# Gas dispersion model DRIFT 3.6.14: evaluation and assessment

Prepared by researchers at the
**Health and Safety Executive**

## RR1165 (2022)

## Research Report

Prepared 2017
First published 2022

**HSE uses gas dispersion modelling in its assessment of the hazards and risks posed by toxic and flammable substances stored at major hazards sites. To update its dispersion modelling capability, HSE commissioned ESR Technology to develop a new version of the gas dispersion model DRIFT. The new version, DRIFT 3, includes a significant number of modelling enhancements over the version previously used within HSE (DRIFT 2.31). These include the extension of the model to treat buoyant plumes and time varying releases. Before DRIFT 3 is adopted for use by HSE, it must undergo thorough evaluation and assessment for a range of release scenarios. The initial phases of the DRIFT 3 testing programme used DRIFT 3.6.4 and are described in reports RR1100 and RR1101. Further testing is described in four reports including this one: RR1165, RR1166, RR1167 and RR1168. The four reports cover the evaluation of the model and assessment for a range of scenarios using the enhanced version DRIFT 3.6.14.**

**Firstly, this report describes validation of DRIFT 3.6.14 against a Model Evaluation Protocol for dense gas dispersion models. It compares the DRIFT 3.6.14 outputs with those for the previous version, DRIFT 3.6.4 (see RR1100). This evaluation exercise finds DRIFT 3.6.14 to be fit for purpose. Secondly, the report describes an assessment of the performance of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids. (See RR1101 for the assessment for the previous version DRIFT 3.6.4.) The enhancements to the model implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have not significantly affected the dispersion predictions. As a result of this detailed evaluation and assessment, DRIFT 3.6.14 has been adopted by HSE to model the dispersion of vapour from pools of toxic liquids.**

This report and the work it describes were funded by the Health and Safety Executive. Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

# Gas dispersion model DRIFT 3.6.14: evaluation and assessment

**Helen Cruse and Simon Coldrick**

**Health and Safety Executive**

Harpur Hill, Buxton, Derbyshire, SK17 9JN

## Acknowledgements

The authors would like to thank Graham Tickle of ESR Technology for his guidance on the use of the DRIFT model, and David Webber for his review of the DRIFT 3.6.14 mathematical model.

# KEY MESSAGES

The Health and Safety Executive (HSE) uses gas dispersion modelling in its assessment of the hazards and risks posed to people in the vicinity by toxic and flammable substances stored at major hazards sites. A new version of the gas dispersion model DRIFT (Dispersion of Releases Involving Flammables or Toxics), DRIFT 3, was commissioned by HSE to update its dispersion modelling capability.

To ensure that DRIFT 3 is fit for purpose, a programme of work has been undertaken at HSE. This has included an evaluation of the dispersion modelling capabilities of DRIFT 3 and an assessment of the performance of DRIFT 3 for modelling the types of release scenario typically considered by HSE for Hazardous Substances Consent assessments.

The initial phases of the testing programme were carried out using DRIFT 3.6.4. The most recent version of DRIFT currently available to HSE is DRIFT 3.6.14. Building on the previous model testing, this report describes the validation of DRIFT 3.6.14 against a Model Evaluation Protocol for dense gas dispersion models. This included validation against a database of 33 wind tunnel and field scale experiments. It was found that DRIFT 3.6.14 meets the criteria for an ‘acceptable’ model, as defined in the Model Evaluation Protocol. The DRIFT 3.6.14 concentration predictions for the validation test cases were compared with the outputs reported for DRIFT 3.6.4. Minor changes in concentration predictions were obtained with DRIFT 3.6.14 for scenarios for which updated substance property data was used. For all other test cases, the results obtained using the two versions of DRIFT were practically identical.

This report also presents an assessment of the performance of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids. The original testing for this type of release scenario was carried out using DRIFT 3.6.4. A selection of ethylene oxide and methyl iodide release scenarios was modelled and the DRIFT 3.6.14 outputs were compared to those obtained using DRIFT 3.6.4. This assessment demonstrated that the enhancements to the DRIFT mathematical model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have not significantly affected the dispersion predictions for vapour evolved from pools of toxic liquids.

As a result of this detailed evaluation and assessment, DRIFT 3.6.14 has been adopted by HSE to model the dispersion of vapour evolved from pools of toxic liquids.

This detailed technical report is aimed at technical specialists in consequence modelling and risk assessment.

# EXECUTIVE SUMMARY

The Health and Safety Executive (HSE) uses gas dispersion modelling in its assessment of the hazards and risks posed to people in the vicinity by toxic and flammable substances stored at major hazards sites. To update its dispersion modelling capability, HSE recently commissioned ESR Technology to develop a new version of the gas dispersion model DRIFT (Dispersion of Releases Involving Flammables or Toxics). The new version of the model, DRIFT version 3 (DRIFT 3), includes a significant number of modelling enhancements over the version of DRIFT previously used by HSE (DRIFT 2.31). These include the extension of the model to treat buoyant plumes and time varying releases.

Under the Planning (Hazardous Substances) Regulations, the presence of hazardous chemicals above specified threshold quantities requires consent from a Hazardous Substances Authority (HSA), which is usually the local Planning Authority. HSE is a statutory consultee on all Hazardous Substances Consent applications. Its role is to consider the hazards and residual risk which would be presented by the hazardous substance(s) to people in the vicinity, and on the basis of this to advise the HSA whether or not consent should be granted. The outputs of these assessments are also used to set Land Use Planning (LUP) zones around major hazards sites. DRIFT 3 will be used by HSE in this assessment process.

To ensure that DRIFT 3 is fit for purpose, a programme of work has been undertaken at HSE. This has included an evaluation of the dispersion modelling capabilities of DRIFT 3 and an assessment of the performance of DRIFT 3 for modelling the types of release scenario typically considered by HSE for Hazardous Substances Consent assessments. The scenarios examined include releases of toxic or flammable pressure-liquefied gases and dispersion of vapour from pools of toxic or flammable liquids.

The initial phases of the testing programme were carried out using DRIFT 3.6.4. The most recent version of DRIFT currently available to HSE is DRIFT 3.6.14. Building on the previous model testing, this report describes the validation of DRIFT 3.6.14 against a Model Evaluation Protocol for dense gas dispersion models, following the same approach as was used for the validation of DRIFT 3.6.4. This report also presents an assessment of the performance of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids, as the original testing for this type of release scenario was carried out using DRIFT 3.6.4. Releases of toxic pressure-liquefied gases and flammable substances are not considered in this report because the assessment of the performance of DRIFT 3.6.14 for these types of releases is described elsewhere.

## Objectives

The first objective of this project was to carry out an evaluation of DRIFT 3.6.14 in accordance with a dense gas Model Evaluation Protocol, including validation of the model using experimental data. The outputs of the model evaluation have been compared to the results reported for DRIFT 3.6.4.

The second aim of this work was to determine whether the enhancements to the DRIFT mathematical model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have affected the dispersion predictions for vapour evolved from pools of toxic liquids. In this study, the release scenarios were modelled using the D5 and F2 weather categories, for consistency with the methodology previously used by HSE to model such releases. (The letters D and F represent Pasquill stability classes: D denotes neutral conditions and F denotes stable conditions. The associated number gives the wind speed in metres per second at a reference height of 10 m.)

A further aim of this work was to present the DRIFT 3.6.14 outputs obtained when the toxic pool scenarios were modelled using the D2.4, D4.3, D6.7 and F2.4 weather categories. HSE has recently made a policy decision to model all toxic release scenarios using this weather set. Sensitivity studies on future versions of DRIFT will only consider the D2.4, D4.3, D6.7 and F2.4 weather set for releases of toxic substances, and the results presented in this report will enable DRIFT 3.6.14 to be compared to future versions of DRIFT.

## Main Findings

The modifications to the DRIFT mathematical model that were introduced between DRIFT 3.6.4 and DRIFT 3.6.14 have been subject to a scientific assessment by a dispersion modelling expert who was not involved in the development of the DRIFT 3 model. The reviewer concluded that the changes to the model were relatively minor and that these changes were logical and justifiable developments of the model.

DRIFT 3.6.14 has been evaluated using a Model Evaluation Protocol, which included validation against a database of 33 wind tunnel and field scale experiments. The DRIFT 3.6.14 concentration predictions for the validation test cases have been compared with the outputs reported for DRIFT 3.6.4. Minor changes in the predictions were obtained with DRIFT 3.6.14 for spills of liquefied natural gas (LNG). These changes appear to have arisen mostly from updates that were made to the LNG substance property data, rather than the modifications to the DRIFT 3 mathematical model. Overall the changes to the DRIFT model have no effect on the predictions with respect to the acceptance criteria and therefore DRIFT 3.6.14 also meets the criteria for an ‘acceptable’ model. A further validation exercise has been carried out to test the passive dispersion model in DRIFT 3.6.14. The results obtained for DRIFT 3.6.14 were identical to those obtained using DRIFT 3.6.4.

The performance of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids has been assessed. A subset of the ethylene oxide and methyl iodide scenarios previously modelled using DRIFT 3.6.4 has been rerun in DRIFT 3.6.14, and the DRIFT 3.6.4 and DRIFT 3.6.14 outputs have been compared. There are no significant differences in the downwind distances and crosswind extents predicted by DRIFT 3.6.14 and DRIFT 3.6.4 for the test scenarios. The modifications to the DRIFT mathematical model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have therefore not significantly affected the dispersion predictions for vapour from pools of toxic liquids.

In the original DRIFT 3.6.4 assessment, releases from evaporating pools of toxic liquids were modelled in D5 and F2 weather conditions for consistency with the methodology previously used by HSE to model such releases. HSE has since made a policy decision to use four weather categories when modelling the dispersion of vapour from pools of toxic liquids for Hazardous Substances Consent assessments. These weather categories are D2.4, D4.3, D6.7 and F2.4, and have been chosen to be consistent with the weather categories used when modelling releases of toxic pressure-liquefied gases. The ethylene oxide and methyl iodide test scenarios have been run in DRIFT 3.6.14 using the D2.4, D4.3, D6.7 and F2.4 weather set. DRIFT 3.6.14 ran without problem for each of the scenarios and weather conditions modelled.

## Outcomes

HSE now uses four weather categories when modelling releases from pools of toxic liquids. Daytime weather is represented by the D2.4, D4.3 and D6.7 weather categories, and night-time weather is represented by the F2.4 weather category. These weather categories are consistent with those used by HSE to model releases of toxic pressure-liquefied gases.

As a result of the detailed evaluation and assessment described in this report, DRIFT 3.6.14 has been adopted by HSE to model the dispersion of vapour evolved from pools of toxic liquids for the purposes of Hazardous Substances Consent assessment.

# CONTENTS

# 1 INTRODUCTION

The gas dispersion model DRIFT (Dispersion of Releases Involving Flammables or Toxics) was originally developed in the late 1980s, to model ground-based clouds released instantaneously or as a steady continuous source [1, 2]. DRIFT was developed for the Health and Safety Executive (HSE) by ESR Technology. ESR Technology has recently released a new version of the model, DRIFT 3.

HSE will use DRIFT 3 in its assessment of the hazards and risks posed by toxic and flammable substances stored at major hazards sites. Under the Planning (Hazardous Substances) Regulations [3], the presence of hazardous chemicals above specified threshold quantities requires consent from a Hazardous Substances Authority (HSA), which is usually the local Planning Authority. HSE is a statutory consultee on all Hazardous Substances Consent applications. Its role is to consider the hazards and residual risk which would be presented by the hazardous substance(s) to people in the vicinity, and on the basis of this to advise the HSA whether or not consent should be granted [4]. The outputs of these assessments are also used to set Land Use Planning (LUP) zones around major hazards sites [5].

DRIFT 3 includes a significant number of modelling enhancements compared to the version of DRIFT previously used by HSE (DRIFT 2.31) [6, 7]. These include extensions to the model to allow it to be applied to buoyant plumes and time varying releases. An overview of these enhancements is given in Section 1.1 of this report. DRIFT 3 is still undergoing development and the additional model enhancements that were implemented between DRIFT version 3.6.4 and DRIFT version 3.6.14 are also described in Section 1.1.

To ensure that DRIFT 3 remains fit for purpose it is important to continue to validate it against experimental data and to assess the effect of changes to the model on its predictions for the types of release scenario typically modelled by HSE for Hazardous Substances Consent assessments.

To meet these needs, a programme of work has been undertaken at HSE, covering the following topics:

- Evaluation of the dispersion modelling capabilities of DRIFT 3

  Coldrick and Webber [8] describe the evaluation of DRIFT 3.6.4 using a Model Evaluation Protocol (MEP) for dense gas dispersion models [9]. This evaluation included the validation of the model using a database of wind tunnel and field scale experimental data. Coldrick and Webber also carried out an evaluation of the passive dispersion capabilities of DRIFT.

- Assessment of the use of DRIFT for modelling the dispersion of vapour from pools of toxic liquids

  Cruse et al. [10] present an assessment of the use of DRIFT 3.6.4 for modelling the dispersion of vapour from pools of toxic liquids. The dispersion of such releases was previously modelled by HSE using DRIFT 2.31. Methyl iodide and ethylene oxide test scenarios were used to assess the effect on the model predictions of the enhancements implemented between DRIFT 2.3.1 and DRIFT 3.6.4. The report also provides guidance on how DRIFT 3 should be used to model the dispersion of vapour from pools of toxic liquids.

  Cruse et al. modelled releases from evaporating pools of toxic liquids in D5 and F2 weather conditions for consistency with the methodology previously used by HSE to model such releases. (The letters D and F represent Pasquill stability classes: D denotes neutral conditions and F denotes stable conditions. The associated number gives the wind speed in metres per second at a reference height of 10 m.) HSE has since made a policy decision to use four weather categories when modelling releases from evaporating pools of toxic liquids for Hazardous Substances

Consent assessments. These weather categories are D2.4, D4.3, D6.7 and F2.4, and have been chosen to be consistent with the weather categories used when modelling releases of toxic pressure-liquefied gases.

- Assessment of the use of DRIFT for modelling releases of toxic pressure-liquefied gases

  Lamb and Cruse [11] describe the assessment of the use of DRIFT 3.6.14 for modelling the dispersion of continuous releases of toxic pressure-liquefied gases. The dispersion of such releases was previously modelled by HSE using CRUNCH [12]. The outputs of DRIFT 3.6.14 and CRUNCH were compared for a selection of chlorine, sulphur dioxide and ammonia release scenarios.

  McGillivray and Cruse [13] present an assessment of the use of DRIFT 3.6.14 for modelling the dispersion of flashing instantaneous releases of toxic substances. The dispersion of such releases was previously modelled by HSE using DENZ [14]. The outputs of DRIFT 3.6.14 and DENZ were compared for a selection of chlorine, sulphur dioxide and ammonia release scenarios. Releases of substances heated above their normal boiling point in process vessels were also considered. Lamb and Cruse [11] and McGillivray and Cruse [13] also provide guidance on how DRIFT 3 should be used to model releases of toxic pressure-liquefied gases.

- Assessment of the use of DRIFT for modelling flammable releases

  Chaplin and Cruse [15] present an assessment of the use of DRIFT 3.6.14 for modelling the dispersion of flammable vapour, considering both releases of flammable pressure-liquefied gases and the dispersion of vapour from pools of flammable liquids. The dispersion of vapour from pools of flammable liquids was previously modelled by HSE in DRIFT 2.31. Liquefied hydrogen and liquefied natural gas (LNG) test cases were used to assess the effect on the model predictions of changing from DRIFT 2.31 to DRIFT 3.6.14. Continuous flashing releases of flammable substances were previously modelled by HSE using either DRIFT 2.31 (holes in vessels or pipework) or CRUNCH [12] (holes in pipelines). The CRUNCH and DRIFT 3.6.14 predictions were compared for releases from ethylene and liquefied petroleum gas (LPG) pipelines. Instantaneous flashing releases of flammable substances were previously modelled by HSE in DRIFT 2.31. The effect on the model predictions of changing from DRIFT 2.31 to DRIFT 3.6.14 was assessed for a selection of isobutane and propane release scenarios. The report also provides guidance on how DRIFT 3 should be used to model the dispersion of flammable vapour.

An assessment of the use of DRIFT 3 for modelling passive releases, including spray releases, is also planned.

The most recent version of DRIFT currently available to HSE is DRIFT 3.6.14. Building on the work described above, the aims of this report are:

- Validation of DRIFT 3.6.14

  This report describes the validation of DRIFT 3.6.14 against the MEP for dense gas dispersion models [9], following the same approach as was used for the validation of DRIFT 3.6.4 [8]. Validation of DRIFT 3.6.14 against a set of passive tracer releases is also discussed.

- Assessment of the use of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids

  This report presents an assessment of the effect of changing from DRIFT 3.6.4 to DRIFT 3.6.14 on the model predictions for the dispersion of vapour from pools of toxic liquids. A subset of the toxic pool scenarios considered by Cruse et al. [10] has been rerun.

- Application of the new weather categories to releases from pools of toxic liquids

  This report presents the DRIFT 3.6.14 outputs obtained when the toxic pool scenarios described by Cruse et al. [10] were modelled using the D2.4, D4.3, D6.7 and F2.4 weather categories. These outputs will be used to compare DRIFT 3.6.14 to future versions of DRIFT in subsequent assessment and evaluation reports.

Releases of toxic pressure-liquefied gases and flammable substances are not considered in this report because the assessment of the performance of DRIFT 3.6.14 for these types of releases is described in references [11], [13] and [15].

## 1.1 MODEL ENHANCEMENTS IN DRIFT 3

A number of additions and modelling enhancements have been implemented in DRIFT 3, expanding the scope and potential uses of the model. A comprehensive account of these changes is given by Tickle and Carlisle [6, 7]. The model enhancements include:

- The inclusion of finite duration and time varying releases in addition to the instantaneous and steady continuous releases available in DRIFT 2;
- The option to calculate initial dilution over the source and upwind spreading;
- The extension of the model to include buoyant lift-off and buoyant rise;
- Allowance for the effect of the vertical variation of atmospheric pressure, temperature and humidity on the cloud thermodynamics (necessitated by the extension of the model to include buoyant plumes);
- Inclusion of a lateral meander model, which accounts for the dilution caused by fluctuations in wind direction, and a vertical meander model, which accounts for the effects of updraughts and downdraughts in unstable atmospheric conditions;
- Incorporation of a momentum jet model. The jet model is based on the stand-alone model EJECT [16], which was used in conjunction with DRIFT 2.31;
- The generalisation of the model to include multi-component mixtures;
- The facility to read in data from SPI (Substance Property Information) files [17]. HSE's substance property database is in the form of SPI files. SPI files are text files containing spot values of physical properties at specified temperatures and equation coefficients which allow the calculation of various substance physical properties at a range of temperatures. SPI files are used by the majority of HSE's in-house models;
- The ability to run DRIFT 3 either via the GUI (Graphical User Interface) or via a COM (Component Object Model) interface [18]; and
- An improved and updated user interface. Plume footprints are plotted automatically within DRIFT 3, whereas when DRIFT 2.31 is used, the plume footprints have to be plotted using a separate spreadsheet tool.

DRIFT 3 is still undergoing development. Coldrick and Webber's original validation exercise was carried out on DRIFT 3.6.4 [8]. However, during the HSE testing programme [11, 13], further enhancements were made to the DRIFT model, to allow it to better model time varying releases and releases of pressure-liquefied gases. The main model enhancements that were implemented between DRIFT version 3.6.4 and DRIFT version 3.6.14 are described below, with reference to the version number at which they were first introduced. The intermediate versions between DRIFT 3.6.4 and DRIFT 3.6.14 were interim versions that were not used by HSE for the purposes of Hazardous Substances Consent assessment.

### 1.1.1 Instantaneous model

The instantaneous model has been modified to ensure that the initial depth of the instantaneous cloud is less than the mixing layer height. The mixing layer height defines the depth of the turbulent atmospheric boundary layer within which dispersion typically occurs: above this height, mixing is suppressed by the presence of a temperature inversion [19]. In DRIFT 3.6.8 and subsequent versions, all of the dispersing material in the cloud is assumed to remain entirely trapped within the mixing layer. The new initialisation procedure keeps the cloud within the mixing layer and grows the lateral dimensions. For dense releases this also allows gravity slumping to reduce the cloud height. Prior to DRIFT 3.6.8, if the initial depth of the instantaneous cloud was greater than the mixing layer height then DRIFT 3 would keep the cloud depth fixed, even for dense releases. In some circumstances DRIFT 3 would fail to find a solution to the initialisation equations, resulting in an error message.

The user can now choose whether to model an instantaneous release as a stationary initial cloud or a non-stationary initial cloud [6]. The non-stationary cloud option should be used to model clouds that are expected to be initially moving, for example due to momentum associated with any ambient air entrained prior to the DRIFT run. The empirical time delay in gravity spreading, which was previously included for all instantaneous releases to improve the fit with observations from the Thorney Island instantaneous trials [20, 21], has been removed for non-stationary initial clouds.

The stationary initial cloud option should be used to model instantaneous releases which start from rest with zero centroid velocity and zero initial radial spread, such as the Thorney Island releases. The empirical delay for gravity spreading is maintained for these clouds as it accounts for the initial radial acceleration of the cloud from rest [22].

For dense ground-based clouds, the advection speed now has an empirical dependence on the cloud Richardson number, a dimensionless number that measures the gravitational potential energy of the cloud relative to the turbulent kinetic energy [23]. Clouds with a high Richardson number advect at approximately 0.7 times the wind speed at the cloud centroid height, a condition set from a comparison with the Thorney Island instantaneous trials. A high Richardson number (much greater than one) implies that cloud dispersion is significantly affected by dense gas effects, such as gravitational spreading and suppressed mixing through the top of the cloud. When the Richardson number tends towards zero the dispersion is dominated by atmospheric turbulence (or jet- or crossflow-induced turbulence in the case of a jet) and the cloud is assumed to move at the wind speed at the cloud centroid height [6].

### 1.1.2 Time varying model

DRIFT 3 includes a lateral meander model, which accounts for the dilution caused by fluctuations in wind direction. The plume meander model that is implemented in DRIFT 3 is based on the model of Nielsen et al. [24] from the EU COFIN project (Concentration Fluctuations in Gas Releases by Industrial Accidents, 1998-2001, EU ENV4-CT97-0629). Changes have been made to the way in which lateral meander time averaging is applied for time varying releases. If the time varying model is selected, DRIFT 3 uses an algorithm to split the release into segments, each of which is modelled as a finite duration release. Prior to DRIFT 3.6.7, the lateral meander averaging time for each segment was capped by the time duration of the segment. This led to time averaging having a lesser effect, giving higher concentrations and doses when more segments were selected for simulation, or when segment durations were much smaller than the averaging time. In DRIFT 3.6.7 and later versions, each segment has time averaging applied based on the total release duration for the time varying release. Generally, this change results in a lowering of the concentration and dose for time-averaged time varying releases and closer correspondence with the continuous model in the ‘steady’ limit.

### 1.1.3 Other enhancements

Improvements have been made to the way in which DRIFT 3 processes source term data imported from the program GASP (Gas Accumulation over Spreading Pools) [25]. These changes are discussed in more detail in Section 1.2.

The graphical user interface now has the capability to read toxicity information from SPI (Substance Property Information) files [17].

DRIFT 3.6.6 and later versions perform a check for when the number of moles of liquid becomes negative outside the solver tolerance limits, which is an indication of a failure of an evaporation or condensation test, and contain an improvement to the evaporation and condensation tests to reduce the likelihood of this.

### 1.1.4 Windows 7 compatibility

DRIFT 3 has been modified to run under Windows 7 without the requirement of administrator privileges, whilst maintaining compatibility with Windows XP. Administrator privileges are still required for installation.

## 1.2 USE OF DRIFT 3 TO MODEL THE DISPERSION OF TOXIC VAPOUR FROM POOLS

HSE models the spreading and vaporisation of pools resulting from accidental releases of toxic liquids using the program GASP (Gas Accumulation over Spreading Pools) [25]. The subsequent dispersion of the vapour evolved from the pool is modelled using DRIFT 3.

GASP was developed for HSE by ESR Technology. It requires the user to define the nature of the liquid release, the ambient conditions, and the terrain onto which the liquid is spilt. Supplied with this information, GASP can calculate the time evolution of many quantities (including the pool size, pool temperature, vaporisation rate, and the total mass of vapour generated), which are then saved in a format that can be used in DRIFT.

Two options are available for importing the GASP output into DRIFT 3.6.14. The user can either create a DRIFT input file (DIN file) in GASP, which can then be opened in DRIFT, or alternatively the complete GASP output can be imported into DRIFT 3 in the form of a GASP (.gasp) file. These options are discussed in more detail in the following sections.

### 1.2.1 Use of DIN files generated in GASP

Either a continuous or an instantaneous DIN file can be created from the results of a GASP run. The continuous DIN file contains values for the vaporisation rate, the pool diameter, the pool temperature, the vapour mass fraction and the plume velocity, averaged over the duration of interest. For the purposes of Hazardous Substances Consent assessment this duration is generally 1800 s, or the time taken for all the material in the pool to be vaporised, if shorter. The instantaneous DIN file contains the total mass vaporised within the duration of interest, and average values for the vapour mass fraction and the pool temperature and dimensions. The ambient conditions used in the GASP run are exported in both continuous and instantaneous DIN files.

Cruse et al. [10] recommend the use of a continuous DIN file to model the dispersion of vapour evolved from pools of toxic liquids. The continuous DIN file should be modelled in DRIFT 3.6.14 using the finite duration option. The DRIFT 3 finite duration model uses the same basic equations as are used in the steady continuous model, but the cloud is treated differently in post-processing. The finite duration model includes dilution of the leading and trailing edges of the plume, which means that the cloud spreads longitudinally. Long after the release has ceased, when the cloud travel time is much greater than the release duration, the concentration profiles of the finite duration model tend to those of the instantaneous model. This condition is met if the observer is positioned far from the source. In the limit of a long release time compared with the cloud travel time, the concentration profiles tend to those of the steady continuous model. The finite duration model gives smooth behaviour between these limits, thereby removing the need to use the Britter McQuaid criteria [26] to determine whether a release would be better approximated as continuous or instantaneous for a particular downwind distance.

### 1.2.2 Importing GASP output

When a GASP file is imported into DRIFT, DRIFT uploads the time varying vaporisation rate, pool temperature and pool radius calculated by GASP. This can be modelled in DRIFT using either the finite duration model or the time varying model. The facility to model an imported GASP run using the finite duration option was introduced in DRIFT 3.6.7.

If the finite duration model is selected, the GASP outputs are averaged over the duration of interest. This approach is equivalent to using the continuous DIN file generated by GASP, except that the averaging is done within DRIFT rather than in GASP. Prior to DRIFT 3.6.13, the average release radius for an imported GASP run was calculated using a simple average. However, in DRIFT 3.6.13 and later versions, the average release radius is calculated from the average area, giving a root mean square value. This approach is consistent with that used within GASP to generate DIN files.

If the time varying model is selected, DRIFT 3 uses an algorithm to split the release into segments, each of which is modelled as a finite duration release. The concentration profiles from each segment are summed to give an overall time varying concentration profile. The time varying option is ideally suited to modelling sources with a release rate that varies with time, such as vaporising pools. However, the time varying model in DRIFT 3.6.14 is not recommended for use in Hazardous Substances Consent assessments as it does not run for all scenarios, can be significantly slower to run than the finite duration option, and has not undergone thorough evaluation.

### 1.2.3 Recommended approach

Cruse et al. [10] recommend that for releases of substances with a toxic exponent ($n$) of one [27], a continuous DIN file should be created and then modelled in DRIFT 3.6.4 using the finite duration option. This remains the recommended approach when using DRIFT 3.6.14, although it is also permissible to use the finite duration option to model a directly imported GASP file. These two approaches should give practically identical outputs. Instructions on how to model substances with a toxic exponent greater than one are provided by Cruse et al. [10].

## 1.3 STRUCTURE OF REPORT

The remainder of this report is structured as follows:

- Section 2 describes the validation of DRIFT 3.6.14 in accordance with a dense gas Model Evaluation Protocol. The validation of DRIFT 3.6.14 against a set of passive tracer releases is also presented.

- Section 3 describes the additional assessment of DRIFT 3.6.14 that has been carried out, to determine whether the recent enhancements to the model have affected the dispersion predictions for vapour evolved from pools of toxic liquids. A subset of the scenarios modelled by Cruse et al. [10] has been rerun.

- Section 4 presents the DRIFT 3.6.14 outputs obtained when the toxic pool scenarios considered in Section 3 were modelled using the D2.4, D4.3, D6.7 and F2.4 weather categories. These weather categories are now used when modelling releases from evaporating pools of toxic liquids for the purposes of Hazardous Substances Consent assessment. The outputs in Section 4 will be used to compare DRIFT 3.6.14 to future versions of DRIFT in subsequent assessment and evaluation reports.

- The conclusions from this work are presented in Section 5.

# 2 DRIFT 3.6.14 VALIDATION FOR DENSE AND PASSIVE GAS RELEASES

Validation of DRIFT 3.6.4 in accordance with a dense gas Model Evaluation Protocol is described by Coldrick and Webber [8]. This section gives an update of the validation using DRIFT 3.6.14. The same set of test cases has been run and revised values for Statistical Performance Measures have been obtained for comparison with those from DRIFT 3.6.4. Version 11 of the Model Evaluation Protocol Database was used [28]. The validation of DRIFT 3.6.14 against a set of passive tracer releases is also presented.

## 2.1 REVIEW OF THE MODIFICATIONS TO THE MATHEMATICAL MODEL

A scientific assessment of the modifications to the DRIFT mathematical model that were introduced between DRIFT 3.6.4 and DRIFT 3.6.14 has been carried out by Dr David Webber, a dispersion modelling expert who was involved in the development of the original DRIFT model. This assessment concentrated on the mathematical equations themselves, and not their implementation within the code. Dr Webber concluded that the changes to the mathematical model were minor and that these changes were logical and justifiable developments of the model.

The most significant changes have been made to the instantaneous model, which now provides the user with the choice of modelling an instantaneous release as a stationary initial cloud or a non-stationary initial cloud [6]. The stationary initial cloud option should be used to model scenarios where there is no initial motion of the cloud. It includes a time delay for the start of gravity spreading for agreement with the Thorney Island instantaneous trials [20, 21]. The non-stationary cloud option should be used to model clouds that are expected to be initially moving, for example due to momentum associated with any ambient air entrained prior to the DRIFT run. The empirical delay in gravity spreading is not included for non-stationary initial clouds. Dr Webber commented that this appears reasonable, because this delay is unnecessary for a cloud that is already spreading at time zero. Any changes to the output which are caused by the removal of the time delay would therefore appear to be warranted.

Dr Webber noted that the provision for initially non-stationary instantaneous releases, as implemented in DRIFT 3.6.7, is a logical development for scenarios such as a catastrophic two-phase flashing release from pressurised storage. An instantaneous release of a pressure-liquefied gas will expand rapidly, and the radial momentum will not decay to zero before the processes associated with heavy gas dispersion start to become important and then, possibly, dominant. Dr Webber commented that he would expect the new non-stationary instantaneous release option to be a big improvement for scenarios of this type, in comparison to the modelling capabilities of previous versions of DRIFT. The new non-stationary option is possibly also less conservative, as erroneously stopping the radial movement (as would have occurred in earlier versions of DRIFT) would also slow the entrainment.

In DRIFT 3.6.7 and subsequent versions, the advection speed for dense ground-based clouds has an empirical dependence on the cloud Richardson number. Clouds with a high Richardson number are assumed to advect at approximately 0.7 times the wind speed at the cloud centroid height, a condition set from a comparison with the Thorney Island instantaneous trials [20, 21]. Dr Webber observed that this change appears to be motivated entirely by improvements in fits to data. He noted that he would expect the advection velocity to be of the order of one times the wind velocity at the centroid height, but there is no theoretical reason to prefer any particular value within that criterion, so 0.7 would appear to be an appropriate choice. He also noted that the dilution rate is dependent on the value chosen for the advection velocity.

## 2.2 RERUN OF TEST CASES

### 2.2.1 Dense gas releases

The test cases described by Coldrick and Webber [8] were rerun using DRIFT 3.6.14. These are summarised in Tables 1 to 3 below.

**Table 1** Specific test cases modelled

| *Trial* | *Field (F) or Wind tunnel (WT)* | *Obstructed (O) or unobstructed (U)* | *Trial/Case number and/or description* |
|---|---|---|---|
| Maplin Sands, 1980 [29-32] | F | U<br>U<br>U | 27 dispersion over sea<br>34 dispersion over sea<br>35 dispersion over sea |
| Burro, 1980 [33, 34] | F | U<br>U<br>U<br>U | 3<br>7<br>8<br>9 |
| Coyote, 1981 [35] | F | U<br>U<br>U | 3<br>5<br>6 |
| Falcon, 1987 [36] | F | O<br>O<br>O | 1 with vapour barrier fence<br>3 with vapour barrier fence<br>4 with vapour barrier fence |
| Thorney Island, 1982-4 [20, 21] | F | U<br>U | 45 continuous release<br>47 continuous release |
| CHRC, 2006 [37-39] | WT | U<br>O<br>O | A without obstacles<br>B with storage tank & dyke<br>C with dyke |
| BA-Hamburg, 1991 [40] | WT | U<br>O<br>O<br>O | Unobstructed<br>Upwind fence<br>Downwind fence<br>Circular fence |
| BA-TNO, 1991 [40] | WT | U | FLS – 3-D mapping |

**Table 2** Field trials summary

| | *Maplin Sands* | *Burro* | *Coyote* | *Falcon* | *Thorney Island* |
|---|---|---|---|---|---|
| ***Material*** | LNG | LNG | LNG | LNG | Freon 12 / nitrogen |
| ***Maximum amount spilled*** | 3658 kg | 17289 kg | 12676 kg | 28074 kg | 4855 kg |
| ***Maximum spill rate*** | 27.1 kg/s | 135 kg/s | 129 kg/s | 202 kg/s | 10.67 kg/s |
| ***Maximum duration*** | 160 s | 174 s | 98 s | 301 s | 465 s |
| ***Source*** | Spill onto water pool | Spill onto water pool | Spill onto water pool | Spill onto water pool | Vapour source |

**Table 3** Wind tunnel trials summary

| | *CHRC* | *BA-Hamburg* | *BA-TNO* |
|---|---|---|---|
| ***Material*** | $CO_2$ | $SF_6$ | $SF_6$ |
| ***Maximum spill rate*** | 0.001056 kg/s | 0.000872 kg/s | 0.001045 kg/s |
| ***Maximum duration*** | Continuous | Continuous | Continuous |
| ***Source*** | Area vapour source | Area vapour source | Area vapour source |

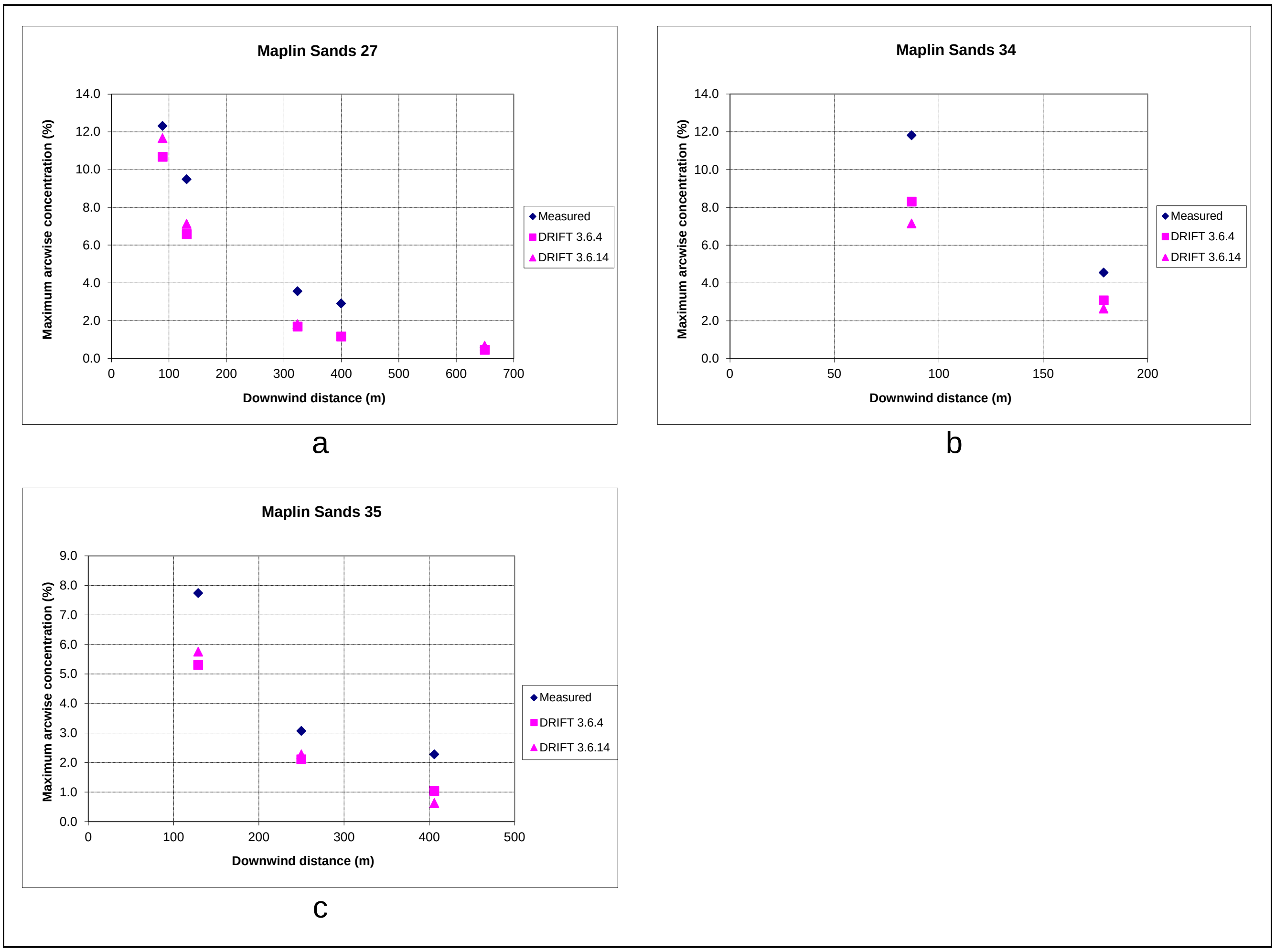
When modelling the scenarios that involved spills onto water (listed in Table 2), the source term was rerun using an updated version of GASP (version 4.2.12). These updated GASP runs were imported directly into DRIFT. This function was used following the changes to allow imported GASP runs to be used in conjunction with the finite duration model, as detailed in Section 1.2.2.

In the DRIFT 3.6.4 evaluation, the liquefied natural gas (LNG) releases were modelled using substance property data from the internal DRIFT database. When the test cases were rerun in DRIFT 3.6.14, data from the appropriate SPI (Substance Property Information) file was used instead, as this is the data source that would be used by HSE for Hazardous Substances Consent assessments. No changes were made to the substance property data used in any of the other test cases. In both DRIFT 3.6.4 and DRIFT 3.6.14, releases of Freon 12 and $SF_6$ were modelled using user-defined substance property information and releases of $CO_2$ were modelled using SPI file data.

### 2.2.2 Results

#### *2.2.2.1 Maplin Sands*

Results for the Maplin Sands trials are shown in Figure 1, using the ‘short’ 3 s averaging time. Updated GASP runs were used for these trials, along with the alternative substance property data source, and the overall result is marginally increased predictions for Trials 27 and 35, and slightly lower predictions for Trial 34.



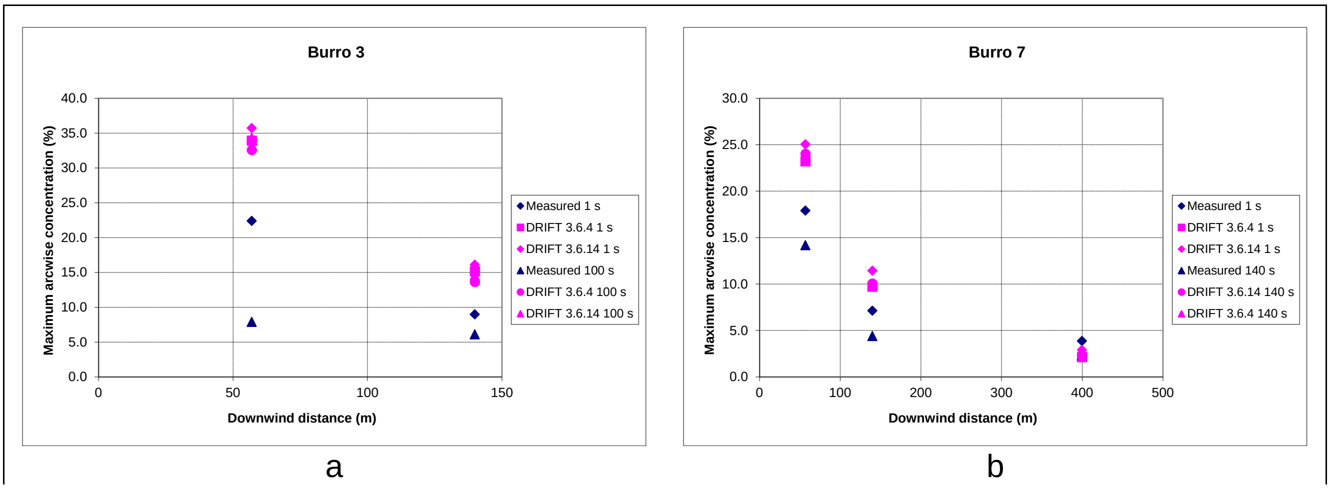
a

b

c

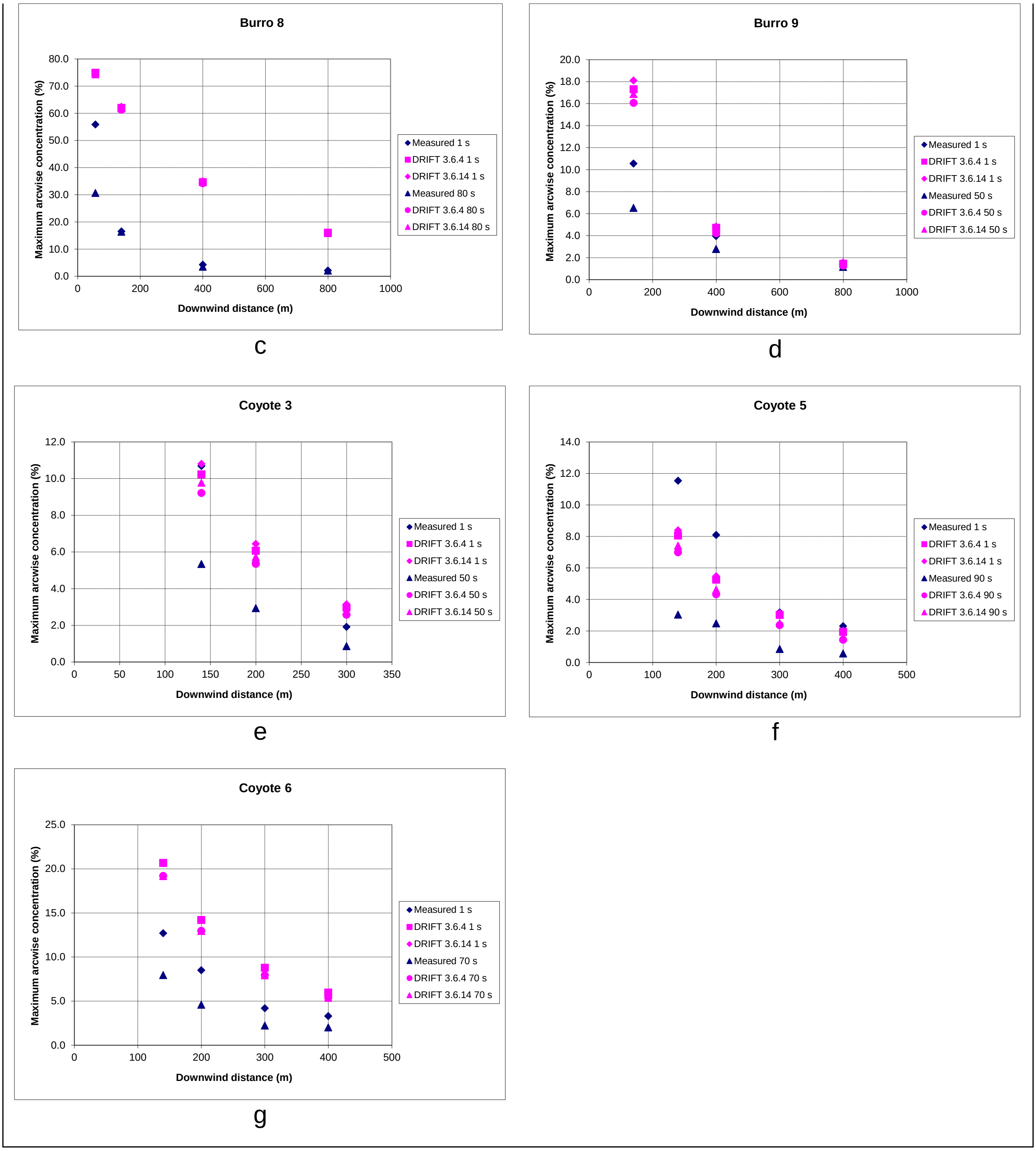
**Figure 1** Measured and predicted concentrations for the Maplin Sands trials

Results for the Burro and Coyote trials are shown in Figure 2. Again, updated GASP runs and substance property data were used for these trials. Slightly lower predictions were obtained for the Coyote 6 Trial, and slightly higher predictions were obtained for the other six Trials. Predictions were generated for both the short 1 s averaging time and the longer averaging times.



a

b



c

d

e

f

g

**Figure 2** Measured and predicted concentrations for the Burro and Coyote trials for different averaging times

### 2.2.2.2 Falcon

Results for the Falcon trials are shown in Figure 3. Practically identical predictions were obtained using the two versions of DRIFT for both the 1 s and longer time averages.

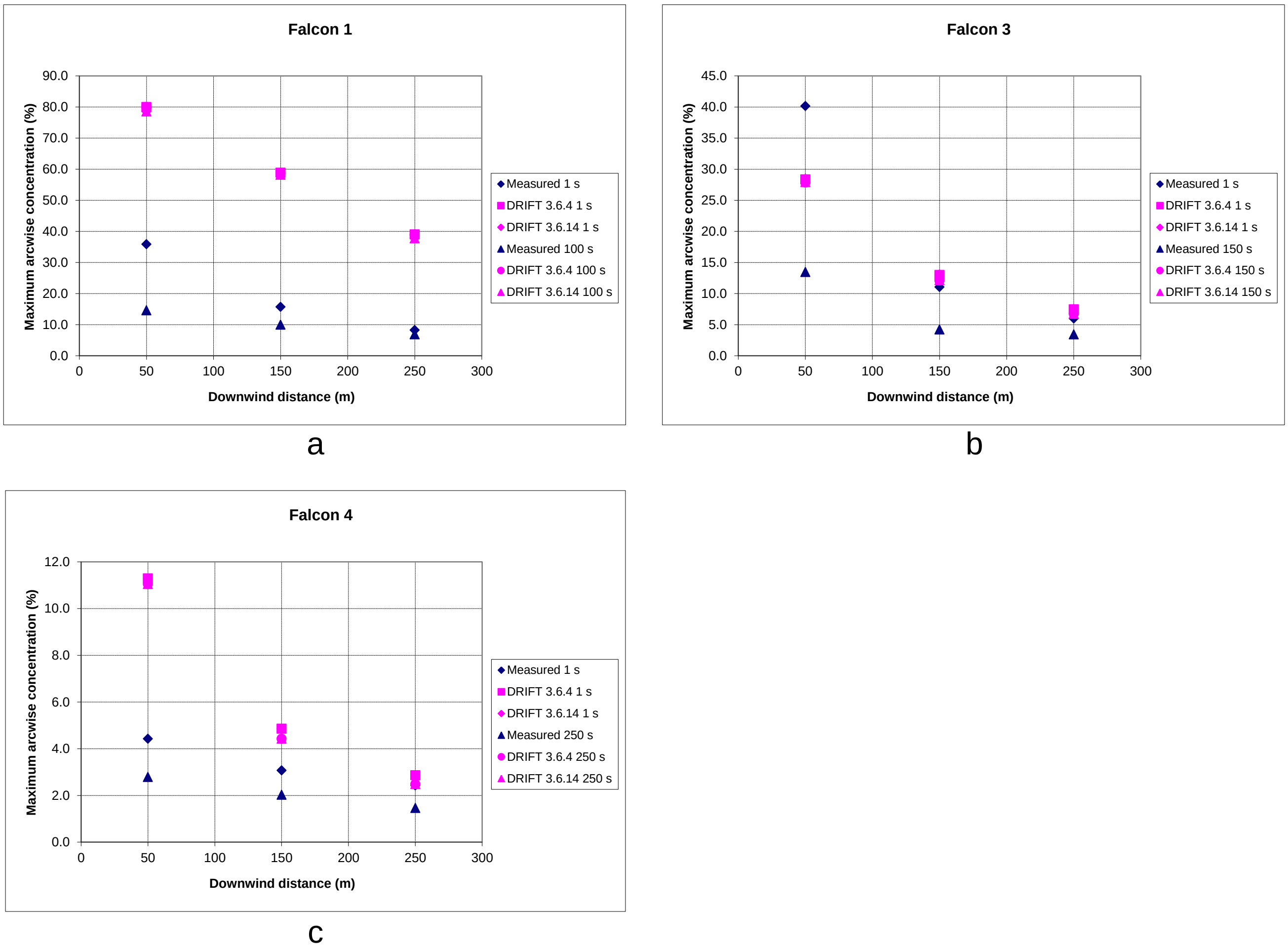


**Figure 3** Measured and predicted concentrations for the Falcon trials

### 2.2.2.3 Thorney Island

Results for the Thorney Island trials are shown in Figure 4. Identical results were obtained using DRIFT 3.6.4 and DRIFT 3.6.14.

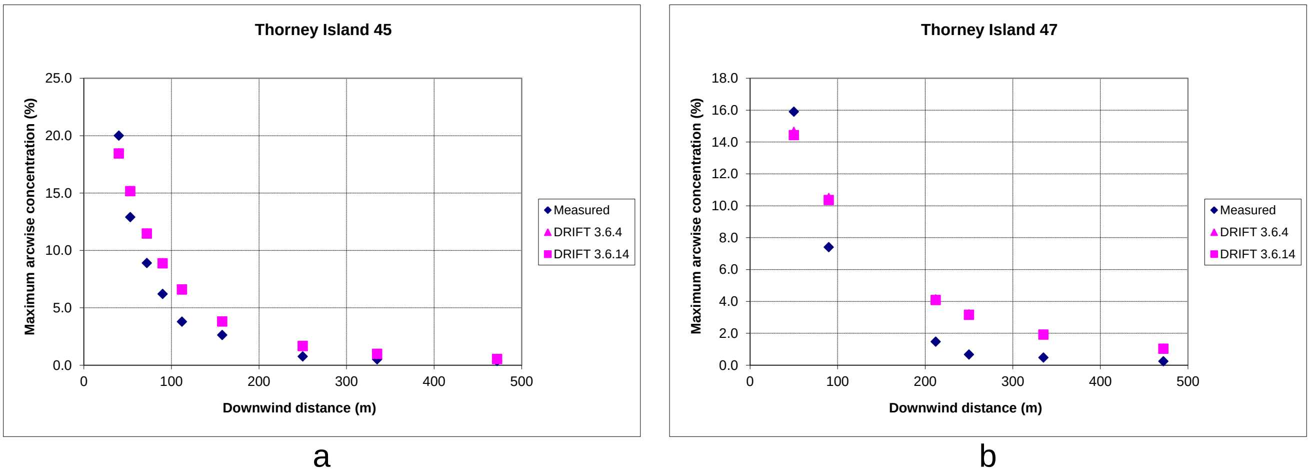
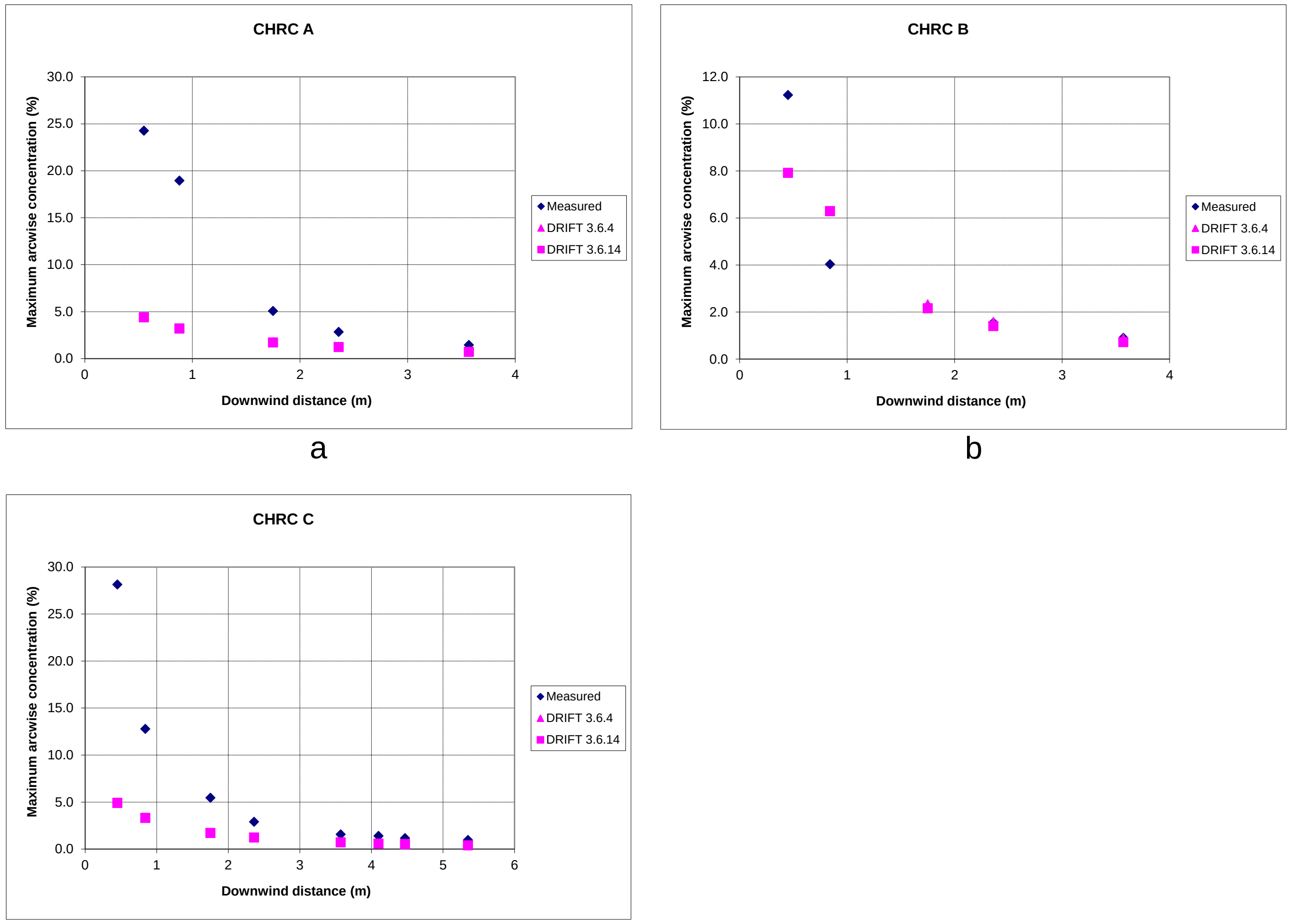


**Figure 4** Measured and predicted concentrations for the Thorney Island trials

### *2.2.2.4 CHRC, BA-Hamburg and BA-TNO*

Results for the CHRC, BA-Hamburg and BA-TNO wind tunnel trials are shown in Figures 5 to 7. Practically identical predictions were obtained using DRIFT 3.6.4 and DRIFT 3.6.14.

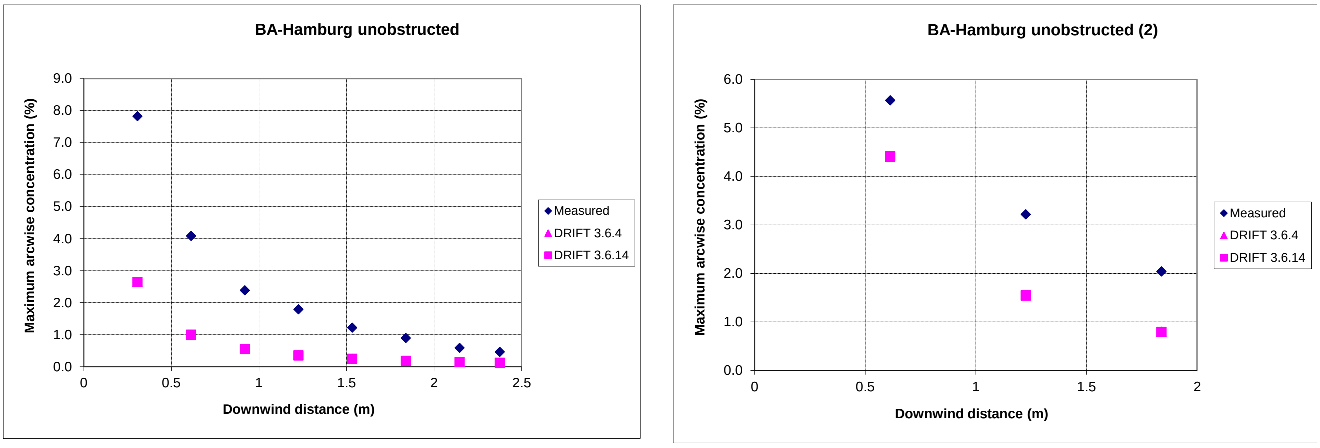


a

b

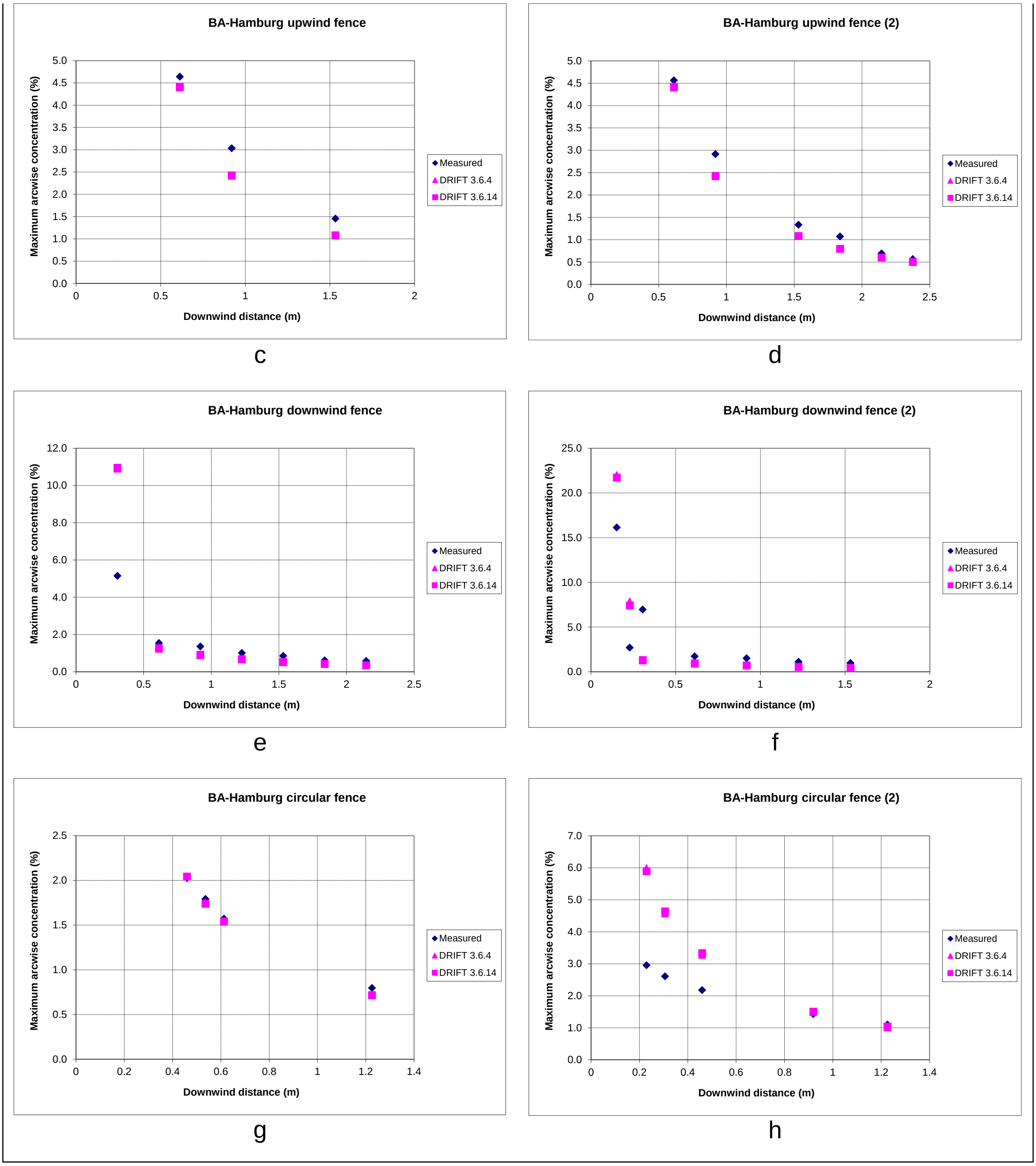
c

**Figure 5** Measured and predicted concentrations for the CHRC wind tunnel trials



a

b



c

d

e

f

g

h

**Figure 6** Measured and predicted concentrations for the BA-Hamburg wind tunnel trials

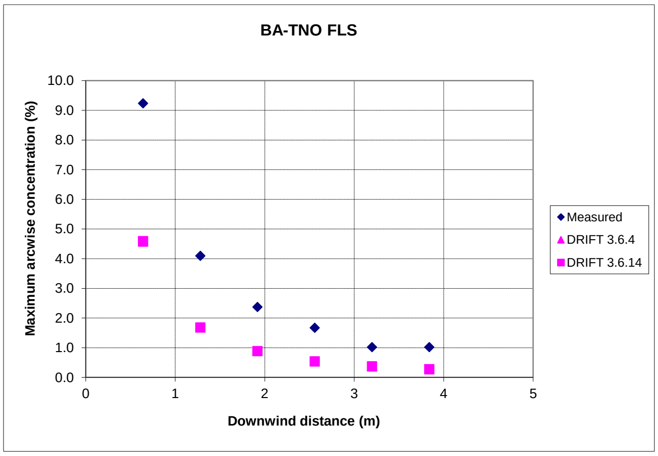


**Figure 7** Measured and predicted concentrations for the BA-TNO wind tunnel trials

### 2.2.3 Statistical performance measures

The Statistical Performance Measures (SPM) used in the evaluation database are those recommended by Ivings et al. [9] and reproduced in Table 4. The angle brackets used in the formulas denote an average over all the measured/predicted pairs of concentrations entered in the database, for all test cases including both the field and wind tunnel trials.

**Table 4** Statistical performance measure definitions

| ***SPM*** | ***Definition*** |
|---|---|
| Mean Relative Bias | $\mathrm{MRB} = \left\langle \dfrac{C_m - C_p}{\frac{1}{2}(C_p + C_m)} \right\rangle$ |
| Geometric mean bias | $\mathrm{MG} = \exp\left\langle \log_e\left(\dfrac{C_m}{C_p}\right)\right\rangle$ |
| Mean Relative Square Error | $\mathrm{MRSE} = \left\langle \dfrac{(C_p - C_m)^2}{\frac{1}{4}(C_p + C_m)^2} \right\rangle$ |
| Geometric variance | $\mathrm{VG} = \exp\left\langle \left[\log_e\left(\dfrac{C_m}{C_p}\right)\right]^2\right\rangle$ |
| FAC2: the fraction of predictions which are within a factor of two of the measurements | $0.5 \leq \left(\dfrac{C_p}{C_m}\right) \leq 2.0$ |

The SPM are shown in Tables 5 and 6 for the maximum arc-wise concentration predictions. The changes in concentration predictions appear to arise mostly from the change in the substance data source used for the LNG releases, rather than the modifications to the DRIFT 3 mathematical model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14. The only significant changes are therefore to the SPM for the unobstructed cases in Table 5. However, even for these cases the changes are small and do not alter the relationship with the model acceptance criteria proposed by Ivings et al. [9]. Table 7 shows the SPM results for the cloud width predictions; again there is minimal difference between the two versions of DRIFT. The SPM results for the geometric mean bias (MG) and the geometric variance (VG) are depicted graphically in Figure 8.

**Table 5** SPM for maximum arc-wise concentration for short time averages, comparing the results of DRIFT 3.6.4 and DRIFT 3.6.14

| ***SPM*** | ***Value for unobstructed cases (Group 1)*** | | ***Value for obstructed cases (Group 2)*** | | ***Acceptability range*** |
|---|---|---|---|---|---|
| | **DRIFT 3.6.4** | **DRIFT 3.6.14** | **DRIFT 3.6.4** | **DRIFT 3.6.14** | |
| MRB | -0.11 | -0.14 | -0.53 | -0.52 | -0.4 < MRB < 0.4 |
| MG | 0.86 | 0.84 | 0.56 | 0.56 | 0.67 < MG < 1.5 |
| MRSE | 0.36 | 0.38 | 0.53 | 0.52 | MRSE < 2.3 |
| VG | 1.64 | 1.70 | 1.97 | 1.94 | VG < 3.3 |
| FAC2 | 0.79 | 0.82 | 0.56 | 0.56 | 0.5 < FAC2 |

**Table 6** SPM for maximum arc-wise concentration for long time averages, comparing the results of DRIFT 3.6.4 and DRIFT 3.6.14

| ***SPM*** | ***Value for unobstructed cases (Group 1)*** | | ***Value for obstructed cases (Group 2)*** | | ***Acceptability range*** |
|---|---|---|---|---|---|
| | **DRIFT 3.6.4** | **DRIFT 3.6.14** | **DRIFT 3.6.4** | **DRIFT 3.6.14** | |
| MRB | -0.08 | -0.09 | 0.06 | 0.06 | -0.4 < MRB < 0.4 |
| MG | 0.92 | 0.91 | 1.06 | 1.06 | 0.67 < MG < 1.5 |
| MRSE | 0.85 | 0.87 | 0.48 | 0.47 | MRSE < 2.3 |
| VG | 3.13 | 3.19 | 1.86 | 1.84 | VG < 3.3 |
| FAC2 | 0.30 | 0.30 | 0.59 | 0.61 | 0.5 < FAC2 |

**Table 7** SPM for cloud width, comparing the results of DRIFT 3.6.4 and DRIFT 3.6.14

| ***SPM*** | ***Value for unobstructed cases (Group 1)*** | | ***Value for obstructed cases (Group 2)*** | | ***Acceptability range*** |
|---|---|---|---|---|---|
| | **DRIFT 3.6.4** | **DRIFT 3.6.14** | **DRIFT 3.6.4** | **DRIFT 3.6.14** | |
| MRB | 0.04 | 0.00 | -0.19 | -0.12 | -0.4 < MRB < 0.4 |
| MG | 1.04 | 1.00 | 0.82 | 0.88 | 0.67 < MG < 1.5 |
| MRSE | 0.06 | 0.04 | 0.12 | 0.10 | MRSE < 2.3 |
| VG | 1.07 | 1.04 | 1.14 | 1.11 | VG < 3.3 |
| FAC2 | 1.00 | 1.00 | 0.92 | 0.92 | 0.5 < FAC2 |

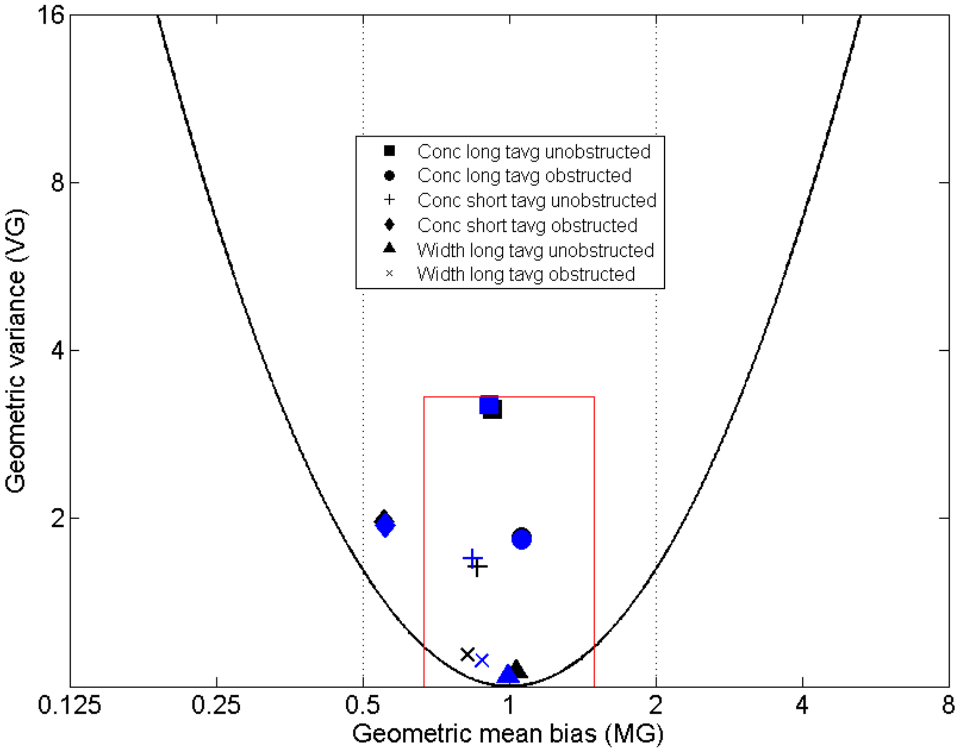


**Figure 8** Graphical depiction of SPM results (DRIFT 3.6.4 shown in black and DRIFT 3.6.14 shown in blue). The red lines indicate acceptance criteria.

Evaluations of models against the same Model Evaluation Protocol have been carried out by Kohout [41], Hansen et al. [42] and Witlox et al. [43]. The Model Evaluation Protocol is not intended to be a platform for comparison of models against each other, though reference to plots of concentration with distance presented in Kohout [41] and Hansen et al. [42] show that DRIFT 3.6.14 gives comparable results to the other models.

### 2.2.4 Passive releases

#### *2.2.4.1 Hanford and Prairie Grass*

The passive dispersion test cases described by Coldrick and Webber [8] were rerun using DRIFT 3.6.14. Results for the Hanford [44] and Prairie Grass [45] trials are shown in Figures 9 and 10. Results are only shown for DRIFT 3.6.14 as the results were identical to those obtained using DRIFT 3.6.4. The release rate of the tracer in the Hanford trials is not known. The release rate used in DRIFT has therefore been scaled so that the measured and predicted concentrations at the 200 m arc are identical. Consequently, meaningful comparisons can only be made by examining the difference in the measured and predicted concentrations at the second (800 m) arc.

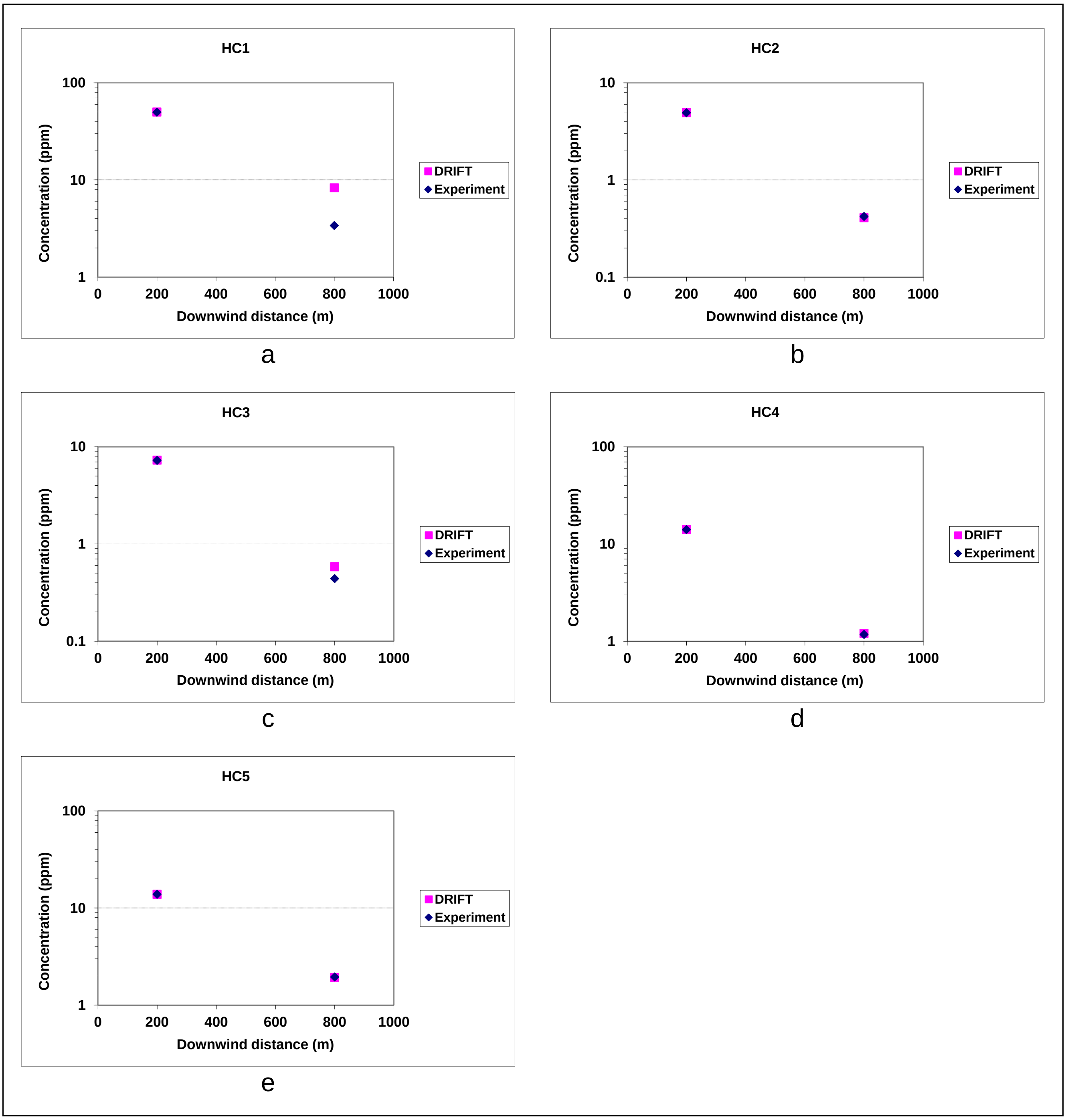


**Figure 9** Measured and predicted concentrations for the Hanford trials

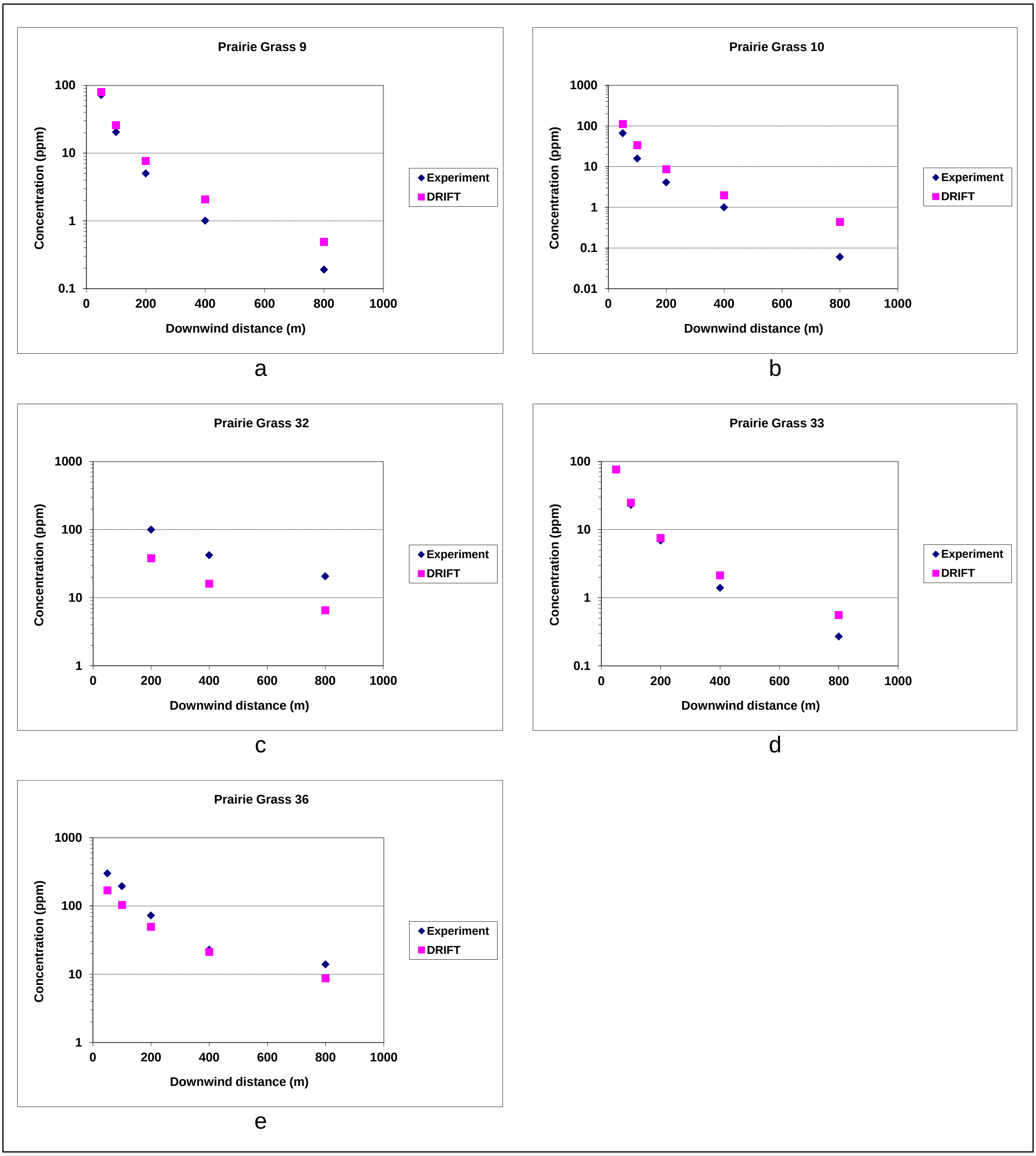


**Figure 10** Measured and predicted concentrations for the Prairie Grass trials

### 2.2.5 Statistical performance measures

Table 8 shows the SPM results for the Prairie Grass passive experiments. Identical values were obtained using DRIFT 3.6.4 and DRIFT 3.6.14. The results are shown graphically in Figure 11. Meaningful SPM cannot be derived for the Hanford trials because the release rate of the tracer is not known.

**Table 8** SPM results for the Prairie Grass passive experiments, computed from DRIFT 3.6.4 and DRIFT 3.6.14 simulations

| *SPM* | *Concentration* | | *Cloud width* | | *Acceptability range* |
|---|---|---|---|---|---|
| | **DRIFT 3.6.4** | **DRIFT 3.6.14** | **DRIFT 3.6.4** | **DRIFT 3.6.14** | |
| MRB | -0.12 | -0.12 | 0.64 | 0.64 | -0.4< MRB < 0.4 |
| MG | 0.87 | 0.87 | 1.93 | 1.93 | 0.67 < MG < 1.5 |
| MRSE | 0.43 | 0.43 | 0.41 | 0.41 | MRSE < 2.3 |
| VG | 1.72 | 1.72 | 1.56 | 1.56 | VG < 3.3 |
| FAC2 | 0.61 | 0.61 | 0.70 | 0.70 | 0.5 < FAC2 |

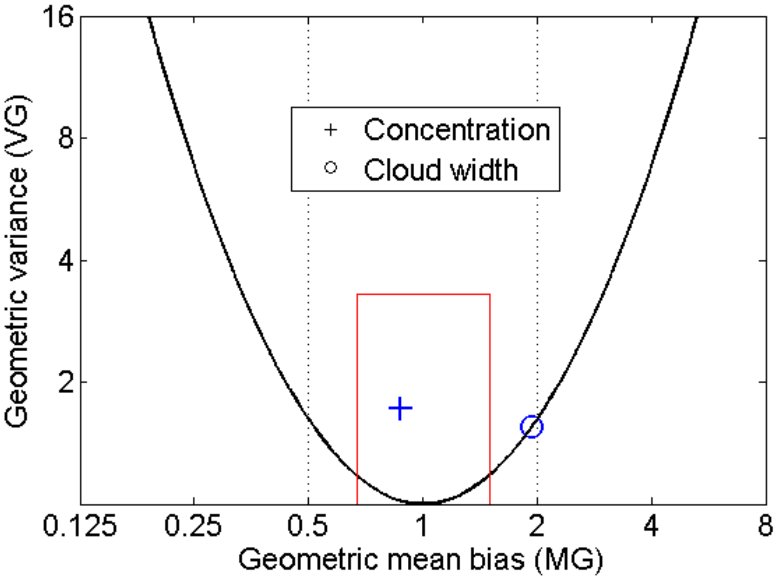


**Figure 11** Graphical depiction of the SPM results for the Prairie Grass trials. DRIFT 3.6.4 and DRIFT 3.6.14 give identical results. The red box represents the acceptance criteria for dense gas dispersion models proposed by Ivings et al. [9].

## 2.3 CONCLUSIONS

The modifications to the DRIFT mathematical model that were introduced between DRIFT 3.6.4 and DRIFT 3.6.14 were subject to a scientific assessment by a dispersion modelling expert. The reviewer concluded that the changes to the model were minor and that these changes were logical and justifiable developments of the model.

The set of validation test cases described by Coldrick and Webber [8] was rerun using DRIFT 3.6.14 and the results compared with those from DRIFT 3.6.4. Minor changes in concentration predictions were obtained with DRIFT 3.6.14 for the spills of LNG. These changes in the concentration predictions appear to have arisen mostly from the change in the substance data source used for the

LNG releases, rather than the modifications to the DRIFT 3 mathematical model. Overall the changes to the DRIFT model have no effect on the predictions with respect to the acceptance criteria for an ‘acceptable’ model.

# 3 DRIFT 3.6.14 ASSESSMENT FOR THE DISPERSION OF TOXIC VAPOUR FROM POOLS

## 3.1 INTRODUCTION

The assessment of the performance of DRIFT 3 when modelling releases from evaporating pools of toxic liquids was carried out by Cruse et al. using DRIFT 3.6.4 [10]. This section describes the testing of DRIFT 3.6.14 that has been carried out to determine whether the recent enhancements to the model have affected the dispersion predictions for vapour evolved from pools of toxic liquids. None of the changes implemented between DRIFT 3.6.4 and DRIFT 3.6.14 are expected to have a significant effect on the output of the model for these types of scenario.

## 3.2 TEST SCENARIOS

Cruse et al. [10] reassessed recent consent applications for methyl iodide and ethylene oxide using DRIFT 3.6.4. Following an accidental release, these substances form evaporating pools, which can be modelled in GASP and DRIFT.

A subset of the scenarios modelled by Cruse et al. has been rerun in DRIFT 3.6.14. The selected scenarios have been chosen to encompass the range of release scenarios typically modelled in GASP and DRIFT and consist of an instantaneous release and a continuous release as follows:

- Catastrophic failure of a storage vessel, resulting in the release of 90 tonnes of ethylene oxide; and
- A leak from a hole in a methyl iodide storage vessel. The continuous release scenario that was reassessed was a release of methyl iodide through a 250 mm diameter hole in a tank. The release rate was determined using the liquid flow rate sub-model in STREAM (HSE's suite of programs to calculate outflow from vessels and pipes) and was found to be 462 kg/s for 364 s. The liquid flow rate sub-model in STREAM carries out an iterative flow calculation, based on a friction factor calculated using the method of Serghides [46].

Each scenario has been modelled in D5 and F2 weather conditions, which have been used to represent daytime and night-time conditions, respectively. (The letters D and F represent Pasquill stability classes: D denotes neutral conditions and F denotes stable conditions. The associated number gives the wind speed in metres per second at a reference height of 10 m.) Table 9 summarises the GASP and DRIFT inputs that are affected by the choice of weather category. The 'additional heat flux' input in GASP allows the user to account for the effect of solar radiation.

**Table 9** Weather categories

| ***Weather category*** | ***Ambient temperature (K)*** | ***Additional heat flux (W/m$^2$)*** | ***Air changes per hour (ac/h)*** |
|---|---|---|---|
| D5 (day) | 288.15 | 200 | 2 |
| F2 (night) | 278.15 | 0 | 2 |

For calculating the indoor consequences of toxic releases, HSE uses ventilation rates that are applicable to normally ventilated houses. For wind speeds of 2 m/s to 5 m/s inclusive, a ventilation rate of 2 ac/h (air changes per hour) is normally used, and for wind speeds greater than 5 m/s, the ventilation rate is usually assumed to be 3 ac/h. These ventilation rates are based on work carried out by the Building Research Establishment (BRE) [47].

### 3.2.1 Creation of source terms for DRIFT

Both ethylene oxide and methyl iodide have a toxic exponent (*n*) of one [27]. Cruse et al. [10] recommend that for the purposes of Hazardous Substances Consent assessment, releases of substances with a toxic exponent of one should be modelled by creating a continuous DIN file in GASP and using the finite duration option in DRIFT. The finite duration option is expected to give a better representation of the physical processes that would occur during an actual release than the steady continuous model in DRIFT 3 [6, 10].

For each scenario, the spreading and vaporisation of the pool has been modelled in the latest version of GASP (version 4.2.12). Table 10 shows the physical properties of the cloud that were calculated by GASP and used to generate DIN files for input into DRIFT. The proportion of liquid in the cloud (labelled as the cloud quality in the DIN file) was zero in all cases. In each case, the physical properties of the cloud have been averaged over a release duration of 1800 s. A full list of the GASP and DRIFT input values used in this study is provided in Section 6.1 of the appendices.

**Table 10** The cloud physical properties calculated by GASP for the test release scenarios

| *Release Scenario* | *Weather* | *Mean vaporisation rate (kg/s)* | *Contaminant mass fraction* | *Cloud temperature (K)* | *Plume half-width (m)* | *Plume velocity (m/s)* |
|---|---|---|---|---|---|---|
| Catastrophic failure of an ethylene oxide tank | D5 | 27.3 | 0.306 | 250 | 48.8 | 1.08 |
| | F2 | 15.8 | 0.375 | 255 | 49.4 | 0.463 |
| 250 mm hole in a methyl iodide tank | D5 | 2.29 | 0.668 | 284 | 7.79 | 0.312 |
| | F2 | 1.08 | 0.683 | 285 | 7.79 | 0.137 |

Cruse et al. [10] used DRIFT 3.6.4 to reassess consent applications that were originally assessed using DRIFT 2.31. The GASP 4.0 files that were used in the original DRIFT 2.31 assessment were also used in the DRIFT 3.6.4 reassessment. For this report, simulations have been carried out using both DRIFT 3.6.4 and DRIFT 3.6.14 and in all cases the latest version of GASP has been used with the currently recommended input assumptions and up to date substance property information. Consequently, there are some differences between the DRIFT 3.6.4 outputs shown here and those presented by Cruse et al.

## 3.3 COMPARISON OF DRIFT 3.6.4 AND DRIFT 3.6.14

Each scenario has been modelled using DRIFT 3.6.4 and DRIFT 3.6.14, and the SLOT DTL (Specified Level of Toxicity, Dangerous Toxic Load) isopleths have been calculated for indoor and outdoor targets. These isopleths enclose the area within which the SLOT DTL is exceeded. The SLOT DTL is assumed to be equivalent to the LD1 (Lethal Dose 1), the dose that causes approximately 1% mortality in a normal population [27]. The SLOT DTL is also referred to as the HSE Dangerous Dose for toxic substances, which is defined as the dose which is sufficient to cause:

- Severe distress to almost everyone exposed to it;
- A substantial fraction of the exposed population to require medical attention;
- Serious injuries to some people, requiring prolonged treatment; and
- Possible fatalities to highly susceptible people.

A sensitivity analysis has been carried out for each scenario. The base case is the DRIFT run in which the finite duration model has been used, together with the input values and assumptions recommended by Cruse et al. [10]. The values used for a number of key inputs have been varied individually. Table 11 lists the recommended values for these inputs and the variations used in the sensitivity analysis. One of the parameters considered in the sensitivity analysis was dilution over source and Cruse et al. recommend that this option should be switched on. The dilution over source option models the gravitational spreading of the initial cloud. It also models the mixing of the contaminant evolved from the pool with air flowing over the pool, ensuring that the source is consistent with a steady plume.

The sensitivity analysis described in this section is identical to that carried out by Cruse et al. using DRIFT 3.6.4. The studies have been repeated in DRIFT 3.6.14 to investigate whether the finite duration, plume meander and dilution over source options are affected by the changes that have been made to the DRIFT mathematical model since the release of DRIFT 3.6.4.

**Table 11** Assumptions used for sensitivity analysis

| ***Parameter*** | ***Recommended DRIFT 3.6.14 input values (base case)*** | ***Sensitivity*** |
|---|---|---|
| Release type | Finite duration | Continuous |
| Source dilution | On | Off |
| Plume meander (averaging time) | 1800 s | Off |
| Receiver height[1] | Centreline height | 0 m |

[1] The receiver height is the height at which the SLOT DTL isopleths are calculated.

### 3.3.1 Graphical representation of the SLOT DTL isopleths

The following SLOT DTL isopleths have been calculated in DRIFT 3.6.4 and DRIFT 3.6.14 for each release scenario:

a) The SLOT DTL isopleth calculated using the input values recommended by Cruse et al. [10] and shown in Section 6.1 of the appendices. This is the base case and is represented by a bold black line in the figures, labelled ‘base case’.

b) The SLOT DTL isopleth calculated as for case (a), but modelling the release as continuous rather than finite duration. In the figures, this case is labelled ‘release type: continuous’ and is represented by a dashed red line.

c) The SLOT DTL isopleth calculated as for case (a), except that the option to include dilution over source is switched off. In the figures, this case is labelled ‘source dilution: off’ and is represented by a solid blue line.

d) The SLOT DTL isopleth calculated as for case (a), except that the option to include the effects of plume meander is switched off. In the figures, this case is labelled ‘plume meander: off’ and is represented by a dotted green line.

e) The SLOT DTL isopleth calculated as for case (a), except that the receiver height is set to 0 m, rather than the cloud centreline height. This comparison is included in the methyl iodide analysis only. On the figures, this case is labelled ‘receiver height: 0 m’ and is represented by a dash-dot orange line.

### 3.3.2 SLOT DTL isopleths predicted in DRIFT 3.6.4 and DRIFT 3.6.14

Figures 12 to 15 show the SLOT DTL isopleths obtained for a catastrophic release of ethylene oxide for indoor and outdoor recipients in D5 and F2 weather conditions. Figures 16 to 19 show the corresponding SLOT DTL isopleths for a continuous release of methyl iodide. In all cases, the DRIFT 3.6.14 outputs are plotted on the upper half of the graph, and the DRIFT 3.6.4 outputs are plotted beneath. Note that the scales are not the same in all of the figures.

There are no significant differences in the downwind distances and crosswind extents predicted by DRIFT 3.6.14 and DRIFT 3.6.4 for any of the test scenarios. In some cases, the upwind distance predicted when the dilution over source option is switched on is slightly smaller in DRIFT 3.6.14 than in DRIFT 3.6.4. This trend can be seen in Figures 12 and 14 for the 'base case' and 'plume meander: off' isopleths obtained for an outdoor recipient for a catastrophic ethylene oxide release.

When the dilution over source option is selected, DRIFT feeds material into an initially low cylindrical shaped cloud located directly over the source. This cylindrical cloud grows and spreads according to the same equations as DRIFT's instantaneous model [6], modified to include addition of material at a steady rate from the underlying source. The cylindrical cloud growth over the source continues until the cloud is sufficiently large that the released material can be transported downstream at a rate equal to the source rate (within DRIFT this is referred to as the point at which a steady source window is established). This then forms the basis of a modified source for the subsequent cloud evolution, which is determined by either the steady continuous or finite duration model equations [6]. The spreading over the source behaviour may therefore be affected by the changes to the instantaneous model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14. For example, by default DRIFT 3.6.14 does not include the empirical delay in gravity spreading that is included in DRIFT 3.6.4, and this may affect the time at which at steady source window is established.

In addition, since DRIFT 3.6.4 was released, some changes have been made to the way in which the concentration over the source is included in the concentration time history. These changes may also affect the predicted upwind extent for low momentum area releases.

## 3.4 DISCUSSION AND CONCLUSIONS

There are no significant differences in the downwind distances and crosswind extents predicted by DRIFT 3.6.14 and DRIFT 3.6.4 for the test scenarios examined. For some scenarios, there are minor differences between the upwind distances predicted by DRIFT 3.6.14 and DRIFT 3.6.4, but these differences will have a negligible effect on the outputs of any risk assessment. The enhancements to the DRIFT mathematical model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have therefore not significantly affected the dispersion predictions for vapour evolved from pools of toxic liquids, when such releases are modelled using the finite duration option.

The general trends that are observed in both the DRIFT 3.6.4 and the DRIFT 3.6.14 outputs are discussed in detail by Cruse et al. [10].

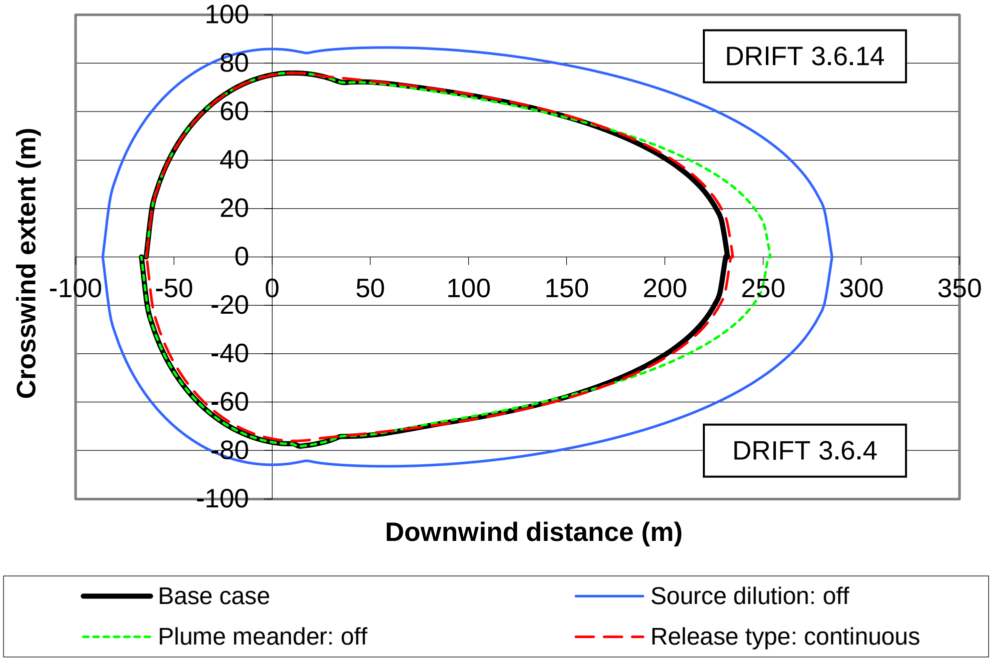


**Figure 12** SLOT DTL isopleths obtained for outdoor recipients for a catastrophic ethylene oxide release in D5 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

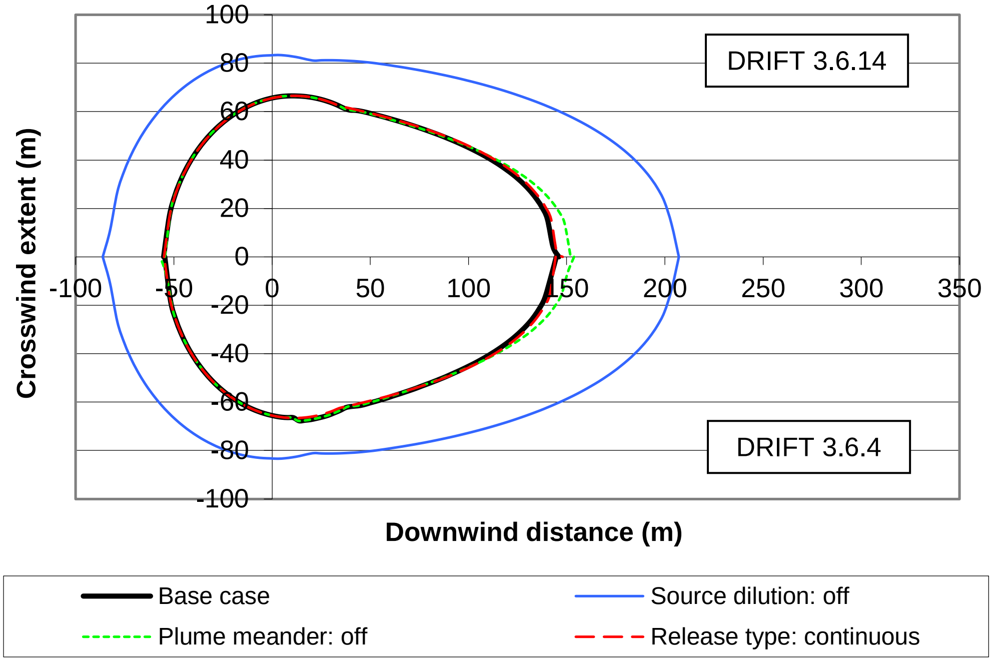


**Figure 13** SLOT DTL isopleths obtained for indoor recipients for a catastrophic ethylene oxide release in D5 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

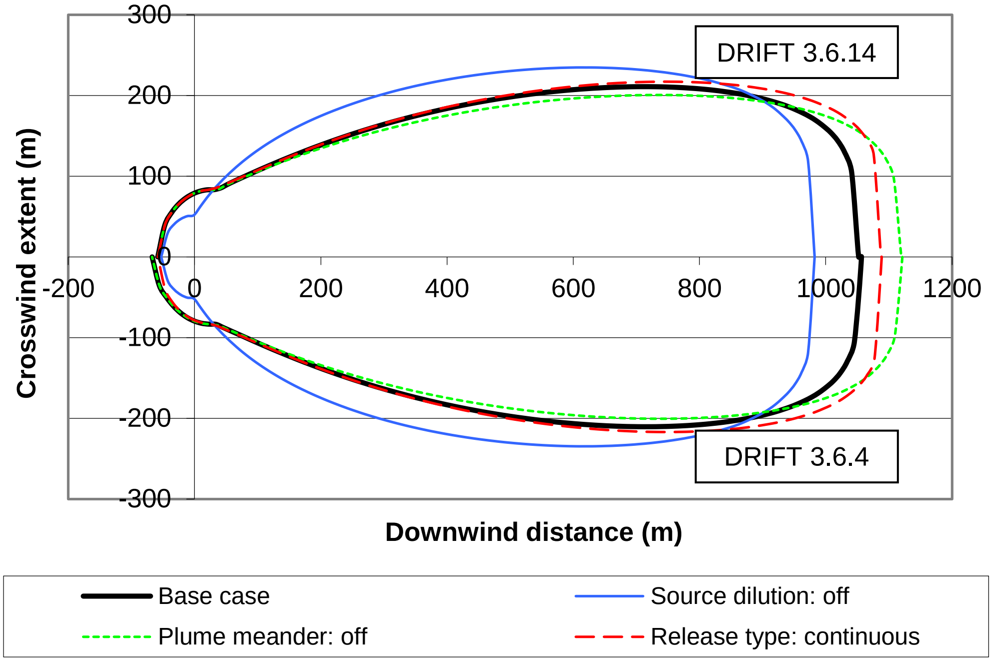


**Figure 14** SLOT DTL isopleths obtained for outdoor recipients for a catastrophic ethylene oxide release in F2 weather conditions

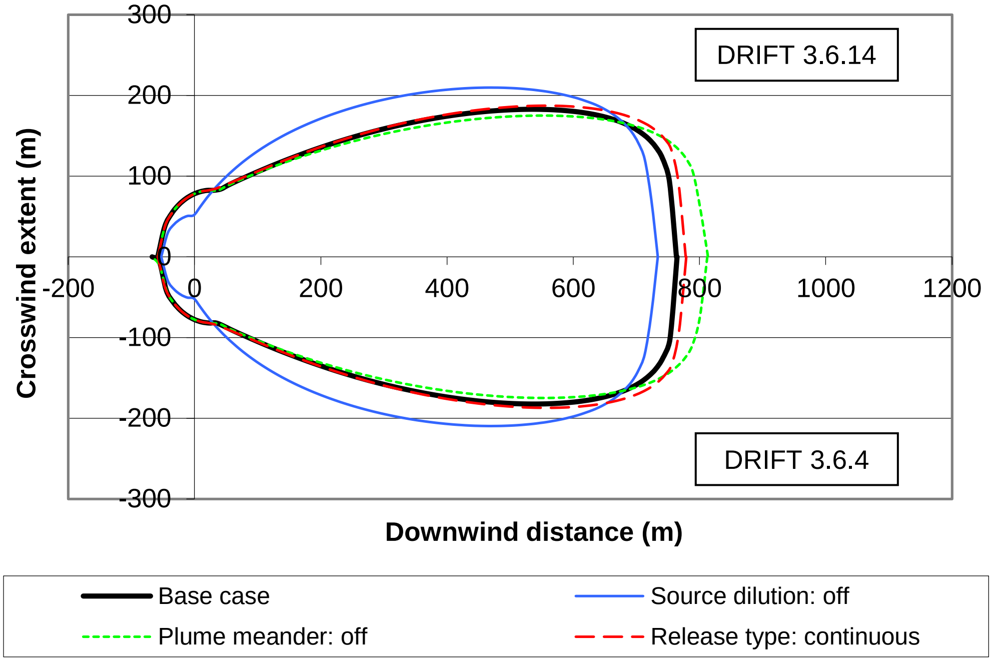


**Figure 15** SLOT DTL isopleths obtained for indoor recipients for a catastrophic ethylene oxide release in F2 weather conditions

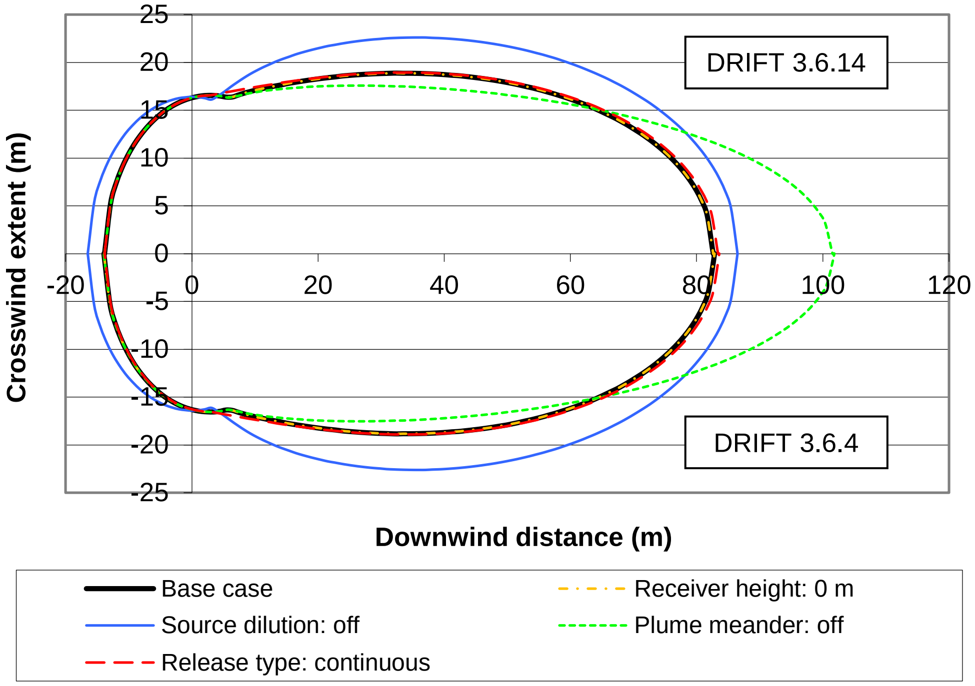


**Figure 16** SLOT DTL isopleths obtained for outdoor recipients for a continuous methyl iodide release in D5 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

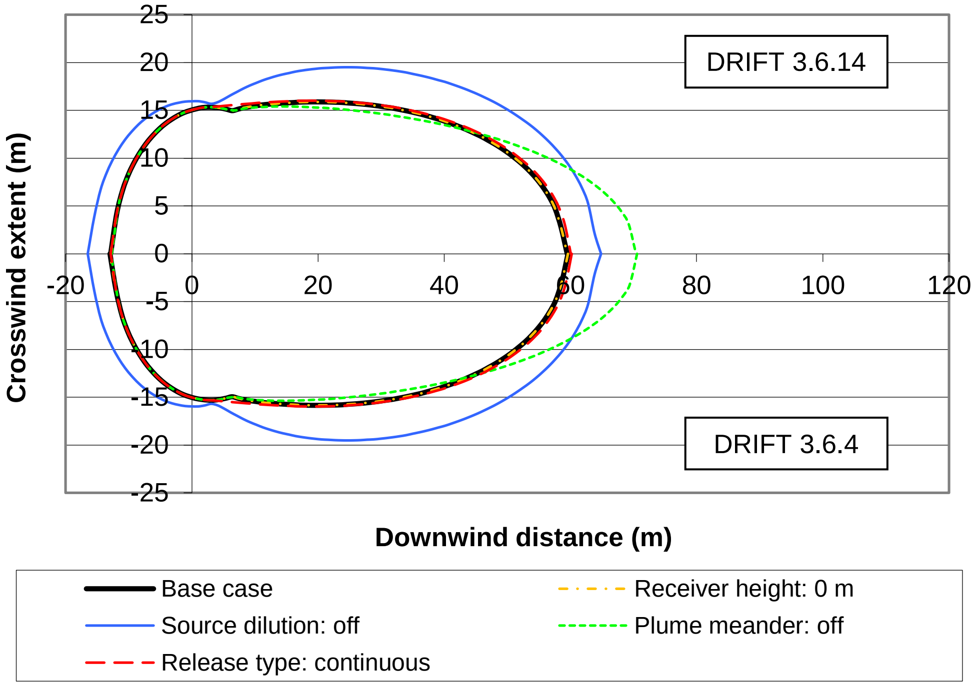


**Figure 17** SLOT DTL isopleths obtained for indoor recipients for a continuous methyl iodide release in D5 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

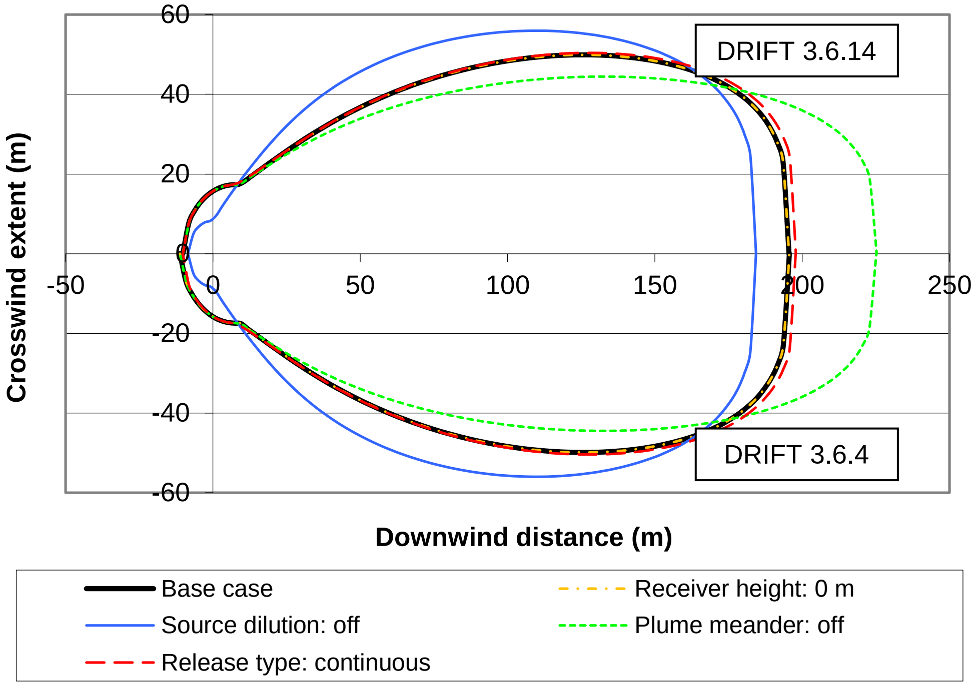


**Figure 18** SLOT DTL isopleths obtained for outdoor recipients for a continuous methyl iodide release in F2 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

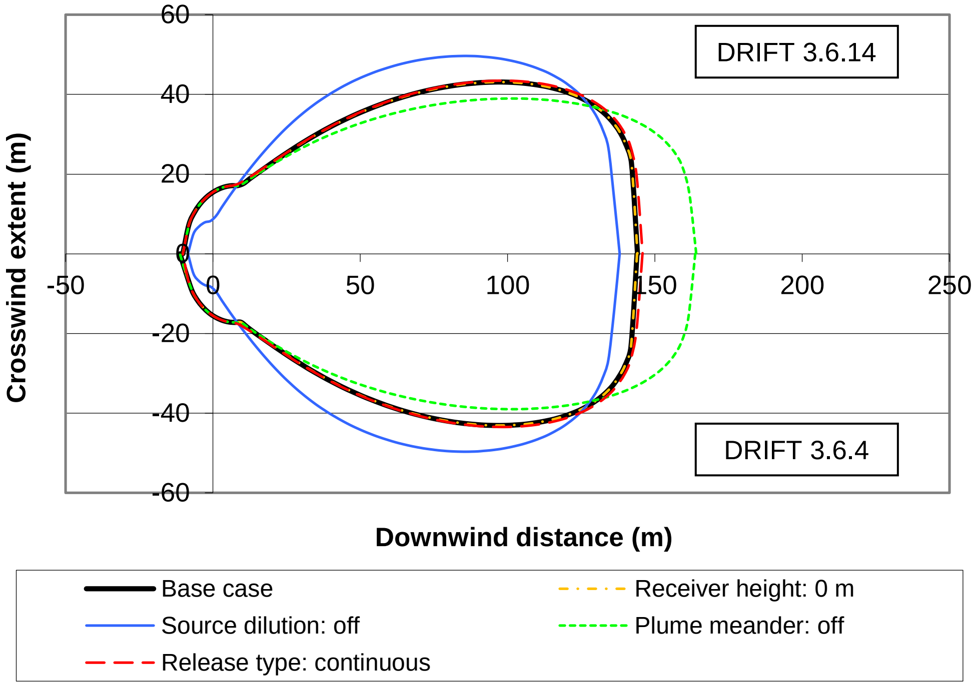


**Figure 19** SLOT DTL isopleths obtained for indoor recipients for a continuous methyl iodide release in F2 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

# 4 CHANGES TO THE RECOMMENDED WEATHER SET

## 4.1 INTRODUCTION

Cruse et al. [10] recommended that the D5 and F2 weather categories should be used to represent daytime and night-time conditions, respectively, when modelling the dispersion of vapour evolved from pools of toxic substances. This approach was consistent with the methodology previously used by HSE to model such releases.

HSE has since made a policy decision to use four weather categories when modelling releases from evaporating pools of toxic liquids for Hazardous Substances Consent assessments. Daytime weather should be represented by the D2.4, D4.3 and D6.7 weather categories, and night-time weather should be represented by the F2.4 weather category. These weather categories have been chosen to be consistent with the weather categories used when modelling releases of toxic pressure-liquefied gases.

Turner et al. [48] carried out test risk assessment calculations for selected sites across the UK using representative sets of weather categories. The conditional probability of a person being exposed to the HSE dangerous dose or greater (a metric that is proportional to the individual risk) was calculated as a function of distance from source for typical release scenarios. The outputs of the calculations using the representative weather sets were compared to those obtained when the full set of UK Meteorological Office wind speed and Pasquill stability data for each site was used. The D2.4, D4.3, D6.7 and F2.4 weather set provided a better correlation than the D5 and F2 weather set to the risk versus distance profiles obtained using the full set of weather data.

Sensitivity studies on future versions of DRIFT will only consider the D2.4, D4.3, D6.7 and F2.4 weather set for releases of toxic substances. The test scenarios described in Section 3.2 have been rerun in DRIFT 3.6.14 using the new weather set, and the results are presented here to enable comparisons to be carried out with future versions of DRIFT.

## 4.2 TEST SCENARIOS

The test scenarios considered are the catastrophic failure of an ethylene oxide storage vessel and the leak from a hole in a methyl iodide storage vessel that were modelled in Section 3. Each scenario has been modelled in D2.4, D4.3, D6.7 and F2.4 weather conditions, with the D2.4, D4.3 and D6.7 categories representing daytime weather, and the F2.4 category representing night-time weather. Table 12 summarises the GASP and DRIFT inputs that are affected by the choice of weather category. The ‘additional heat flux’ input in GASP allows the user to account for the effect of solar radiation.

**Table 12** New weather categories

| *Weather category* | *Ambient temperature (K)* | *Additional heat flux (W/m$^2$)* | *Air changes per hour (ac/h)* |
|---|---|---|---|
| D2.4 (day) | 288.15 | 200 | 2 |
| D4.3 (day) | 288.15 | 200 | 2 |
| D6.7 (day) | 288.15 | 200 | 3 |
| F2.4 (night) | 278.15 | 0 | 2 |

### 4.2.1 Creation of source terms for DRIFT

For each scenario, the spreading and vaporisation of the pool has been modelled in the latest version of GASP (version 4.2.12). Table 13 shows the physical properties of the cloud that were calculated by GASP and used to generate continuous DIN files for input into DRIFT. The proportion of liquid in the cloud (labelled as the cloud quality in the DIN file) was zero in all cases. In each case, the physical properties of the cloud have been averaged over a release duration of 1800 s. The equivalent information for the D5 and F2 weather set is shown in Table 10.

**Table 13** The cloud physical properties calculated by GASP for the test release scenarios

| *Release Scenario* | *Weather* | *Mean vaporisation rate (kg/s)* | *Contaminant mass fraction* | *Cloud temperature (K)* | *Plume half-width (m)* | *Plume velocity (m/s)* |
|---|---|---|---|---|---|---|
| Catastrophic failure of an ethylene oxide tank | D2.4 | 21.5 | 0.419 | 257 | 49.4 | 0.557 |
| | D4.3 | 26.0 | 0.327 | 252 | 48.9 | 0.940 |
| | D6.7 | 30.0 | 0.268 | 247 | 48.5 | 1.40 |
| | F2.4 | 17.1 | 0.349 | 253 | 49.4 | 0.547 |
| 250 mm hole in a methyl iodide tank | D2.4 | 1.31 | 0.694 | 286 | 7.79 | 0.162 |
| | D4.3 | 2.06 | 0.675 | 285 | 7.79 | 0.273 |
| | D6.7 | 2.82 | 0.655 | 283 | 7.79 | 0.403 |
| | F2.4 | 1.25 | 0.678 | 285 | 7.79 | 0.161 |

The GASP and DRIFT inputs listed in Section 6.1 of the appendices, which were used for the modelling described in Section 3, are still applicable, apart from the wind speeds and ventilation rates.

## 4.3 DRIFT 3.6.14 OUTPUTS

Each scenario has been modelled using DRIFT 3.6.14, and the SLOT DTL (Specified Level of Toxicity, Dangerous Toxic Load) isopleths have been calculated for indoor and outdoor targets.

As in Section 3, a sensitivity analysis has been carried out for each scenario. In the base case, the finite duration model has been used, and the input values and assumptions recommended by Cruse et al. [10] have been used for the inputs that are not affected by the choice of weather category. The inputs that were varied in the sensitivity analysis are summarised in Table 11 in Section 3.3.

Figures 20 to 27 show the SLOT DTL isopleths obtained for a catastrophic release of ethylene oxide for indoor and outdoor recipients in D2.4, D4.3, D6.7 and F2.4 weather conditions. Figures 28 to 35 show the corresponding SLOT DTL isopleths for a continuous release of methyl iodide. The SLOT DTL isopleths are presented in the same format as used in Section 3 and the legend is explained in detail in Section 3.3.1. Note that the scales in Figures 20 to 35 are not all the same.

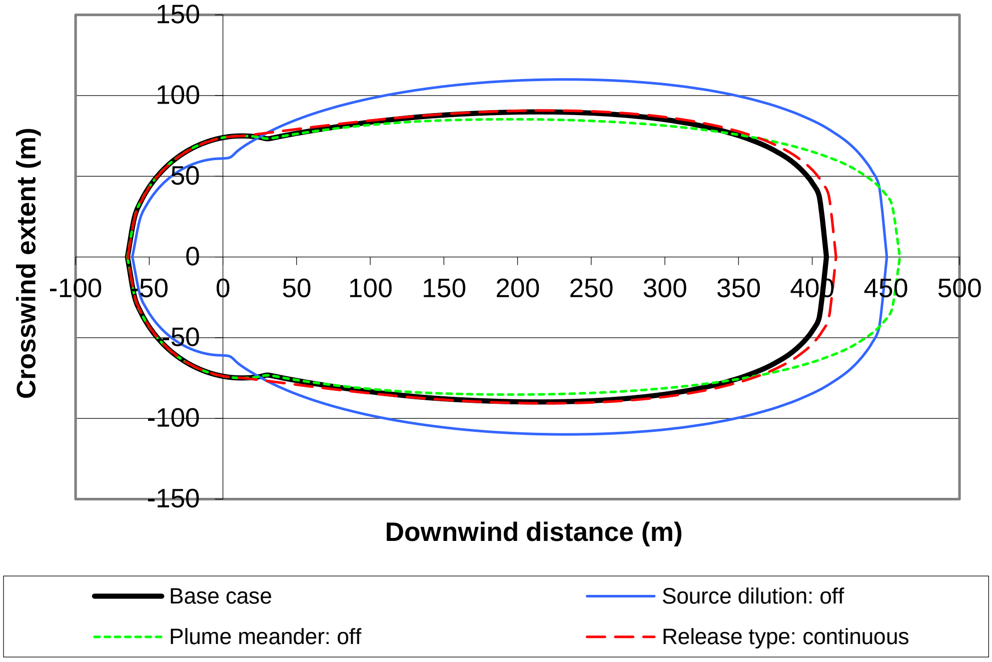


**Figure 20** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a catastrophic ethylene oxide release in D2.4 weather conditions

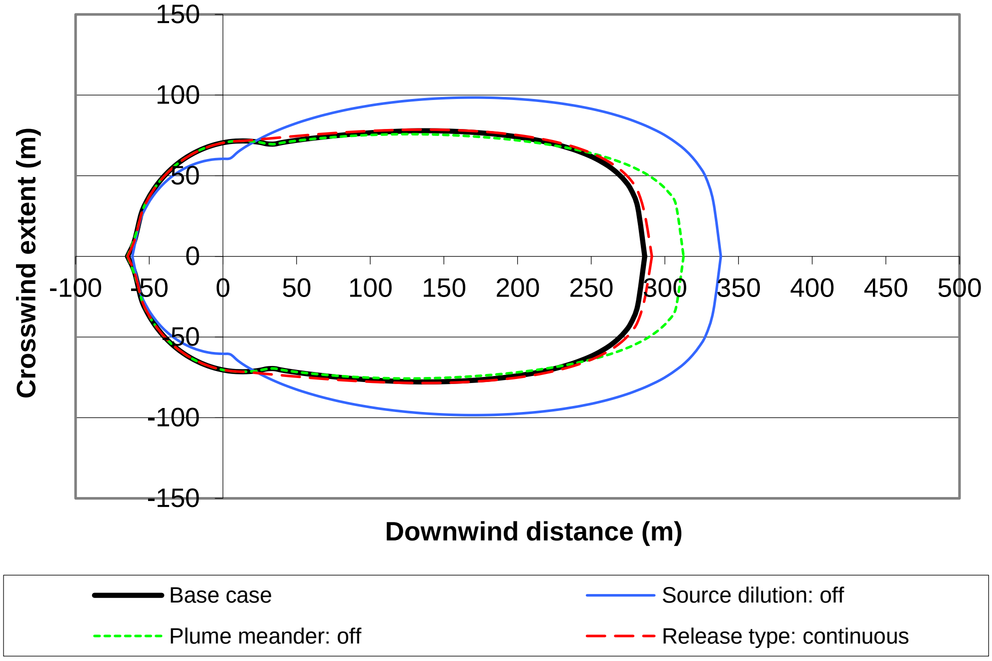


**Figure 21** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a catastrophic ethylene oxide release in D2.4 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

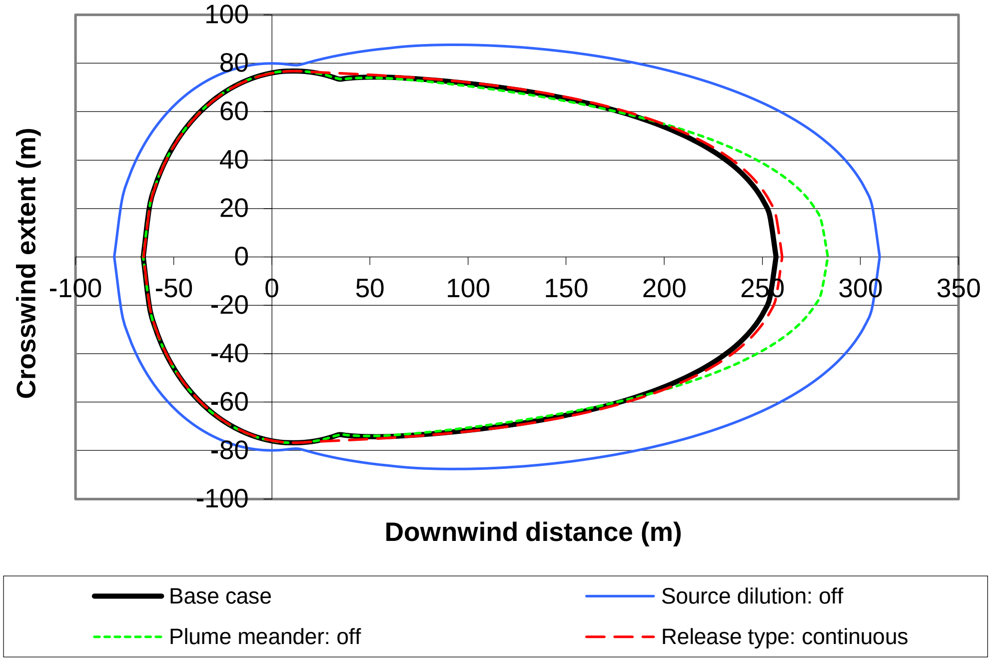


**Figure 22** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a catastrophic ethylene oxide release in D4.3 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

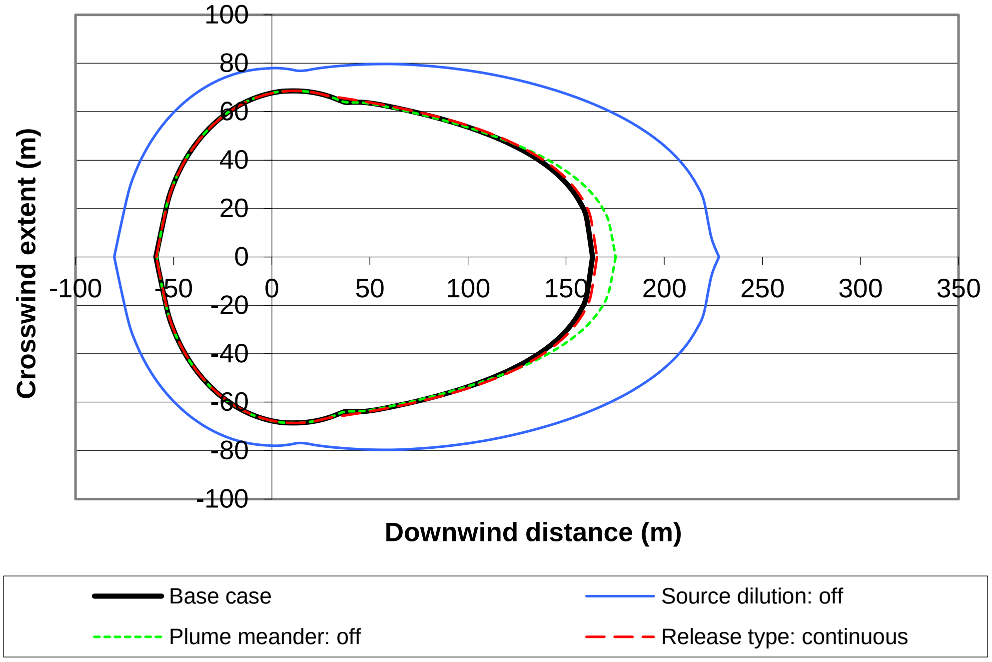


**Figure 23** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a catastrophic ethylene oxide release in D4.3 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

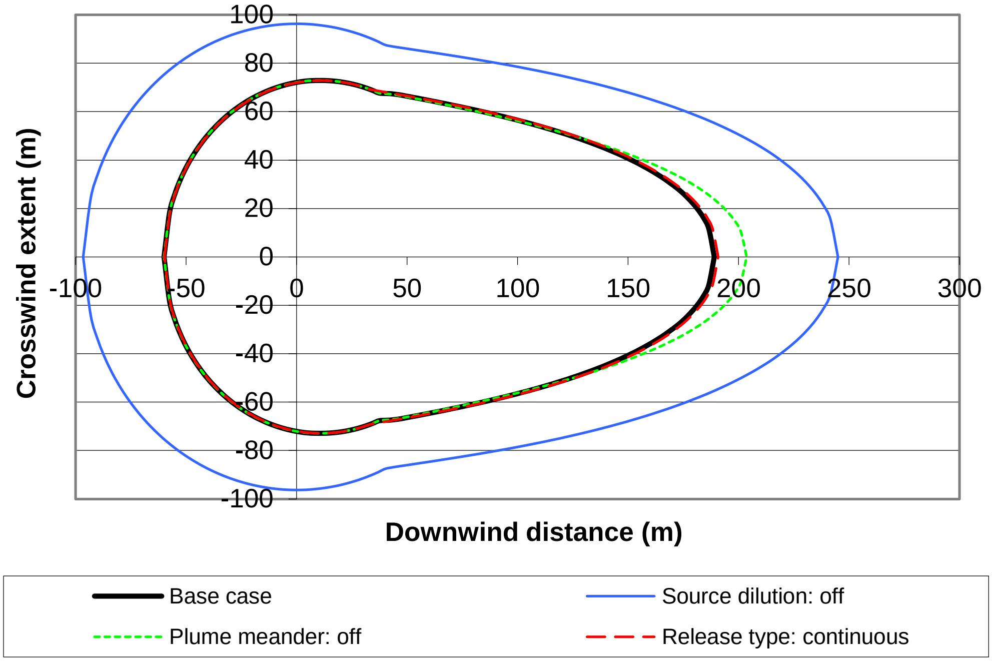


**Figure 24** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a catastrophic ethylene oxide release in D6.7 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

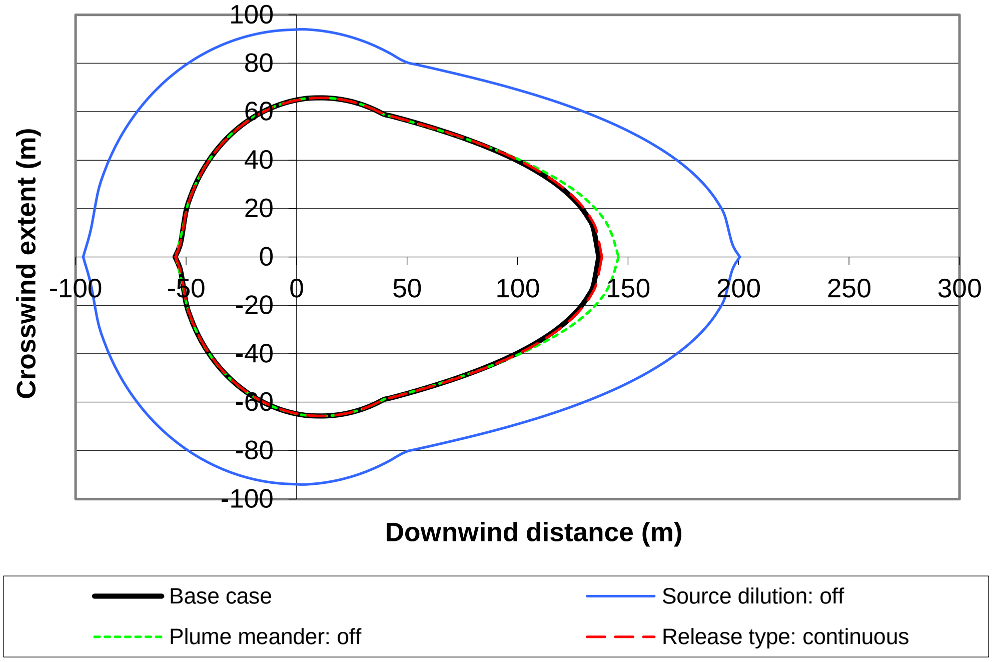


**Figure 25** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a catastrophic ethylene oxide release in D6.7 weather conditions. The case with a release type of continuous gives a similar isopleth to the base case.

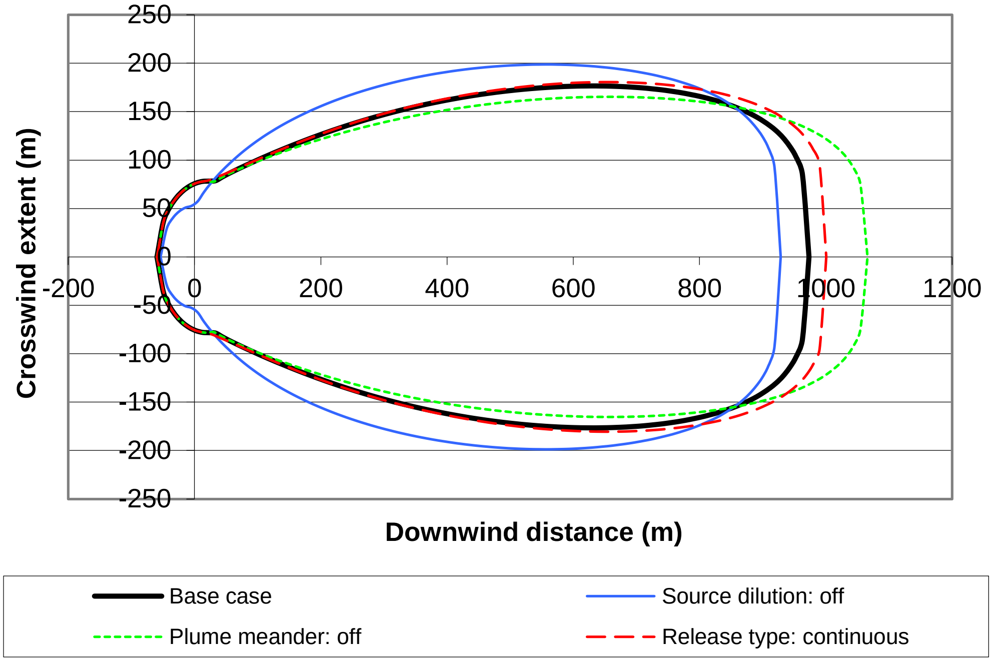


**Figure 26** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a catastrophic ethylene oxide release in F2.4 weather conditions

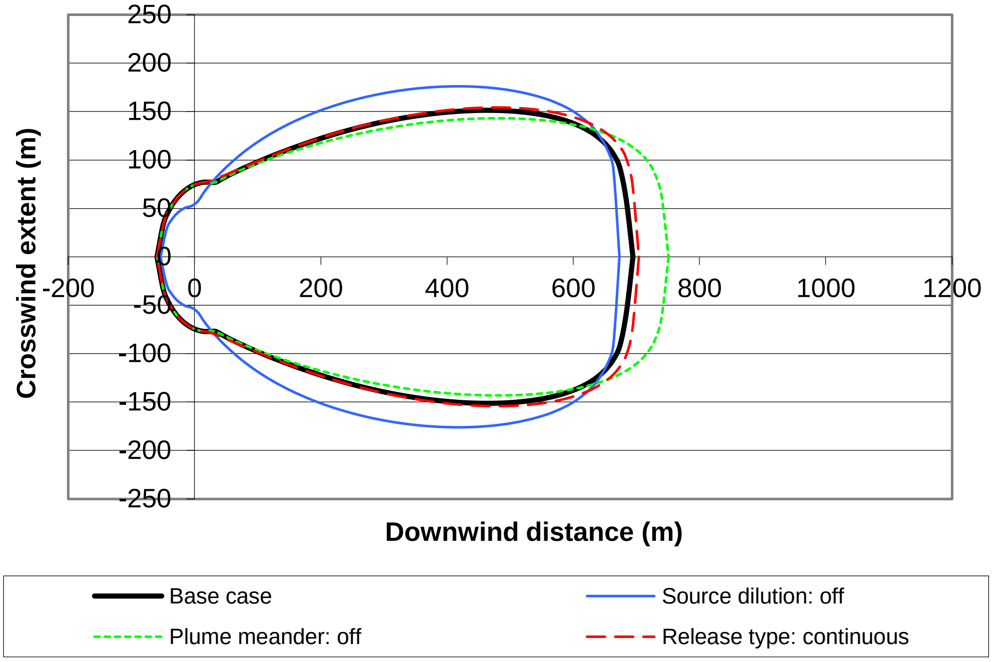


**Figure 27** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a catastrophic ethylene oxide release in F2.4 weather conditions

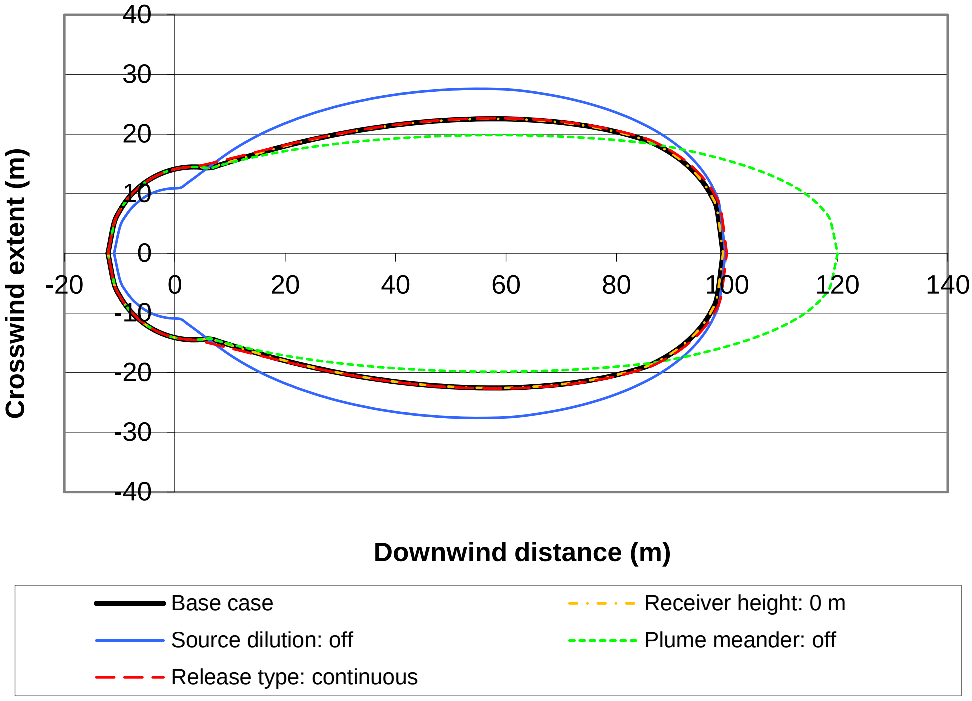


**Figure 28** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a continuous methyl iodide release in D2.4 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

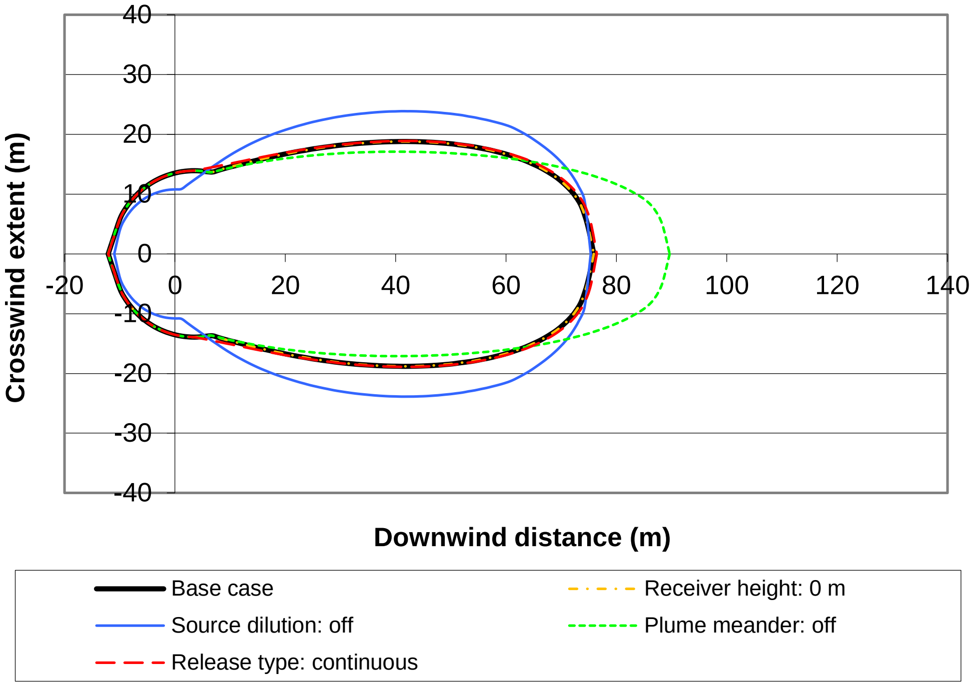


**Figure 29** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a continuous methyl iodide release in D2.4 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

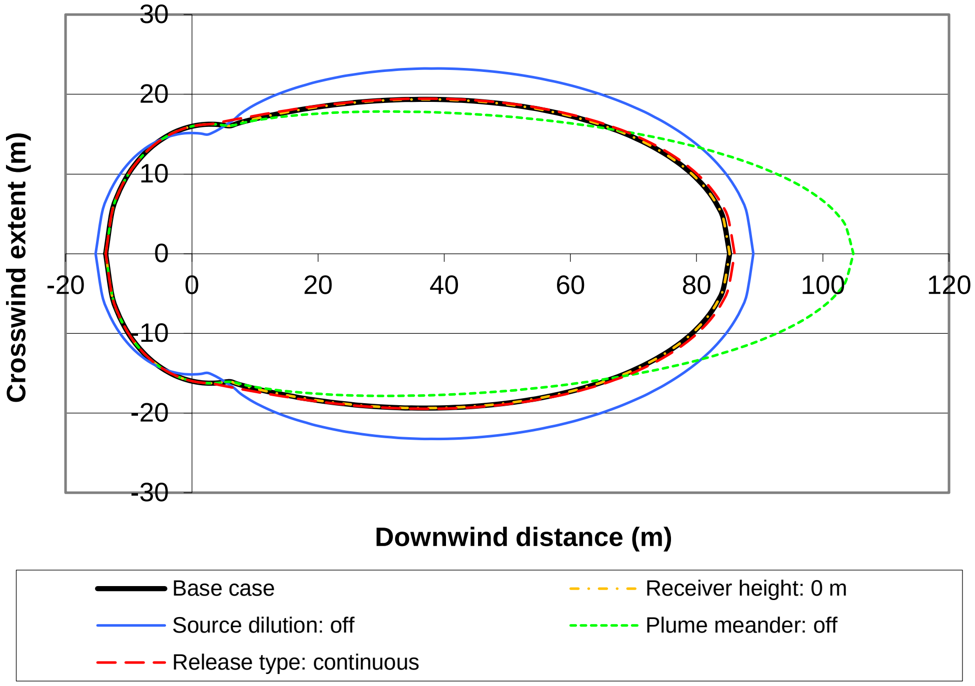


**Figure 30** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a continuous methyl iodide release in D4.3 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

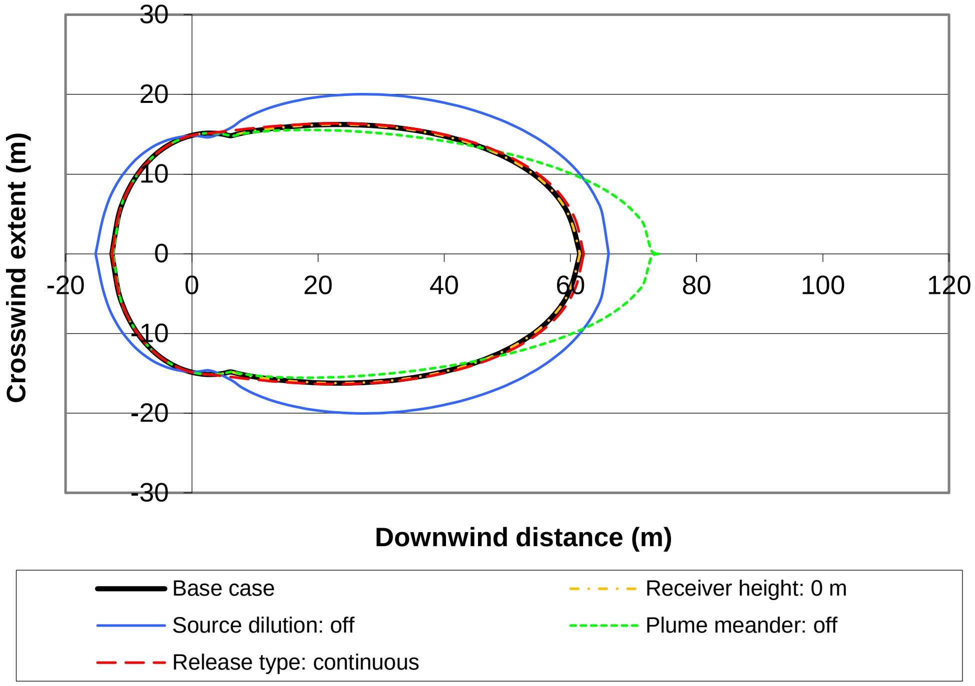


**Figure 31** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a continuous methyl iodide release in D4.3 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

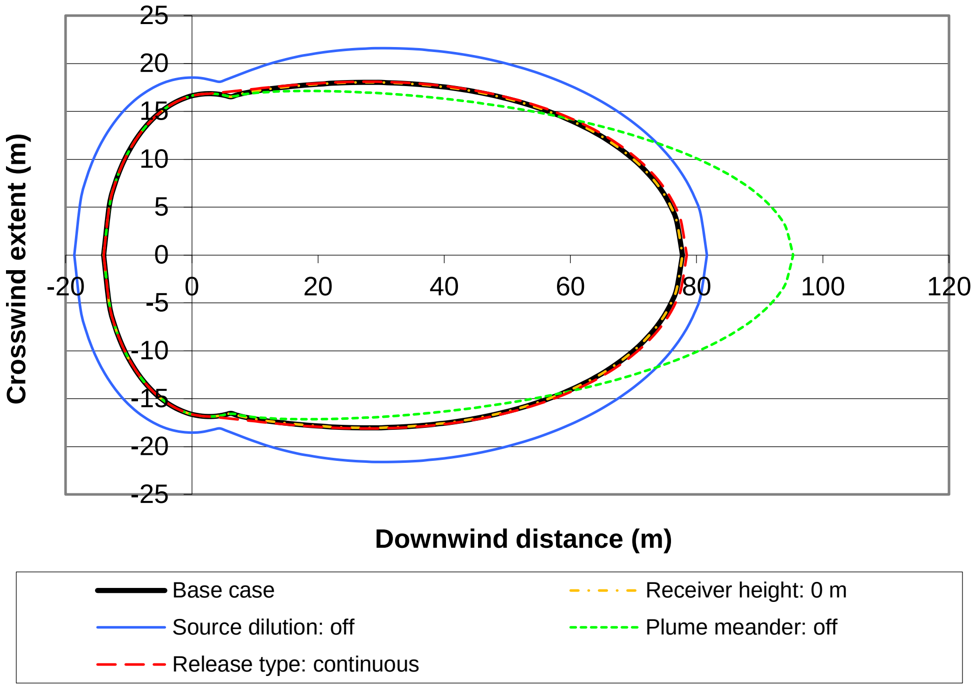


**Figure 32** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a continuous methyl iodide release in D6.7 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

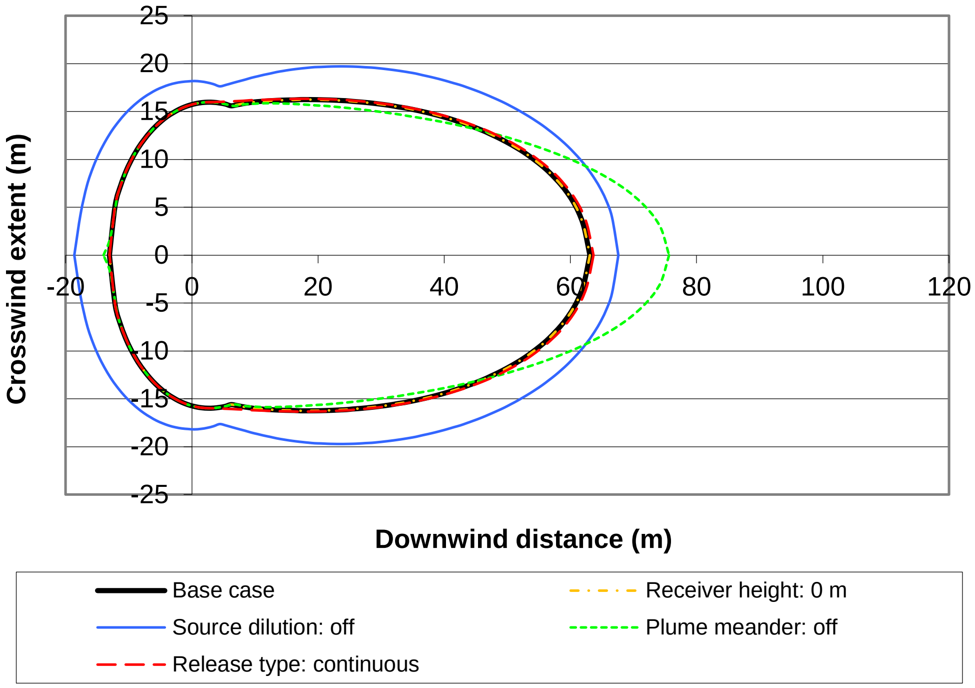


**Figure 33** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a continuous methyl iodide release in D6.7 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

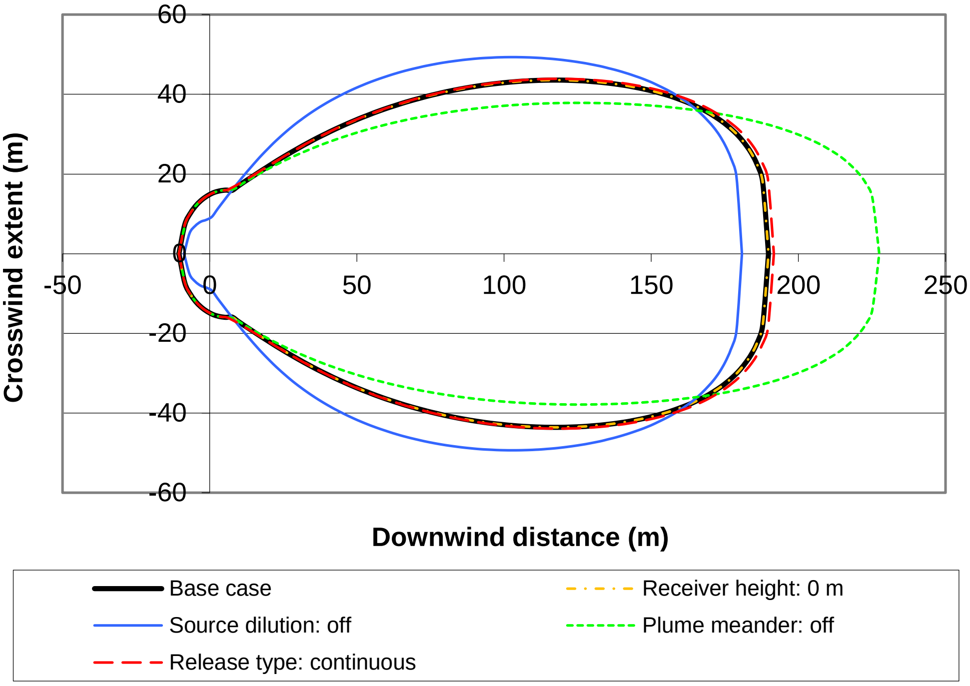


**Figure 34** SLOT DTL isopleths obtained in DRIFT 3.6.14 for outdoor recipients for a continuous methyl iodide release in F2.4 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

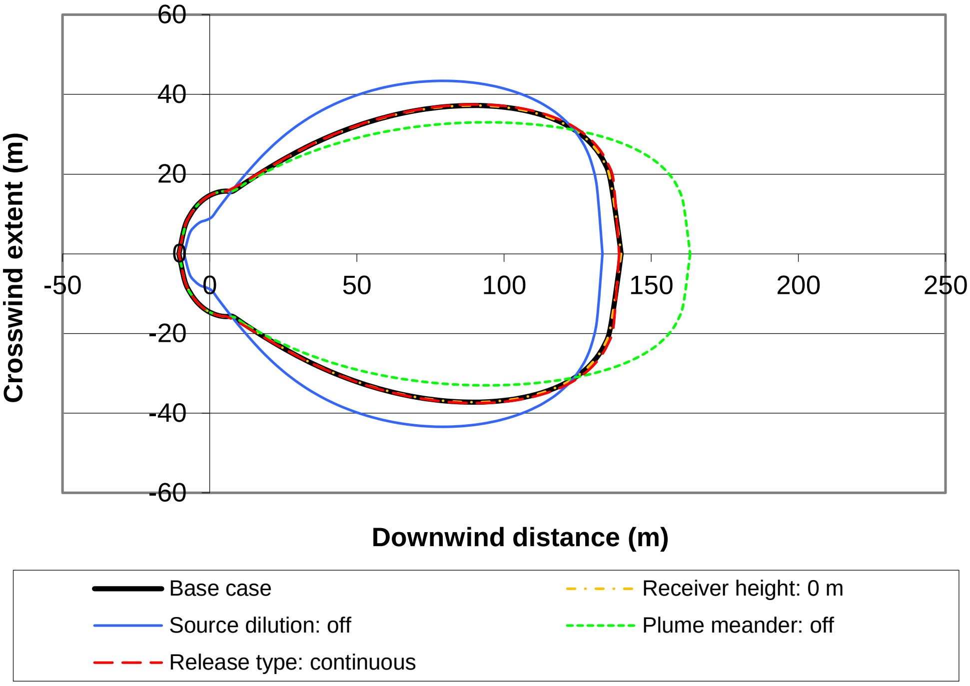


**Figure 35** SLOT DTL isopleths obtained in DRIFT 3.6.14 for indoor recipients for a continuous methyl iodide release in F2.4 weather conditions. The cases with a receiver height of 0 m and a release type of continuous give similar isopleths to the base case.

## 4.4 DISCUSSION AND CONCLUSIONS

DRIFT 3.6.14 ran without problem for each of the toxic pool scenarios and weather conditions modelled, and the sensitivity analysis shows the same trends as were observed when the same scenarios were modelled in D5 and F2 weather conditions. Explanations of these trends are provided by Cruse et al. [10]. The outputs presented here will be used to compare DRIFT 3.6.14 to future versions of DRIFT in subsequent assessment and evaluation reports.

# 5 CONCLUSIONS

HSE uses gas dispersion modelling in its assessment of the hazards and risks posed by toxic and flammable substances stored at major hazards sites. To update its dispersion modelling capability, HSE recently commissioned ESR Technology to develop a new version of the gas dispersion model DRIFT. The new version of the model, DRIFT 3, includes a significant number of modelling enhancements over the version of DRIFT previously used by HSE (DRIFT 2.31) [6, 7].

To ensure that DRIFT 3 is fit for purpose, a programme of work has been undertaken at HSE. This has included an evaluation of the dispersion modelling capabilities of DRIFT 3 [8] and an assessment of the performance of DRIFT 3 for modelling the types of release scenario typically considered by HSE for Hazardous Substances Consent assessments [10, 11, 13, 15].

The most recent version of DRIFT currently available to HSE is DRIFT 3.6.14. Building on the previous model testing carried out by HSE, this report describes the validation of DRIFT 3.6.14 against a Model Evaluation Protocol for dense gas dispersion models [9], following the same approach as was used for the validation of DRIFT 3.6.4 [8]. The validation of DRIFT 3.6.14 against a set of passive tracer releases is also discussed. This report also describes an assessment of the performance of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids. The conclusions of this work are summarised in the following sections.

## 5.1 EVALUATION OF DRIFT 3.6.14

The modifications to the DRIFT mathematical model that were introduced between DRIFT 3.6.4 and DRIFT 3.6.14 have been subject to a scientific assessment by a dispersion modelling expert. The reviewer concluded that the changes to the model were minor and that these changes were logical and justifiable developments of the model.

DRIFT 3.6.14 has been evaluated using the Model Evaluation Protocol described by Ivings et al. [9], which includes validation against a database of 33 wind tunnel and field scale experiments. The DRIFT 3.6.14 concentration predictions for the validation test cases have been compared with the results obtained from DRIFT 3.6.4 [8]. Minor changes in concentration predictions were obtained with DRIFT 3.6.14 for spills of liquefied natural gas (LNG). These changes in the concentration predictions appear to have arisen mostly from the change in the substance data source used for the LNG releases, rather than the modifications to the DRIFT 3 mathematical model. Overall the changes to the DRIFT model have no effect on the predictions with respect to the acceptance criteria and therefore DRIFT 3.6.14 also meets the criteria for an ‘acceptable’ model.

## 5.2 ASSESSMENT OF DRIFT 3.6.14 FOR TOXIC POOL SCENARIOS

Cruse et al. [10] present an assessment of the use of DRIFT 3.6.4 for modelling the dispersion of vapour from pools of toxic liquids. A subset of the ethylene oxide and methyl iodide scenarios modelled by Cruse et al. has been rerun in DRIFT 3.6.14, and the DRIFT 3.6.4 and DRIFT 3.6.14 outputs have been compared. There are no significant differences in the downwind distances and crosswind extents predicted by DRIFT 3.6.14 and DRIFT 3.6.4 for the test scenarios. The enhancements to the DRIFT mathematical model that were implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have therefore not significantly affected the dispersion predictions for vapour evolved from pools of toxic liquids, when such releases are modelled using the finite duration option.

## 5.3 APPLICATION OF NEW WEATHER CATEGORIES

Cruse et al. [10] modelled releases from evaporating pools of toxic liquids in D5 and F2 weather conditions, for consistency with the methodology previously used by HSE to model such releases. HSE has since made a policy decision to use four weather categories when modelling the dispersion of vapour from pools of toxic liquids for Hazardous Substances Consent assessments. These weather categories are D2.4, D4.3, D6.7 and F2.4, and have been chosen to be consistent with the weather categories used when modelling releases of toxic pressure-liquefied gases. The ethylene oxide and methyl iodide test scenarios have been run in DRIFT 3.6.14 using the D2.4, D4.3, D6.7 and F2.4 weather set. DRIFT 3.6.14 ran without problem for each of the scenarios and weather conditions modelled. Sensitivity studies on future versions of DRIFT will only consider the D2.4, D4.3, D6.7 and F2.4 weather set for releases of toxic substances, and the outputs presented in this report will enable DRIFT 3.6.14 to be compared to future versions of DRIFT.

## 5.4 OUTCOMES

The time varying model in DRIFT 3.6.14 has not yet undergone thorough evaluation so is not recommended for use in Hazardous Substances Consent assessments. HSE therefore models the dispersion of vapour from pools of liquids with a toxic exponent (*n*) of one using the finite duration option in DRIFT 3.6.14. The user can choose either to create a continuous DIN file in GASP or to directly import the GASP file. The finite duration option is expected to give a better representation of the physical processes that would occur during an actual release than the steady continuous model in DRIFT 3 [6, 10]. The recommended approach for modelling the dispersion of vapour from pools of liquids with a toxic exponent greater than one is described by Cruse et al. [10].

HSE now uses four weather categories when modelling releases from pools of toxic substances. Daytime weather is represented by the D2.4, D4.3 and D6.7 weather categories, and night-time weather is represented by the F2.4 weather category. These weather categories are consistent with those used by HSE to model releases of toxic pressure-liquefied gases and provide a better correlation than the D5 and F2 weather set to risk profiles calculated using a full set of wind speed and Pasquill stability class data [48].

As a result of the detailed evaluation and assessment described in this report, DRIFT 3.6.14 has been adopted by HSE to model the dispersion of vapour evolved from pools of toxic liquids. DRIFT 3.6.14 has replaced DRIFT 3.6.4 for use in conjunction with GASP in Hazardous Substances Consent assessments.

# 6 APPENDICES

## 6.1 INPUT VALUES USED FOR THE ASSESSMENT OF DRIFT 3.6.14

Tables 14 to 16 summarise the input values used in GASP when carrying out the assessment of DRIFT 3.6.14 described in Section 3. This assessment considered the performance of DRIFT 3.6.14 when modelling the dispersion of vapour from pools of toxic liquids. The latest version of GASP (version 4.2.12) was used to create source terms for DRIFT.

**Table 14** General GASP input values used for the assessment of DRIFT 3.6.14 described in Section 3

| ***Input*** | ***Value used*** |
|---|---|
| Surface type | Land |
| Substrate | Concrete |
| Heat transfer mode | Perfect thermal contact, temperature varying substrate |
| Pool roughness length | 0.00023 m [49] |
| Air temperature | 288.15 K (D5); 278.15 K (F2) |
| Wind speed (at 10 m) | 5 m/s (day) or 2 m/s (night) |
| Pasquill stability class | D (day) or F (night) |
| Relative humidity | 60% |
| Surface roughness length | 0.1 m |
| Additional heat flux | 200 W/m$^2$ (day) or 0 W/m$^2$ (night) |
| Termination criteria | Pool age is greater than 1800 s or 1% of the pool remains |
| Evaporation mode | Calculated (default) |

The default values were used for all the thermodynamic options and numerical control inputs on the GASP options tab.

**Table 15** Scenario-specific GASP input values used to model the catastrophic failure of an ethylene oxide tank

| ***Input*** | ***Value used*** |
|---|---|
| Bund radius | 50 m |
| Puddle depth | 0.0055 m |
| Release type | Instantaneous |
| Pool mass | 90000 kg |
| Pool radius | 2 m |
| Spreading velocity | 0 m/s |
| Release temperature | 270 K |

**Table 16** Scenario-specific GASP input values used to model a 250 mm hole in a methyl iodide tank

| ***Input*** | ***Value used*** |
|---|---|
| Bund radius | 7.8 m |
| Puddle depth | N/A |
| Release type | Continuous |
| Mass release rate | 462 kg/s |
| Aperture diameter | 0.25 m |
| Release constraints | Time limited: 364 s |
| Release temperature | 288.15 K |

Table 17 summarises the input values used in DRIFT 3.6.4 and DRIFT 3.6.14 when carrying out the modelling described in Section 3.

**Table 17** DRIFT input values used for the modelling described in Section 3

| ***Input*** | ***Value used*** |
|---|---|
| Release type | Finite duration |
| Phase | Gaseous (imported from DIN file) |
| Substance; temperature; contaminant fraction; release rate and release duration | As imported from DIN file (see Table 10) |
| Location (initial displacement) | (0,0,0) |
| Source type | Low momentum area source |
| Source diameter | As imported from DIN file (twice the plume half-width output by GASP; see Table 10) |
| Include dilution over source | Yes |
| Weather scheme | Pasquill |
| Input inversion height | No |
| Temperature | 288.15 K (D5); 278.15 K (F2) |
| Relative humidity | 60% |
| Reference height | 10 m |
| Roughness length | 0.1 m |
| Wind angle from North | 270° |
| Pasquill stability | D (day) or F (night) |
| Wind speed | 5 m/s (day) or 2 m/s (night) |
| Time averaging | Yes – set equal to release duration |
| Maximum exposure duration | 1800 s |
| Ventilation rate | 2 ac/h (D5 and F2) |
| Indoors lag time | 600 s |
| Levels of interest | SLOT DTL ($LD_1$) dose contours |
| Receiver height | Use centreline height |

# 7 REFERENCES

1. Webber DM, Jones SJ, Tickle GA and Wren T. *A model of a dispersing dense gas cloud, and the computer implementation DRIFT. I. Near-instantaneous releases*. UKAEA Report SRD/HSE R586, 1992. Available from HSE.

2. Webber DM, Jones SJ, Tickle GA and Wren T. *A model of a dispersing dense gas cloud, and the computer implementation DRIFT. II. Steady continuous releases*. UKAEA Report SRD/HSE R587, 1992. Available from HSE.

3. The Planning (Hazardous Substances) Regulations 2015. UK Statutory Instrument SI 2015/627. http://www.legislation.gov.uk/uksi/2015/627/contents/made (accessed March 2017).

4. *Hazardous Substances.* https://www.gov.uk/guidance/hazardous-substances (accessed March 2017).

5. *HSE's land use planning methodology*. https://www.hse.gov.uk/landuseplanning/methodology.htm (accessed July 2021).

6. Tickle GA and Carlisle JE. *DRIFT Version 3.6.7: Mathematical Model Description.* ESR Technology report ESR/UC000417/001, 2013. Available from HSE.

7. Tickle GA and Carlisle JE. *Extension of the dense gas dispersion model DRIFT to include buoyant lift-off and buoyant rise.* HSE Research Report RR629, 2008. Available from https://www.hse.gov.uk/research/rrhtm/rr629.htm (accessed March 2017).

8. Coldrick S and Webber D. *Evaluation of the DRIFT gas dispersion model version 3.6.4*. HSE Research Report RR1100, 2017.
Available from https://www.hse.gov.uk/research/rrhtm/rr1100.htm (accessed March 2017).

9. Ivings MJ, Jagger SF, Lea CJ and Webber DM. *Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities*. Fire Protection Research Foundation, National Fire Protection Association, April 2007. Available from http://www.nfpa.org/ (accessed March 2017).

10. Cruse H, Lamb A and McGillivray A. *Modelling the dispersion of vapour from pools of toxic liquids using DRIFT 3.* HSE Research Report RR1101, 2017.
Available from https://www.hse.gov.uk/research/rrhtm/rr1101.htm (accessed March 2017).

11. Lamb A and Cruse H. *Gas dispersion model DRIFT 3.6.14: modelling the dispersion of continuous releases of toxic pressure-liquefied gases.* HSE Research Report RR1167, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1167.htm

12. Jagger SF. *Development of CRUNCH: A dispersion model for continuous releases of a denser-than-air vapour into the atmosphere.* UKAEA Report SRD/HSE R229, 1983. Available from HSE.

13. McGillivray A and Cruse H. *Gas dispersion model DRIFT 3.6.14: modelling the dispersion of flashing instantaneous releases of toxic substances.* HSE Research Report RR1166, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1166.htm

14. Fryer LS and Kaiser GD. *DENZ – A computer program for the calculation of the dispersion of dense toxic or explosive gases in the atmosphere.* UKAEA Report SRD R152, 1979. Available from HSE.

15. Chaplin Z and Cruse H. *Gas dispersion model DRIFT 3.6.14: modelling the dispersion of flammable vapour*. HSE Research Report RR1168, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1168.htm

16. Tickle GA, Martin D and Ramsdale SA. *EJECT – An integral model of a two-phase jet in a cross-flow.* AEA Technology Report AEAT-1517 Issue 2, 1998. Available from HSE.

17. Macbeth R. *The derivation of the physical properties of hazardous substances for Substance Property Information (SPI) data files.* Health and Safety Laboratory, HSL Report RAS/04/05, 2004. Available from HSE.

18. Walton E. *DRIFT COM Interface Guide*. ESR Technology report ESR/D1000846/SUG02/Issue 5, 2011. Available from HSE.

19. Hanna SR and Britter RE. *Wind flow and vapor cloud dispersion at industrial and urban sites*. Center for Chemical Process Safety of the American Institute of Chemical Engineers, ISBN: 0-8169-0863-X, 2002.

20. McQuaid J and Roebuck B. *Large scale field trials on dense vapour dispersion*. Commission of the European communities indirect action programme "Safety of thermal water reactors", 1979-83, Final report on contracts 029SRUK and 036SRUK with the Health and Safety Executive, 1985. Available from HSE.

21. McQuaid J (Editor). *Heavy gas dispersion trials at Thorney Island – 2*. Proceedings of a symposium held at the University of Sheffield, Great Britain, September 1986, J. Hazard. Mater., Vol. 16, pp 1-502, 1987.

22. Tickle G. *DRIFT 3 Predictions Compared with Thorney Island Instantaneous Trials Data*. ESR Technology report ESR/UC000417/002/Issue 1, 2017. Available from HSE.

23. Lees FP. *Loss Prevention in the Process Industries – Hazard Identification, Assessment and Control*. Volume 1, Second edition, Butterworth Heinemann, 1996.

24. Nielsen M, Chatwin PC, Jorgensen HE, Mole N, Munro RJ and Ott S. *Concentration fluctuations in gas releases by industrial accidents.* Technical Report Risø-R-1329(EN), Risø National Laboratory, Denmark, May 2002. Available from Risø National Laboratory.

25. Webber DM. *A model for pool spreading and vaporisation and its implementation in the computer code GASP.* SRD/HSE R507, ISBN: 0-853563519, September 1990. Available from HSE.

26. Britter RE and McQuaid J. *Workbook on the dispersion of dense gases.* HSE Contract Research Report 17/1988, 1988.
Available from http://www.hse.gov.uk/research/crr_pdf/1988/crr88017.pdf (accessed March 2017).

27. *Toxicity levels of chemicals.* http://www.hse.gov.uk/chemicals/haztox.htm (accessed March 2017).

28. Coldrick S, Lea CJ and Ivings MJ. *Validation Database for Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities*. Fire Protection Research Foundation, National Fire Protection Association, February 2009. Available from http://www.nfpa.org/ (accessed March 2017).

29. Puttock JS, Blackmore DR and Colenbrander GW. *Field experiments on dense gas dispersion*. J. Hazard. Mater., Vol. 6, pp 13–41, 1982.

30. Colenbrander GW, Evans A and Puttock JS. *Spill tests of LNG and refrigerated liquid propane on the sea*. Maplin Sands 1980: Dispersion Data Digest; Trial 27, Shell Research Ltd, Thornton Research Centre, Report TNER.84.028, May 1984. Available from Shell Research and Development.

31. Colenbrander GW, Evans A and Puttock JS. *Spill tests of LNG and refrigerated liquid propane on the sea.* Maplin Sands 1980: Dispersion Data Digest; Trial 34, Shell Research Ltd, Thornton Research Centre, Report TNER.84.030, May 1984. Available from Shell Research and Development.

32. Colenbrander GW, Evans A and Puttock JS. *Spill tests of LNG and refrigerated liquid propane on the sea*. Maplin Sands 1980: Dispersion Data Digest; Trial 35, Shell Research Ltd, Thornton Research Centre, Report TNER.84.031, May 1984. Available from Shell Research and Development.

33. Koopman RP, Baker J, Cederwall RT, Goldwire HC Jr, Hogan WJ, Kamppinen LM, Kiefer RD, McClure JW, McRae TG, Morgan DL, Morris LK, Spann MW Jr and Lind CD. *Burro series data report LLNL/NWC 1980 LNG spill tests.* Vols 1 & 2, UCID-19075, Lawrence Livermore National Laboratory, 1982.
Available from https://e-reports-ext.llnl.gov/pdf/194414.pdf and https://e-reports-ext.llnl.gov/pdf/194606.pdf (accessed March 2017).

34. Koopman RP, Cederwall RT, Ermak DL, Goldwire HC Jr, Hogan WJ, McClure JW, McRae TG, Morgan DL, Rodean HC and Shinn JH. *Analysis of Burro series 40* $m^3$ *LNG spill experiments*. J. Hazard. Mater., Vol. 6, pp 43–83, 1982.

35. Goldwire HC Jr, Rodean HC, Cederwall RT, Kansa EJ, Koopman RP, McClure JW, McRae TG, Morris LK, Kamppinen L, Kiefer RD, Urtiew PA and Lind CD. *Coyote series data report: LLNL/NWC 1981 LNG spill tests. Dispersion, vapor burn and rapid-phase transition*. Vols 1 & 2, UCID-19953, Lawrence Livermore National Laboratory, 1983.
Available from https://e-reports-ext.llnl.gov/pdf/195030.pdf and https://e-reports-ext.llnl.gov/pdf/195363.pdf (accessed March 2017).

36. Brown TC, Cederwall RT, Chan ST, Ermak DL, Koopman RP, Lamson KC, McClure JW and Morris LK. *Falcon series data report: 1987 LNG vapor barrier verification field trials*. Gas Research Institute, Report No. GRI-89/0138, 1990.
Available from https://www.osti.gov/scitech/biblio/6633087 (accessed March 2017).

37. Havens J and Spicer T. *LNG vapor cloud exclusion zones for spills into impoundments.* Process Saf. Prog., Vol. 24, Iss. 3, pp 181–186, 2005.

38. Havens J and Spicer T. *Vapor dispersion and thermal hazard modelling*. Final topical report to Gas Technology Institute under sub-contract K100029184, October 2006. Available from the Gas Technology Institute.

39. Havens J, Spicer T and Sheppard W. *Wind tunnel studies of LNG vapor dispersion from impoundments*. AIChE National Spring Meeting, Houston, 2007. Available from AIChE.

40. Nielsen M and Ott S. *A collection of data from dense gas experiments*. Technical Report Risø-R-845 (EN), Risø National Laboratory, Denmark, March 1996. Available from Risø National Laboratory.

41. Kohout AJ. *Evaluation of fire dynamics simulator for liquefied natural gas vapor dispersion hazards*. Department of Fire Protection Engineering, Graduate School of the University of Maryland, 2011. Available from the University of Maryland.

42. Hansen OR, Gavelli F, Ichard M and Davis SG. *Validation of FLACS against experimental data sets from the model evaluation database for LNG vapor dispersion*. J. Loss Prevent. Proc., Vol. 23, pp 857-877, 2010.

43. Witlox HWM, Harper M and Pitblado R. *Validation of PHAST Dispersion Model as Required for USA LNG Siting Applications*. The Italian Association of Chemical Engineering, Chemical Engineering Transactions, Vol. 31, 2013.

44. Nickola PW, Ramsdell JV Jr and Ludwick JD. *Detailed time-histories of concentrations resulting from puff and short-period releases of an inert radioactive gas: a volume of atmospheric diffusion data*. BNWL-1272 UC-53, Battelle Pacific Northwest Laboratories, Richland, WA 99352, 1970. Available from Pacific Northwest National Laboratory.

45. Barad ML. Project *Prairie Grass, A Field Program in Diffusion*. Vol. I, AFCRC-TR-58-235 (I), AD 152572, AFGL, Hanscom AFB, MA 01731, 1958.
Available from https://www.harmo.org/jsirwin/PrairieGrassDiscussion.html (accessed August 2021).

46. Serghides TK. *Estimate friction factor accurately.* Chem. Eng. J., Vol. 91(5), pp 63-64, 1984.

47. Davies PC and Purdy G. *Toxic gas risk assessments – the effect of being indoors.* Refinement of Estimates of the Consequences of Heavy Toxic Vapour Releases. IChemE Symposium No 1, Manchester; January 1986. Available from IChemE.

48. Turner S, Macbeth R and McGillivray A. *Development within the Health and Safety Executive of a streamlined risk assessment approach for the assessment of toxic hazards.* Safety and Reliability for Managing Risk 3, pp 2047-2054, 2006.

49. Brighton PWM. *Evaporation from a plane liquid surface into a turbulent boundary layer*. SRD/HSE R375, ISBN: 0-85-356-223-7, January 1987. Available from HSE.

# 8 BIBLIOGRAPHY

## 8.1 HSE REPORTS ON THE ASSESSMENT AND EVALUATION OF DRIFT 3.6.4

Coldrick S and Webber D. *Evaluation of the DRIFT gas dispersion model version 3.6.4*. HSE Research Report RR1100, 2017. Available from https://www.hse.gov.uk/research/rrhtm/rr1100.htm (accessed March 2017).

Cruse H, Lamb A and McGillivray A. *Modelling the dispersion of vapour from pools of toxic liquids using DRIFT 3.* HSE Research Report RR1101, 2017.
Available from https://www.hse.gov.uk/research/rrhtm/rr1101.htm (accessed March 2017).

## 8.2 HSE REPORTS ON THE ASSESSMENT AND EVALUATION OF DRIFT 3.6.14

Cruse H and Coldrick S. *Gas dispersion model DRIFT 3.6.14: evaluation and assessment*. HSE Research Report RR1165, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1165.htm

McGillivray A and Cruse H. *Gas dispersion model DRIFT 3.6.14: modelling the dispersion of flashing instantaneous releases of toxic substances.* HSE Research Report RR1166, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1166.htm

Lamb A and Cruse H. *Gas dispersion model DRIFT 3.6.14: modelling the dispersion of continuous releases of toxic pressure-liquefied gases.* HSE Research Report RR1167, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1167.htm

Chaplin Z and Cruse H. *Gas dispersion model DRIFT 3.6.14: modelling the dispersion of flammable vapour*. HSE Research Report RR1168, 2022. To be made available at https://www.hse.gov.uk/research/rrhtm/rr1168.htm

**HSE uses gas dispersion modelling in its assessment of the hazards and risks posed by toxic and flammable substances stored at major hazards sites. To update its dispersion modelling capability, HSE commissioned ESR Technology to develop a new version of the gas dispersion model DRIFT. The new version, DRIFT 3, includes a significant number of modelling enhancements over the version previously used within HSE (DRIFT 2.31). These include the extension of the model to treat buoyant plumes and time varying releases. Before DRIFT 3 is adopted for use by HSE, it must undergo thorough evaluation and assessment for a range of release scenarios. The initial phases of the DRIFT 3 testing programme used DRIFT 3.6.4 and are described in reports RR1100 and RR1101. Further testing is described in four reports including this one: RR1165, RR1166, RR1167 and RR1168. The four reports cover the evaluation of the model and assessment for a range of scenarios using the enhanced version DRIFT 3.6.14.**

**Firstly, this report describes validation of DRIFT 3.6.14 against a Model Evaluation Protocol for dense gas dispersion models. It compares the DRIFT 3.6.14 outputs with those for the previous version, DRIFT 3.6.4 (see RR1100). This evaluation exercise finds DRIFT 3.6.14 to be fit for purpose. Secondly, the report describes an assessment of the performance of DRIFT 3.6.14 for modelling the dispersion of vapour from pools of toxic liquids. (See RR1101 for the assessment for the previous version DRIFT 3.6.4.) The enhancements to the model implemented between DRIFT 3.6.4 and DRIFT 3.6.14 have not significantly affected the dispersion predictions. As a result of this detailed evaluation and assessment, DRIFT 3.6.14 has been adopted by HSE to model the dispersion of vapour from pools of toxic liquids.**

**Published by the Health and Safety Executive 12/22**