Modelling flammable chemical major hazards using the DRIFT 3 dispersion model

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This paper describes work undertaken to incorporate ESR Technology's gas dispersion model DRIFT 3 within the Health and Safety Executive's (HSE) process for assessing the risks to the public near flammable chemical major hazards. These major hazards include sites storing and processing flammable chemicals, and some transmission pipelines transporting flammable substances. HSE assesses the risks of individuals being harmed in the event of a release of a flammable chemical to provide advice to Local Planning Authorities (LPAs) on the safety of developments near these major hazards. This paper presents key findings on the impact of the introduction of this model on HSE's advice. DRIFT 3's capabilities were assessed in modelling dispersion from the wide range of release scenarios used by HSE to assess the risks from the storage and transport of hazardous flammable chemicals.

The work was divided into three stages:

1. Modelling the dispersion of evaporating spills of flammable substances
2. The dispersion of a range of sizes of spills of liquid hydrogen and liquefied natural gas (LNG) that lead to evaporating pools was modelled in DRIFT 3.
3. Modelling the dispersion of continuous flashing releases of flammable substances

DRIFT 3 was used to model the dispersion of continuous flashing releases from pressurised vessels, pipework and pipelines. Ethylene, liquefied petroleum gas (LPG) and natural gas were considered.

Modelling the dispersion from near-instantaneous flashing releases of flammable substances

The dispersion of near-instantaneous flashing releases of isobutane, propane and o-cresol following catastrophic pressure vessel failure were modelled in DRIFT 3.

The substances and scenarios chosen represented a range of flammable chemical major hazards assessed by HSE and aimed to rigorously test the performance of DRIFT 3 when modelling the dispersion of flammable chemicals.

For each test case, the results from DRIFT 3 were compared to the results obtained using the previous methodology. Differences seen between the two sets of results were explained by the variation in the underlying science between DRIFT 3 and the previous methodologies.

Sensitivity tests were undertaken for the scenarios modelled to determine the sensitivity of the DRIFT 3 results to the inputs chosen. Explanations for the sensitivities observed were given based on the underlying science or modelling techniques used within DRIFT 3.

The impact of the implementation of DRIFT 3 on HSE advice was assessed. The results of the modelling and the sensitivity testing have led to guidelines being provided to HSE assessors on the use of DRIFT 3 in hazardous flammable chemical assessments. The testing of DRIFT 3 for use with flammable chemical hazards has provided assurance that HSE is using a fit-for-purpose model and that the model is being used in an appropriate manner.

Keywords: gas dispersion modelling, flammable substances, land use planning, hazardous substance consents, pipelines, major hazards

Introduction

The Health and Safety Executive (HSE) uses gas dispersion modelling in its assessment of the hazards and risks posed by flammable substances stored at major hazards sites or transported in some Major Accident Hazard (MAH) Pipelines. 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. HSE is also a statutory consultee for Land Use Planning (LUP) for developments near major hazards sites and for developments near Major Accident Hazard Pipelines that fall under the Pipelines Safety Regulations (1996).

The storage, processing or transportation of flammable chemicals poses a hazard to people in the vicinity because an accidental release of these substances could lead to the formation of a flammable vapour cloud. A flammable vapour cloud has the potential to ignite and rapidly burn as a flash fire; people exposed to thermal radiation from a flash fire could suffer serious or fatal injuries. Dispersion modelling can be used to predict the extent of the flammable vapour cloud and therefore the area over which it poses a hazard.

To improve its dispersion modelling capability, HSE commissioned ESR Technology to develop a new version of the gas dispersion model DRIFT (Dispersion of Releases Involving Flammables or Toxics; Tickle, 2008). The new version of the model, DRIFT 3, includes a significant number of modelling enhancements over the version of DRIFT previously used within HSE. These include the extension of the model to treat buoyant plumes and time varying releases. An overview of the model enhancements in DRIFT 3 and its validation and verification has been presented previously (Cruse, 2016). This paper aims to summarise the verification work and sensitivity studies carried out to assess the suitability of DRIFT 3 for use by HSE when:

1. Modelling the dispersion of evaporating spills of flammable substances;
2. Modelling the dispersion of continuous flashing releases of flammable substances; and
3. Modelling the dispersion from near-instantaneous flashing releases of flammable substances.

The work identified methodologies for modelling the different hazardous release scenarios, including the most appropriate source term models.

The impact of the use of the DRIFT 3 model on HSE's LUP advice was assessed by re-evaluating risk assessments for a number of sites and pipelines and comparing the hazard zones predicted by DRIFT 3 with those generated in the original assessment (Chaplin, 2014). DRIFT 3 was used to calculate the hazard footprints based on the distance to the Lower Flammability Limit (LFL). These hazard footprints, referred to as LFL isopleths, have been used to determine the extent of a flash fire event. For pipelines, where flash fire is relevant, the effects of the change in the hazard footprints has been assessed by comparing the final LUP risk based zones that are calculated from the pipeline risk assessment methodology.

Evaporating spills

The first stage of the work investigated the use of DRIFT 3 to model the dispersion of vapour clouds that evolve from pools following spills of flammable liquids. HSE uses the pool spreading and evaporation model GASP (Webber, 1990) to generate the source term conditions for these types of spills. GASP can calculate the time evolution of parameters such as the pool size, pool temperature, vaporisation rate and the total mass of vapour generated, and its outputs are in a format that can be easily read by DRIFT 3.

Hazardous Substances Consent applications for liquefied natural gas (LNG) and liquid hydrogen were re-evaluated using GASP 4.2.12 and DRIFT 3. The original assessments had used GASP 4.0.0 and DRIFT Version 2. The sensitivity of the DRIFT 3 outputs to variations in the modelling assumptions was assessed.

LNG

A catastrophic failure of a 21000 te LNG tank was modelled in DRIFT 3. A major and a minor failure of the tank with release rates of 3970 kg s^{-1} and 327 kg s^{-1} respectively were also modelled. For some scenarios, the peak vaporisation rate from the pool predicted by GASP was more than twice the mean vaporisation rate when calculated over the entire release duration. In these circumstances, HSE adjusts the inputs to DRIFT to give more weight to the peak in the vaporisation rate, whilst ensuring that the overall mass of the release is conserved.

Two weather conditions were modelled, F2 and D5, where the letter refers to the Pasquill stability class (F is very stable and D is neutral weather) and the number is the wind speed in m s^{-1}. These categories correspond to the weather conditions modelled in the original assessment.

Table 1 shows that DRIFT 3 predicts significantly larger maximum downwind distances to the LFL in F2 conditions than in D5 weather conditions. At the higher wind speed, the edges of the cloud are subject to greater turbulence and this occurs from the point of release onwards. This process dilutes the cloud with air more rapidly, meaning that the width and maximum downstream extent of the cloud to the LFL is smaller in D5 conditions than in F2 weather. This is particularly noticeable for a large release.

Two soil conditions were modelled, wet and dry soil. HSE assumes wet soil as a standard default assumption for most cases. The change in soil conditions can have a significant effect on the vaporisation rate of the pool, and therefore the cloud dimensions predicted by DRIFT 3. Table 1 shows that the maximum downwind distances more than double in F2 weather when wet soil is assumed as opposed to dry soil. In D5 weather, the maximum downwind distances calculated in wet soil conditions are at least six times those calculated in dry soil conditions. Wet soil has higher ground thermal conductivity and diffusivity than dry soil, which gives a higher heat flux to the cold pool. The result is boiling of the pool, in which case, the vaporisation rate is mainly determined by the heat flux from the ground rather than by air flow over the pool. For dry soil, the heat flux from the ground is much less and the pool is further below the boiling temperature, meaning that the pool is less likely to boil. In this case, the vaporisation rate is determined mainly by turbulent (diffusive) transport of vapour from the pool surface due to air flow over the pool.

Table 1 Maximum downwind distances to the LFL for catastrophic, major and minor releases of LNG

Weather and soil conditions	**Maximum downwind distance to the LFL (m) for the specified scenario**		
	Catastrophic	**Major**	**Minor**
D5 dry soil	718	105	22
F2 dry soil	3653	1396	454
D5 wet soil	4482	783	239
F2 wet soil	7770	4307	1216

Sensitivity tests were performed to test the impact on the results of changing key input parameters:

- Changing the release option from finite duration to steady continuous. The finite duration model is recommended as the standard option for evaporating pools in DRIFT 3. The finite duration option is new to DRIFT 3 and so the original assessment in DRIFT 2 used the Britter-McQuaid criteria [Britter, 1988] to determine whether a release would be better approximated as a continuous release or as an instantaneous release at a particular downwind distance;
- Modifying the pool surface roughness length from 0 m, as used in the original assessment, to the recommended value for outdoor pools of 0.00023 m (Brighton, 1987);
- Measuring the effect of modifying the relative humidity from 70% as used in the original assessment to the standard HSE value of 60% and a higher test value of 80%.

The most significant effect of using the steady continuous model option was observed for the F2 wet soil scenario results, where the downwind distance to the LFL was increased by over 30%. The finite duration model is a modification of the steady continuous model that accounts for longitudinal mixing and spreading at the front and back along-wind edges of the cloud. The finite duration model can be thought of as gradually eroding a steady continuous ‘core’. The effect of this is that the concentration predicted by the finite duration model will decay more rapidly in the far field (i.e. some distance from the source) than the concentration predicted by the steady continuous model. This, in turn, leads to shorter predicted maximum downwind distances for some scenarios, particularly those with large release rates where the cloud is still above criterion concentrations at long downwind distances. The finite duration model is considered to provide a better representation than the steady continuous model of the physical processes that are occurring.

Adjusting the pool surface roughness length to 0.00023 m had no significant impact on the wet soil results, but led to an increase in the maximum downwind distances for the dry soil scenarios. This is due to the vaporisation rate calculated in GASP being approximately 50% higher for the 0.00023 m pool surface roughness length than for the 0 m pool surface roughness length, when modelling dry soil. On wet soil, the vaporisation rate does not change significantly.

As explained previously, the dominant mechanism for vaporisation on wet soil is the boiling of the pool. On dry soil, the dominant mechanism is diffusive transport of vapour from the pool surface due to air flow over the pool. The pool surface roughness enhances the diffusive transport of vapour from the pool surface, which leads to the greater observed differences in the results between smooth and rough pools when modelling spills onto dry soil.

The sensitivity tests on the relative humidity showed that the cloud extents were found to increase as the relative humidity decreases. This is due to the increased latent heat that is released into the cloud as the water content increases (i.e. as the relative humidity increases), which leads to enhanced mixing. The value of 60% is relatively cautious and is consistent with that used in other HSE models.

The comparison with the results from DRIFT 2 found that, in D5 weather, the maximum downwind distances to the LFL were reduced in most cases by using DRIFT 3 when compared to either the continuous model or instantaneous model in DRIFT 2. This is due to the increased dilution at the leading and trailing edges of the plume in the DRIFT 3 finite duration model.

In F2 weather, the DRIFT 2 steady continuous model did not run for most of the wet soil scenarios. DRIFT 3 generally produced larger downwind distances than the instantaneous model in DRIFT 2 for F2 weather. Longer downwind distances were observed in F2 weather output from DRIFT 3 than those generated by DRIFT 2. This is because a release over a shorter duration, represented by the instantaneous model, is affected more by initial gravity-driven radial spreading than a release over a longer duration, which is represented by the finite duration model. The increased radial spreading can shorten the downwind LFL extent, usually with greater upwind and crosswind spread. Reducing the release rate reduces the initial gravitational spread at the expense of a greater downwind distance to the LFL.

Liquid hydrogen

Two liquid hydrogen scenarios were modelled: an instantaneous release of 3.5 te of liquid hydrogen and a continuous release equivalent to a 50 mm hole in the vessel.

Four weather conditions (F2, D5, D10 and D15) were modelled, consistent with the weather conditions that were considered in the original assessment. The standard weather conditions used at the time of the original assessment were F2 and D5. It was found that the cloud was buoyant, however, and the higher wind speeds were investigated as buoyant lift off of a cloud is considered less likely at higher wind speeds. Modelling high wind speeds in the assessment ensures that scenarios that could harm a receiver at ground level are being considered.

In the instantaneous release scenario it was found that the cloud was buoyant. For the continuous release scenario, the cloud was buoyant for all weathers other than D15.

The downwind distances predicted by DRIFT 3 are significantly smaller (between 15% and 40%) than the distances predicted by DRIFT 2 in the original assessment. This is likely to be due to DRIFT 3 modelling lift-off of the buoyant cloud, which DRIFT 2 was not able to do.

Buoyancy is an important issue when considering the downwind extent of the cloud in any subsequent risk calculations. HSE generally use the downwind distance to the LFL for non-buoyant clouds. As can be seen from Figure 1, which shows the LFL isopleths at different receiver heights for an instantaneous release in D5 weather, the downwind distance to the LFL in buoyant clouds depends on the height that is being considered e.g. the cloud extends to approximately 180 m at ground level, but up to 200 m at a height of 50 m. If the centreline through the cloud is considered as an alternative, the distance is approximately 220 m. For a non-buoyant cloud, the centreline distance is approximately the same as the downwind distance.

These observations can be explained by considering Figure 2, which shows the height of the cloud. The centreline distance through the cloud is the dotted line on the figure. The cloud extends to a height of approximately 130 m and it is clear to see that the centreline distance is longer than the maximum downwind extent of the cloud. It can also be seen that the cloud extends further at a height of approximately 40 m than at a height of 0 m.

For buoyant clouds, it has been determined that the centreline height should be used as a cautious estimate of the downwind distance for the cloud. If a person is underneath the buoyant part of the cloud, they could suffer adverse effects if the cloud ignites, even though they are not within the cloud itself.

The discontinuity observed in Figure 2 close to the release point is due to the superposition of the assumed initial cloud over the source at t = 0 s, and the subsequent steady plume that moves away from the source. It is caused by the model transition from the ground area source to the plume. These types of contouring issues can arise in integral models such as DRIFT with complex concentration profiles and cloud trajectories. They do not affect the final conclusions that can be drawn from the results, however.

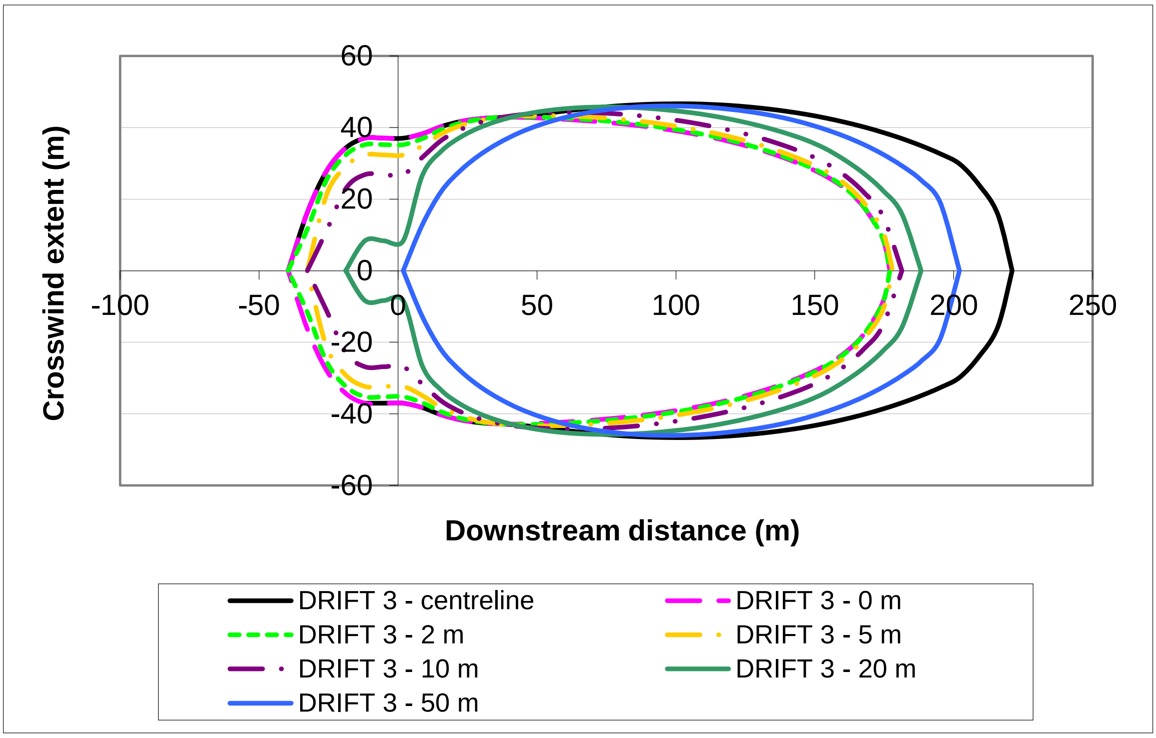

Figure 1 LFL isopleths obtained for a liquefied hydrogen release from a catastrophic vessel failure in D5 weather conditions for a range of receiver heights

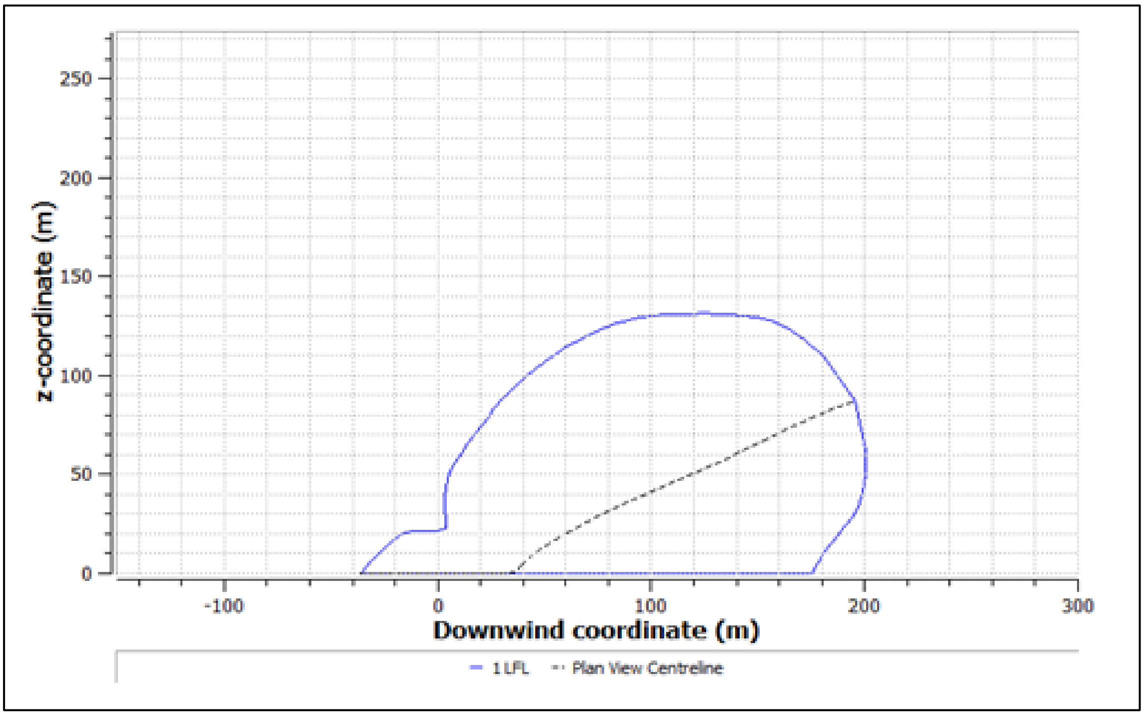

Figure 2 DRIFT 3 elevation plot for a liquefied hydrogen release from a catastrophic vessel failure in D5 weather conditions

Sensitivity studies were carried out on the liquid hydrogen release to determine how sensitive the DRIFT 3 results are to a change in some of the input parameters. The same trends were observed as for the LNG scenario, with the differences observed in the cloud extents at different values of the relative humidity being more significant at higher wind speeds. An example of the change in the cloud extents is shown in Figure 3 for D15 weather.

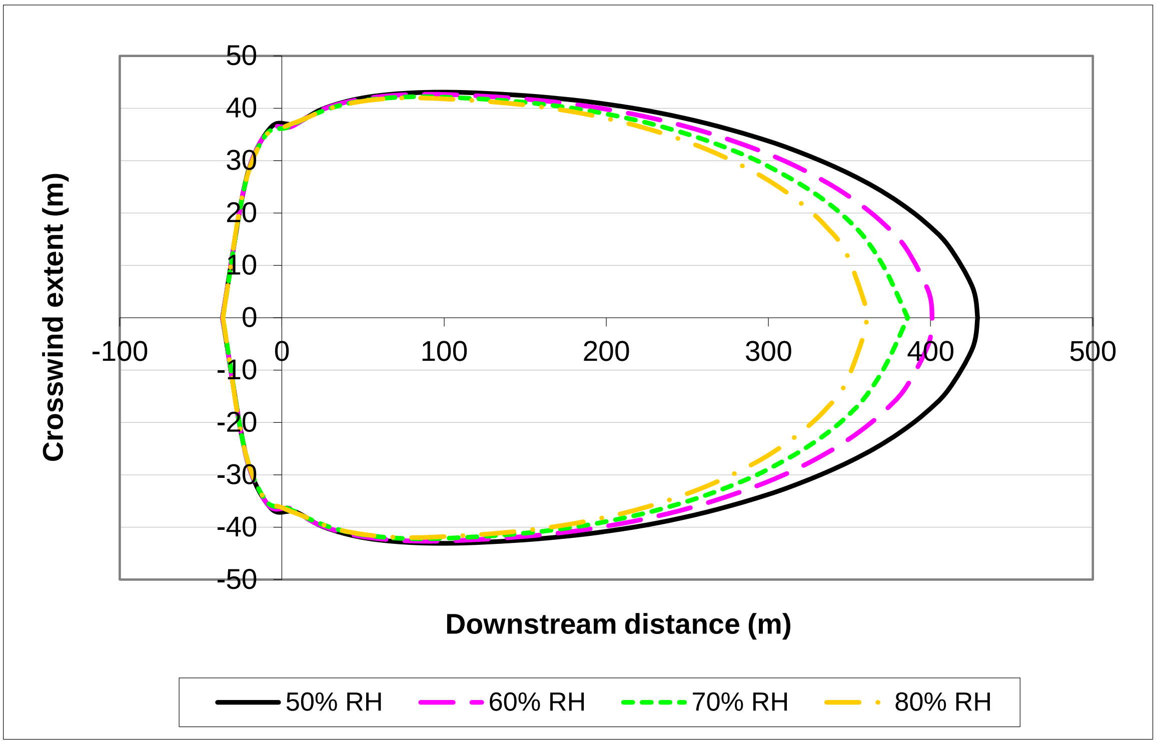

Figure 3 LFL isopleths obtained for a liquefied hydrogen release from a catastrophic vessel failure in D15 weather conditions, along the centreline height of the cloud, varying the relative humidity

Continuous flashing releases

The second stage of work investigated the use of DRIFT 3 to model the dispersion of flammable clouds from continuous flashing releases.

Two buried pipeline releases were modelled, one transporting ethylene and one transporting liquefied petroleum gas (LPG). The results were compared to the distances obtained from the dense gas dispersion model CRUNCH (Jagger, 1983), which was previously used by HSE to model flash fires from major accident hazard pipelines.

DRIFT 3 does not contain an option to consider releases from trenches. Sensitivity tests were carried out for the pipeline scenarios to determine an appropriate release height to use when modelling such releases.

Ethylene pipeline

Four release scenarios were modelled from a 219.1 mm diameter ethylene pipeline at 98.6 barg operating pressure and with a wall thickness of 7.04 mm. The pipeline was buried to a depth of 0.9 m. The four scenarios correspond to a full bore rupture, a large hole equivalent to 110 mm in diameter, a small hole equivalent to 75 mm in diameter and a pin hole equivalent to 25 mm in diameter. D5 and F2 weather were modelled. Source terms for DRIFT 3 were calculated using a pipeline release rate model appropriate to the hole size being modelled.

The results using both DRIFT 3 and CRUNCH for the dispersion modelling are shown in Table 2. The maximum downwind distances obtained when DRIFT 3 is used to model the dispersion are significantly lower than those obtained when CRUNCH is used, with the exception of the rupture release in D5 weather. The differences between the model outputs are greater in F2 weather than in D5 weather. The CRUNCH model can model high wind speed conditions better than lower wind speeds, where a high wind speed is defined as being ≥ 5 m/s (Jagger, 1983). This is one reason to explain why there are such large differences observed between the DRIFT 3 and CRUNCH outputs in F2 weather. CRUNCH cannot model the initial jet phase of continuous flashing releases, whilst DRIFT 3 does model this initial jet phase as part of the release. The downwind distances to the LFL predicted by DRIFT 3 for any weather conditions are therefore likely to be smaller than those predicted by CRUNCH due to the dilution caused by the turbulent interactions between the jet and the atmosphere.

Table 2 shows that the maximum downwind distances predicted for the two weather conditions are similar when DRIFT 3 is used, with the distances in F2 weather being slightly shorter than in D5 weather. This is likely to be due to the velocity of the initial jet release being significantly greater than the ambient wind speed, which leads to turbulence and increased mixing of the gas with the surrounding air at the leading edge of the jet. At lower wind speeds, the difference between the two velocities is greater, meaning that the amount of turbulent mixing is also likely to be greater. The net effect of this is that the pollutant is dispersed more quickly at the lower wind speed in DRIFT leading to slightly shorter downwind LFL distances in F2 weather than in D5 weather.

As CRUNCH does not model the jet phase, the modelling of the dispersion of the cloud leads to much greater distances to the LFL in F2 weather than in D5 weather, as would normally be expected.

The use of DRIFT 3 in preference to CRUNCH in HSE's LUP methodology for pipelines leads to a significant reduction (between 5% and 50%) in the predicted zone sizes.

Table 2 The maximum downwind distances of the cloud predicted by DRIFT 3 and CRUNCH for all hole sizes and weather conditions

Scenario	**Maximum downwind distance (m) to the LFL for the specified dispersion model and weather conditions**			
	DRIFT 3		**CRUNCH**	
	D5	**F2**	**D5**	**F2**
Rupture	365	362	350	780
110 mm hole	226	211	310	690
75 mm hole	156	148	220	520
25 mm hole	53	53	72	200

Sensitivity tests were performed to test the impact on the results of changing key input parameters:

Changing the release option from finite duration to steady continuous. The finite duration model is recommended as the standard option for continuous flashing releases in DRIFT 3;

Measuring the effect of modifying the relative humidity from 60%, the standard HSE value, to 80%;

Modifying the release height to determine the most appropriate value to use for buried pipelines, as DRIFT 3 cannot directly model buried pipelines;

Changing the ground surface roughness length from 0.3 m, which is used by HSE for suburban pipelines, to 0.1 m corresponding to a rural environment; and

Varying the angle of release. HSE assume that the release is horizontal.

There was no significant difference in the results when the steady continuous option was chosen in preference to the finite duration option. The steady continuous model uses the same basic equations as the finite duration model, but with differences in the post processing. When the release duration is long compared with the cloud travel time, as in this example, the concentration profiles tend to those of the steady continuous model.

No significant difference was seen when the relative humidity was increased from 60% to 80% for the three hole sizes investigated. Slightly larger differences were seen for the rupture scenarios, although they were still not significant. Ethylene is assumed to be two-phase for the rupture scenarios but was modelled as purely gaseous for the holes. The difference in behaviour observed when changing the relative humidity is likely to be due to some of the release being liquid for the two-phase scenario. The two-phase release cools to much lower temperatures than the vapour release due to the latent heat removed when the liquid ethylene vaporises. By this mechanism, the two-phase release cools to below the normal boiling temperature of 169 K before increasing due to the mixing with air. In comparison, the vapour release continuously warms from its initial temperature by mixing with air. This leads to the two-phase release producing a significantly denser cloud than the vapour release. For a ground-based cloud, mixing with overlying air is suppressed by the stabilising effect of the dense cloud lying below warmer air. This suppression of mixing increases with cloud density and cloud size. Water vapour from moist air mixed into the cold cloud will condense releasing its latent heat. This latent heat warms the cloud and reduces the density, hence reducing the density suppression effect on mixing. Due to the cloud from the two-phase release being significantly colder and denser than from the vapour release, a much greater amount of water vapour is condensed in the two-phase cloud with a greater effect on the density dependent mixing.

Heights of 0 m, 0.2 m, 0.5 m, 1 m and 2 m were investigated to test the sensitivity of the results to the release height. Although it may appear that the nearest approximation to a buried pipeline is to assume a ground based jet, there may be interactions occurring within the surface roughness length (0.3 m in this scenario) that impact on the results. Shorter distances, both crosswind and downwind, were observed in all cases when a height of 2 m or 1 m was used, instead of a lower release height. This reflects differences in the behaviour of the elevated and grounded regions of the jet.

Elevation plots indicate that the cloud is immediately grounded at the lower release heights, but, at the higher release heights, the cloud travels a few metres before touching the ground. When the release is along the ground, only the upper surface and sides of the jet interact with the atmosphere, leading to less mixing. Within the jet region, the ground surface roughness acts to slow the jet down if the release is at ground level. This, in turn, means that the difference in velocities between the jet and the wind is less, which leads to less turbulence at the edge of the jet. The lateral spreading of the jet is enhanced when grounded and vertical mixing is suppressed due to the stabilising effect of the dense cloud at ground level. The net effect is that less mixing occurs for the dense ground-level jet and the cloud extends further, in both the crosswind and downwind directions in this case.

Figure 4 shows the effect of modifying the release height for a pipeline rupture in D5 weather conditions.

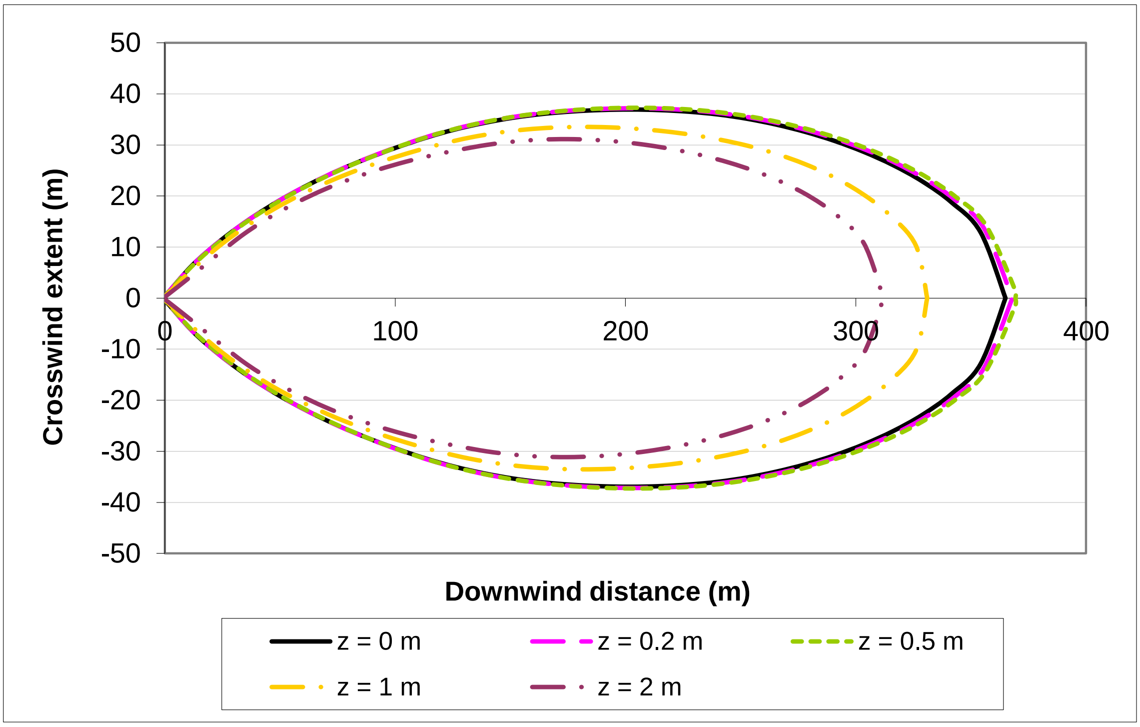

Figure 4 LFL isopleths for rupture of an ethylene pipeline in D5 weather varying the release height

In a pipeline release, the jet may interact with the crater formed, depending on the angle of release. The jet is then likely to become angled slightly upwards, but may reattach to the ground due to the Coandă effect[1]. The closest approximation within DRIFT is to assume a release height of 0 m. This is the recommendation for HSE when modelling buried pipelines.

The sensitivity of the cloud extents to the ground surface roughness length was tested by using a value of 0.1 m as opposed to the value of 0.3 m used in the original assessment. It was found that the maximum downwind LFL distances are reduced in all cases modelled when the ground surface roughness length is reduced to 0.1 m, except when modelling the rupture in D5 weather. The crosswind extents are also reduced slightly. These effects are due to the decrease in friction between the release and the ground as the surface roughness length is decreased. The effect of the decrease in friction is that the jet does not slow down as quickly, leading to increased turbulent mixing with the atmosphere and hence the cloud concentration falling below the criterion concentration at shorter distances.

The effect of modifying the ground surface roughness length is shown in Figure 5 for rupture of an ethylene pipeline in F2 weather.

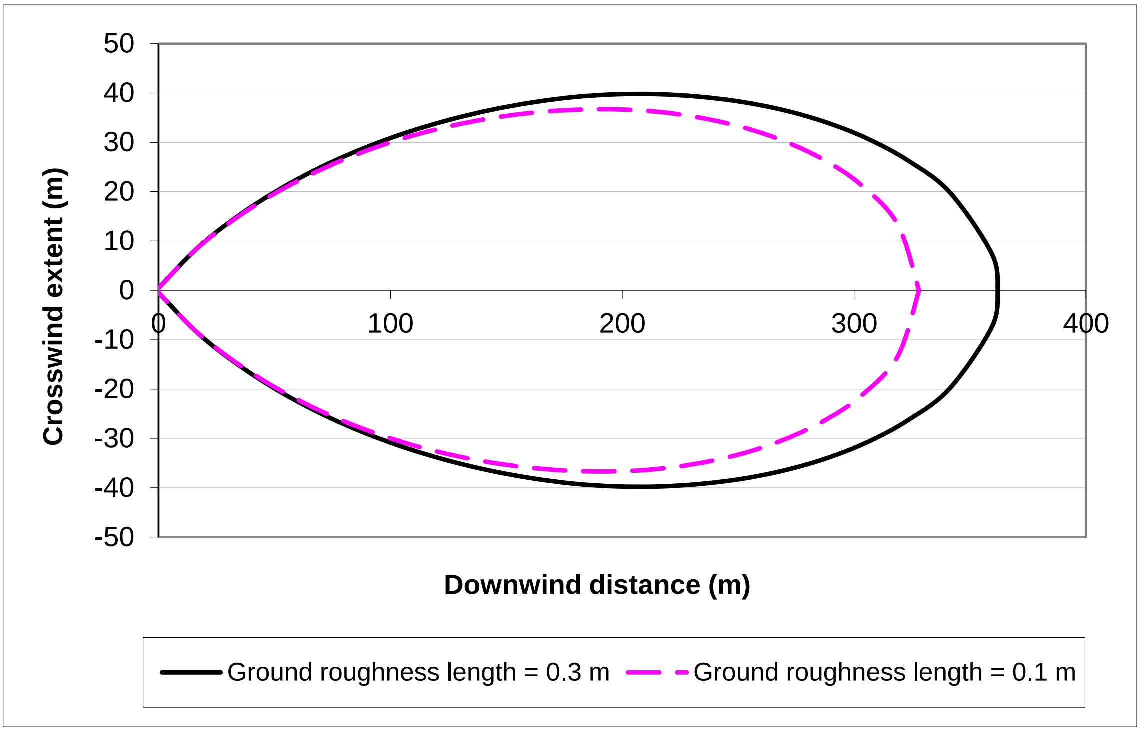

Figure 5 LFL isopleths for rupture of an ethylene pipeline in F2 weather, varying the ground surface roughness length

Tests were undertaken to observe the effects of modifying the angle of release in DRIFT 3 from the original assumption of a horizontal release. The LFL isopleths reduced in size as the angle from the horizontal was increased. This is to be expected, given that there is a vertical component to the jet momentum when modelling any angle other than a horizontal release. Releasing a jet into an ambient cross-flow greatly enhances its mixing rate with air, which dilutes the cloud with air quicker leading to smaller extents to the LFL.

The conclusions drawn from the ethylene and LPG studies were the same and so the results from the LPG pipeline are not discussed here.

Instantaneous flashing releases

The final stage of this work considered instantaneous flashing releases of flammable substances. Three Hazardous Substances Consent applications were re-evaluated for isobutane, propane and o-cresol.

The source terms for input to DRIFT 3 were calculated using HSE's Airborne Concentration Estimate (ACE) model (Gilham, 1999, Coldrick, 2013, Tickle, 2015). ACE models the rapid expansion phase that occurs following an instantaneous release of a flashing substance, and the subsequent turbulent growth phase. It can also predict whether rainout will occur, which could lead to pool formation. The ACE outputs can be read directly into DRIFT 3. ACE has the option of modelling the release as spherical, where the substance is assumed to be released in all directions forming a spherical cloud, or hemispherical, where the release is assumed to be downwards, forming a hemispherical ground-based cloud. Tests were carried out to determine the how to use ACE to provide the source terms for DRIFT 3. In all cases, the instantaneous release option in DRIFT 3 was used.

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[1] The Coandă effect is the tendency of a fluid jet to attach itself to a nearby surface and to remain attached, even if the surface curves away from the initial jet direction.

Isobutane

DRIFT 3 was used to model an instantaneous flashing release from a sphere containing 1056 te of isobutane at a pressure of 5.5 barg and at ambient temperature. ACE predicts the properties of the airborne puff following a release of isobutane, but the outputs also indicate that some of the isobutane will rain out and form a pool. DRIFT 3 was used to model the dispersion of the initial airborne component of the release and the dispersion of the flammable cloud that evolves from the pool of rained out material. GASP was used to provide the source term for the pool component. In both cases, D5 and F2 weather was assumed. The results are shown in Table 3.

Table 3 Maximum downwind distances to the LFL for an instantaneous flashing release of isobutane

Scenario	**Maximum downwind distance to the LFL (m) for the specified scenario**		
	Initial hemispherical release	**Initial spherical release**	**Pool**
D5 weather	649	368	225
F2 weather	549	320	980

Table 3 shows that shorter downwind distances are observed for both the hemispherical and spherical release in F2 weather than in D5 weather. In F2 weather, the gravity driven radial spreading exceeds the downwind advection (driven by the wind) for longer. In some circumstances, this effect (which includes “edge” entrainment driven by the gravity spreading front) dominates over the reduced “top” entrainment in F2 conditions. This has the effect of shortening the downwind extent but increasing the upwind and crosswind extents, which was observed in the results.

The maximum downwind distances to the LFL are larger when modelling a hemispherical release in ACE than those predicted when modelling a spherical release. This is due to a combination of a decrease in the surface area that is interacting with the surrounding atmosphere and an increase in the concentration of isobutane in the cloud i.e. the same amount of pollutant is contained in a smaller volume. The decrease in the volume from modelling a hemispherical release means that less mixing with the surrounding atmosphere can occur at any given time, which leads to longer dispersion times and longer overall distances to the criterion concentration when a hemispherical release is modelled. A hemispherical release is considered the more realistic scenario when considering a release point that is 2 m from the ground.

The results from modelling the pool formed from the rainout of released material indicate that the clouds formed from the pool are of similar magnitude to those modelled from the airborne puff generated following the release. When modelled in F2 weather, the maximum downwind extents to the LFL from the pool dispersion are further downwind than those generated from the initial airborne puff. Although the timescales involved in the dispersion of the initial puff release and the pool that is formed from rainout of the cloud are different, when calculating the risk from a release it is necessary to work out the maximum extent of any cloud formed, regardless of the mechanism involved in its formation. It is therefore important to ensure that both the initial airborne component and the pool component are modelled and considered as part of HSE’s process. Future versions of DRIFT will allow the two components to be modelled together but this is not possible in the version of DRIFT discussed in this paper.

When the propane hazardous consent application was re-evaluated, the cloud that results from the pool formed from rainout of released material was also found to be of a similar size to the cloud formed from the initial release itself.

For o-cresol, ACE predicted that there would be rainout from the initial release and that a pool would be formed. It was found, however, that the predicted cloud temperature was lower than the freezing point of o-cresol. Any o-cresol that rained out of the cloud was likely to be either a solid, or form a solid on contact with the ground, and so an evaporating pool was not deemed to be a credible scenario.

The remaining conclusions drawn from the results for propane and o-cresol were the same as those for isobutane, and so the detailed results from the propane and o-cresol assessments are not discussed here.

Conclusions

Work has been carried out to assess the suitability of DRIFT 3 for modelling the dispersion of flammable substances. The work investigated flammable substance releases from evaporating pools, continuous flashing releases and instantaneous flashing releases. The work was undertaken to establish how the DRIFT 3 model should be used by HSE for assessing the vapour dispersion of flammable substances. Sensitivity analyses were used to inform the selection of the inputs and source terms used when modelling these types of releases.

It is concluded that:

- The finite duration release option should be used as standard for evaporating pools and continuous flashing releases as the use of the steady continuous option can lead to over predictions for some scenarios. For instantaneous flashing releases, the instantaneous release option should be used;
- Some sensitivity to the value of relative humidity has been observed. The value of relative humidity of 60% used by HSE represents neither the worst case nor the most optimistic choice when modelling the dispersion of flammable releases;

- Some of the clouds calculated by DRIFT 3 are buoyant. In this case, the centreline distance through the cloud should be used to determine the maximum downwind distance as this will provide a cautious estimate. The exception to this is if the cloud is highly buoyant and the distance to a person underneath it is significantly large so that they would be unaffected should the cloud ignite;
- GASP should be used to provide the source terms for DRIFT 3 when modelling evaporating pools;
- For some evaporating pools, GASP predicts that there is a peak in the vaporisation rate that is more than twice the mean vaporisation rate calculated over the duration of the release. In these cases, the inputs to DRIFT should be modified to take greater account of the peak vaporisation rate;
- The pool surface roughness length input to GASP can have an impact on the results produced by DRIFT 3 in some cases due to the change in the vaporisation rate predicted by GASP. The standard HSE value of 0.00023 m should be used;
- DRIFT 3 produces significantly smaller flammable clouds than an earlier dispersion model used for some scenarios, CRUNCH. CRUNCH is an older model written at a time when computing power was limited. It does not consider the initial jet phase of the release and is more suited to higher wind speeds (> 5 ms^{-1}) than lower wind speeds. The reduction in the flammable cloud extents produced by DRIFT 3 has the effect of reducing the size of the LUP zones around pipelines;
- For buried pipelines, a release height of 0 m should be assumed in DRIFT 3;
- A horizontal release should be assumed for continuous flashing releases;
- The hemispherical option in ACE should be used to provide the source terms for DRIFT 3 when modelling instantaneous catastrophic releases.
- When modelling instantaneous catastrophic releases, any pool formed from the rainout of the released fluid should be considered in conjunction with the initial cloud to determine which release mechanism leads to the greatest hazard.

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