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DETERMINATION OF ODOUR EMISSIONS TO ATMOSPHERE FROM INDAVER IRELAND LTD, CARRANSTOWN, CO. MEATH

Technical Report Prepared For

Indaver Ireland Ltd
Carranstown
Duleek
Co. Meath

Technical Report Prepared By

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Our Reference

EP/247501.0044AR01

Date Of Issue

01 March 2024

Document History

Document Reference		Original Issue Date	
EP/247501.0044AR01		08/02/2024	
Revision Level	Revision Date	Description	Sections Affected
EP/247501.0044AR01a	01/03/2024	Minor Updates	All Sections

Record of Approval

Details	Written by	Checked by
Signature		
Name	Dr. Edward Porter	Ciara Nolan
Title	Director (Air Quality)	Senior Air Quality Consultant
Date	01/03/2024	01/03/2024

EXECUTIVE SUMMARY

AWN Consulting Ltd (AWN) was commissioned to carry out an odour modelling assessment of the Indaver Ireland Ltd facility in Carranstown, County Meath. The purpose of the assessment was to ensure that no odour nuisance is occurring at nearby sensitive receptors.

The assessment has determined, through dispersion modelling of emissions from the facility, whether the predicted ambient odour concentration at the nearest dwelling-house was less than 1.5 OU_E/m^3 as a 98^{th} percentile of the hourly average concentrations (as per the EPA AG4 and AG9 Guidance documents and the UK Environment Agency H4 Draft Guidance document).

Odour dispersion modelling was carried out using the United States Environmental Protection Agency's regulatory model AERMOD (Version 22112). The aim of the study was to assess the contribution of all odorous emission points from the facility to off-site levels of odour and to identify the location and maximum of the worst-case ground level odour concentrations.

This report describes the outcome of this study. The study consists of the following components:

- Review of activities which are likely to generate odorous emissions based on the current operations at the facility;
- Estimate the odour emissions (in terms of OU_E/s) and other relevant information needed for the modelling study;
- Dispersion modelling of odour under the maximum emission scenario to determine the likely level of odour in the ambient environment;
- Presentation of predicted ground level concentrations of released odours;
- Evaluation of the significance of these predicted concentrations, including consideration of whether these ground level concentrations are likely to exceed the relevant ambient Odour Guidelines.

Assessment Summary

An assessment of the Indaver Ireland Ltd facility has found that the main stack (A1-1) is the main source of odour at the facility. Some additional fugitive sources are also possible from, for example, the storage of waste in the bunker or waste vehicle deliveries, but due to the operational controls and mitigation measures in place on site as part of the on-site environmental management system, which is certified to ISO 14001, they should not be detectable beyond the site boundary. An odour management plan is also in place at the facility.

Odour modelling, based an odour emission concentration of 141 OU_E/m^3 from the main stack (A1-1), and using the USEPA approved AERMOD model has found that the worst case scenario for the 98^{th}%ile of 1-hour concentrations occurs in 2019 where the maximum off-site concentration is 8% of the guideline value of 1.5 OU_E/m^3 at the worst case receptor. Based on the results, no residential receptors are predicted to experience odour nuisance issues as a result of the Indaver Ireland Ltd facility.

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1.0 INTRODUCTION

AWN Consulting Ltd (AWN) was commissioned to carry out an odour modelling assessment of the Indaver Ireland Ltd facility in Carranstown, County Meath. The purpose of the assessment was to ensure that no odour nuisance is occurring at nearby sensitive receptors. The site is located in close proximity to some residential receptors as shown in Figure 2.

The purpose of this modelling study is to determine whether the emissions from the site, are leading to ambient concentrations which are in compliance with the criterion of 1.5 OU_E/m^3 as a 98th percentile of the hourly average concentrations and to identify the location and maximum of the worst-case ground level odour concentrations.

This report describes the outcome of this study. The study consists of the following components:

- Review of activities which are likely to generate odorous emissions based on the current operations at the facility;
- Estimate the odour emissions (in terms of OU_E/s) and other relevant information needed for the modelling study;
- Dispersion modelling of odour under the maximum emission scenario to determine the likely level of odour in the ambient environment;
- Presentation of predicted ground level concentrations of released odours;
- Evaluation of the significance of these predicted concentrations, including consideration of whether these ground level concentrations are likely to exceed the relevant ambient Odour Guidelines.

Information supporting the conclusions has been detailed in the following sections. The assessment methodology and study inputs are presented in Section 2. The dispersion modelling results and assessment summaries are presented in Section 3. The model formulation is detailed in Appendix I, a review of the meteorological data used is detailed in Appendix II, comprehensive meteorological data is presented in Appendix III and a summary of the odour monitoring results are detailed in Appendix IV.

2.0 ASSESSMENT METHODOLOGY

Emissions from the facility have been modelled using the AERMOD dispersion model (Version 22112) which has been developed by the U.S. Environmental Protection Agency (USEPA)[4] and following guidance issued by the EPA[1,2]. The model is a steady-state Gaussian plume model used to assess pollutant concentrations associated with industrial sources and has replaced ISCST3[5] as the regulatory model by the USEPA for modelling emissions from industrial sources in both flat and rolling terrain[6]. The model has more advanced algorithms and gives better agreement with monitoring data in extensive validation studies[7,8]. An overview of the AERMOD dispersion model is outlined in Appendix I.

The odour dispersion modelling input data consisted of information on the physical environment (including building dimensions and terrain features), design details from all emission points on-site and five years of appropriate hourly meteorological data. Using this input data the model predicted ambient ground level concentrations beyond the site boundary for each hour of the modelled meteorological years. The model post-processed the data to identify the location and maximum of the worst-case ground level concentration.

2.1 Characteristics of Odour

Odours are sensations resulting from the reception of a stimulus by the olfactory sensory system, which consists of two separate subsystems: the olfactory epithelium and the trigeminal nerve. The olfactory epithelium, located in the nose, is capable of detecting and discriminating between many thousands of different odours and can detect some of them in concentrations lower than those detectable by currently available analytical instruments[9]. The function of the trigeminal nerve is to trigger a reflex action that produces a painful sensation. It can initiate protective reflexes such as sneezing to interrupt inhalation. The olfactory system is extremely complex and peoples' responses to odours can be variable. This variability is the result of differences in the ability to detect odour; subjective acceptance or rejection of an odour due to past experience; circumstances under which the odour is detected and the age, health and attitudes of the human receptor.

Odour Intensity and Threshold

Odour intensity is a measure of the strength of the odour sensation and is related to the odour concentration. The odour threshold refers to the minimum concentration of an odorant that produces an olfactory response or sensation. This threshold is normally determined by an odour panel consisting of a specified number of people, and the numerical result is typically expressed as occurring when 50% of the panel correctly detect the odour. This odour threshold is given a value of one odour unit and is expressed as 1 OU_E/m^3. The odour threshold is not a precisely determined value, but depends on the sensitivity of the odour panellists and the method of presenting the odour stimulus to the panellists. An odour detection threshold relates to the minimum odorant concentration required to perceive the existence of the stimulus, whereas an odour recognition threshold relates to the minimum odorant concentration required to recognise the character of the stimulus. Typically, the recognition threshold exceeds the detection threshold by a factor of 2 to 10[9-10].

Odour Character

The character of an odour distinguishes it from another odour of equal intensity. Odours are characterised on the basis of odour descriptor terms (e.g. putrid, fishy, fruity etc.). Odour character is evaluated by comparison with other odours, either directly or through the use of descriptor words.

Hedonic Tone

The hedonic tone of an odour relates to its pleasantness or unpleasantness. When an odour is evaluated in the laboratory for its hedonic tone in the neutral context of an olfactometric presentation, the panellist is exposed to a stimulus of controlled intensity and duration. The degree of pleasantness or unpleasantness is determined by each panellist's experience and emotional associations. The responses among panellists may vary depending on odour character; an odour pleasant to many may be declared highly unpleasant by some.

Adaptation

Adaptation, or Olfactory Fatigue, is a phenomenon that occurs when people with a normal sense of smell experience a decrease in perceived intensity of an odour if the stimulus is received continually. Adaptation to a specific odorant typically does not interfere with the ability of a person to detect other odours. Another phenomenon known as habituation or occupational anosmia occurs when a worker in an industrial situation experiences a long-term exposure and develops a higher threshold tolerance to the odour.

2.2 Odour Guidelines

The exposure of the population to a particular odour consists of two factors; the concentration and the length of time that the population may perceive the odour. By definition, 1 OU_E/m^3 is the detection threshold of 50% of a qualified panel of observers working in an odour-free laboratory using odour-free air as the zero reference.

Currently there is no general statutory odour standard in Ireland relating to industrial installations. The EPA[(2)] has issued guidance specific to intensive agriculture which has outlined the following standards:

- Target value for new pig-production units of 1.5 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods,
- Limit value for new pig-production units of 3.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods,
- Limit value for existing pig-production units of 6.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods.

Guidance from the UK[(3)], and adapted for Irish EPA use, recommends that odour standards should vary from 1.5 – 6.0 OU_E/m^3 as a 98^{th}%ile of one hour averaging periods at the worst-case sensitive receptor based on the offensiveness of the odour and with adjustments for local factors such as population density. A summary of the indicative criterion is given below in Table 1 (taken from EPA Guidance document AG9[(2)]):

Industrial Sectors	Relative Offensiveness of Odour	Indicative Criterion Note 1
• Processes involving decaying animal or fish remains. • Processes involving septic effluent or sludge • Waste sites including landfills, waste transfer stations and non-green waste composting facilities.	Most Offensive	1.5 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor
• Intensive Livestock Rearing • Fat Frying / Meat Cooking (Food Processing) • Animal Feed • Sugar Beet Processing • Well aerated green waste composting Most odours from regulated processes fall into this category i.e. any industrial sector which does not obviously fall within the "most offensive" or "less offensive" categories.	Moderately Offensive	3.0 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor
• Brewery / Grain / Oats Production • Coffee Roasting • Bakery • Confectionery	Less Offensive	6.0 OU_E/m^3 as a 98^{th}%ile of hourly averages at the worst-case sensitive receptor

Note 1 Professional judgement should be applied in the determination of where the worst-case sensitive receptor is located.

Table 1 Indicative Odour Standards Based On Offensiveness Of Odour And Adapted for Irish EPA(2)

Based on the guidance above, an odour threshold of 1.5 OU_E/m^3 as a 98^{th}%ile of hourly mean values has been selected for identifying the potential for odour nuisance for the facility. The selection of the "most offensive" category is conservative as all odours are extracted to a series of abatement units and thus no untreated odours are emitted directly from the facility.

2.3 Odour Dispersion Modelling Methodology

The United States Environmental Protection Agency (USEPA) approved AERMOD dispersion model has been used to predict the ground level concentrations (GLC) of compounds emitted from the principal emission sources on-site.

The modelling incorporated the following features:

- A nested receptor grid was created at which concentrations would be modelled. Receptors were mapped with sufficient resolution to ensure all localised "hot-spots" were identified without adding unduly to processing time. The inner receptor grid was based on Cartesian grids with the site at the centre. The grid extended over a distance of 2000m with concentrations calculated at 25m intervals. The middle receptor grid was also based on Cartesian grids with the site at the centre. The grid extended over a distance of 5000m with concentrations calculated at 50m intervals. The outer receptor grid was also based on Cartesian grids with the site at the centre. The grid extended over a distance of 18000m with concentrations calculated at 1000m intervals. Boundary receptor locations were also placed along the boundary of the site, at 25m intervals. Discrete sensitive receptors were created to represent residential homes in close proximity to the site. In total, 17,044 calculation points were input into the air dispersion model.

- All on-site buildings and significant process structures were mapped into the computer to create a three dimensional visualisation of the site and its emission points. Buildings and process structures can influence the passage of airflow over the emission stacks and draw plumes down towards the ground (termed building downwash). The stacks themselves can influence airflow in the same way as buildings by causing low pressure regions behind them (termed stack tip downwash). Both building and stack tip downwash were incorporated into the modelling.

- Detailed terrain has been mapped into the model using SRTM data with 30m resolution. The site is located in gentle terrain. This takes account of all significant features of the terrain. All terrain features have been mapped in detail into the model using the terrain pre-processor AERMAP(11).

- Hourly-sequenced meteorological information has been used in the model. Meteorological data over a five year period (Dublin Airport 2018 - 2022) was used in the model (see Figure 1 and Appendix III).

- The source and emission data, including stack dimensions, volume flows and emission temperatures have been incorporated into the model.

2.4 Terrain

The AERMOD air dispersion model has a terrain pre-processor AERMAP(11) which was used to map the physical environment in detail over the receptor grid. The digital terrain input data used in the AERMAP pre-processor was obtained from SRTM. This data was run to obtain for each receptor point the terrain height and the terrain height scale. The terrain height scale is used in AERMOD to calculate the critical dividing streamline height, H_{crit}, for each receptor. The terrain height scale is derived from the Digital Elevation Model (DEM) files in AERMAP by computing the relief height of the DEM point relative to the height of the receptor and determining the slope. If the slope is less than 10%, the program goes to the next DEM point. If the slope is 10% or greater, the controlling hill height is updated if it is higher than the stored hill height.

In areas of complex terrain, AERMOD models the impact of terrain using the concept of the dividing streamline (H_c). As outlined in the AERMOD model formulation(4) a plume embedded in the flow below H_c tends to remain horizontal; it might go around the hill or impact on it. A plume above H_c will ride over the hill. Associated with this is a tendency for the plume to be depressed toward the terrain surface, for the flow to speed up, and for vertical turbulent intensities to increase.

AERMOD model formulation states that the model “captures the effect of flow above and below the dividing streamline by weighting the plume concentration associated with two possible extreme states of the boundary layer (horizontal plume and terrain-following). The relative weighting of the two states depends on: 1) the degree of atmospheric stability; 2) the wind speed; and 3) the plume height relative to terrain. In stable conditions, the horizontal plume "dominates" and is given greater weight while in neutral and unstable conditions, the plume traveling over the terrain is more heavily weighted”[(4)].

The terrain in the region of the facility is complex in the sense that the maximum terrain in the modelling domain peaks at 179m which is above the stack top of all emission points onsite. However, the region of the site has moderate terrain in the immediate vicinity of the facility.

2.5 Meteorological Data

The selection of the appropriate meteorological data has followed the guidance issued by the USEPA[(6)]. A primary requirement is that the data used should have a data capture of greater than 90% for all parameters. Dublin Airport meteorological station, which is located approximately 30 km south of the site, collects data in the correct format and has a data collection of greater than 90%. Long-term hourly observations at Dublin Airport meteorological station provide an indication of the prevailing wind conditions for the region (see Figure 1 and Appendix III). Results indicate that the prevailing wind direction is south-westerly in direction over the period 2018 - 2022. Calm conditions account for only a small fraction of the time in any one year peaking at 54 hours in 2019 (0.61% of the time). There are no missing hours over the period 2018 – 2022.

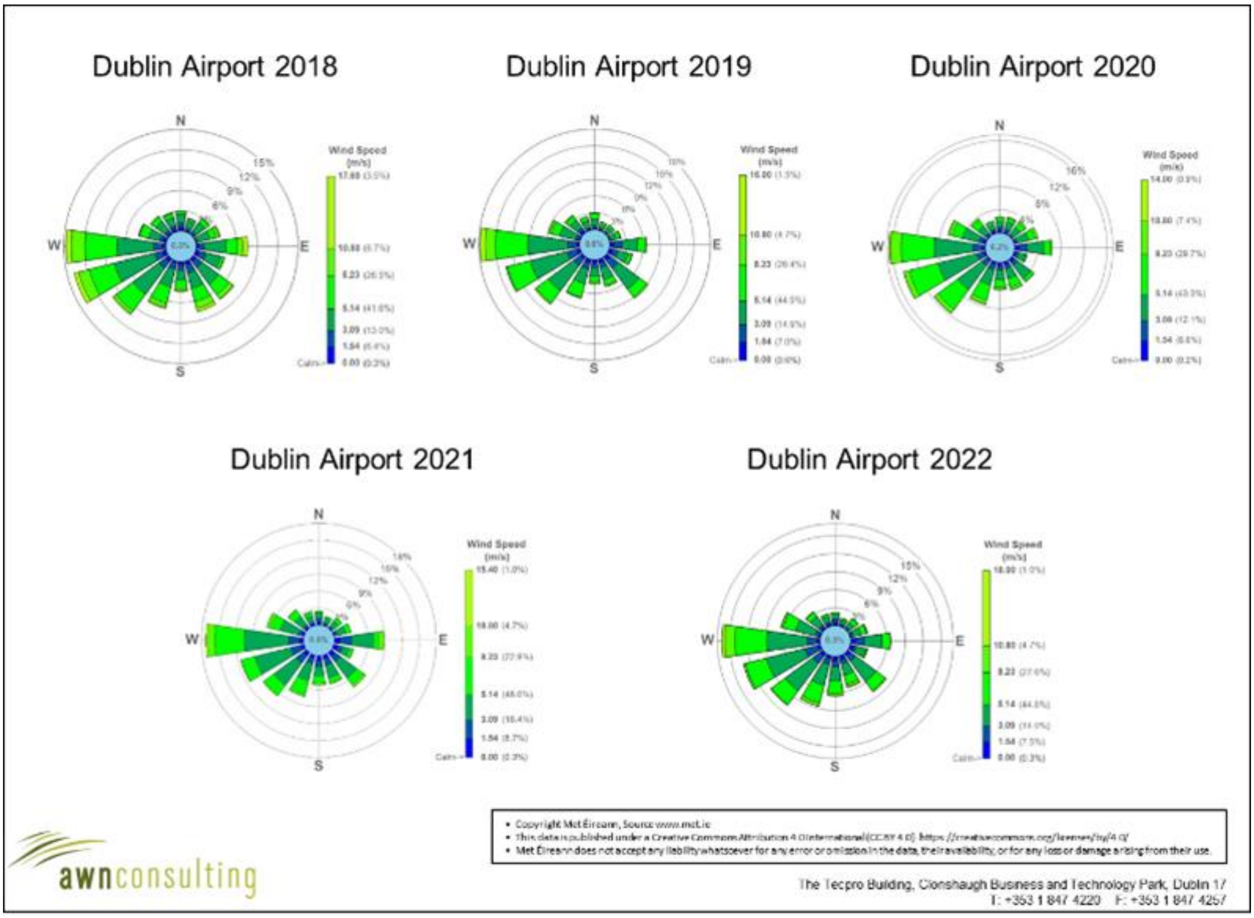

Figure 1 Dublin Airport Windrose 2018-2022

2.6 Review of AG9 To Control Odour

EPA publication "*AG9 – Odour Emissions Guidance Note*" (2019)[(2)] outlines a range of mitigation options which should be explored, on a case-by-case basis to ensure odour emissions are prevented, minimised and controlled. These include:

- Mitigation measures for the storage and handling of odorous materials located outdoors include constructing 3-sided enclosures and relocating activities indoors.
- Good housekeeping of all outdoor areas should be implemented particularly during periods of unfavourable meteorological conditions (for example, decomposition of organic material will accelerate during warmer periods).
- All spills, overflows and leaks should be cleaned up promptly with all operators aware and trained in the relevant SOP for this procedure.
- A local fume hood collection system with flexible hoses may be useful for capturing and extracting fugitive odours from sources with odour potential. Localised containment will reduce the volume of air to be extracted and, if necessary, treated.
- For the transfer or delivery of odorous liquids, vapour recovery or a closed-loop system should be used.
- Extraction of air through a negative pressure system to a point source will reduce fugitive emissions associated with passive sources such as general ventilation exhausts, louvers, windows or doors.
- A building integrity test is recommended for any building where odorous material is stored. Ideally, the building should have a negative pressure system installed with the extracted air ducted to a vertically pointed stack (and possibly with an abatement system prior to release where the need arises). Self-closing doors and trigger alarms on roller doors should also be installed.
- The facility should have a high level of cleanliness with outdoor surfaces washed down regularly with any remaining stagnant water removed. Cleaning of waste and storage bins, trucks carrying odorous materials and holding vessels should be undertaken regularly with an increased frequency in summer months.
- A closed-door policy should be strictly enforced where there is the potential for odorous releases through open doors.
- Keeping the temperature as low as possible will reduce evaporation and thus odorous material should be kept out of direct sunlight and refrigerated if possible.
- Increasing the humidity and reducing airflow over the surface of the odorous liquid will reduce the rate of evaporation (the rate of evaporation is directly proportional to the speed of air flow over the liquid surface).
- Reducing the exposed surface area of liquid storage tanks by using floating covers will reduce the rate of evaporation and subsequent release to atmosphere.

- Activities such as agitation, shredding and mixing (turbulence) in liquids and solids will increase the odour emission rate significantly. These activities should be undertaken with appropriate mitigation measures in place.

- Adjustment to pH can increase the solubility of certain odorous compounds in water. For example, acidic conditions will suppress the evaporation of ammonia and similar alkaline compounds. Likewise, increasing alkalinity will help suppress H_2S release to atmosphere.

- Stack design to ensure that extracted air is dispersed adequately is important. The exhausted air should have sufficient stack exit velocity and an appropriate stack diameter to avoid stack-tip downwash (typically greater than 10 - 15 m/s required). The stack height should be sufficient to avoid significant building downwash and be directed in a vertical direction without rain caps on top of the stacks.

- Fugitive emissions such as valves, pump seals, flanges and leaks should be investigated using appropriate methods (for example photoionisation detection (PID)) and followed up with a corrective action programme.

2.7 Odour Emission Rates From The Indaver Ireland Ltd Facility

The Indaver Ireland Ltd site is located near Duleek in Co. Meath. In consultation with Indaver Ireland Ltd, the main odour sources at the facility were identified. The main stack (A1-1) associated with the facility has been identified as the emission point on site with the highest potential for odour emissions. There is also the possibility of odours, for example, from storage of waste in the bunker or waste vehicle deliveries, but due to the operational controls and mitigation measures in place on site as part of the on-site environmental management system, which is certified to ISO 14001, they should not be detectable beyond the site boundary. An odour management plan is also in place at the facility.

Odour modelling has been undertaken based on an odour emission concentration of 141 OU_E/m^3 from the main stack as shown in Table 2 which is based on site-specific odour monitoring undertaken by Exova in February 2019 (summary shown in Appendix IV). The operating details of this major emission point has been taken from information supplied by Indaver Ireland and are outlined in Table 2 with buildings model input data is shown in Table 3.

Table 2 Process Emission Design Details

Stack Reference	Stack Co-ordinates (ITM)	Stack Height (m)	Exit Diameter (m)	Cross-Sectional Area (m^2)	Temp (K)	Volume Flow (Nm^3/hr)(1)	Actual Volume Flow (m^3/s)(1)	Exit Velocity (m/sec actual)	Concentration (OU_E/m^3)	Mass Emission (OU_E/s)
A1-1	E 706260 N 770982	95.5m OD 65m above ground level	2.2	3.80	413	200,000	73.6	19.4(2)	141	7833

(1) Normalised to 273K, 11% Oxygen, dry gas.
(2) Actual - 413K, 6.5% Oxygen, 21.5% H_2O

Table 3 Building Model Input Data

Building / Tier Reference	Base Elevation (m O.D.)	Height (m)	Length (m)	Width	Angle (°)
Tipping Hall	30.5	21	36.4	35.2	144.2
Furnace / Boiler Room	30.5	40	70.7	25.8	144.2
Cranelift	30.5	34	27.0	44.3	144.2
Flue Gas Cleaning	30.5	29.6	34.3	30.4	144.2
Warehouse	30.5	12	25.0	45.0	52.3

3.0 RESULTS & DISCUSSION

3.1 Ambient Odour Levels

Details of the 98th%ile of 1-hour mean odour concentrations at the worst case off site location are given in Table 4 over a five-year period based on the USEPA approved AERMOD model. The worst case scenario for the 98th%ile of 1-hour concentrations occurs in 2019 where the maximum off-site concentration is 8% of the guideline value at the worst case receptor. Table 5 shows the 98th%ile of one-hour guideline values at the worst-case nearby residential receptors for all five years.

Figure 2 shows the ambient odour concentration contour pattern (as a 98th%ile of one-hour concentrations) in the vicinity of the facility for the worst-case year of 2019.

Based on the results detailed below, no receptors are predicted to experience odour nuisance as a result of the Indaver Ireland Ltd facility.

Model Scenario / Meteorological Year	Averaging Period	Predicted Overall Odour Concentration (OU_E/m^3)	Guideline (OU_E/m^3) Note 1
Ambient Odour Concentration / 2018	Maximum 1-Hour (as a 98th%ile)	0.12	**1.5**
Ambient Odour Concentration / 2019	Maximum 1-Hour (as a 98th%ile)	**0.12**	
Ambient Odour Concentration / 2020	Maximum 1-Hour (as a 98th%ile)	0.11	
Ambient Odour Concentration / 2021	Maximum 1-Hour (as a 98th%ile)	0.11	
Ambient Odour Concentration / 2022	Maximum 1-Hour (as a 98th%ile)	0.12	

Note 1 Guideline limit value based on EPA Guidance AG9 (2019) based on most offensive odour.

Table 4 Predicted Odour Concentration At Worst-Case Offsite Receptor(OU_E/m^3)

Sensitive Receptor Grid Co-ordinates (ITM)	Maximum 1-Hour 98th%ile Predicted Odour Conc. (OU_E/m^3)				
Nearby Sensitive Receptors	**2018**	**2019**	**2020**	**2021**	**2022**
Receptor 1 – 706451, 770995	0.001	0.002	0.001	0.001	0.001
Receptor 2 – 706537, 771022	0.004	0.004	0.004	0.004	0.003
Receptor 3 – 706298, 770660	0.002	0.003	0.002	0.002	0.001
Receptor 4 – 705566, 770947	0.008	0.008	0.008	0.008	0.008
Receptor 5 – 706400, 770446	0.005	0.006	0.003	0.003	0.002
Receptor 6 – 706103, 770544	0.005	0.005	0.007	0.004	0.004

Table 5 Predicted Odour Concentration At Closest Sensitive Receptors (OU_E/m^3)

Figure 2 Contour Plot Of Predicted Odour Concentration At Closest Sensitive Receptors (OU$_E$/m^3)

3.2 Assessment Summary

An assessment of the Indaver Ireland Ltd facility has found that the main stack (A1-1) is the main source of odour at the facility. There is also the possibility of odours from, for example, from storage of waste in the bunker or waste vehicle deliveries, but due to the operational controls and mitigation measures in place on site as part of the on-site environmental management system, which is certified to ISO 14001, they should not be detectable beyond the site boundary. An odour management plan is also in place at the facility.

Odour modelling, based an odour emission concentration of 141 OU_E/m^3 from the main stack, and using the USEPA approved AERMOD model has found that the worst case scenario for the 98th%ile of 1-hour concentrations occurs in 2019 where the maximum off-site concentration is 8% of the guideline value of 1.5 OU_E/m^3 at the worst case receptor. Based on the results, no residential receptors are predicted to experience odour nuisance issues as a result of the Indaver Ireland Ltd facility.

References

(1) EPA (2020) Air Dispersion Modelling from Industrial Installations Guidance Note (AG4)
(2) EPA (2019) Odour Emissions Guidance Note (AG9)
(3) UK EA (2011) H4 – Odour Management
(4) USEPA (2022) AERMOD Description of Model Formulation
(5) USEPA (1995) User's Guide for the Industrial Source Complex (ISC3) Dispersion Model Vol I & II
(6) USEPA (2017) Guidelines on Air Quality Models, Appendix W to Part 51, 40 CFR Ch.1
(7) USEPA (1999) Comparison of Regulatory Design Concentrations: AERMOD vs. ISCST3 vs. CTDM PLUS
(8) Schulman, L.L; Strimaitis, D.G.; Scire, J.S. (2000) Development and evaluation of the PRIME plume rise and building downwash model. Journal of the Air & Waste Management Association, 50, 378-390.
(9) Water Environment Federation (1995) Odour Control in Wastewater Treatment Plants
(10) AEA Technology (1994) Odour Measurement and Control – An Update, M. Woodfield and D. Hall (Eds)
(11) USEPA (2018) AERMAP Users Guide
(12) USEPA (2018) User's Guide to the AERMOD Meteorological Preprocessor (AERMET)
(13) Alaska Department of Environmental Conservation (2008) ADEC Guidance re AERMET Geometric Means (http://dec.alaska.gov/air/ap/modeling.htm)
(14) EPA. (2001) Odour Impacts & Odour Emission Control Measures for Intensive Agriculture.
(15) USEPA (2018) ARMET User's Guide

APPENDIX I

Description of the AERMOD Model

The AERMOD dispersion model has been developed in part by the U.S. Environmental Protection Agency (USEPA)[4,6]. The model is a steady-state Gaussian model used to assess pollutant concentrations associated with industrial sources. The model is an enhancement on the Industrial Source Complex-Short Term 3 (ISCST3) model which has been widely used for emissions from industrial sources.

Improvements over the ISCST3 model include the treatment of the vertical distribution of concentration within the plume. ISCST3 assumes a Gaussian distribution in both the horizontal and vertical direction under all weather conditions. AERMOD with PRIME, however, treats the vertical distribution as non-Gaussian under convective (unstable) conditions while maintaining a Gaussian distribution in both the horizontal and vertical direction during stable conditions. This treatment reflects the fact that the plume is skewed upwards under convective conditions due to the greater intensity of turbulence above the plume than below. The result is a more accurate portrayal of actual conditions using the AERMOD model. AERMOD also enhances the turbulence of night-time urban boundary layers thus simulating the influence of the urban heat island.

In contrast to ISCST3, AERMOD is widely applicable in all types of terrain. Differentiation of the simple versus complex terrain is unnecessary with AERMOD. In complex terrain, AERMOD employs the dividing-streamline concept in a simplified simulation of the effects of plume-terrain interactions. In the dividing-streamline concept, flow below this height remains horizontal, and flow above this height tends to rise up and over terrain. Extensive validation studies have found that AERMOD (precursor to AERMOD with PRIME) performs better than ISCST3 for many applications and as well or better than CTDMPLUS for several complex terrain data sets[7-8].

Due to the proximity to surrounding buildings, the PRIME (Plume Rise Model Enhancements) building downwash algorithm has been incorporated into the model to determine the influence (wake effects) of these buildings on dispersion in each direction considered. The PRIME algorithm takes into account the position of the stack relative to the building in calculating building downwash. In the absence of the building, the plume from the stack will rise due to momentum and/or buoyancy forces. Wind streamlines act on the plume leads to the bending over of the plume as it disperses. However, due to the presence of the building, wind streamlines are disrupted leading to a lowering of the plume centreline.

When there are multiple buildings, the building tier leading to the largest cavity height is used to determine building downwash. The cavity height calculation is an empirical formula based on building height, the length scale (which is a factor of building height & width) and the cavity length (which is based on building width, length and height). As the direction of the wind will lead to the identification of differing dominant tiers, calculations are carried out in intervals of 10 degrees.

In PRIME, the nature of the wind streamline disruption as it passes over the dominant building tier is a function of the exact dimensions of the building and the angle at which the wind approaches the building. Once the streamline encounters the zone of influence of the building, two forces act on the plume. Firstly, the disruption caused by the building leads to increased turbulence and enhances horizontal and vertical dispersion. Secondly, the streamline descends in the lee of the building due to the reduced pressure and drags the plume (or part of) nearer to the ground, leading to higher ground level concentrations. The model calculates the descent of the plume as a function of the building shape and, using a numerical plume rise model, calculates the change in the plume centreline location with distance downwind.

The immediate zone in the lee of the building is termed the cavity or near wake and is characterised by high intensity turbulence and an area of uniform low pressure. Plume mass captured by the cavity region is re-emitted to the far wake as a ground-level volume source. The volume source is located at the base of the lee wall of the building, but is only evaluated near the end of the near wake and beyond. In this region, the disruption caused by the building downwash gradually fades with distance to ambient values downwind of the building.

AERMOD has made substantial improvements in the area of plume growth rates in comparison to ISCST3[4,6]. ISCST3 approximates turbulence using six Pasquill-Gifford-Turner Stability Classes and bases the resulting dispersion curves upon surface release experiments. This treatment, however, cannot explicitly account for turbulence in the formulation. AERMOD is based on the more realistic modern planetary boundary layer (PBL) theory which allows turbulence to vary with height. This use of turbulence-based plume growth with height leads to a substantial advancement over the ISCST3 treatment.

Improvements have also been made in relation to mixing height[4,6]. The treatment of mixing height by ISCST3 is based on a single morning upper air sounding each day. AERMOD, however, calculates mixing height on an hourly basis based on the morning upper air sounding and the surface energy balance, accounting for the solar radiation, cloud cover, reflectivity of the ground and the latent heat due to evaporation from the ground cover. This more advanced formulation provides a more realistic sequence of the diurnal mixing height changes.

AERMOD also has the capability of modelling both unstable (convective) conditions and stable (inversion) conditions. The stability of the atmosphere is defined by the sign of the sensible heat flux. Where the sensible heat flux is positive, the atmosphere is unstable whereas when the sensible heat flux is negative the atmosphere is defined as stable. The sensible heat flux is dependent on the net radiation and the available surface moisture (Bowen Ratio). Under stable (inversion) conditions, AERMOD has specific algorithms to account for plume rise under stable conditions, mechanical mixing heights under stable conditions and vertical and lateral dispersion in the stable boundary layer.

AERMOD also contains improved algorithms for dealing with low wind speed (near calm) conditions. As a result, AERMOD can produce model estimates for conditions when the wind speed may be less than 1 m/s, but still greater than the instrument threshold.

APPENDIX II

Meteorological Data - AERMET

AERMOD incorporates a meteorological pre-processor AERMET[15]. AERMET allows AERMOD to account for changes in the plume behaviour with height. AERMET calculates hourly boundary layer parameters for use by AERMOD, including friction velocity, Monin-Obukhov length, convective velocity scale, convective (CBL) and stable boundary layer (SBL) height and surface heat flux. AERMOD uses this information to calculate concentrations in a manner that accounts for changes in dispersion rate with height, allows for a non-Gaussian plume in convective conditions, and accounts for a dispersion rate that is a continuous function of meteorology.

The AERMET meteorological pre-processor requires the input of surface characteristics, including surface roughness (z_0), Bowen Ratio and albedo by sector and season, as well as hourly observations of wind speed, wind direction, cloud cover, and temperature. A morning sounding from a representative upper air station, latitude, longitude, time zone, and wind speed threshold are also required.

Two files are produced by AERMET for input to the AERMOD dispersion model. The surface file contains observed and calculated surface variables, one record per hour. The profile file contains the observations made at each level of a meteorological tower, if available, or the one-level observations taken from other representative data, one record level per hour.

From the surface characteristics (i.e. surface roughness, albedo and amount of moisture available (Bowen Ratio)) AERMET calculates several boundary layer parameters that are important in the evolution of the boundary layer, which, in turn, influences the dispersion of pollutants. These parameters include the surface friction velocity, which is a measure of the vertical transport of horizontal momentum; the sensible heat flux, which is the vertical transport of heat to/from the surface; the Monin-Obukhov length which is a stability parameter relating the surface friction velocity to the sensible heat flux; the daytime mixed layer height; the nocturnal surface layer height and the convective velocity scale which combines the daytime mixed layer height and the sensible heat flux. These parameters all depend on the underlying surface.

The values of albedo, Bowen Ratio and surface roughness depend on land-use type (e.g., urban, cultivated land etc) and vary with seasons and wind direction. The assessment of appropriate land-use types was carried out in line with USEPA recommendations[6].

<u>Surface roughness</u>

Surface roughness length is the height above the ground at which the wind speed goes to zero. Surface roughness length is defined by the individual elements on the landscape such as trees and buildings. In order to determine surface roughness length, the USEPA recommends that a representative length be defined for each sector, based on an upwind area-weighted average of the land use within the sector, by using the eight land use categories outlined by the USEPA. The inverse-distance weighted surface roughness length derived from the land use classification within a radius of 1km from Dublin Airport Meteorological Station is shown in Table A1.

Sector	Area Weighted Land Use Classification	Spring	Summer	Autumn	Winter Note 1
0-360	100% Grassland	0.050	0.100	0.010	0.010

Note 1: Winter defined as periods when surfaces covered permanently by snow whereas autumn is defined as periods when freezing conditions are common, deciduous trees are leafless and no snow is present (Iqbal, 1983). Thus for the current location autumn more accurately defines "winter" conditions at the proposed facility.

Table A1 Surface Roughness based on an inverse distance weighted average of the land use within a 1km radius of Dublin Airport Meteorological Station.

Albedo

Noon-time albedo is the fraction of the incoming solar radiation that is reflected from the ground when the sun is directly overhead. Albedo is used in calculating the hourly net heat balance at the surface for calculating hourly values of Monin-Obuklov length. A 10km x 10km square area is drawn around the meteorological station to determine the albedo based on a simple average for the land use types within the area independent of both distance from the station and the near-field sector. The classification within 10km from Dublin Airport is shown in Table A2.

Area-weighted Land Use Classification	Spring	Summer	Autumn	Winter[1]
0.5% Water, 30% Urban, 0.5% Coniferous Forest 38% Grassland, 19% Cultivated Land	0.155	0.180	0.187	0.187

(1) For the current location autumn more accurately defines "winter" conditions in Ireland.

Table A2 Albedo based on a simple average of the land use within a 10km × 10km grid centred on Dublin Airport Meteorological Station.

Bowen Ratio

The Bowen ratio is a measure of the amount of moisture at the surface of the earth. The presence of moisture affects the heat balance resulting from evaporative cooling which, in turn, affects the Monin-Obukhov length which is used in the formulation of the boundary layer. A 10km x 10km square area is drawn around the meteorological station to determine the Bowen Ratio based on geometric mean of the land use types within the area independent of both distance from the station and the near-field sector. The classification within 10km from Dublin Airport is shown in Table A3.

Geometric Mean Land Use Classification	Spring	Summer	Autumn	Winter[1]
0.5% Water, 30% Urban, 0.5% Coniferous Forest 38% Grassland, 19% Cultivated Land	0.549	1.06	1.202	1.202

(1) For the current location autumn more accurately defines "winter" conditions in Ireland.

Table A3 Bowen Ratio based on a geometric mean of the land use within a 10km × 10km grid centred on Dublin Airport Meteorological Station.

APPENDIX III

Detailed Meteorological Data – Dublin Airport 2018 - 2022

Dublin Airport 2018

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	40	67	109	40	1	0	257
22.5	14	34	94	30	7	0	179
45.0	10	39	141	62	10	0	262
67.5	4	20	164	88	38	12	326
90.0	33	66	286	149	67	64	665
112.5	48	91	199	42	3	0	383
135.0	43	99	269	167	62	12	652
157.5	48	109	206	172	96	40	671
180.0	40	77	120	105	32	9	383
202.5	29	82	233	215	53	20	632
225.0	48	108	418	266	41	18	899
247.5	50	104	535	334	141	58	1,222
270.0	44	110	473	415	178	67	1,287
292.5	41	51	141	121	10	5	369
315.0	26	41	144	65	16	0	292
337.5	40	39	112	52	9	0	252
Total	558	1,137	3,644	2,323	764	305	8,731
Calms							29
Missing							0
Total							8760

Dublin Airport 2019

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	23	48	96	85	13	2	267
22.5	11	19	53	45	5	1	134
45.0	8	21	79	36	6	0	150
67.5	5	21	92	60	11	0	189
90.0	67	127	243	120	20	1	578
112.5	61	83	164	61	6	1	376
135.0	64	162	407	150	25	0	808
157.5	55	80	194	89	22	3	443
180.0	54	68	141	83	29	0	375
202.5	55	106	236	212	18	3	630
225.0	34	137	493	238	22	2	926
247.5	49	159	596	366	22	4	1,196
270.0	44	145	623	505	161	79	1,557
292.5	23	53	252	134	30	19	511
315.0	50	53	144	70	18	10	345
337.5	13	25	118	62	0	3	221
Total	616	1,307	3,931	2,316	408	128	8,706
Calms							54
Missing							0
Total							8,760

Dublin Airport 2020

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	44	37	76	11	0	0	168
22.5	25	34	53	46	1	0	159
45.0	48	66	85	78	3	0	280
67.5	93	164	328	98	4	0	687
90.0	124	110	248	64	1	0	547
112.5	29	37	58	23	1	1	149
135.0	30	30	36	20	6	1	123
157.5	47	35	56	38	30	5	211
180.0	62	64	126	130	107	75	564
202.5	75	84	286	450	267	131	1,293
225.0	72	87	400	575	325	123	1,582
247.5	55	121	437	470	224	121	1,428
270.0	111	160	338	317	78	22	1,026
292.5	45	43	112	57	5	0	262
315.0	33	36	53	14	0	0	136
337.5	29	37	52	10	0	0	128
Total	922	1,145	2,744	2,401	1,052	479	8,743
Calms							41
Missing							0
Total							8,784

Dublin Airport 2021

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	40	29	33	5	0	0	107
22.5	44	55	74	17	0	0	190
45.0	72	75	111	16	0	0	274
67.5	125	185	358	101	10	1	780
90.0	110	111	180	68	24	3	496
112.5	56	57	79	57	7	2	258
135.0	51	35	48	16	8	4	162
157.5	85	67	86	26	10	18	292
180.0	84	90	151	111	53	63	552
202.5	107	106	398	483	215	59	1,368
225.0	99	142	466	523	160	28	1,418
247.5	112	185	629	389	133	33	1,481
270.0	86	119	299	158	44	11	717
292.5	70	76	139	54	9	2	350
315.0	48	39	74	17	0	0	178
337.5	31	46	46	8	0	0	131
Total	1,220	1,417	3,171	2,049	673	224	8,754
Calms							6
Missing							0
Total							8,760

Dublin Airport 2022

Dir \ Spd	<= 1.54	<= 3.09	<= 5.14	<= 8.23	<= 10.80	> 10.80	Total
0.0	34	48	49	18	2	0	151
22.5	20	23	56	24	3	0	126
45.0	8	35	86	76	16	0	221
67.5	20	44	126	100	9	0	299
90.0	54	96	196	94	6	0	446
112.5	75	54	146	37	13	0	325
135.0	60	104	393	175	21	1	754
157.5	65	59	172	149	40	13	498
180.0	41	76	150	114	29	7	417
202.5	55	93	321	277	49	2	797
225.0	55	150	565	287	17	0	1,074
247.5	51	198	593	336	33	7	1,218
270.0	37	109	463	382	125	30	1,146
292.5	28	63	337	224	35	24	711
315.0	46	43	184	92	14	2	381
337.5	34	36	87	34	1	0	192
Total	683	1,231	3,924	2,419	413	86	8,756
Calms							4
Missing							0
Total							8,760

APPENDIX IV

Exova Odour Monitoring Summary

Executive Summary

(Page 2 of 7)

MONITORING RESULTS

Indaver Ireland Ltd, County Meath
A1-1 Exhaust Stack
11th - 14th February 2019

where MU = Measurement Uncertainty associated with the Result

	Concentration				Mass Emission			
Parameter	Units	Result	MU +/-	Limit	Units	Result	MU +/-	Limit
Sulphur Dioxide [1]	mg/m³	85.68	7.19	200	g/hr	11799.6	1130.2	-
Carbon Dioxide	% v/v	Dry 11.83	0.50					
Oxygen	% v/v	Dry 7.38	0.29					
Water Vapour	% v/v	22.2	1.1					
Stack Gas Temperature	°C	148.6						
Stack Gas Velocity	m/s	14.9	0.13					
Volumetric Flow Rate (ACTUAL)	m³/hr	203614	9384					
Volumetric Flow Rate (REF) [1]	m³/hr	137712	6347	183700				
Volumetric Flow Rate (REF) [2]	m³/hr	147801	6812.1					

NOTE: VOLUMETRIC FLOW RATE & VELOCITY DATA TAKEN FROM THE PRELIMINARY VELOCITY TRAVERSE.

[1] Reference Conditions (REF) are: 273K, 101.3kPa, dry gas, 11% oxygen.

RESULTS FROM ODOUR SAMPLES

	Concentration				Mass Emission			
Parameter	Units	Result	LOWER CI	UPPER CI	Units	Result	LO CI	HI CI
Odour - A1-1 [2]	ouE/m³	97	55	170	ouE/s	3986.9	2276.51	6985.01

Where CI stands for Confidence Interval (or Uncertainty associated with the result)

[2] Reference Conditions (REF) are: 293K, 101.3kPa, without correction for water vapour content

MONITORING DATE(S) & TIMES

Indaver Ireland Ltd, County Meath
A1-1 Exhaust Stack
11th - 14th February 2019

Parameter		Units	Concentration	Units	Mass Emission	Sampling Date(s)	Sampling Times	Duration mins
Carbon Dioxide	R1	% v/v	11.83			13/02/2019	20:00 - 21:00	4
Oxygen	R1	% v/v	7.38			13/02/2019	20:00 - 21:00	4
Sulphur Dioxide	R1	mg/m³	85.7	g/hr	11799.6	13/02/2019	20:00 - 21:00	60
Water Vapour	R1	% v/v	22.8			13/02/2019	20:00 - 21:00	60
Odour - A1-1	B1	ouE/m³	141	ouE/s	5788.9	13/02/2019	16:00 - 16:04	4
Odour - A1-1	B2	ouE/m³	67	ouE/s	2745.8	13/02/2019	16:05 - 16:09	4
Water Vapour	R1	% v/v	21.7			13/02/2019	13:20 - 13:50	30
Velocity Traverse	R1					13/02/2019	07:30 - 08:00	

All results are expressed at the respective reference conditions.