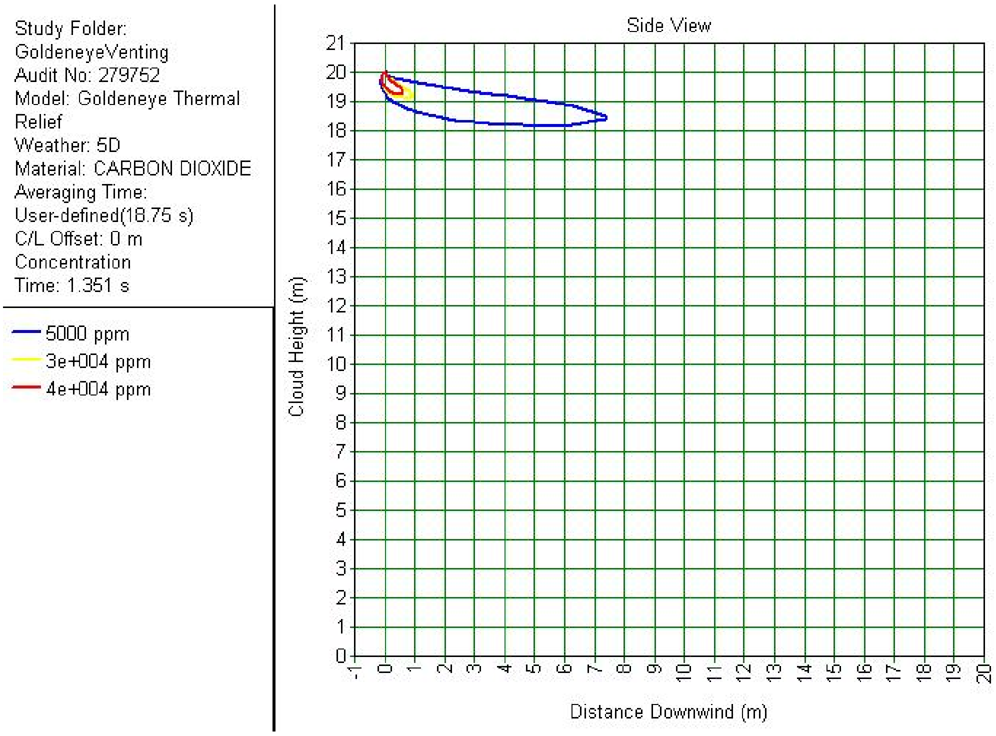


Figure 7: Case C – Thermal relief with under deck discharge. Wind speed of 5m/s (stability class D).

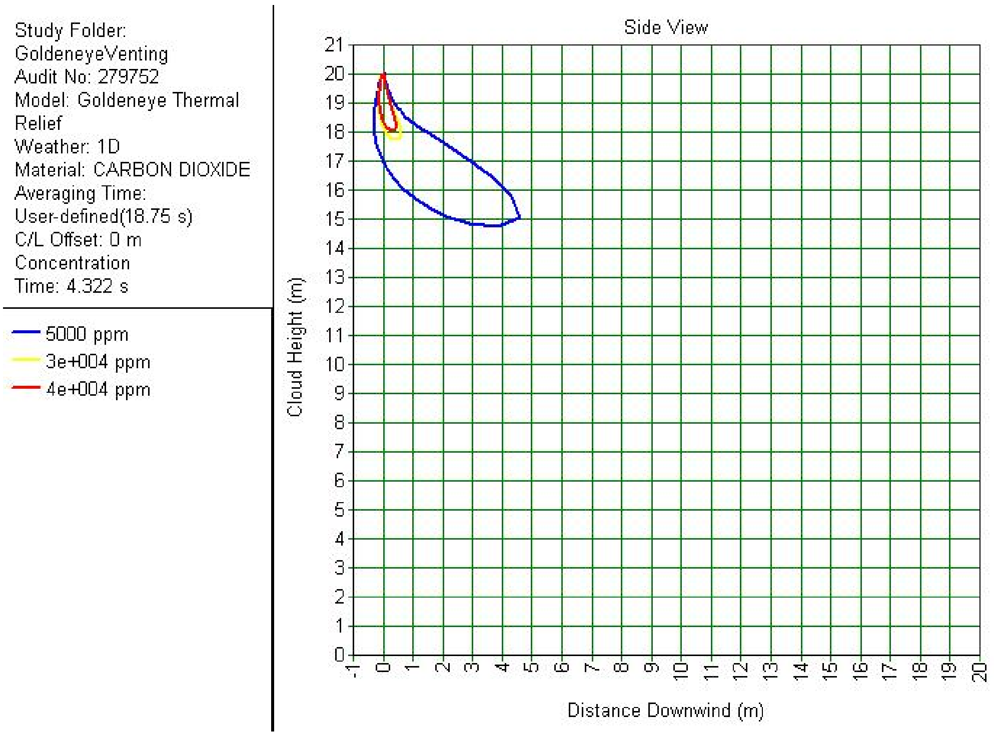


Figure 8: Case C – Thermal relief with under deck discharge. Wind speed of 1m/s (stability class D).

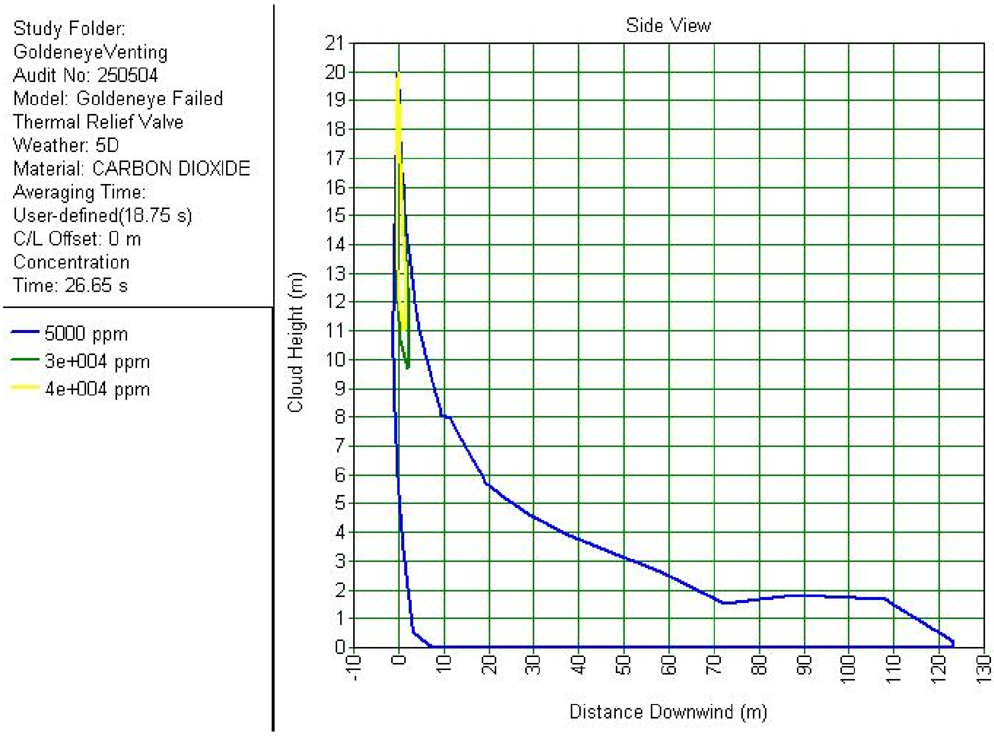


Figure 9: Case D – One thermal relief valve. Wind speed of 5m/s (stability class D).

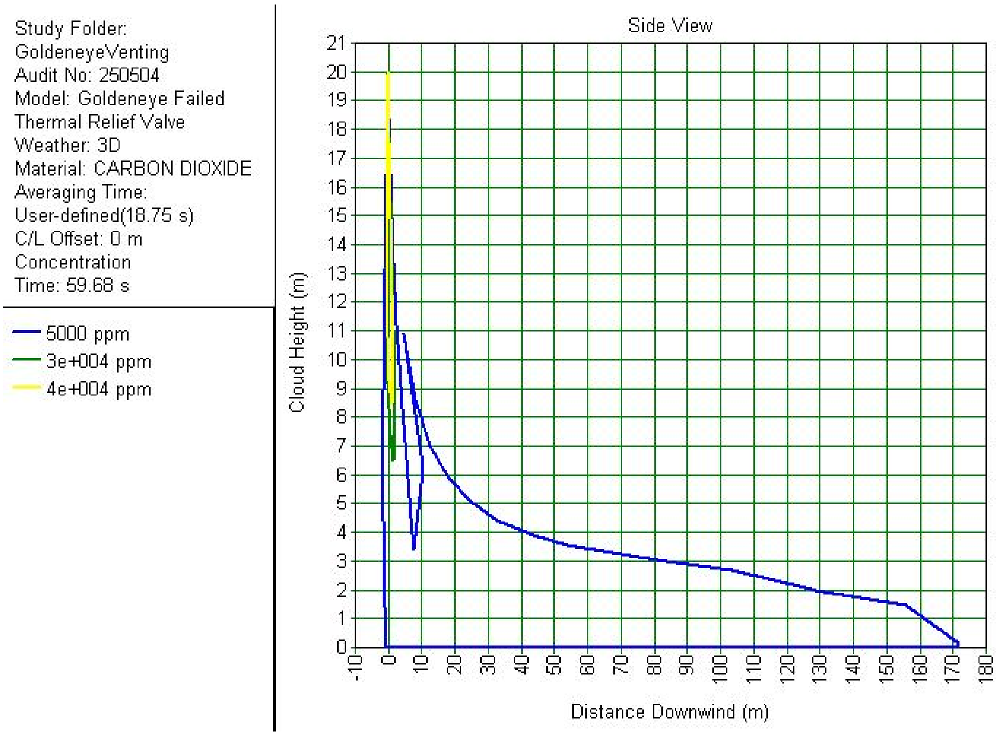


Figure 10: Case D – One thermal relief valve. Wind speed of 3m/s (stability class D).

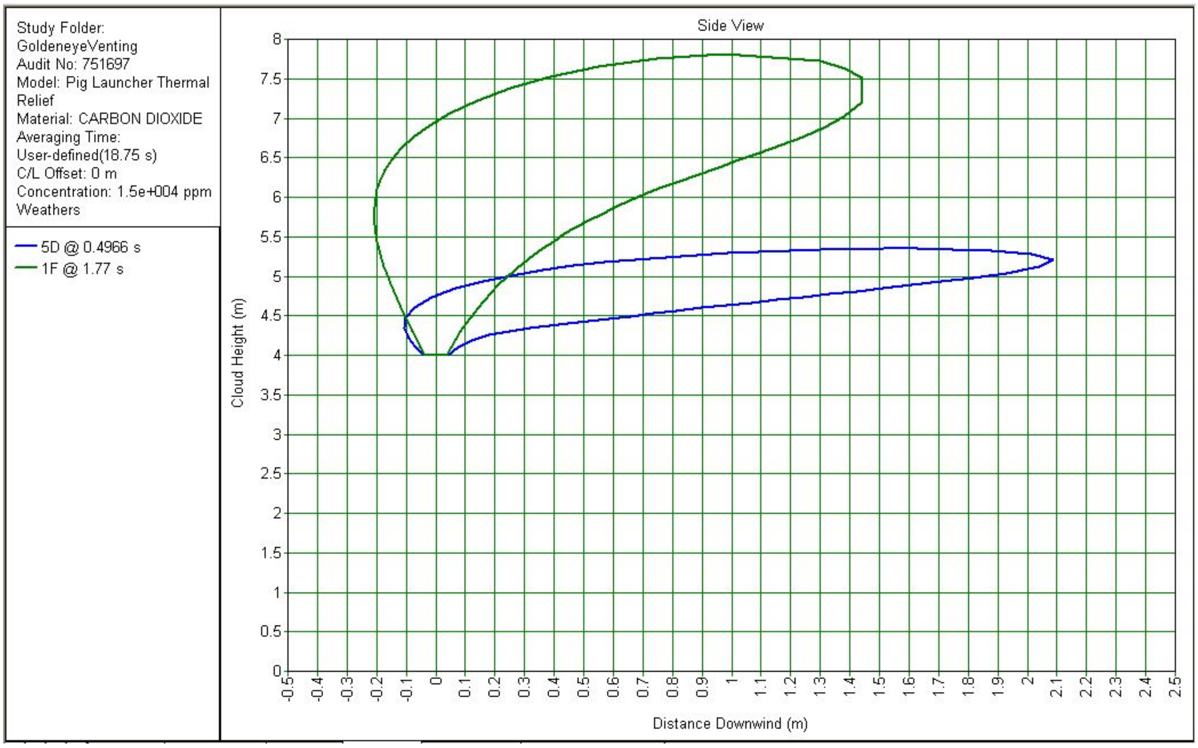


Figure 11: Side view of 1.5% CO_2 mole fraction contours for thermal relief at the onshore pig launcher, in 1m/s (green) and 5m/s (blue) winds.

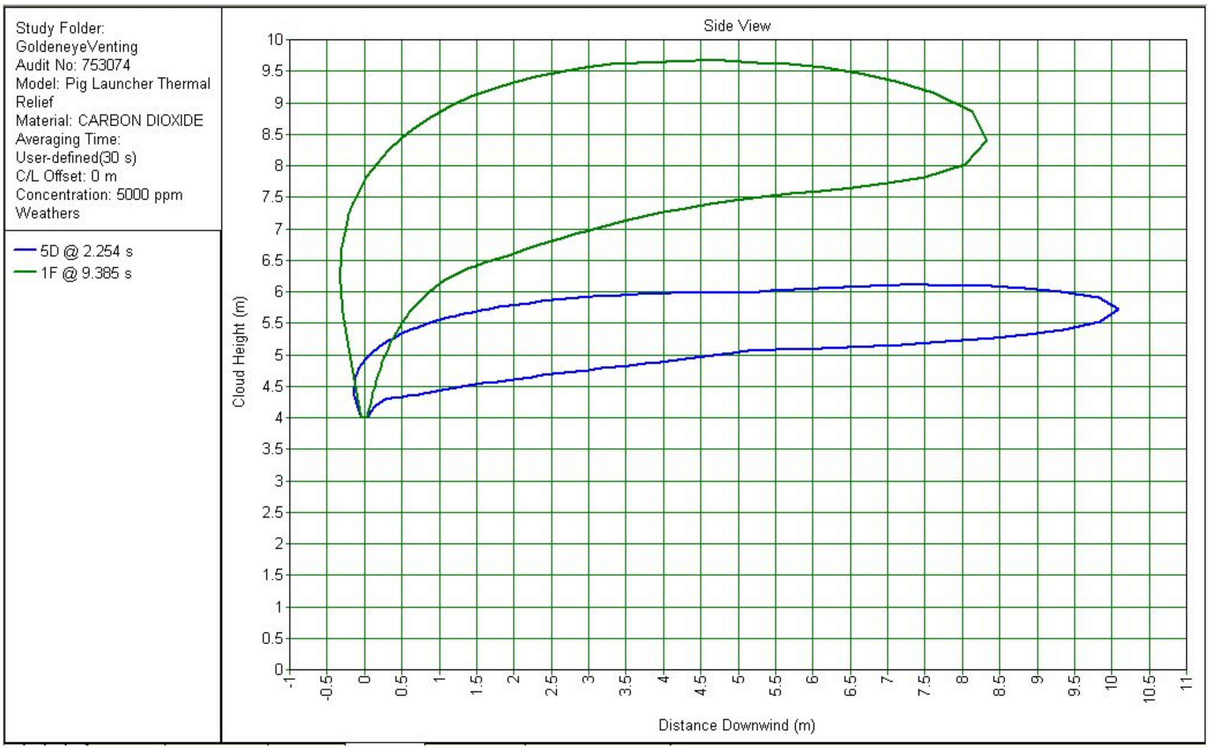


Figure 12: Side view of 0.5% CO_2 mole fraction contours for thermal relief at the onshore pig launcher, in 1m/s (green) and 5m/s (blue) winds.

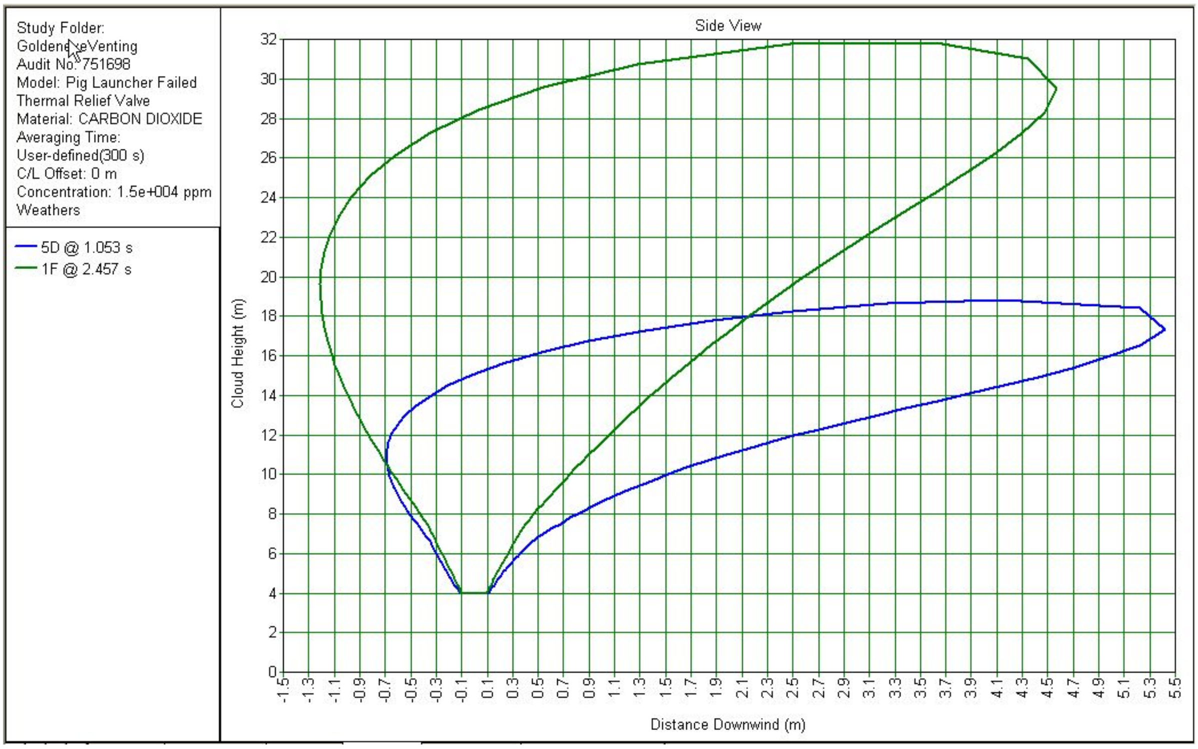


Figure 13: Side view of 1.5% CO_2 mole fraction contours for a failed thermal relief valve at the onshore pig launcher, in 1m/s (green) and 5m/s (blue) winds.

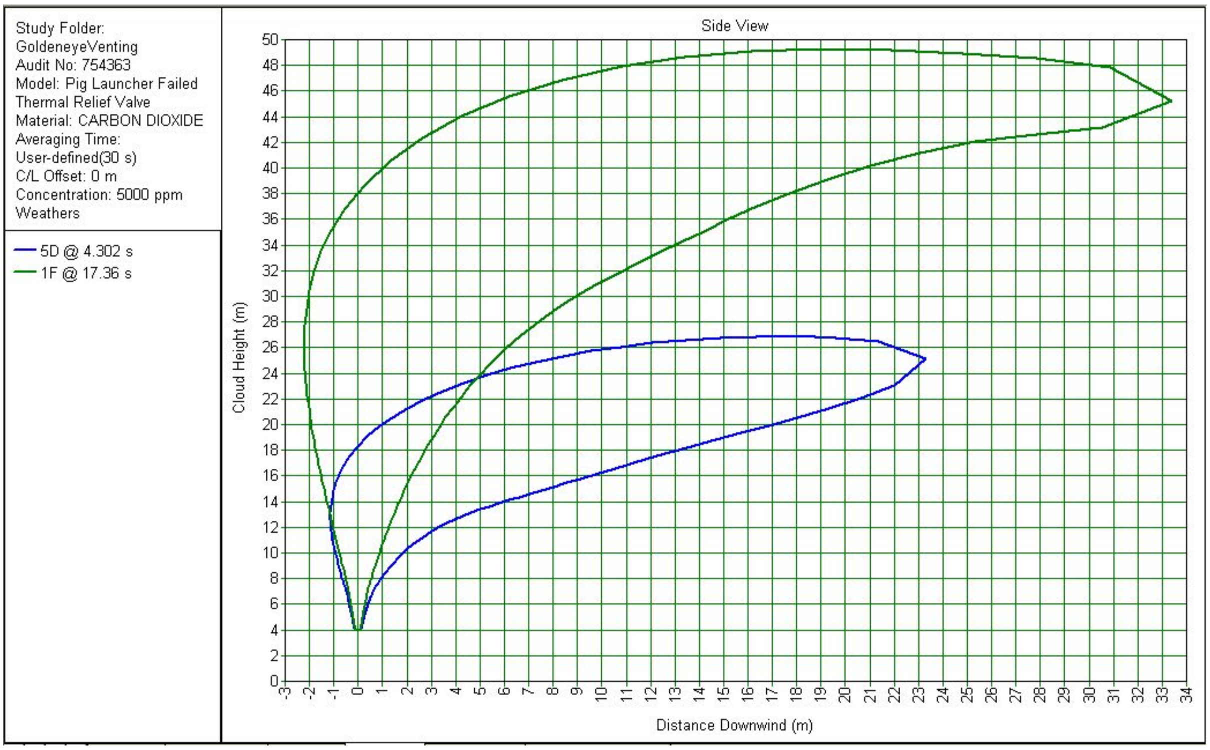


Figure 14: Side view of 0.5% CO_2 mole fraction contours for a failed thermal relief valve at the onshore pig launcher, in 1m/s (green) and 5m/s (blue) winds.