U.S. Department
of Transportation

**Pipeline and Hazardous
Materials Safety
Administration**

Administrator

1200 New Jersey Avenue SE
Washington, DC 20590

OCT - 7 2011

Dr. Robin Pitblado
Vice President and Director of ISA-1 – SHE Risk Management Services
Det Norske Veritas (USA), Inc.
DNV Energy
1400 Ravello Drive
Katy, TX 77449

Re: PHMSA Docket No. 2011-0075

Dear Dr. Pitblado:

Enclosed please find a Final Decision on your petition for approval of the PHAST-UDM Version 6.6 and 6.7 vapor gas dispersion models. Service of this Final Decision by UPS Overnight Express is deemed effective upon the date of mailing, or as otherwise provided under 49 C.F.R. § 190.5.

Thank you for your cooperation in this matter.

Regards,

Cynthia L. Quarterman

Enclosure

UPS OVERNIGHT EXPRESS - RETURN RECEIPT REQUESTED

U.S. DEPARTMENT OF TRANSPORTATION
PIPELINE AND HAZARDOUS MATERIALS SAFETY ADMINISTRATION
OFFICE OF PIPELINE SAFETY
WASHINGTON, D.C. 20590

In the Matter of	)	
Det Norske Veritas (USA), Inc.,	)	**PHMSA Docket No. 2011-0075**
Respondent.	)	

FINAL DECISION

Det Norske Veritas (USA), Inc. (Petitioner or DNV) has filed a petition for approval (Petition) of the PHAST-UDM (Process Hazard Analysis Software Tool – Unified Dispersion Model) under 49 C.F.R. §§ 190.9 and 193.2059(a).[1] On July 12, 2011, the Pipeline and Hazardous Materials Safety Administration (PHMSA) issued a Draft Decision proposing to approve the Petition and providing the public with a 30-day comment period. After reviewing those comments and making appropriate modifications to the determinations in the Draft Decision, PHMSA is approving the Petition in this Final Decision.

Procedural History

On October 25, 2010, DNV submitted this Petition. It included general information on vapor gas dispersion modeling and specific information about the history and capabilities of PHAST-UDM Version 6.6. As recommended in an August 30, 2010 PHMSA advisory bulletin, it also included a completed Model Evaluation Report with information on the suitability of PHAST-UDM as demonstrated under the three-stage Model Evaluation Protocol.

On February 4, 2011, PHMSA sent DNV a request for additional information relating to the numerical solver used in its validation study, the user input for the model, an uncertainty analysis, and experimental data specific performance measurement values. After additional consultation with PHMSA and the Federal Energy Regulatory Commission (FERC), DNV submitted the requested information on February 11, May 5, and June 8, 2011. The Petitioner also requested that PHAST-UDM Version 6.7 be approved as part of this proceeding, stating

---

[1] The electronic docket for this Petition is available at http://www.regulations.gov/#!searchResults;rpp=10;po=0;s=PHMSA+2011-0075.

that the changes made in that newer version of the model would not affect the scientific assessment or verification or validation results.

On July 12, 2011, PHMSA issued a Draft Decision proposing to approve the Petition and providing the public with a 30-day comment period. PHMSA also published a Notice in the Federal Register on July 18, 2011, stating that the Draft Decision was available for public inspection.[2]

DNV was the only party who offered comments. Those comments, submitted by letter dated August 5, 2011, focused on five aspects of the Draft Decision: (1) the limitation of PHAST-UDM for evaluating dispersion from high aspect ratio sources, such as trenches and line sources; (2) the limitation of PHAST-UDM for evaluating dispersion from releases that are not along the direction of the wind; (3) the recommended safety factor of 2 for the lower flammability limit (LFL); (4) the limitations of the experiments used a part of the current validation study; and (5) the limitation of PHAST-UDM for evaluating multiple, coincident releases from different locations.

Background

PHMSA issues federal safety standards for siting Liquefied Natural Gas (LNG) facilities.[3] Those standards require that an operator or governmental authority exercise control over the activities that can occur within an "exclusion zone," defined as the area around an LNG facility that could be exposed to unsafe levels of thermal radiation or flammable vapor gas in the event of a release or ignition.[4] PHMSA also requires that certain mathematical models be used to calculate the dimensions of these exclusion zones.[5]

Under the current regulations, vapor-gas-dispersion exclusion zones may be calculated using either the DEGADIS Dense Gas Dispersion Model (DEGADIS) or FEM3A.[6] The

---

[2] 76 Fed. Reg. 42163

[3] Pipeline Safety Act of 1979, Pub. L. No. 96-129, § 152, 93 Stat. 989 (1979) (currently codified at 49 U.S.C. § 60103(a)).

[4] 49 C.F.R. § 193.2007 (defining exclusion zone).

[5] 49 C.F.R. §§ 193.2057-2059.

[6] Liquefied Natural Gas Regulations—Miscellaneous Amendments, 62 Fed. Reg. 8402 (Feb. 25, 1997) (incorporating "the model described in the Gas Research Institute Report GRI-89/0242 . . ., 'LNG Vapor Dispersion Prediction with the DEGADIS Dense Gas Dispersion Model.'"); Pipeline Safety: Incorporation of Standard NFPA 59A in the Liquefied Natural Gas Regulations 65 Fed. Reg. 10950 (March 1, 2000) (incorporating FEM3A "to account for additional cloud dilution which may be caused by the complex flow patterns induced by tank and dike structure.").

Administrator may also approve the use of alternative vapor-gas dispersion models that "take into account the same physical factors and have been validated by experimental test data."[7]

On August 30, 2010, PHMSA issued an Advisory Bulletin with guidance on obtaining approval of alternative vapor gas dispersion models.[8] The Advisory Bulletin stated that a petitioner could seek the Administrator's approval of an alternative vapor gas model by following the three-stage Model Evaluation Protocol (MEP) and submitting a Model Evaluation Report (MER) with satisfactory information about the proposed model.[9] As the Advisory Bulletin explained:

> The MEP is based on three distinct phases: scientific assessment, model verification and model validation. The scientific assessment is carried out by obtaining detailed information on a model from its current developer using a specifically designed questionnaire and with the aid of other papers, reports and user guides. The scientific assessment examines the various aspects of a model including its physical, mathematical and numerical basis, as well as user oriented aspects. . . . The outcome of this scientific assessment is recorded in a[n] [MER] . . . , along with the outcomes of the verification and validation stages. . . .
>
> [In] [t]he verification stage of the protocol[,] . . . evidence . . . is sought from the model developer and this is then assessed and reported in the MER. The validation stage of the MEP involves applying the model against a database of experimental test cases including both wind tunnel experiments and large-scale field trials. The aim of the validation stage is . . . to quantify the performance of a model by comparison of its predictions with measurements.[10]

---

[7] 49 C.F.R. §§ 193.2057(a), 193.2059(a); *see also* 49 C.F.R. § 190.11 (2010) (authorizing the submission of petition for finding or approval with the Administrator).

[8] Liquefied Natural Gas Facilities: Obtaining Approval of Alternative Vapor-Gas Dispersion Models, 75 Fed. Reg. 53371-53374 (Aug. 31, 2010).

[9] An industry-commissioned panel of experts in the field of consequence modeling developed the MEP and MER in the late 2000s. M.J. Iving et al., Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities Research Project: Technical Report (Apr. 2007) (available at www.nfpa.org) (Original FPRF Report), and supplemented in S. Coldrick et al., Validation Database for Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities: Guide to the LNG Model Validation Database, Version 11.0 (May 2010) (available at www.nfpa.org) (Supplemental FPRF Report). A PHMSA-commissioned panel of experts performed an independent review of the MEP and produced a separate technical report, National Association of State Fire Marshals, Review of the LNG Vapor Dispersion Model Evaluation Protocol (Jan. 2009) (NASFM MEP Report); *see also* National Association of State Fire Marshals, Review of the LNG Source Term Models for Hazard Analysis: A Review of the State-of-the-Art and an Approach to Model Assessment (Jun. 2009) (NASFM Source Term Report).

[10] 75 Fed. Reg. at 53372.

The Advisory Bulletin further stated that a petitioner should consider addressing other concerns in completing the MEP and MER; that the guidance it contained was not binding and may require modification or clarification in appropriate cases; and that a petitioner could seek the Administrator's approval of an alternative vapor gas dispersion model by any other appropriate means.

Analysis[11]

Evaluating the suitability of an alternative vapor gas dispersion model is a task that involves "making predictions, within [PHMSA's] area of special expertise."[12] The Advisory Bulletin provided interested parties with guidance on obtaining approval of an alternative vapor gas dispersion model under 49 C.F.R. § 193.2059(a).[13] DNV followed that guidance in preparing this Petition, i.e., it subjected PHAST-UDM to the MEP and submitted an MER with detailed information about its model, including the results of the scientific assessment, verification, and validation.

In the Draft Decision, PHMSA noted that it had reviewed the information submitted by DNV and determined that PHAST-UDM could be used to calculate the vapor gas dispersion exclusion zone for an LNG facility in certain scenarios.[14] PHMSA also asked the public to comment on its determinations.

Response to Public Comments

DNV submitted comments on five aspects of the Draft Decision. First, DNV asked for removal of the limitation of PHAST-UDM for evaluating dispersion from high aspect ratio sources, such as trenches and line sources.

---

[11] This analysis relates solely to the use of PHAST- UDM for the purpose of complying with the specific requirements of 49 C.F.R. Part 193 and is not intended authorize or restrict its use in any other applications.

[12] *Baltimore Gas and Electric Company v. Natural Resources Defense Council*, 462 U.S. 87, 103 (1983); *see Wisconsin Electric Power Company v. Costle*, 715 F.2d 323, 329 (7th Cir. 1983) (upholding EPA's use of a particular dispersion model and stating that its "choice to rely on an air quality model is a policy judgment deserving great deference.").

[13] *Howmet Corp. v. E.P.A.*, 614 F.3d 544, 549 (D.C. Cir. 2010) (describing strong level of deference owed to agency in administering technically complex regulations).

[14] PHMSA agrees with DNV that the conclusions from PHAST-UDM Version 6.6 and 6.7 evaluations are appropriate for both versions of the model. Therefore, all references to UDM cover both versions, except where noted.

As stated in Section 2.1.1.2 of the Advisory Bulletin, Source Geometry Handled by the Dispersion Model, the proponent of an alternative model should describe and clearly state the limitations of the model for handling different source terms, including the ability to handle dispersion from geometries with high aspect ratios (i.e., long trenches) in the cross-wind and parallel wind direction. DNV stated in its Petition that the UDM model allows time-varying pools using pool segmentation, that the pool is modeled as an equivalent circle with uniform thickness, and that long trenches cannot be modeled.

The Petitioner commented that PHAST-UDM is suitable for high aspect ratio sources, such as trenches and line sources, and provided information regarding the validation of the PHAST-UDM against the McQuaid wind-tunnel experiments from ground-level line sources with wind speed perpendicular to the line source. To model these release scenarios, the PHAST-UDM model requires changes to the PHAST-UDM Version 6.6 and 6.7 code and non-default parameters. Since the PHAST-UDM code would require modification from the evaluated PHAST-UDM Version 6.6 and 6.7 to model geometries with high aspect ratios (i.e., trenches or line sources) in the cross-wind direction, PHMSA concludes that PHAST-UDM Version 6.6 and 6.7 cannot be approved for such use, and that the limitation in the Draft Decision is still appropriate. If DNV makes an appropriate modification in a subsequently-released version of the code, it can submit another petition for approval that reflects these changes.

In the second comment, DNV asked for the removal of the limitation of PHAST-UDM for evaluating dispersion from releases that are not along the direction of the wind. The Petitioner stated that presuming the direction along the wind is a worst-case assumption—and, therefore, gives conservative results in case the direction is not along the wind direction— and that only in the case of high momentum releases would there be potentially be a significant deviation of the PHAST-UDM predictions.

As stated in the Draft Decision, PHMSA agrees that assuming the release is along the direction of the wind is conservative (i.e., worst case). PHMSA also agrees that the deviation of the dispersion distance model prediction would be dependent on the release directionality and the momentum of the release. These points have been further clarified in the Final Decision. In addition, PHMSA has clarified in this Final Decision that the conservative assumption that the release is along the direction of the wind (i.e., worst case) is appropriate for 49 C.F.R. § 193.2059 applications and not seen as a limitation.

DNV's third comment acknowledged that the recommended safety factor of 2 for the LFL is in line with the default values for both LFL and 0.5 LFL provided by UDM-PHAST Version 6.6 and 6.7.

DNV's fourth comment requested clarification of the fact that the current validation study is limited to experiments carried out as part of the PHMSA validation study, and that substantially more validation has been carried out by DNV. The MEP evaluates a model against a limited dataset intended to represent the dispersion of LNG vapors, and is not all inclusive of other validation datasets that a model may be validated against. Further clarification has been added to the Final Decision that the current validation study is limited to trials specified in the MEP.

DNV's last comment requested the removal of the limitation of PHAST-UDM for evaluating multiple, coincident releases from different locations. The Petitioner stated that if the multiple releases are sufficiently separated, such that they do not significantly overlap in the near-field jet or heavy region, that it is recommended that the user sums up the concentrations from the two separate PHAST calculations. DNV also stated that if the multiple releases are sufficiently close, such that they can be combined, that it is recommended that the user treats the releases as a single release with appropriate consideration of conservation of total mass release rate, total release momentum, etc.

PHMSA has clarified in the Final Decision that UDM may not be suitable to model multiple concurrent releases at different locations where the dispersion characteristics of the multiple releases may influence each other. PHMSA has also clarified that the evaluation of a LNG design spill under 49 CFR Part 193 currently requires the examination of specific scenarios with a single release, and therefore the assumption of a single release that is not influenced by other coincident LNG design spills is appropriate for 49 C.F.R. § 193.2059 applications and not seen as a limitation.

Other Issues

PHMSA noticed during additional review of the Draft Decision that further clarification may be needed in the following areas.

The stated limitations in the beginning of the Draft Decision did not include the recommended safety factor necessary to compensate for model uncertainty or the statement regarding the conservative nature of the ambient conditions required per 49 CFR § 193.2059 as was stated at the end of the Draft Decision. These statements have been included in both locations in the Final Decision.

The term "aspect ratio" is intended to represent the ratio of the length of the source term relative to the width of the source term (e.g., ratio of the surface dimensions of the impoundment), and is not intended to represent the ratio of the length or width relative to the depth of an impoundment. Therefore, sources with high aspect ratios would include long trenches or channeled liquid flow, while low aspect ratio would include square and most rectangular impoundments or radial liquid flow. The spill containment layout and pool spread calculations should be included with model submissions for use in exclusion zone calculations.

The term "sloped terrain" is not intended to prohibit dispersion over upward slopes or moderately graded slopes. Site grade information should be included with model submissions for use in exclusion zone calculations.

Additional clarifications and information that should be included with model submissions for use in exclusion zone calculations has also been provided throughout the document.

Summary of Findings, Limitations, and Conclusions

UDM may be used to model the maximum arc-wise concentration for:

- Dispersion from circularly shaped LNG pools;
- Dispersion from LNG pools in impoundments with low-aspect ratios (ratio of the surface dimensions of the impoundment); or
- Dispersion from releases in any direction (horizontal, vertical, or otherwise), including releases from flashing, venting, vent stacks, and pressure relief discharge.

However, UDM may not be appropriate to be used to model the maximum arc-wise concentration for:

- Dispersion from irregularly shaped LNG pools;
- Dispersion from LNG pools with high-aspect ratios, including some impoundments and nearly all trenches; or
- Dispersion from multiple coincident releases that may influence each other from multiple release locations;

In some cases, UDM may also not be appropriate to be used to model the maximum arc-wise concentration for:

- Dispersion over varying or sloped terrain; or
- Dispersion between large obstructions that may cause wind-channeling.

The ambient conditions required under 49 C.F.R. § 193.2059 should produce conservative results (i.e., higher downwind gas concentrations and dispersion distances) and should be used.

UDM should be used with a safety factor of 2 (i.e., ½ LFL) to compensate for uncertainties related to potential turbulent fluctuations, source term specification, wind tunnel experiment validation results, dispersion over water, and low wind speed and high atmospheric stability validation results.

Scientific Assessment

Unified Dispersion Model (UDM) is an integral model developed by Det Norske Veritas (DNV) that is part of a larger linked software package, Process Hazards Analysis Software

Tool (PHAST). UDM is intended to simulate continuous, instantaneous, and time-varying release gas concentrations, advecting downwind, with parameterized turbulent diffusion coefficients and top and edge entrainment velocity. Crosswind and vertical concentration profiles are based on similarity shapes. UDM also predicts for the centerline temperature using an equilibrium (with or without chemical reaction) or non-equilibrium (without chemical reaction) thermodynamics model, and includes heat transfer from the air, from relative humidity phase changes, from the free and forced convection at the ground, and from chemical reactions (applicable to hydrogen fluoride (HF) polymerization only).

Numerical solver

UDM Version 6.6 solves ordinary differential equations (ODE) using two methods – a default Runge-Kutta-Milne method using a variable step, and an optional public domain ODE solver, the Double precision Livermore Solver for Ordinary Differential equations - Implicit (DLSODI) from the ODEPACK suite developed at the Center for Applied Scientific Computing of Lawrence Livermore National Laboratories. The validation database that DNV submitted to PHMSA used the more robust optional DLSODI solver, which is the default solver in UDM Version 6.7. Therefore, the approval is limited to the DLSODI solver for 49 C.F.R. § 193.2059 applications.

User input/output

UDM requires the specification of the material properties, release conditions, scenario type, and corresponding scenario data. UDM contains a list of 59 materials and associated properties based on the Design Institute for Physical Properties (DIPPR) database, which includes all the major components that constitute typical LNG compositions. The user also has access to the more than 1600 chemicals in the entire DIPPR database, and has the ability to alter the defined materials and properties or define other materials and properties not included in the DIPPR database. UDM may be purchased to model a single-component or multiple-components. The release conditions may be specified based on temperature and pressure or based on the corresponding condition of a saturated liquid. The corresponding phase to be released (i.e., vapor, liquid, or two-phase) is then automatically generated based on the release conditions chosen. The scenario type specified will be dependent on the release scenario considered and may be specified as a catastrophic rupture, leak, line rupture, fixed duration, long pipeline, disc rupture, relief valve, vent from vapor space, or tank roof failure. Corresponding scenario data (e.g., hole diameter, pump head, etc) may then be specified. Based on information supplied, UDM automatically guides subsequent options and selects the appropriate type of release model (i.e., instantaneous, continuous, or time-varying).

UDM includes a unified linked source term model to simulate the flashing of superheated liquid release, the formation, vaporization, and rainout of aerosol droplets of a pressurized liquid release, and the formation, vaporization, and spreading of a liquid pool after rainout.

UDM may not be suitable to model multiple concurrent releases at different locations where the dispersion characteristics of the multiple releases may influence each other. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which references sections 2.2.3.3 and 2.2.3.4 of NFPA 59A (2001 edition). Section 2.2.3.3 and 2.2.3.4 of NFPA 59A (2001 edition) requires the evaluation of a LNG design spill specified in 2.2.3.5, which requires the examination of specific scenarios with a single release; therefore the assumption of a single release that is not influenced by other releases is appropriate for 49 C.F.R. § 193.2059 applications and not seen as a limitation.

The input and output parameters should be included with model submissions for use in exclusion zone calculations.

Liquid flashing and jetting

UDM assumes the release is along the direction of the wind (i.e., worst case). UDM may not be suitable for releases that are not along the direction of the wind where release directionality is important (e.g., unobstructed high momentum releases). For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which does not specify a wind direction relative to the release direction. However, 49 C.F.R. § 193.2059 gives deference to conditions that result in longer predicted downwind dispersion distances; therefore, the conservative assumption that the release is along the direction of the wind (i.e., worst case) is appropriate for 49 C.F.R. § 193.2059 applications and not seen as a limitation.

Liquid pool spreading

The PHAST pool model, PVAP, must be preceded by a liquid jet. The pool model vaporization assumes the source is vertically oriented, circular geometry with no momentum. Therefore, for the formation of liquid pools, UDM is limited to vertically oriented, low-momentum releases with regular geometries, such as vapors emanating from circular or rectangular sources (i.e., liquid pools or sumps). UDM cannot be used for releases that result in the emanation of vapors from irregular or high aspect ratio sources (i.e., trenches, or irregular liquid pools).

Wind profile

UDM is limited to simulating steady state wind profiles. UDM cannot model transient wind speed or direction. Assuming a steady state wind speed and direction is often sufficient for hazard analyses, but can pose limitations in validation against experimental data where varying wind speed and direction may affect the experimental results. Assuming a steady wind direction will generally produce higher concentrations, because there would be less cloud meander and turbulent mixing caused from the change in wind direction. Steady state wind speed and direction is not expected to be a limitation of the model for 49 C.F.R. § 193.2059 applications. UDM must be supplied with a non-zero wind speed. Assuming lower wind speeds will generally result in higher downwind concentrations and assuming a higher wind speed will generally result in lower downwind concentrations. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the use of weather conditions that occur 90% of time for the area that result in longer predicted downwind dispersion distances than other weather conditions, or alternative conditions with a wind speed of 4.5 mph (2.01 m/s) at reference height of 10 meters for models that result in longer predicted downwind dispersion distances at lower wind speeds. The weather conditions reflective of the site should be included with model submissions for use in exclusion zone calculations. If alternative weather conditions are specified, the dispersion distances should be verified to produce the worst case results.

Sloped and varying level terrain

Sloped or varying terrain will affect the gravity spreading of a dense gas release. For dense gas releases, such as LNG vapor, the cloud will be stretched out as the dense gas plume flows along downward slopes. Therefore, for downward slopes, the centerline concentrations may be over-predicted in the near field, but under-predicted in the far field. Correspondingly, cross-wise concentrations and cloud widths may be over-predicted in the near field, but under-predicted in the far field. In contrast, upward slopes will oppose the movement of the dense gas, causing the vapor to accumulate and spread perpendicular to the upward slopes. Therefore, for upward slopes, the centerline concentrations may be under-predicted in the near field, but over-predicted in the far field. Correspondingly, cross-wise concentrations and cloud widths may be under-predicted in the near field, but over-predicted in the far field. UDM cannot account for sloped or varying terrain. Therefore, UDM was not validated against sloped terrain tests, since it is not designed to simulate those scenarios. Accordingly, there may be cases where UDM should not be used to model dispersion along downward slopes or varying terrain where the model may under-predict concentrations. Site grade information should be included with model submissions for use in exclusion zone calculations.

Varying surface roughness terrain

UDM is limited to the specification of a single surface roughness. UDM cannot account for terrain with varying surface roughness length. Assuming a uniform surface roughness is often sufficient. Assuming a higher surface roughness will generally result in lower downwind concentrations and assuming a lower surface roughness will generally result in higher downwind concentrations. UDM should be specified with the lowest surface roughness that is reflective of the area to produce conservative results. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the surface roughness of 0.03 m or higher. The 0.03 m surface roughness prescribed in 49 C.F.R. § 193.2059 would generally provide reasonable, or conservative, results for LNG releases that disperse over land. Higher surface roughness values may be used if it can be shown that the terrain both upwind and downwind of the vapor cloud has dense vegetation and that the vapor cloud height is more than ten times the height of the obstacles encountered by the vapor cloud. Lower surface roughness values should be considered for LNG releases that disperse over water. Site location should be included with model submissions for use in exclusion zone calculations.

Atmospheric stability

UDM is able to model stable, neutral and unstable atmospheric stabilities. Lower atmospheric stabilities generally produced lower downwind concentrations and dispersion distances, and higher atmospheric stabilities produced higher downwind concentrations and dispersion distances. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the use of weather conditions that occur 90% of time for the area that result in longer predicted downwind dispersion distances than other weather conditions, or alternative conditions with an atmospheric stability (Pasquill-Gifford Class) of F.

The F stability prescribed in 49 C.F.R. § 193.2059 would generally provide reasonable, or conservative, results for LNG releases that disperse over land or water. The weather conditions reflective of the site should be included with model submissions for use in exclusion zone calculations. If alternative weather conditions are specified, the dispersion distances should be verified to produce the worst case results.

Obstructed flow

UDM does not explicitly model turbulence generated in the flow field from obstructions and cannot take into account the change in flow field around obstructions that are relatively larger than the vapor cloud. For most instances, downwind concentrations assuming unobstructed terrain will be over-predictive since less turbulence, and subsequent mixing, would be generated in the flow field and no obstructions would restrict the movement of the dispersing vapor. However, there are instances where downwind concentrations could be under-predictive due to wind channeling effects (Melton & Cornwell, 2009, Gavelli 2011) or reduction of release momentum. Wind channeling may occur between adjacent LNG storage tanks, buildings, or large structures, which may result in the model being under-predictive for concentrations. A reduction of the release momentum may occur when a high momentum release impinges on an obstruction, which may result in less turbulent mixing from the initial release and the model being under-predictive for downwind concentrations. UDM includes a sub-model to take into account the loss of momentum due from an impinged release and a sub-model for building wake effects. However, the building wake effects are based on passive dispersion releases from atop and around a rectangular structure that may not have the same characteristics of a dense gas dispersion release around storage tanks. Therefore, there may be cases where UDM should not be used to model releases if releases channel between large adjacent structures. In addition, there may be cases where UDM should account for the loss of momentum, if the release impinges on an obstruction. The facility layout should be included with model submissions for use in exclusion zone calculations.

UDM accounts for atmospheric turbulent mixing and dilution through the use of empirically derived turbulent mixing coefficients and top and edge entrainment. UDM does not explicitly calculate stochastic fluctuations due to turbulence in the flow field. Stochastic fluctuations in concentration can result in concentrations higher or lower than predicted. Therefore, it is recommended that concentrations should be provided with a safety factor of 2 for the LFL to account for estimated peak to mean turbulent fluctuations. In addition, UDM assumes a no-momentum release and therefore does not take into account possible turbulence generated by the release. Assuming no turbulence at a low-momentum source (i.e., turbulence generated at the surface of a boiling pool) will generally result in higher downwind concentrations because there is less turbulent mixing.

Verification

UDM numerical results have been verified against a number of "simple" analytical solutions (i.e., not using differential equations, but non-linear equations for unknown variables only).

For more "complex" scenarios where analytical solutions do not exist, UDM has been compared against well-known correlations and other dispersion models. The verification covers multiple components of the model (e.g., dense gas dispersion, passive dispersion, finite-duration releases, thermodynamics, etc) and includes sensitivity analyses to a number of variables. The UDM numerical results for heavy gas dispersion was shown to be identical to an analytical solution for a 2-D isothermal ground level plume, and compares well against DEGADIS and the HGSYSTEM models HEGADAS and AEROPLUME; the UDM numerical results for jet and near-field passive dispersion was shown to be identical to an analytical solution for an elevated horizontal continuous jet of air; and the UDM numerical results for far-field passive dispersion to be in close agreement with the vertical and crosswind dispersion coefficients and concentrations from the commonly adopted Gaussian passive dispersion formula. The transition from dense to passive dispersion has also been compared to HGSYSTEM and SLAB and shows good agreement.

In addition to the UDM numerical solutions being identical to the limited number of analytical solutions, DNV has an extensive quality management system that helps assure the models have been translated into the code correctly, including a line-by-line check to confirm consistency against the documented theory. DNV adheres to many of the quality assurance publications, certifications, and standards. DNV is covered by the ISO 9001 standard, which requires formal quality systems for DNV, including its software division. The company also adheres to TickIT, a variant of ISO 9001 developed for software businesses, which requires a number of software development and maintenance specific items, such as a software "bug" tracking log reported by users of the software. The software is proprietary and its executable files are available at a cost to the public.

Validation

As discussed in "Scientific Assessment," the UDM is limited to dispersion over unobstructed level terrain specified by the user. Therefore, the current validation study is limited to the following trials specified in the Model Evaluation Protocol:

- LNG Field Trials: Maplin Sands 27, 34, 35; Burro 3, 7, 8, 9; Coyote 3, 5, 6;
- Other Field Trials: Thorney Island 45, 47;
- Wind Tunnel Experiments: CHRC A; BA-Hamburg DA0120 (Unobstructed), DAT223 (Unobstructed 2); and BA-TNO TUV01, FLS.

UDM met all of the MEP quantitative acceptance criteria with the exception of wind tunnel tests and maximum point-wise concentrations for field trials with long time averages, as shown in Table 1. As shown in Table 1, and supported by the statistical performance measure values, UDM is generally under-predictive of maximum arc-wise concentrations for field trials with short time averages, and over-predictive of maximum arc-wise concentrations for field trials with long time averages. A large majority of UDM maximum arc-wise concentration predictions for field trials are within a factor of 2. UDM is generally under-predictive of wind tunnel tests by a factor of 3. Similarly, UDM maximum gas concentration arc-wise distance predictions are generally under-predictive for short time averages and slightly over-predictive for long time-averages with a large majority being within a factor of 2. However, UDM maximum gas concentration arc-wise distance predictions fair better and are generally within a factor of 2.

UDM maximum point-wise predictions are generally over-predictive for field trials with short and long time averages, with higher over-prediction for longer time averages. UDM maximum point-wise predictions are generally under-predictive for wind tunnel trials. A majority of UDM maximum point-wise concentration predictions were within a factor of 2, but showed a moderate degree of scatter among the predictions. UDM cloud width predictions for all trials agree very well with experimental cloud width calculations with very little scatter. All UDM cloud width predictions were within a factor of 2.

Table 1:
SPM Evaluation against Quantitative Assessment Criteria: Averaged

Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Arc-wise Gas Concentration									
Field Trials (Short Time Avg.)	0.34	1.47	0.45	1.77	67%	0.82	0.88	N/A	N/A
Field Trials (Long Time Avg.)	-0.09	0.91	0.31	1.41	76%	1.28	N/A	N/A	N/A
Wind-Tunnel Tests (Scaled)	0.99	3.09	1.11	4.31	9%	0.36	N/A	N/A	N/A
Maximum Gas Concentration Arc-wise Distance									
Field Trials (Short Time Avg.)	0.29	1.37	0.31	1.46	82%	N/A	N/A	0.82	1.30
Field Trials (Long Time Avg.)	-0.04	0.97	0.22	1.29	87%	N/A	N/A	1.15	N/A
Wind-Tunnel Tests (Scaled)	0.66	2.01	0.50	1.74	40%	N/A	N/A	0.52	N/A
Maximum Point-wise Gas Concentration									
Field Trials (Short Time Avg.)	0.06	1.05	0.37	1.70	74%	1.39	N/A	N/A	N/A
Field Trials (Long Time Avg.)	-0.22	0.75	0.53	2.40	65%	2.43	N/A	N/A	N/A
Wind-Tunnel Tests (Scaled)	0.79	2.48	0.92	3.88	29%	0.56	N/A	N/A	N/A
Cloud Width									
Field Trials (Short Time Avg.)	0.07	1.07	0.02	1.02	100%	N/A	N/A	0.94	N/A
Field Trials (Long Time Avg.)	0.05	1.05	0.03	1.03	100%	N/A	N/A	0.96	N/A
Wind-Tunnel Tests (Scaled)	-0.04	0.96	0.01	1.01	100%	N/A	N/A	1.05	N/A

However, the MEP specific performance measures and quantitative acceptance criteria are based on an average of all the trials, which can be misleading. Therefore, the Advisory Bulletin recognized that the approval or disapproval of a model should not be contingent only on the average of the experiments meeting the MEP quantitative acceptance criteria. Careful examination of all the sensor data and trends must be considered in concert with the MEP quantitative acceptance criteria. As shown in Figure 1 and Table 2, these trends provide additional insight into the model performance against subsets of data.

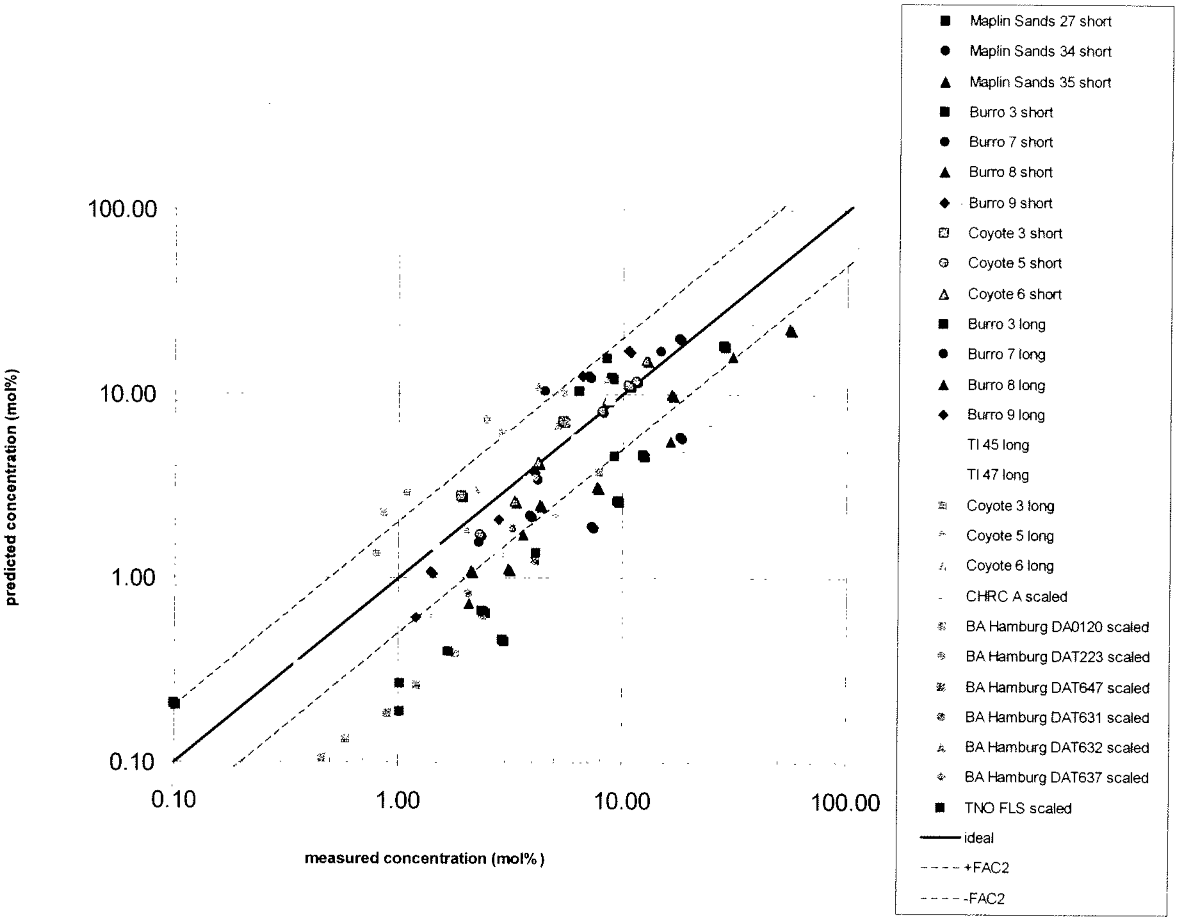

Figure 1 Predicted Concentration against Measured Concentration

Table 2:
SPM Evaluation against Quantitative Assessment Criteria: Averaged Test Data

Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Arc-Wise Gas Concentration									
Maplin Sands 27 (short)	**1.24**	**2.54**	1.20	**5.16**	**0%**	0.64	**0.38**	N/A	N/A
Maplin Sands 34 (short)	**1.10**	**3.45**	1.21	**4.70**	**0%**	**0.29**	**0.24**	N/A	N/A
Maplin Sands 35 (short)	**0.89**	**2.61**	0.79	2.51	**0%**	**0.38**	**0.38**	N/A	N/A
Burro 3 (short)	0.06	1.06	0.14	1.15	100%	1.01	**2.17**	N/A	N/A
Burro 3 (long)	**-0.53**	**0.58**	0.28	1.35	100%	1.72	N/A	N/A	N/A
Burro 7 (short)	-0.03	0.97	0.21	1.24	100%	1.14	0.91	N/A	N/A
Burro 7 (long)	-0.18	0.82	0.26	1.33	67%	1.37	N/A	N/A	N/A
Burro 8 (short)	**0.63**	**1.92**	0.41	1.57	75%	0.53	0.58	N/A	N/A
Burro 8 (long)	**0.82**	**2.42**	0.70	2.26	**25%**	**0.42**	N/A	N/A	N/A
Burro 9 (short)	-0.06	0.94	0.10	1.10	100%	1.12	1.08	N/A	N/A
Burro 9 (long)	0.11	1.12	0.30	1.37	100%	1.05	N/A	N/A	N/A
Coyote 3 (short)	-0.23	0.79	0.07	1.08	100%	1.28	1.33	N/A	N/A
Coyote 3 (long)	**-0.74**	**0.46**	0.56	1.86	**33%**	**2.20**	N/A	N/A	N/A
Coyote 5 (short)	0.11	1.12	0.03	1.03	100%	0.90	0.89	N/A	N/A
Coyote 5 (long)	**-0.82**	**0.42**	0.70	2.26	**25%**	**2.46**	N/A	N/A	N/A
Coyote 6 (short)	-0.02	0.98	0.03	1.03	100%	1.03	1.04	N/A	N/A
Coyote 6 (long)	-0.22	0.80	0.08	1.08	100%	1.26	N/A	N/A	N/A
Thorney Island 45 (long)	0.14	1.15	0.11	1.12	100%	0.91	N/A	N/A	N/A
Thorney Island 47 (long)	-0.03	0.97	0.14	1.15	100%	1.10	N/A	N/A	N/A
CHRC A (scaled)	**0.94**	**2.83**	0.93	3.16	**0%**	**0.37**	N/A	N/A	N/A
Hamburg DA0120 (scaled)	**1.17**	**3.89**	1.40	**6.78**	**0%**	**0.27**	N/A	N/A	N/A
Hamburg DAT 223 (scaled)	0.39	**1.51**	0.36	1.48	67%	0.74	N/A	N/A	N/A
TNO FLS (scaled)	**1.09**	**3.49**	1.24	**5.23**	**0%**	**0.30**	N/A	N/A	N/A

Table 2 (cont'd):
SPM Evaluation against Quantitative Assessment Criteria: Averaged Test Data

Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Gas Concentration Arc-Wise Distance									
Maplin Sands 27 (short)	1.30	2.60	0.81	2.60	20%	N/A	N/A	0.39	0.54
Maplin Sands 34 (short)	0.59	1.83	0.35	1.45	100%	N/A	N/A	0.55	0.41
Maplin Sands 35 (short)	0.70	2.08	0.50	1.74	67%	N/A	N/A	0.48	0.54
Burro 3 (short)	0.19	1.23	0.25	1.30	100%	N/A	N/A	0.91	5.72
Burro 3 (long)	-0.67	0.49	0.55	1.93	50%	N/A	N/A	2.19	N/A
Burro 7 (short)	-0.20	0.82	0.14	1.16	100%	N/A	N/A	1.29	0.94
Burro 7 (long)	-0.29	0.74	0.20	1.23	100%	N/A	N/A	1.42	N/A
Burro 8 (short)	0.68	2.19	0.67	2.72	75%	N/A	N/A	0.53	0.66
Burro 8 (long)	0.93	2.84	0.94	3.42	25%	N/A	N/A	0.37	N/A
Burro 9 (short)	-0.11	0.89	0.09	1.10	100%	N/A	N/A	1.17	1.06
Burro 9 (long)	0.01	1.01	0.14	1.16	100%	N/A	N/A	1.07	N/A
Coyote 3 (short)	-0.12	0.88	0.02	1.02	100%	N/A	N/A	1.13	1.13
Coyote 3 (long)	-0.38	0.68	0.15	1.16	100%	N/A	N/A	1.47	N/A
Coyote 5 (short)	-0.03	0.97	0.00	1.00	100%	N/A	N/A	1.00	0.95
Coyote 5 (long)	-0.56	0.56	0.33	1.42	75%	N/A	N/A	1.71	N/A
Coyote 6 (short)	-0.02	0.98	0.01	1.01	100%	N/A	N/A	1.03	1.02
Coyote 6 (long)	-0.15	0.86	0.04	1.04	100%	N/A	N/A	1.17	N/A
Thorney Island 45 (long)	0.12	1.13	0.06	1.07	100%	N/A	N/A	0.91	N/A
Thorney Island 47 (long)	-0.05	0.95	0.03	1.03	100%	N/A	N/A	1.07	N/A
CHRC A (scaled)	0.66	2.02	0.49	1.74	67%	N/A	N/A	0.51	N/A
Hamburg DA0120 (scaled)	0.79	2.32	0.64	2.04	13%	N/A	N/A	0.43	N/A
Hamburg DAT 223 (scaled)	0.21	1.24	0.10	1.10	100%	N/A	N/A	0.83	N/A
TNO FLS (scaled)	0.71	2.11	0.52	1.77	33%	N/A	N/A	0.48	N/A

Table (cont'd):
SPM Evaluation against Quantitative Assessment Criteria: Averaged Test Data

Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	**0.67< MG<1.5**	**MRSE<2.3**	**VG<3.3**	**FAC2 >50%**	**0.5<CSF<2**	**0.5< CSF_LFL<2**	**0.5<DSF<2**	**0.5< DSF_LFL<2**
Maximum Point-Wise Gas Concentration									
Burro 3 (short)	0.92	1.35	0.18	1.22	86%	0.78	N/A	N/A	N/A
Burro 3 (long)	0.51	0.70	0.21	1.25	100%	1.49	N/A	N/A	N/A
Burro 7 (short)	-0.06	0.85	0.63	3.87	80%	3.13	N/A	N/A	N/A
Burro 7 (long)	-0.52	0.48	1.01	9.46	40%	6.12	N/A	N/A	N/A
Burro 8 (short)	0.03	1.03	0.26	1.33	82%	1.12	N/A	N/A	N/A
Burro 8 (long)	0.25	1.30	0.27	1.36	76%	0.87	N/A	N/A	N/A
Burro 9 (short)	0.02	1.02	0.15	1.17	100%	1.06	N/A	N/A	N/A
Burro 9 (long)	0.27	1.34	0.39	1.58	70%	0.89	N/A	N/A	N/A
Coyote 3 (short)	0.29	1.36	0.28	1.37	63%	0.82	N/A	N/A	N/A
Coyote 3 (long)	-0.30	0.73	0.21	1.25	75%	1.46	N/A	N/A	N/A
Coyote 5 (short)	0.40	1.60	0.61	2.27	50%	0.82	N/A	N/A	N/A
Coyote 5 (long)	-0.48	0.57	0.68	2.47	45%	2.30	N/A	N/A	N/A
Coyote 6 (short)	-0.42	0.62	0.45	1.75	58%	1.91	N/A	N/A	N/A
Coyote 6 (long)	-0.65	0.43	0.88	5.38	58%	4.16	N/A	N/A	N/A
CHRC A (scaled)	0.60	1.94	0.77	2.69	38%	0.78	N/A	N/A	N/A
Hamburg DAT 223 (scaled)	0.61	1.92	0.51	1.79	38%	0.57	N/A	N/A	N/A
BA TNO TUV01 (scaled)	0.88	2.74	0.92	3.72	38%	0.42	N/A	N/A	N/A
BA TNO FLS (scaled)	1.02	3.37	1.18	6.85	15%	0.35	N/A	N/A	N/A

Table 2 (cont'd):
SPM Evaluation against Quantitative Assessment Criteria: Averaged Test Data

Data Set	Quantitative Criteria								
	-0.4<MRB <0.4	0.67< MG<1.5	MRSE<2.3	VG<3.3	FAC2 >50%	0.5<CSF<2	0.5< CSF_LFL<2	0.5<DSF<2	0.5< DSF_LFL<2
Cloud Width									
Burro 3 (short)	0.10	1.10	0.01	1.01	100%	N/A	N/A	0.91	N/A
Burro 3 (long)	0.09	1.10	0.03	1.03	100%	N/A	N/A	0.92	N/A
Burro 7 (short)	0.02	1.02	0.01	1.01	100%	N/A	N/A	0.99	N/A
Burro 7 (long)	-0.06	0.94	0.02	1.02	100%	N/A	N/A	1.07	N/A
Burro 8 (short)	-0.01	0.99	0.01	1.01	100%	N/A	N/A	1.01	N/A
Burro 8 (long)	0.03	1.03	0.01	1.01	100%	N/A	N/A	0.97	N/A
Burro 9 (short)	0.08	1.09	0.01	1.01	100%	N/A	N/A	0.92	N/A
Burro 9 (long)	0.10	1.11	0.01	1.01	100%	N/A	N/A	0.90	N/A
Coyote 3 (short)	0.12	1.13	0.02	1.02	100%	N/A	N/A	0.88	N/A
Coyote 3 (long)	0.07	1.07	0.01	1.01	100%	N/A	N/A	0.94	N/A
Coyote 5 (short)	0.27	1.31	0.08	1.08	100%	N/A	N/A	0.77	N/A
Coyote 5 (long)	0.28	1.33	0.09	1.09	100%	N/A	N/A	0.76	N/A
Coyote 6 (short)	-0.08	0.92	0.01	1.01	100%	N/A	N/A	1.08	N/A
Coyote 6 (long)	-0.14	0.87	0.03	1.03	100%	N/A	N/A	1.16	N/A
CHRC A (scaled)	-0.08	0.92	0.01	1.01	100%	N/A	N/A	1.09	N/A
BA TNO FLS (scaled)	-0.01	0.99	0.01	1.01	100%	N/A	N/A	1.01	N/A

UDM is generally in good agreement for maximum arc-wise concentrations for field trials with the exception of the Maplin Sands trials and Burro 8. A large percentage of the data is within a factor of 2. Field trials over land with short time averages may be the most pertinent data set for onshore LNG flammable hazards, and agree the best with the data, often within the experimental uncertainty bounds. The over-prediction is generally more severe for field trials with long time averages with the exception of Burro 8. The higher CSF for longer time averages can be attributed to the lesser sensitivity the model shows to longer time averages compared to the sensitivity the averaging of the experimental data exhibits. UDM becomes slightly less conservative as the vapor cloud disperses downwind. UDM may be under-predictive by a factor of 2 or more for dispersion over water (i.e., Maplin Sands trials) and may be under-predictive by a factor of 2 for low wind speeds (<2 m/s) and high atmospheric stabilities (F stability), which is especially pertinent to the current federal regulations under 49 C.F.R. Part 193. UDM is generally under-predictive for wind tunnel experiments often by a factor of 3 or more. Nearly all wind tunnel data was under-predicted with the majority of the data being under-predicted by more than a factor of 3.

Although the maximum arc-wise concentrations for field trials over land are most applicable to the scenarios considered under the 49 C.F.R. Part 193 regulations and generally show over-prediction, there are uncertainties that indicate potential under-prediction by a factor of 2 (or more). Until these uncertainties are resolved, it is recommended that at least a safety factor of 2 be used when evaluating predicted maximum arc-wise concentrations from UDM. Alternatively, a distance safety factor of 2 may be used.

UDM compares better with maximum gas concentration distances, and follows similar trends as the maximum arc-wise concentrations. UDM generally agrees very well to the distance to a given concentration for field trials, but under-predicts wind-tunnel tests by approximately a factor of 2. The relatively better agreement is because large concentration differences may manifest themselves as much smaller differences in distance.

UDM generally under-predicts point-wise gas concentrations with short time averages and over-predicts point-wise gas concentrations with long time averages with the exception of Burro 8 and Burro 9. UDM is generally more accurate and conservative for point-wise concentrations that are located at an angle corresponding to the wind direction where the maximum arc-wise concentration often occurred, and is less accurate and under-predicts by a greater margin for point-wise gas concentrations that are located farther from the "centerline". However, no clear or similar trends can be found in the wind tunnel tests.

UDM cloud width predictions compares very well with experimental cloud width calculations. Cloud widths are also less influenced by large concentration differences, which may manifest themselves as much smaller differences in cloud widths. Cloud widths are not a particular concern with 49 C.F.R. Part 193, but may be more important for risk analyses or performance based design of gas detectors.

Sensitivity Analyses

All the LNG field trial releases used in the current validation study were conducted over water and the associated source terms will be different than those used on land. For spills over water with significant depth, the heat transfer to the pool is generally considered constant due to convective motion of the water. For spills over land, the heat transfer to the pool is generally considered to be transient due to conductive cooling of the substrate. Pressurized releases may further deviate from the more idealized source term for spills over water. However, any source term model that is used to calculate an exclusion zone for an LNG facility must have a suitable basis to comply with the siting requirements in 49 C.F.R. Part 193.[15] Therefore, for spills over land and pressurized releases, it is recommended that the source term is evaluated before usage.

---

[15] *In the Matter of Mssrs. Keppel and Miozza*, PHMSA Interp. (Jul. 7, 2010); *In the Matter of Fulbright & Jaworski L.L.P.*, PHMSA Interp. #PI 10-0005 (available at www.phmsa.dot.gov).

The input and output parameters should be included with model submissions for use in exclusion zone calculations.

Longer time averages result in lower maximum arc-wise and point-wise gas concentrations. Similarly, longer time averages of experimental data will result in lesser concentrations as peak concentrations are smoothed out over longer time averages. For higher wind speeds and lower atmospheric stability where turbulent fluctuations and cloud meander may have higher amplitudes, there is a greater reduction in gas concentration when averaged. For trials with lower wind speeds and higher atmospheric stability (i.e., Burro 8), UDM seems to over-predict the reduction in gas concentration from turbulent fluctuation and cloud meandering, resulting in under-prediction for long-time averages for these scenarios. Short time averages are more appropriate for flammable hazards and should be used when predicting flammable vapor centerline concentrations.

Many of the trials did not have wind speeds that differed by more than 10%. For trials that did not have wind speeds that differed by more than 10%, lower wind speeds generally produced higher downwind concentrations and dispersion distances, and higher wind speeds produced lower downwind concentrations and dispersion distances. The exceptions were Burro 8 where very low wind speeds (< 2 m/s) occurred. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the use of weather conditions that occur 90% of time for the area that result in longer predicted downwind dispersion distances than other weather conditions, or alternative conditions with a wind speed of 4.5 mph (2.01 m/s) at reference height of 10 meters for models that result in longer predicted downwind dispersion distances at lower wind speeds. The weather conditions reflective of the site should be included with model submissions for use in exclusion zone calculations. If alternative weather conditions are specified, the dispersion distances should be verified to produce the worst case results.

The surface roughness values have the largest uncertainties and often formed the upper and lower bound of the predictions. The values specified in the MEP are generally low and result in higher concentrations and longer dispersion distances to the LFL, which may cause the model to appear more conservative than it is. Less conservative parameters cause the model to under-predict concentrations by a greater margin, but still is within the quantitative acceptance criteria. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the surface roughness of 0.03 m or higher. The 0.03 m surface roughness prescribed in 49 C.F.R. § 193.2059 would generally provide reasonable, or conservative, results for LNG releases that disperse over land. Higher surface roughness values may be used if it can be shown that the terrain both upwind and downwind of the vapor cloud has dense vegetation and that the vapor cloud height is more than ten times the height of the obstacles encountered by the vapor cloud. Lower surface roughness values should be considered for LNG releases that disperse over water. Site location should be included with model submissions for use in exclusion zone calculations.

The atmospheric stability often formed the upper or lower bound of the predictions where the surface roughness uncertainty was low. Lower atmospheric stabilities generally produced lower downwind concentrations and dispersion distances, and higher atmospheric stabilities produced higher downwind concentrations and dispersion distances. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the use of weather conditions that occur 90% of time for the area that result in longer predicted downwind dispersion distances than other weather conditions, or alternative conditions with an atmospheric stability (Pasquill-Gifford Class) of F. The F stability prescribed in 49 C.F.R. § 193.2059 would generally provide reasonable, or conservative, results for LNG releases that disperse over land or water. The weather conditions reflective of the site should be included with model submissions for use in exclusion zone calculations. If alternative weather conditions are specified, the dispersion distances should be verified to produce the worst case results.

Ambient temperature and surface temperature had little fluctuation, and therefore no sensitivity cases were run. However, higher ambient temperatures and surface temperatures should generally produce lower gas concentrations and downwind dispersion distances. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the use of weather conditions that occur 90% of time for the area that result in longer predicted downwind dispersion distances than other weather conditions, or alternative conditions with an atmospheric temperature equal to the average in the region. The weather conditions reflective of the site should be included with model submissions for use in exclusion zone calculations. If alternative weather conditions are specified, the dispersion distances should be verified to produce the worst case results.

None of the trials had ambient pressures that differed by more than 10% from atmospheric pressure, but in order to gauge the sensitivity, the Burro trials, which had the lowest ambient pressures, were tested. Higher ambient pressure showed lower concentrations and downwind dispersion distances, but did not greatly affect the statistical performance measures. It is recommended that atmospheric pressure be specified.

Many of the trials did not have ambient relative humidity that differed by more than 10%, but some of the values disagreed with those reported in the original data series reports. Unexpectedly, lower ambient relative humidity generally produced lower gas concentrations, and vice-versa, but did not greatly affect the statistical performance measures. For applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the use of weather conditions that occur 90% of time for the area that result in longer predicted downwind dispersion distances than other weather conditions, or alternative conditions with a relative humidity of 50%. The weather conditions reflective of the site should be included with model submissions for use in exclusion zone calculations. If alternative weather conditions are specified, the dispersion distances should be verified to produce the worst case results.

The change in substrate had a fairly significant affect on the concentration and dispersion distance compared to other parameters. For Maplin Sands, the specification of "deep open water" compared to the base case of "shallow open water" that includes possible ice formation, showed higher concentrations for short time averages, but lower concentrations for long time averages. In contrast and unexpectedly, for the Coyote trials, the specification of "shallow open water" compared to the base case of "deep open water" showed higher concentrations for short time averages, but lower concentrations for long time averages. Similarly, for the Burro trials, the specification of "deep open water" compared to the base case of "shallow river or channel" unexpectedly showed lower concentrations for short time averages, but higher concentrations for long time averages. For the Thorney Island trials, the specification of "dry soil" compared to the base case of "wet soil" did not change the results. The input parameters, including the specification of the substrate, should be included with model submissions for use in exclusion zone calculations.

The composition specified in the MEP reflects the composition of the LNG and does not take into account preferential boiloff. The lower molecular weight of methane generally results in higher concentrations and longer dispersion distances to the LFL with the exception of Burro 8 (short time average) and Coyote 6. The molecular weight of methane is recommended to be used to account for potential preferential boiloff and conservatism.

Overall, the sensitivity analysis showed concentrations generally differ by less than a factor of 2 from the base case and downwind dispersion distances to the LFL differ by less than a factor of 2.

Model Suitability and Limitations

UDM has a built-in source term that calculates flashing, jetting, rainout, and pool formation. The specification of the source term is a key parameter in determining the gas concentrations and dispersion distances, but is not examined under the MEP or the Advisory Bulletin. However, any source term that is used to calculate an exclusion zone for an LNG facility must have a suitable basis to comply with the siting requirements in 49 C.F.R. Part 193.[16]

UDM may be used to model the maximum arc-wise concentration for:

- Dispersion from circularly shaped LNG pools;
- Dispersion from LNG pools with low-aspect ratios, including most impoundments; or
- Dispersion from releases in any direction (horizontal, vertical, or otherwise), including releases from flashing, venting, vent stacks, and pressure relief discharge.

UDM may not be appropriate to be used to model the maximum arc-wise concentration for:

- Dispersion from irregularly shaped LNG pools
- Dispersion from LNG pools with high-aspect ratios, including some impoundments and nearly all trenches; or
- Dispersion from multiple coincident releases, including multiple release locations.

In some cases, UDM may also not be appropriate to be used to model the maximum arc-wise concentration for:

---

[16] *In the Matter of Mssrs. Keppel and Miozza*, PHMSA Interp. (Jul. 7, 2010); *In the Matter of Fulbright & Jaworski L.L.P.*, PHMSA Interp. #PI 10-0005 (available at www.phmsa.dot.gov).

- Dispersion over varying or sloped terrain; or
- Dispersion between large obstructions that may cause wind-channeling.

The ambient conditions required under 49 C.F.R. § 193.2059 should produce conservative results (i.e. higher downwind gas concentrations and dispersion distances).

UDM should be used with a safety factor of 2 (i.e. ½ LFL) to compensate for uncertainties related to potential turbulent fluctuations, source term specification, wind tunnel experiment validation results, dispersion over water, and low wind speed and high atmospheric stability validation results.

Environmental Impacts

The National Environmental Policy Act (42 U.S.C. §§ 4321 – 4375) requires Federal agencies to analyze proposed actions to determine whether those actions will have a significant impact on the human environment. Under the Council on Environmental Quality's (CEQ) implementing regulations, Federal agencies must conduct an environmental review that considers (1) the need for the proposed action, (2) alternatives to the proposed action, (3) the probable environmental impacts of the proposed action and alternatives, and (4) the agencies and persons consulted during the consideration process. 40 C.F.R. § 1508.9(b).

1. Purpose and Need

The federal siting standards require an operator or governmental authority to exercise control over the activities that can occur within an exclusion zone, defined as the area around an LNG facility that could be exposed to unsafe levels of thermal radiation or flammable vapor gas in the event of a release or ignition. Certain mathematical models must be used to calculate the dimensions of these exclusion zones, but alternative models may be used subject to the Administrator's approval.

PHMSA is approving DNV's Petition to use PHAST-UDM as an alternative model under 49 C.F.R. § 193.2059(a). "The intent . . . of providing for the use of alternative models [i]s to permit operators to take advantage of new technical information as it becomes available in developing predictive mathematical dispersion models."[17] PHAST-UDM is based on new technical information, and the results of the MEP show that it is suitable for use under 49 C.F.R. § 193.2059(a) in certain scenarios.

2. Alternatives

In arriving at this decision, PHMSA considered two alternatives:

(1) No action or

---

[17] *In the Matter of Energy Terminal Services Corporation*, PHMSA Interp. 82-05-28 (May 28, 1982).

(2) Approving PHAST-UDM for use in calculating the vapor gas dispersion exclusion zone for an LNG facility under 49 C.F.R. § 193.2059(a) where suitable and with limitations.

Alternative 1:

PHMSA has an obligation to ensure that the siting of LNG facilities is consistent with public safety. The information submitted by DNV shows that approving PHAST-UDM for use where suitable and with limitations will accomplish that objective. Failing to approve an alternative model in such circumstances would discourage further improvements and innovation in the field of consequence modeling. It should also be noted that PHAST-UDM may be more suitable for use than the currently approved vapor gas dispersion models in certain situations. Accordingly, PHMSA rejected the no action alternative.

Alternative 2:

PHMSA is approving PHAST-UDM for use in calculating the vapor gas dispersion exclusion zone for LNG facilities where suitable and with limitations. Such approval ensures that these facilities are sited in a manner consistent with public safety. It also encourages further innovation and improvements in the field of consequence modeling. PHAST-UDM may also be more suitable for use than the currently approved vapor gas dispersion models in certain scenarios.

3. Analysis of Environmental Impacts

There are 11 LNG terminals and over 100 smaller LNG facilities in operation in the United States and Puerto Rico. Unless covered by an exception, any significant alteration or addition to these existing LNG facilities would be subject to the siting requirements in 49 C.F.R. Part 193, and PHAST-UDM can potentially be used to calculate the required vapor gas dispersion exclusion zone. There are also 9 proposed and potential LNG terminals and numerous other smaller LNG facilities that might be constructed in the near future. PHAST-UDM can potentially be used to calculate the exclusion zones for these new LNG facilities.

The physical environment potentially affected by this decision includes the airspace, water resources (e.g., oceans, streams, lakes), cultural and historical resources (e.g., properties listed on the National Register of Historic Places), biological and ecological resources (e.g., coastal zones, wetlands, plant and animal species and their habitat, forests, grasslands, offshore marine ecosystems), and special ecological resources (e.g., threatened and endangered plant and animal species and their habitat, national and State parklands, biological reserves, wild and scenic rivers) that exist directly adjacent to and within the vicinity of an existing or new LNG facility.

Projections about the demand for natural gas and LNG are based on a wide range of variables that are subject to change. It is also difficult to make predictions about the use and effect of approving a particular vapor gas dispersion model, which depends on a number of site and project specific parameters. It should be further noted that PHMSA does not determine the location of LNG facilities, and that an individualized environmental analysis is performed by FERC and the other state agencies which make those determinations.

4. Consultations

Several other federal agencies, including FERC, were consulted in the development of this decision.

5. Decision about the Degree of Environmental Impact

PHMSA has determined that approving this Petition would not result in significant impact on the human environment.

Conclusion

For the reasons stated above, PHMSA is approving DNV's Petition to use PHAST-UDM as an alternative vapor gas model under 49 C.F.R. § 193.2059(a) where suitable and with certain limitations.

Cynthia L. Quarterman

Administrator

Date Issued

UPS OVERNIGHT EXPRESS – RETURN RECEIPT REQUESTED