U.S. Department
of Transportation
**Pipeline and Hazardous
Materials Safety
Administration**

Administrator

1200 New Jersey Ave., S E.
Washington, DC 20590

July 12, 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 Draft Decision on your petition for approval of the PHAST-UDM Version 6.6 and 6.7 vapor gas dispersion model. This Draft Decision will be made available for public comment for 30 days before a Final Decision is issued. Service of this Draft Decision by certified mail 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

CERTIFIED MAIL – 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.)

DRAFT 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] This Draft Decision proposes to approve that petition and will be made available for public comment for 30 days. Any comments received during that time will be considered before a Final Decision is issued. Late comments will be considered to the extent practicable.

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, the Pipeline and Hazardous Materials Safety Administration (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. Petitioner also requested that PHAST-UDM Version 6.7 be approved as part of this proceeding, stating that the changes made in that newer version of the model would not affect the scientific assessment or verification or validation results.

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

Background

PHMSA issues federal safety standards for siting Liquefied National Gas (LNG) facilities.[2] 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.[3] PHMSA also requires that certain mathematical models be used to calculate the dimensions of these exclusion zones.[4]

Under the current regulations, vapor-gas-dispersion exclusion zones may be calculated using either the DEGADIS Dense Gas Dispersion Model (DEGADIS) or FEM3A.[5] The 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."[6]

On August 30, 2010, PHMSA issued an Advisory Bulletin with guidance on obtaining approval of alternative vapor gas dispersion models.[7] 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.[8] As the Advisory Bulletin explained:

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

[3] 49 C.F.R. § 193.2007 (defining exclusion zone).

[4] 49 C.F.R. §§ 193.2057-2059.

[5] 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.").

[6] 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).

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

[8] 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).

> 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.[9]

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[10]

Evaluating the suitability of an alternative vapor gas dispersion model is a task that involves "making predictions, within [PHMSA's] area of special expertise."[11] 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).[12] DNV followed that guidance in preparing

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[9] 75 Fed. Reg. at 53372.

[10] This analysis relates solely to the use of PHAST-UDM under 49 C.F.R. Part 193 and is not intended authorize or restrict its use in any other applications.

[11] *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.").

[12] As the U.S. Court of Appeals for the District of Columbia recently explained:

> We accord an agency's interpretation of its own regulations a "high level of deference," accepting it "unless it is plainly wrong." *Gen. Elec. Co. v. EPA*, 53 F.3d 1324, 1327 (D.C.Cir.1995); *see also Exportal Ltda. v. United States*, 902 F.2d 45, 50 (D.C.Cir.1990) ("It is well established that a reviewing court owes deference to an agency's construction of its own regulations."). Under this standard, we must defer to the [agency]'s interpretation as long as it is "logically consistent with the language of the regulation[s] and ... serves a permissible regulatory function." *Gen. Elec.*, 53 F.3d at 1327. *But see Exportal*, 902 F.2d at 50 (explaining deference is due "only when the plain meaning of the rule itself is doubtful or ambiguous" and thus deference to an agency's interpretation "is not in order if the rule's meaning is clear on its face"). Moreover, "[t]he policy

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. PHSMA has reviewed that information and determined that PHAST-UDM may be used to calculate the vapor gas dispersion exclusion zone for an LNG facility in certain scenarios.[13]

Specifically, 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 horizontally or vertically oriented releases, 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, including 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 public is invited to comment on each of these conclusions.

Scientific Assessment

> favoring deference is particularly important where ... a technically complex statutory scheme is backed by an even more complex and comprehensive set of regulations." *Gen. Elec.*, 53 F.3d at 1327 (noting that "[i]n such circumstances, 'the arguments for deference to administrative expertise are at their strongest' ").

Howmet Corp. v. E.P.A., 614 F.3d 544, 549 (D.C. Cir. 2010).

[13] 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.

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).

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 been submitted to PHMSA used the more robust optional DLSODI solver, which is the default solver in UDM Version 6.7.

UDM requires the specification of the scenario type (i.e., catastrophic rupture, leak, line rupture, disc rupture, relief valve, fixed duration, long pipeline, vent from vapor space, or tank roof failure), phase to be released (i.e., vapor, liquid, or two-phase), and corresponding scenario data (e.g., hole diameter, pump head, etc). 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 assumes the release is along the direction of the wind (i.e., worst case). UDM cannot be used to model releases that are not along the direction of the wind. UDM also cannot be used to model multiple concurrent releases at different locations.

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).

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. The selection of wind direction is not pertinent or possible in UDM, since it assumes a source term where the dispersion will be axi-symmetric. 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. 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. UDM should be specified with the lower wind speed that is reflective of the area to produce conservative results. For most applications pertinent to this study, UDM will be used in accordance with 49 C.F.R. § 193.2059, which specifies the lowest wind speed that occurs 90% of time for the area or 2 m/s. Steady state wind speed and direction is not expected to be a large limitation of the model. However, the 2 m/s assumption should be verified to produce the worst case results.

UDM cannot account for sloped or varying 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 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 slopes or varying 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 most 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; therefore, this is not expected to be a limitation of the model.

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). Wind channeling may occur between adjacent LNG storage tanks, buildings, or large structures, which may result in the model being under-predictive for concentrations. Therefore, there may be cases where UDM should not be used to model releases that may disperse between large adjacent structures.

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.

The public is invited to comment on each of these conclusions.

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.

The public is invited to comment on each of these conclusions.

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:

- 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 maximum point-wise concentrations for 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 short time averages, and over-predictive of maximum arc-wise concentrations for long time averages. A large majority of UDM maximum arc-wise concentration predictions are within a factor of 2. 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.

UDM maximum point-wise predictions are generally over-predictive for both short and long time averages, with higher over-prediction for longer time averages. 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 both long and short time averages agree very well with experimental cloud width calculations with very little scatter. All UDM cloud width predictions were within a factor of 2.

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.

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

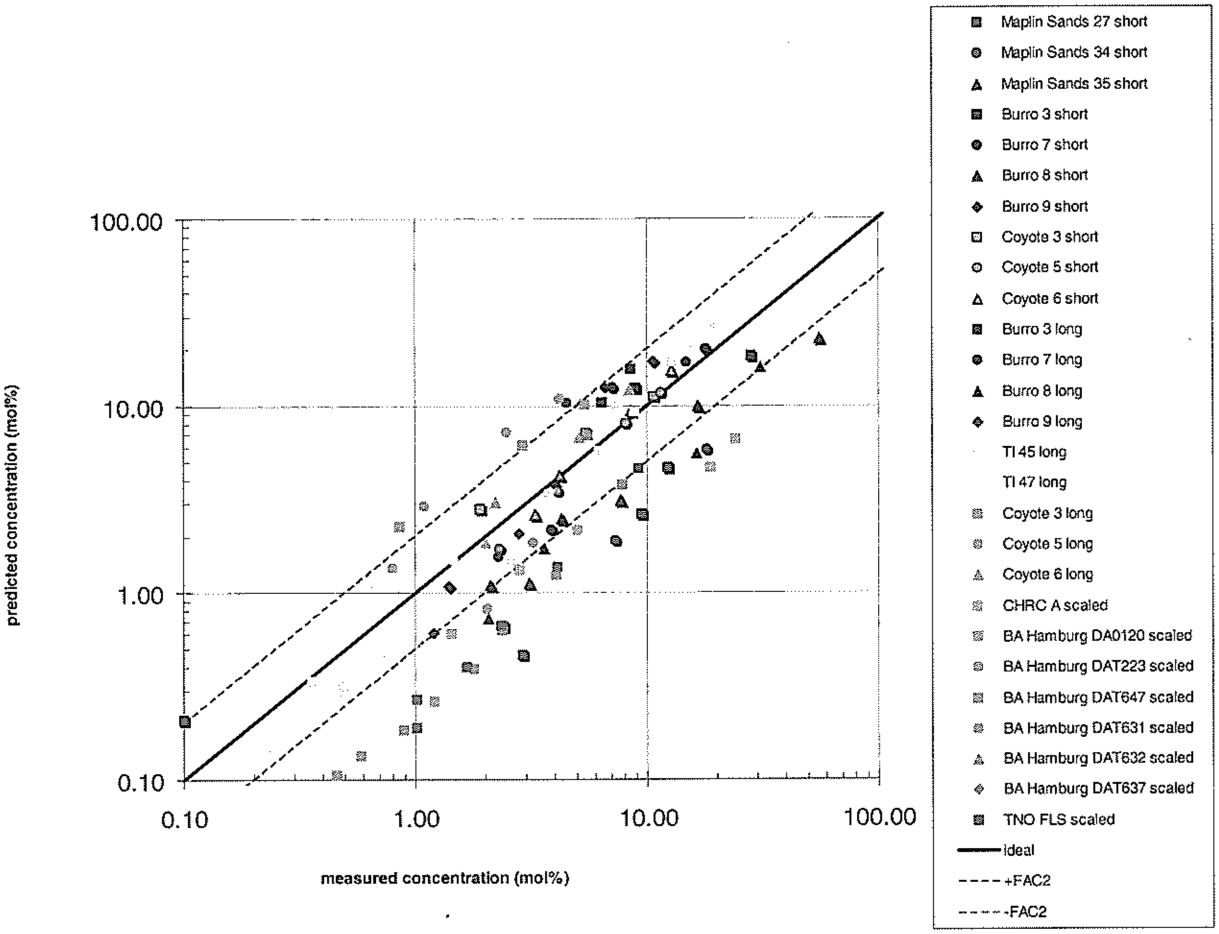

Figure 1 Predicted Concentration against Measured Concentration

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.

The public is invited to comment on each of these conclusions.

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. Therefore, for spills over land and pressurized releases, it is recommended that the source term is evaluated before usage.

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.

The surface roughness values have the largest uncertainties. 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. 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. Lower atmospheric stabilities generally produced lower downwind concentrations and dispersion distances, and higher atmospheric stabilities produced higher downwind concentrations and dispersion distances. Where the surface roughness uncertainty was low, the atmospheric stability often formed the upper or lower bound of the predictions.

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.

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.

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 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 change in substrate had a fairly significant affect on the concentration and dispersion distance compared to other parameters.

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.

The public is invited to comment on each of these conclusions.

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.[14]

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 horizontally or vertically oriented releases, 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.

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[14] *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).

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).

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.

The public is invited to comment on each of these conclusions.

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 proposing to approve 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."[15] 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

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

In arriving at this decision, PHMSA considered two alternatives:

(1) No action or

(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 proposing to approve PHAST-UDM for use in calculating the vapor gas dispersion exclusion zone for LNG facilities where suitable and with limitations. Such approval would ensure that these facilities are sited in a manner consistent with public safety. It would also encourage 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 could 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 could 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.

With that in mind, PHMSA invites public comment on whether either of the alternatives discussed above would result in any significant impacts on the environment.

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 is seeking public comment on whether either of the alternatives discussed above would have a significant impact on the human environment.

Conclusion

For the reasons stated above, I am prepared to approve 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.

This Draft Decision will be made available for public comment for 30 days. Any comments received during that time will be considered before a Final Decision is issued. Late comments will be considered to the extent practicable.

CL Quarterman

Cynthia L. Quarterman
Administrator

7/12/11

Date Issued:

CERTIFIED MAIL – RETURN RECEIPT REQUESTED