A Comprehensive TR Gas Ingress Study Over Multiple Facilities – Summary and Conclusions

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In terms of Temporary Refuge (TR) risk assessment, current UK legislation has moved away from specifying a specific Temporary Refuge Impairment Frequency (TRIF) concluding that the use of such criterion adds little value where similar installations have been previously assessed and shown to operate well within the tolerable if ALARP region. In place, guidance states that:

'*The TR should be specified so far as reasonably practicable such that impairment will not occur, moving the focus from TRIF to Temporary Refuge Integrity (TRI)*' [1].

A study has been performed to investigate TR impairment by smoke and gas ingress on 24 offshore platforms using a 'credible worst case' approach. This approach takes credit for some safety systems such as ESD isolation to avoid very onerous design / performance requirements, which may be impractical or unachievable.

The study was conducted in 3 stages, namely 1: Identification of worst case scenario, 2: Phenomenological (e.g. Phast and hand calculation methods) hazard modelling of the release scenarios, based on HSE guidance [1], 3: CFD (using ANSYS-CFX) hazard modelling of the release scenarios. In total, 129 CFD simulations have been performed, on facilities ranging from monopods and NUIs to multi jacket installations.

In most cases CFD modelling of release scenarios has reduced the apparent concentrations on the outside of the TR when compared to Phenomenological methods. Decks and bulkheads can play a significant role, as release direction and wind speeds are required to be non-concurrent in order to twist plumes in order that a TR may be impinged. Use of CFD also allows much better assessment the actual plume concentration and distribution outside the TR. This has enabled new methods for the calculation of area averaged, and pressure area averaged, external concentration and hence gas ingress into the TR.

The following paper sets out the methodology used in the assessments, both using Phenomenological and CFD techniques, and their relative advantages for the gas releases only. A discussion on the impairment criteria, and methods of calculation is then given. The main bulk of the paper is then to summarise and compare the results of the assessment across all simulations and show all correlations and rule sets derived. This may be then used as an enhancement to Phenomenological methods in order that some conservatism may be removed from their assessments. The approach used is applied to TRs but can be equally applied to other buildings

Introduction

In terms of Temporary Refuge (TR) risk assessment, current UK legislation has moved away from specifying a specific Temporary Refuge Impairment Frequency (TRIF) concluding that the use of such criterion adds little value where similar installations have been previously assessed and shown to operate well within the tolerable if ALARP region. In place, guidance states that:

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General Methodology

The methodology to determine the required air change rate for a TR can be summarised as follows. This methodology can be applied to other buildings such as control rooms (CR), instrument and electrical rooms (IER), and local equipment rooms (LERs) where an endurance time against gas ingress may be required. These four steps are briefly discussed in the following Sections, however the aim of this paper is not to describe the methodology and associated justifications in detail.

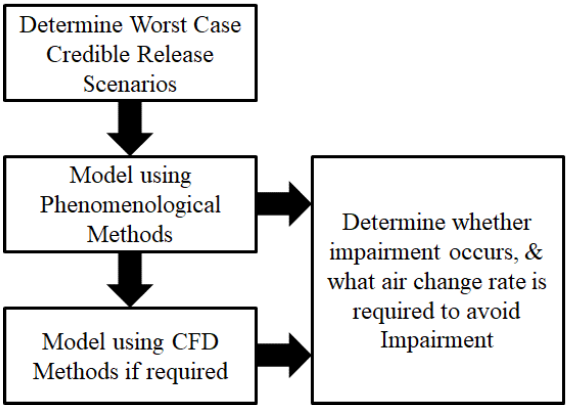


Figure 1: Methodology Overview for Determining Gas Ingress and Corresponding Air tightness Requirements for a Building.

Determining the Worst Case Credible Release Scenarios

As specified earlier, a 'credible worst case' approach is applied to specifying smoke and gas ingress hazards, and the associated building air change rate requirement. This approach takes credit for some safety systems such as ESD isolation to avoid very onerous design / performance requirements, which may be impractical or unachievable.

To determine the worst case release scenarios that may impinge or impair a building, the facility requires dividing into sections with each considered independently. For an offshore installation this would typically consider the following process elements:

- Risers;
- Topsides processing;
- Non-process Hydrocarbons.
- Cargo Tanks, Offloading and Metering (for FPSO type facilities)

For each release location / type, a qualitative or semi quantitative assessment is performed in order to determine whether a credible smoke or gas scenario exists.

Modelling Scenarios using Phenomenological Techniques

Phast or other similar tool is used to model gas plumes from a release. However, a number of subjective assumptions have to be made with regard to:

- The wind speed to select. Lower wind speeds give rise to higher concentrations as there is less turbulent mixing. However, selecting a wind speed that is too low may not be credible for most offshore installations. For the purposes of this study, a wind speed of 5 m/s, with Pasquill stability class D has been applied.
- Distance from the release source to the target building. This distance could be measured in a straight line, or take account of obstacles such as bulkheads and decks. Similarly, the distance could be measured to the closest edge of the building, or centre of the building. For the purpose of this study, the distance has been measured as that to the centre of the building to account for the fact that the building must be engulfed, and no account for bulkheads, decks, or other obstacle has been made that may serve to dilute the plume.
- Concentration at the building. Phenomenological tools typically report the centreline concentration as a function of distance from the release point, and then follows a Gaussian concentration distribution perpendicular to the wind direction. The concentration at a building could be assumed equal to that of the centreline concentration, or determined

using a more complicated method using the Gaussian distribution and size of the building. For the purposes of this study, the centreline concentration has been used with no modification which gives a conservative approach to the analysis.

Due to the relatively fast nature of performing Phenomenological studies, a large number of scenarios can be modelled quickly in order to confidently ascertain the critical scenarios that may give rise to the largest hazard to a building.

Modelling Scenarios using Computational Fluid Dynamic (CFD) Techniques

The following stages are required in order to perform Computational Fluid Dynamics (CFD) analysis of gas or smoke release scenarios

- Model build
- Model set-up
- Post-Processing

For this study, ANSYS-CFX has been used to carry out the CFD analyses. ANSYS-CFX is a robust, general purpose CFD tool which is used extensively in the Oil & Gas industry in fire, smoke and gas dispersion modelling projects. This software is better suited to external smoke and gas dispersion problems than software that uses a Cartesian grid (e.g. FLACS, KFX) due to it employing an unstructured grid than can be refined more efficiently to calculate smoke and gas plume characteristics accurately over large distances.

Platform models were created based on structural drawings and photographs. A computational mesh was applied across the geometry with the density of the cells increased in the regions of importance, particularly where large numerical gradients were predicted.

Impairment of the Building by Smoke or Gas Ingress

The concentration of smoke or flammable gas within the building is determined using the continuously stirred tank model as described in HSE guidance [1] and shown in Equation 1.

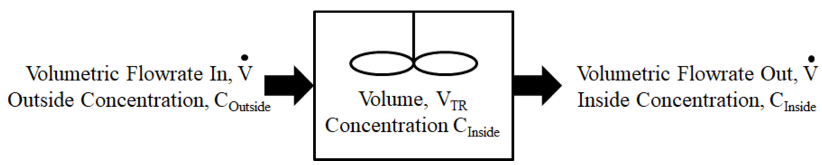


Figure 2: Representation of the Stirred Tank Model

$$V_{TR}\frac{dC_{Inside}}{dt} = \dot{V}\cdot C_{Outside} - \dot{V}\cdot C_{Inside} \qquad \text{(Eqn 1)}$$

$$\frac{dC_{Inside}}{dt} = Ach\cdot\left(C_{Outside} - C_{Inside}\right)$$

Where V_{TR} is the Volume of the TR or building;

C_{Inside} is the concentration of the component inside the building;

t is time;

$\dot{V}$ is the volumetric flowrate of contaminated air through the building;

$C_{Outside}$ is the concentration of the component outside the building;

Ach is the Air Change Rate of the TR.

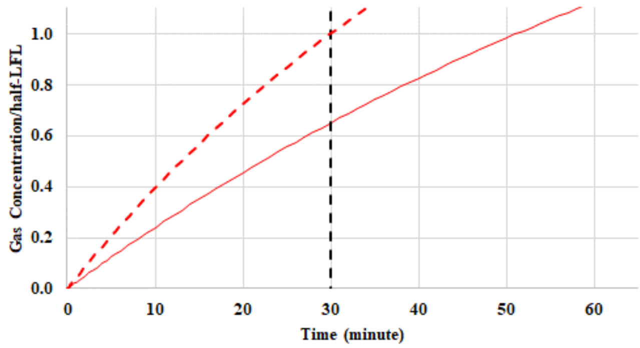


Figure 3: Typical Gas build up transient within a building. The solid line represents the gas build up at the current air change rate, and the dashed line represents the gas build up at an increased air change rate.

For gas ingress, impairment is typically considered at the point that the bulk concentration within the building reaches 50% LFL. For smoke ingress, a similar toxic concentration or temperature build up assessment can be conducted however good practise is moving to favour a toxic and temperature cumulative dose type assessment, as outlined in [1]. A good description of the use of dose type calculations can be found in [2].

A key input to the concentration build up calculation is the concentration outside of the building, $C_{Outside}$. For phenomenological assessments, the concentration is easily established once a representative distance is known. It has been determined as part of this work that the outside concentration from CFD data can be much better refined and hence remove some of the conservatism from the analysis.

CFD analysis reports a range of concentrations across a building surface. This is illustrated in Figure 2 where the concentration on a building ranges from 0 to 10%. The Figure also shows the pressure on the building. An overly conservative assessment could be to take the maximum reported concentration and use this as $C_{Outside}$. This method is considered overly simplistic given the complexity and effort required to perform the CFD analysis.

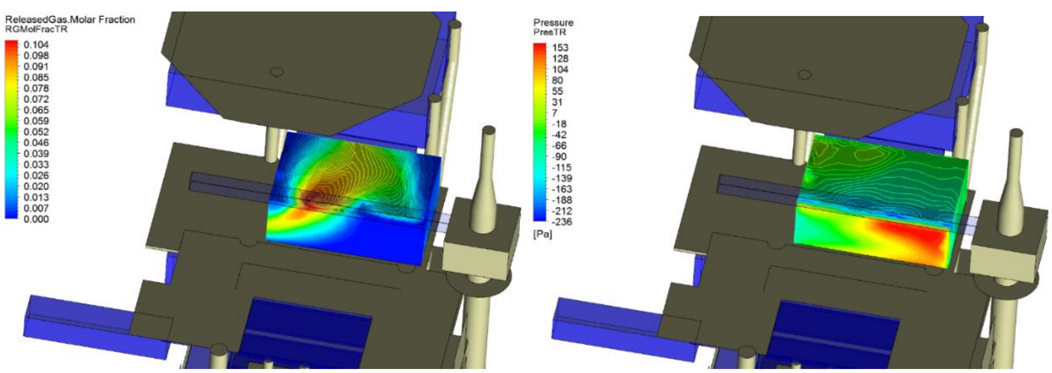


Figure 4: Left: Gas concentration on a building. Right: Gauge pressure on a building.

The method developed by this author (and colleagues at MMI TT) is to determine the 'Area Averaged' concentration and 'Pressure Area Average' concentration on the building. The basis for these approaches hinges on the fact that ingress into a building is driven by convective forces, not diffusive. For this reason, if the inside of a building is at a higher pressure than the outside, a negligible amount of gas ingress will occur.

The first step in the process is to estimate the pressure inside the building. Note that as soon as HVAC stops, the small positive pressure typically maintained in buildings very quickly reduces. The pressure inside the building is estimated using Equation 2, which calculates the area average pressure around the building:

$$\text{Pressure inside Building, } P_{\text{Inside}} = \frac{\sum \text{Area}_i \times \text{Pressure}_i}{\sum \text{Area}_i} \qquad \text{Eqn 2}$$

On the basis that any location where the outside pressure is less than the inside pressure no smoke or gas ingress may occur, the concentration on all external faces with a pressure less than P_{Inside} can therefore be disregarded from the ingress calculations. For the remaining areas, where there is a net positive pressure on the surface relative to the internal building pressure, the following formulas are used

$$\text{Area Average Concentration, } C_{\mathrm{AA}} = \frac{\sum \mathrm{Area_j} \times \mathrm{Conc_j}}{\sum \mathrm{Area_j}} \qquad \text{Eqn 3}$$

$$\text{Pressure Area Average Concentration, } C_{\mathrm{PAA}} = \frac{\sum \mathrm{Pressure_j} \times \mathrm{Area_j} \times \mathrm{Conc_j}}{\sum \mathrm{Pressure_j} \times \mathrm{Area_j}} \qquad \text{Eqn 4}$$

In addition to the method of eliminating areas where the external pressure is less than the estimated internal pressure, regions of the building may be disregarded for external concentration purposes if it is known that the barrier is in good condition.

Summary Of Simulation Types Examined

A study has been performed to investigate TR impairment by smoke and gas ingress on 24 offshore platforms. The study was conducted in the 3 stages described in the previous section, namely 1: Identification of worst case scenario, 2: Phenomenological (e.g. Phast and hand calculation methods) hazard modelling of the release scenarios, based on HSE guidance [1], 3: CFD (using ANSYS-CFX) hazard modelling of the release scenarios. In total, 129 CFD simulations have been performed, on facilities ranging from monopods and NUIs to multi jacket installations. The simulations can be split into the following 6 general groups:

1. Releases requiring the wind to bend the release 90° around a bulkhead or deck
2. Releases into the wind and over a deck, or round a very sharp bend requiring the plume to be blown backwards
3. Releases directly below a building, but where the integrity of the building underside is believed to be sound and not allow ingress through that means.
4. Releases directly into a building wall. This could be the underside, bulkhead or roof.
5. Released into a barrier to produce a low momentum release to be carried by the wind
6. Releases directed downwards underneath the building with the intent of gas buoyancy carrying the plume onto the building

For each of the release types described, the concentration calculated in the CFD simulation is compared to that estimated using the standard Phenomenological approach. The comparison of the two values is indicative of the difference in air change rate requirement that may result from using the two methods.

Release Type 1, Bending a release 90° around a bulkhead or deck

Where a building was located on a different deck to the source of a release, and that deck was plated, one of the only means by which a release may impinge the building is if it were directed outside of the platform, then driven back in by wind once the release momentum had dissipated sufficiently. Similarly, where the release and target building are on the same deck, but separated by a bulkhead, a similar approach can be applied. This scenario is illustrated in Figure 5 below where a well blowout is directed out of the platform in a slightly upwards direction, then bent in towards the target building.

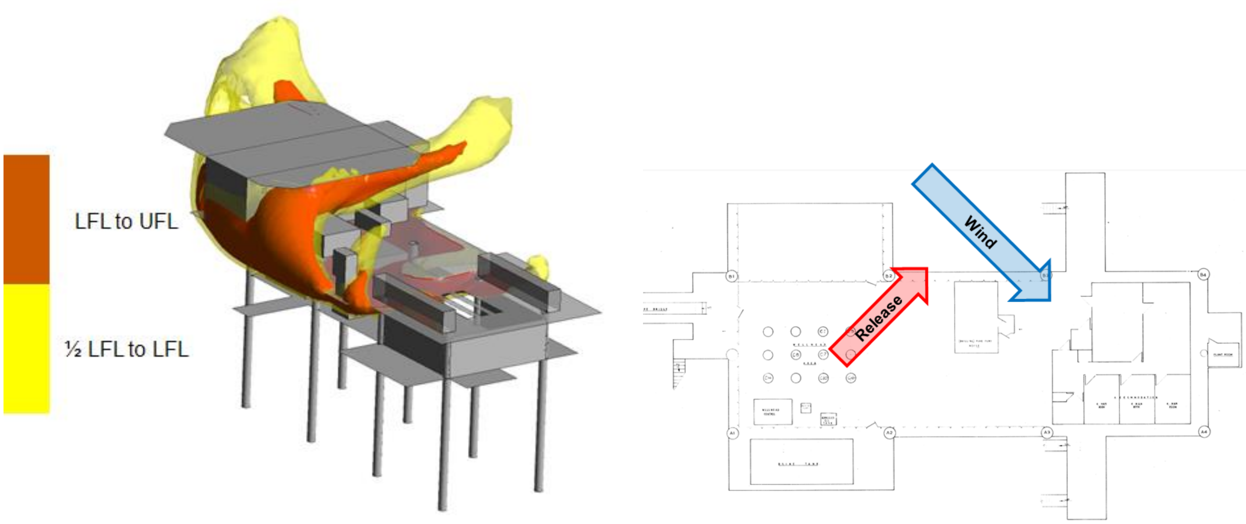


Figure 5: Typical example of a release bent 90° by the wind. The building of interest in this example is the accommodation module underneath the helideck

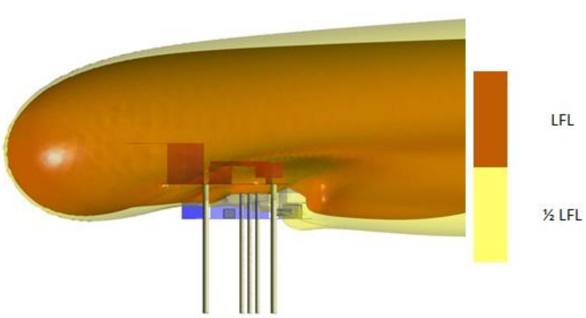
A summary of the types of releases, compared with the results from the phenomenological analysis is given in Table 1.

Table 1: Release Type 1 Simulations Summary

#	Release Rate (kg/s)	Wind speed (m/s)	Distance to Building	Phenomenological Concentration at Building (% of LFL)	CFD Concentration at building (% of LFL)	Comment
23.1	34.0	5	9	441%	139%	Release bent 135°, not 90° around a bulkhead
23.2	34.0	5	9	441%	Misses	Release bent 135°, not 90° around a bulkhead
24.3	15.5	5	9	309%	Misses	Impingement of building walls attempted, as opposed to underside (see simulation 24.1 in Section 3.4)
20.1	14.9	10	9 / 15	311% / 188%	34%	Release bent 135°, not 90°
20.3	14.9	10	9 / 15	311% / 188%	69%	Release bent 135°, not 90° around a bulkhead
18.1	16.7	15	10	304%	Misses	Wind not angled steeply enough to bend the release in
5.3	16.9	5	14	240%	<50%	Release orientated correctly to impinge building, but disperses before impinging
15.1	141	10	15	532%	27%	Release does not fully envelop the TR
15.7	141	10	15	532%	45%	Release does not fully envelop the TR
17.1	15.7	5	14 / 20	224% / 167%	65%	Building between decks at same elevation as release
17.3	15.7	5	14 / 20	224% / 167%	108%	Building between decks at same elevation as release
13.3	17.7	5	16	190%	Misses	Plume travel over the TR
13.4	17.7	5	16	190%	<50%	Release does not fully envelop the TR
13.4	17.7	5	16	190%	56%	Fully engulfed building. No wind walls.
7.1	16.4	4	23	178%	60%	Plumes dissipates before reaching TR
7.4	16.4	4	25	178%	60%	Released from the air gap
10.1	17.5	5	26	165%	58%	Released from a well bay
19.3	5.2	10	31	61%	Misses	Insufficient momentum to exit the platform and be redirected.
19.3	5.2	10	31	61%	Misses	Insufficient momentum to exit the platform and be redirected.
2.2	5.2	5	32 / 35	66% / 61%	105%	Wind walls in the well bay area mean there is little wind, thus the 1st stages of the plume experience little turbulent mixing due to wind.
6.1	17.5	5	43	120%	<50%	Insufficient momentum to exit the platform and be redirected.

Release Type 2, Releases into the wind and over a deck requiring the plume to be blown backwards

The release scenario in Section 3.1 requires a very specific combination of release direction, location, and wind direction for impingement of the building to occur. A more simple release scenario has been considered for a number of platforms where the release is directed into the wind, and the wind blows it back onto the building. This is illustrated in below in Figure 6 for a (very large) release.



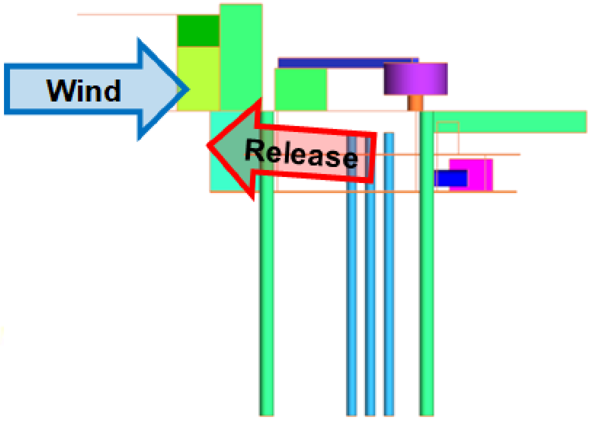


Figure 6: Typical example of a release directed straight into the wind and blown back on to the TR

A summary of the types of releases, compared with the results from the phenomenological analysis is given in Table 2.

Table 2: Release Type 2 Simulations Summary

#	Release Rate (kg/s)	Wind speed (m/s)	Distance to Building	Phenomenological Concentration at Building (% of LFL)	CFD Concentration at building (% of LFL)	Comment
20.3	15.6	5	7	389%	59%	Released from a well bay and blown back onto building on same level. No obstacles between release and building
22.6	16.6	5	10	307%	41%	Directed into process
18.3	16.7	10	10	304%	93%	Bent round a very steep corner
15.9	141	10	15	532%	184%	Passes through some process equipment then back again to the TR
22.5	13.7	15	15	199%	<50%	Directed through a lot of processing then back onto TR face
12.1	451	10	16	>10 x LFL	251% LFL	Unrealistically large sustainable flowrate (blowout)
12.3	23.9	5	16	211%	130% LFL	The 1st sections of the plume pass through uncongested process area, possibly meaning there is reduced wind and hence mixing and dilution
13.1	17.7	5	16	190%	<50%	As 12.3 but to a lesser extent
11.1	16.5	5	17	198%	59%	As 12.3 but to a lesser extent
15.8	141	10	19	455%	75%	Passes through some process equipment then back again to the building
7.1	16.4	4	23	178%	<50%	
7.3	16.4	4	23	178%	<50%	Release is obstructed before leaving the platform and dissipates quickly
10.3	17.5	5	26	165%	<<50%	Dissipates before being momentum is taken away

Release Type 3, Releases directly underneath Buildings

On smaller platforms, it was often the case that a riser or other leak source was located directly beneath a target building. On the assumption that the integrity of underside of the building is sound such that no ingress can occur through this vector, a plume must be directed upwards and be blown back into the target building. This type of scenario is illustrated in Figure 7.

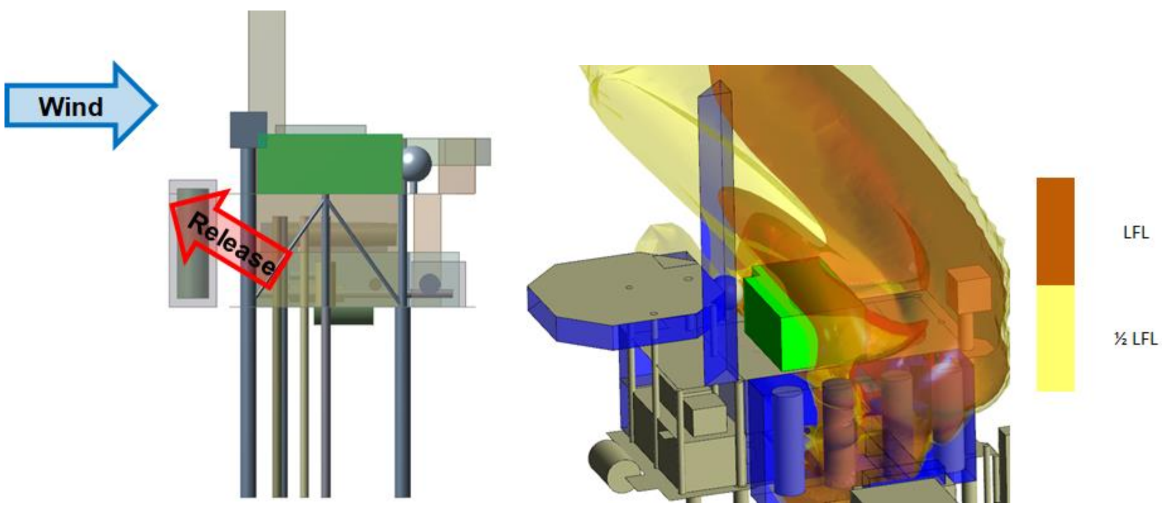


Figure 7: Typical example of a release located underneath a target building. The dark green rectangle is the target building

A summary of the types of releases, compared with the results from the phenomenological analysis is given in Table 3.

Table 3: Release Type 3 Simulations Summary

#	Release Rate (kg/s)	Wind speed (m/s)	Distance to Building	Phenomenological Concentration at Building (% of LFL)	CFD Concentration at building (% of LFL)	Comment
4.1	18.8	5	14	251%	52%	Part of the release impacted the underside of the deck above
4.3	18.8	5	14	251%	Misses	Release angled too steeply such that plume is not pushed back on the TR
15.3	141	10	19	455%	0%	High momentum release cannot be moved by the wind. Negative pressure on the impinged sides

Release Type 4, Releases directly in to target building walls

In some instances there are few obstacles in the way to obstruct a release. These are cases where only grating, or the occasional structural member is in the way. The wind is orientated in the same direction as the release, apart from in the vertical angle to ensure the release reaches the target building.

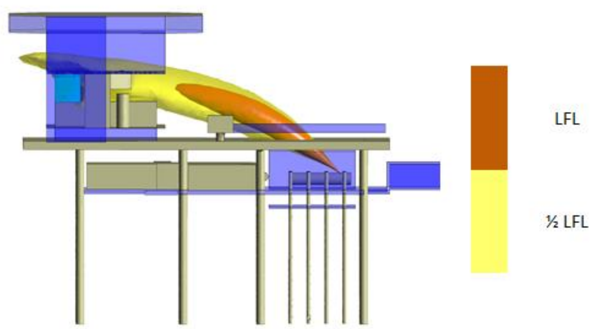


Figure 8: Typical example of a relatively unobstructed release. The plume passes through some grating on the main deck before impinging on the target building

A summary of the types of releases, compared with the results from the phenomenological analysis is given in Table 4.

Table 4: Release Type 4 Simulations Summary

#	Release Rate (kg/s)	Wind speed (m/s)	Distance to Building	Phenomenological Concentration at Building (% of LFL)	CFD Concentration at building (% of LFL)	Comment
20.1	15.6	5	7	389%	1762%	No obstacles at all, directed straight at the TR wall
24.1	15.5	5	9	309%	814%	No obstacles at all, directed straight at TR underside
22.3	16.6	5	10	307%	446%	No obstacles at all
5.1	16.9	5	14	240%	253%	No obstacles. Directed at TR underside
22.1	13.7	15	15	199%	18%	TR extends through an entire internal stairwell leading to high internal pressures. Release does not quite directly impinge either
19.1	5.2	10	31	61%	37%	Passes through a well bay, grating, then between wind walls.

Release Type 5, Releases into a barrier, then the wind carrying the release across a platform

It was sometimes considered that the only way in which a release may impinge on a building was for it to lose it momentum by impacting an obstacle such as a bulkhead or other room, then allow the wind to carry the release to the target building. This scenario is illustrated in Figure 9 below where a well blowout is directed into a wind wall then the diffuse release passes through grating and is carried back towards the platform.

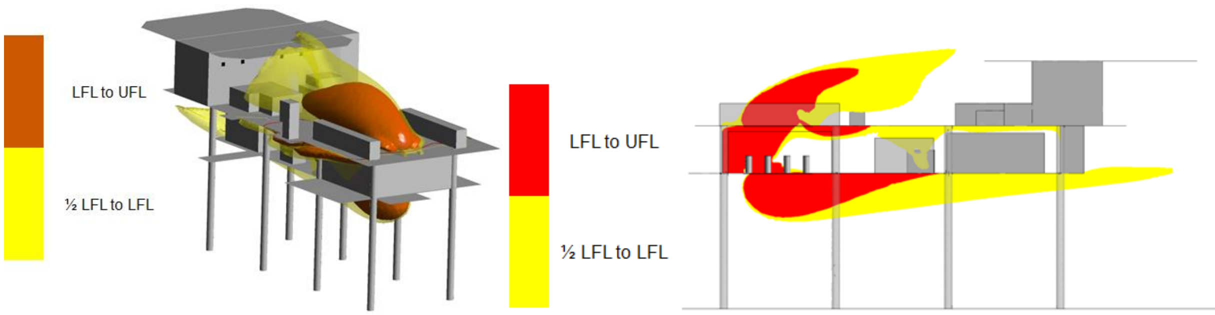


Figure 9: Typical example of a release directed into bulkhead then carried by the wind to the Building. The building of interest in this example is the accommodation module underneath the helideck

A summary of the types of releases, compared with the results from the phenomenological analysis is given in Table 5.

Table 5: Release Type 5 Simulations Summary

#	Release Rate (kg/s)	Wind speed (m/s)	Distance to Building	Phenomenological Concentration at Building (% of LFL)	CFD Concentration at building (% of LFL)	Comment
15.5	11.3	5	21	131%	177%	Building on same level shielded by process equipment and wind walls
2.1	5.2	5	32 / 35	66% / 61%	<<50% LFL	Difficult to ensure the passive release goes in the intended direction
9.3	16.3	5	37	110%	308%	Building on same level shielded by shipping crates and other small buildings

Release Type 6, Releases Directed underneath Buildings

Where there were a lot of obstructions between a release and target building, it was considered that the only reasonable way in which they may interact is if the release were directed downwards into the platform air gap, then rely on the buoyancy of the gas to cause the plume to rise and impinge. This scenario is illustrated in Figure 10 where the target building is located on the right hand side of the platform.

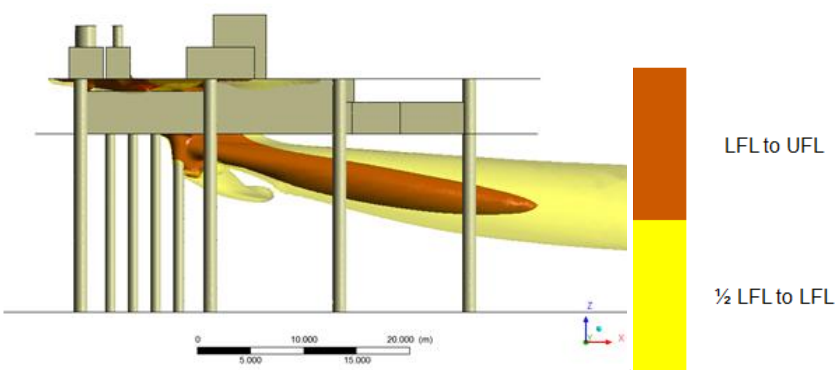


Figure 10: Typical example of a release directed underneath a building, then relying on the buoyancy of the plume to cause impairment of the TR. The target building in this case is located on the far right hand side of the platform.

A summary of the types of releases, compared with the results from the phenomenological analysis is given in Table 6.

Table 6: Release Type 6 Simulations Summary

#	Release Rate (kg/s)	Wind speed (m/s)	Distance to Building	Phenomenological Concentration at Building (% of LFL)	CFD Concentration at building (% of LFL)	Comment
3.1	17.0	5	29	182%	<<50% LFL	Releases momentum does not dissipate fast enough to allow the release to rise
3.3	5.2	5	29	70%	<<50% LFL	As 3.1
6.3	17.5	5	43	120%	<<50% LFL	AS 3.1
9.1	17.5	5	37	114%	<<50% LFL	As 3.1

Conclusions

A summary of CFD gas dispersion scenarios to model gas ingress has been presented in this paper. The key conclusions made are:

- Where it is necessary for a plume to migrate around an angle of approximately 90°, i.e. around a deck or bulkhead (Scenario 1), phenomenological methods tend to overestimate the concentration on the building by a factor of approximately 3 in most cases. The primary reason for this is the entrainment of air as it interacts with the plume and platform structures, which acts to dilute the hazardous plume.
- Of note from the simulations is the fact that where a release occurs in the lee of process equipment or a bulkhead, there is little natural ventilation. This has the effect of significantly reducing turbulent mixing of the release with the surrounding air, leading to higher concentrations at the target buildings when compared to phenomenological models where there is assumed to be an unobstructed line of sight and continuous wind.
- Where a release is directed into the wind, with the intent of the plume momentum being dissipated then carried towards a building (Scenario 2), phenomenological models over predict the concentration at the target building by a factor of approximately 3 in most cases. Where the plume passes through process equipment in CFD cases, the plume dilution is even more pronounced.
- Where gas is released beneath a building but the integrity of the underside of the building is assumed sound (Scenario 3), plumes have been modelled that must first rise to the same elevation as the building then bend round to impinge. In these cases, the high velocity of the gas means it is very likely that the plume will miss the building. If it does not miss, and the plume has a high velocity, negative pressure on the building wall may result due to Bernoulli effects. This would act against gas ingress as the gas inside the building is at a higher pressure.
- Where a release is unobstructed and directed straight into a building wall (Scenario 4), phenomenological models tend to under predict the resulting concentration when compared to CFD. This is believed to be because the releases occur in congested areas where the actual wind speed is much less than the wind speed outside the area. CFD codes can account for this, however phenomenological methods cannot easily do so. With lower ventilation rates, turbulent mixing with the surrounding air and consequent dilution of the plume is less; thus the CFD predicts higher concentrations.
- Where a release is directed into obstacles that serve to reduce the momentum of the release then wind is used to carry the plume to a building (Scenario 5), CFD data again can predict higher concentrations than phenomenological models in some cases. This is similarly believed to be because the obstructions act to reduce the local wind speed which can only be accounted for in CFD codes.
- For the limited number of simulations performed, it has not been possible to direct a release downwards with the intent of gas buoyancy causing the plume to rise and impinge on a building (Scenario 6). Phenomenological methods may therefore significantly overestimate the concentration on buildings in these cases however no specific conclusions should be drawn from this limited data set.

For all releases, in particular scenarios 1, 2, and 3, a very specific release angle, location and wind direction is required to ensure that the plume does not miss the target building. It is for the CFD practitioner to use their expert judgement that where an analysis has been performed, the highest concentration has been obtained.

Further Work

The current study paper only considers gas ingress hazards. Ignited releases and smoke dispersion CFD scenarios have also been modelled and will be reported in a second summary paper.

References

[1] HSL / HSE, "Modelling smoke and gas ingress into offshore temporary refuges, RR997," 2013.

[2] HSE, "Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment," SPC/TECH/OSD/030, 2013.