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

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In the Matter of	)	
	)	
DNV	)	**PHMSA Docket No. 2021-0041**
	)	
Petitioner.	)	
	)	

FINAL DECISION

DNV GL Digital Solutions (DNV or Petitioner) has filed a petition for approval (Petition) of DNV's Process Hazard Analysis Software Tool (Phast) under 49 C.F.R. §§ 190.9 and 193.2059.[1] On January 18, 2023, 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. The public comment period ended on February 18, 2023, with no comments received through February 24, 2023. PHMSA is approving the Petition in this Final Decision.

Background

On May 18, 2020, DNV submitted this Petition to approve Phast version 8.23 as an alternate model for liquefied natural gas (LNG) flammable vapor-gas dispersion exclusion zones. On September 4, 2020, DNV submitted an updated petition requesting approval of Phast version 8.4, instead of version 8.23. PHMSA previously approved DNV's Phast versions 6.6 and 6.7 as alternate models for LNG flammable vapor-gas dispersion on October 7, 2011.[2]

Following the submission of DNV's initial May 18, 2020, petition, DNV provided documentation on May 20, 2020, describing the unified dispersion model (UDM) and the major changes from the previously approved Phast version 6.7. These major changes include modeling for pool-cloud linking, along-wind diffusion (AWD), an updated numerical solver, pool model improvements, and instantaneous expansion (INEX). DNV provided additional supporting information on September 25, 2020, February 5, 2021, and October 20, 2022, including multiple versions of the summary reports, sensitivity simulation results and sensitivity reports, change-log reports, and an LNG model validation database.

[1] The electronic docket for this Petition is available at https://www.regulations.gov/search/docket?filter=PHMSA-2021-0041%20
[2] *See* Final Decision, PHMSA Docket No. 2011-0075.

Procedural History

1. Alternate Vapor-Gas Dispersion Model

Federal safety standards for LNG facilities are codified in 49 CFR Part 193, which prescribes requirements for LNG facilities used in the transportation of gas by pipeline that are subject to federal pipeline safety laws (49 U.S.C. 60101 et seq.) and 49 CFR Part 192. Federal standards for the siting of LNG facilities are found in Part 193, Subpart B. These standards include the requirement that an operator or governmental authority legally control all activities that can occur within an "exclusion zone," which is the area surrounding 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] Federal regulations also require that certain mathematical models be used to calculate the dimensions of these exclusion zones.[4]

Under the current regulations, vapor-gas dispersion exclusion zones must be calculated using either the Dense Gas Dispersion model or FEM3A model.[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 October 7, 2011, the Administrator approved the use of DNV's Phast versions 6.6 and 6.7 as alternate models for LNG flammable vapor-gas dispersion.[7]

2. Model Evaluation Protocol for LNG Vapor Dispersion

On August 31, 2010, PHMSA issued advisory bulletin ADB-10-07 providing guidance on the use of the Model Evaluation Protocol (MEP 2010)[8] for obtaining approval of alternative vapor dispersion models under Subpart B of 49 CFR Part 193. PHMSA evaluated the suitability of Phast versions 6.6 and 6.7 using the three-stage process described in the MEP 2010. In September 2016, an updated version of the MEP (MEP 2016)[9] was issued including the following changes:

1. The inclusion of a prescribed approach for determining predicted maximum arc-wise gas concentrations. For each given arc, the maximum arc-wise concentration must be calculated as the maximum of the point-wise concentrations on that arc (i.e., the maximum

[3] *See* 49 C.F.R. § 193.2007.
[4] *See* 49 C.F.R. §§ 193.2057 and 193.2059.
[5] *See* 49 C.F.R. § 193.2059.
[6] *Id.* 49 C.F.R. § 190.9 establishes the process by which the Administrator, defined to include his or her delegate (*see* § 190.3), makes a finding or approval as authorized by § 193.2059.
[7] In addition to Phast versions 6.6 and 6.7, PHMSA approved FLACS version 9.1 Release 2 on October 7, 2011.
[8] The MEP includes the Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities Research Project: Technical Report (M.J. Ivings *et al.*, April 2007) and supplemented in the Validation Database for Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities: Guide to the LNG Model Validation Database, Version 11.0 (S. Coldrick *et al.*, May 2010).
[9] The new edition includes the Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities - Second Edition (Ivings *et al.*, 2016) and Validation Database for Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities: Guide to the LNG Model Evaluation Database, Version 12 (Stewart *et al.*, 2016) (available at www.nfpa.org).

of the predicted concentrations at the positions of the sensors that recorded concentrations in that experiment).

2. Wind-tunnel experiments modeled at wind-tunnel scale rather than at their equivalent full scale to avoid uncertainties associated with scaling experimental data.
3. Additional physical comparison parameters to include the predicted distances to the measured maximum arc-wise concentrations, distances to the lower flammability limit (LFL) concentrations, and the predicted concentration at the measured distance to the LFL.
4. Additional Statistical Performance Measures (SPM) to include the Concentration Safety Factor (CSF), Concentration Safety Factor to the Lower Flammability Limit (CSF_{LFL}), Distance Safety Factor (DSF), and Distance Safety Factor to the Lower Flammability Limit (DSF_{LFL}).
5. The model validation outputs provided in the model evaluation report.
6. Details of the uncertainty analyses undertaken to assess model sensitivity based on the requirements described in advisory bulletin ADB-10-07.

3. Expedited Review Process for Previously Approved Models

PHMSA considers the changes to previously reviewed models as either minor or major changes. The assessment of minor changes could be expedited to not unduly impede the use of new code developments that may include minor bug fixes and more extensive model improvements. PHMSA defines the minor and major changes as follows:

1. Minor changes shall have no effect on model predictions, numeric, or model physics for LNG dispersion. Minor changes are meant to address four issues:

a. Correction of software bugs or flaws within the software that make it perform less than optimally.
b. Modification of the Graphic User Interface (GUI) of a program.
c. Addition of new compatible hardware support.
d. Modification of sub-models that are not relevant to LNG dispersion.

2. Major changes address the above four issues and also make advances to the scientific model for new and improved modeling capabilities for LNG dispersion. Major changes result in significant differences in the predicted point-wise concentrations as follow:

   a. For absolute predicted concentrations > 10 percent v/v, a relative difference of 1 percent in any of the predicted point-wise concentrations between the new and currently approved version of the model.
   b. For absolute predicted concentrations ≤ 10 percent v/v, an absolute difference of 0.1 percent v/v gas concentration in any of the predicted point-wise concentrations between the new and currently approved version of the model.

PHMSA conducts reviews of updated versions to previously approved models as follows:

1. For a model with minor changes, the petitioner must provide modeling results for the following subset of six LNG dispersion validation cases to confirm that the changes do not affect the results:

a. Burro 8
b. Coyote 5
c. Falcon 1
d. Thorney Island 47
e. Chemical Hazards Research Center (CHRC) Case B
f. BA Hamburg DAT223

2. For a model with major changes, the petitioner must provide a change-log report and provide modeling results for all cases in the LNG model validation database. The change-log report must describe the changes that have been made to the new version of the model in the time since the previous version was approved by PHMSA. The report must be comprised of three parts (i.e., scientific assessment, verification, and validation) that describe the changes to these aspects of the model since the last PHMSA review.

Analysis

The changes between Phast version 6.7 and version 8.4 are considered major changes. DNV followed the guidance described in the MEP 2016 and the process for an updated model with major changes in preparation of this Petition. DNV provided multiple versions of the summary reports, sensitivity simulation results and sensitivity reports, change-log reports, and an LNG model validation database. PHMSA has reviewed that information and determined that Phast version 8.4 may only be used with an uncertainty factor of two to calculate the vapor dispersion exclusion zone for an LNG facility.

1. Scientific Assessment

The UDM is a one-dimensional integral dispersion model that calculates different stages in the evolution of a cloud: momentum jet, heavy gas, and passive. The core dispersion model comprises a set of differential-algebraic equations solved simultaneously for quantities including cloud mass, horizontal and vertical momentum, horizontal and vertical position, cloud width, mass centroid height, and others. The UDM can model continuous and instantaneous releases.

Major changes between version 6.7 and version 8.4 include a model for pool-cloud linking, along-wind diffusion, updated numerical solver, pool model improvements, and INEX.

1. Model for pool-cloud linking – Phast version 6.7 used the concept of time-averaged segments. A dynamic pool was modeled by a set of these segments, each with a representative radius, evaporation rate, temperature, etc. The software calculates the air entrainment over the pool for each segment. In Phast version 8.4, segments are replaced with observers. An observer can be imagined as a particle-sized sensor that is released at the center line of the cloud at a particular time and is then carried along with it. In the case of an evaporating pool, the observer starts from the upwind edge of the pool. The standard set of differential-algebraic equations are solved, with some additions and modifications to account for the presence of the pool.

2. AWD – For short-duration and time varying releases, the application of a steady-state model such as the UDM is likely to overpredict concentrations, especially in the far-field. In Phast version 8.4, a post-processed correction is based on Gaussian integration of observer concentrations with respect to downwind distance, using an empirically determined along-wind dispersion coefficient. For near-field concentrations or long duration releases, AWD will not have a significant effect.

3. Updated numerical solver – The solver used in Phast version 6.7 was ODEPACK, developed by Alan Hindmarsh at Lawrence Livermore. This solver has been replaced by the SUNDIALS suite of solvers developed by the same team.

4. Pool model improvements – The UDM is linked to an updated version of the pool spreading and vaporization model, including the switch to the MacKay and Matsugu correlation for evaporation on land.

5. INEX – The UDM contains sub-model INEX for pressurized instantaneous or catastrophic rupture release scenarios. For two-phase releases, the Phast version 6.7 model may underpredict rainout and over-predict rainout distance. An entirely new version is included with a better physical basis for two-phase releases.

2. Verification

Verification was performed for the newly implemented models, as reported by DNV, and include the following models: gravity spreading correction (GSC), along-wind diffusion (AWD), pool-cloud linking, and INEX. The along-wind GSC post-processor model has been verified using analytical spreadsheet calculations of uncorrected dispersion results of unpressurized steady-state and finite-duration releases from a ground-level area source. The UDM AWD model has been verified analytically for passive dispersion of steady-state and finite-duration horizontal releases. The AWD and cloud-linking models have been verified for steady-state and time-varying releases by comparison to HEGADAS-S and HEGADAS-T,[10] respectively, for dispersion from a pool indicating good agreement to centerline concentrations in the far field. The UDM INEX model has been compared to an analytical model for cloud speed indicating good agreement.

In addition, the following verification cases were previously performed for Phast version 6.7 by DNV and are applicable to Phast version 8.4 since the core models have not changed since version 6.7. Pertaining to heavy gas dispersion, UDM numerical results of a two-dimensional isothermal ground level plume were compared to an analytical solution and were found to have identical agreement. The UDM was also verified against the HGSYSTEM model, HEGADAS, for heavy gas dispersion. For jet and near-field passive dispersion, the UDM numerical results were shown to be identical to an analytical solution for an elevated horizontal continuous jet of air. For far-field passive dispersion, the UDM numerical results were shown to be in close

[10] HEGADAS is a heavy gas dispersion program developed by Shell. HEGADAS-S is for steady state, and HEGADAS-T is for transient.

agreement with the vertical and crosswind dispersion coefficients and concentrations from the commonly adopted Gaussian passive dispersion formula.

3. Validation

The validation cases included for UDM comparison encompass only unobstructed experimental trials since the UDM does not have models applicable to obstructions and/or unlevel terrain. Therefore, the current validation study is limited to the following trials specified in the MEP 2016:

- 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 TUV0l, FLS.

The Final Environmental Assessment (FEA), including Appendix A of the document, discusses the analysis of the validation results.

Conclusion

Based on PHMSA's review of the information provided by DNV and the findings set forth in the FEA, I am approving DNV's Petition for Phast version 8.4 as an alternative model for calculating the flammable vapor dispersion exclusion zones under 49 C.F.R. § 193.2059(a). Consistent with 49 CFR § 193.2059(b)(1), Phast version 8.4 may be used only with an uncertainty factor of two as an alternate flammable vapor-gas dispersion model when computing flammable vapor dispersion distances to the LFL.

The terms and conditions of this order are effective upon service in accordance with 49 CFR § 190.5.

ALAN KRAMER MAYBERRY

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Date: 2023.04.13 13:53:43 -04'00'

Alan K. Mayberry,
Associate Administrator for Pipeline Safety.

Date Issued