PHMSA Pipeline and Hazardous Materials Safety Administration

BLUE Engineering and Consulting®

US DOT PHMSA Research Project #922: Vapor Cloud Explosion at Nil Wind

DOT PHMSA Contract # 693JK32010004POTA

Final Virtually-Held Dissemination Meeting

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Presentation Outline

- Project Sponsors and Project Team
- Project Objective
- Project Tasks
- Results and Conclusions
- Knowledge Transfer / Potential Next Steps
- Closing Discussions / Q&A

Project Sponsor and Project Team

- Prime Sponsor: US DOT PHMSA
  - DOT PHMSA Contract #693JK32010004POTA
  - Project #922 – public webpage: https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=922
  - PHMSA's Project Team:
    - Technical Task Inspector: Katherine Roth
    - Contractual: Robert Smith
- Project Team: Blue Engineering and Consulting Company
  - Filippo Gavelli, Ph.D., PE – Project Manager
  - Jenna Wilson, PE
  - Bryant Hendrickson, PE, CFEI

Project Objective

- Scope of R&D Program
  - Inform PHMSA rulemaking

- Research Statement:
  - *PHMSA is seeking research to determine the criteria for “nil wind” dispersion and whether “nil wind” condition should be considered in the siting analysis of LNG facility hazards. The 2017 PHMSA-sponsored study conducted by the UK Health and Safety Executive concluded that a majority of very large vapor cloud incidents occurred in nil or very low wind conditions.*

- Project Goals:
  - Define “nil wind”
  - Review and critique the 2017 HSE report
  - Evaluate effect of nil wind conditions
    - Prescriptive approach (49 CFR 193 Subpart B)
    - Risk-based approach (NFPA 59A-2019)

Project Tasks

- Task 1: Project Initiation
- Task 2: Define "Nil Wind" Conditions
- Task 3: Statistical Analysis of Weather Data
- Task 4: Review of 2017 HSE Report
- Task 5: Consequence Modeling
- Task 6: Quantitative Risk Assessment
- Task 7: Draft and Final Reports
- Task 8: Project Management

Total Project Funding = $167,630 of which $134,704 funded by DOT PHMSA

Task 1: Project Initiation

- Gathered Technical Advisory Panel:
  - Felix Azenwi-Fru, National Grid
  - Jeff Brightwell, Energy Transfer
  - Pat Convery, Cornerstone Energy Services
  - Tom Drube, Chart Industries
  - Jay Jablonski, Hartford Steam Boiler
  - Andrew Kohout, Federal Energy Regulatory Commission
  - Kevin Ritz, Baltimore Gas & Electric
  - Roberto Vara, Freeport LNG
  - Ted Williams, American Gas Association
- Held kick-off meeting with TAP and PHMSA to confirm scope, tasks, deliverables and project schedule
- TAP met 4 additional times during the project to review and discuss Task results

Task 2: Define "Nil Wind" Conditions

- From 2017 HSE report:
  - "Nil-wind" = wind so weak close to the ground that it does not significantly affect the gravity-driven transport of released vapor

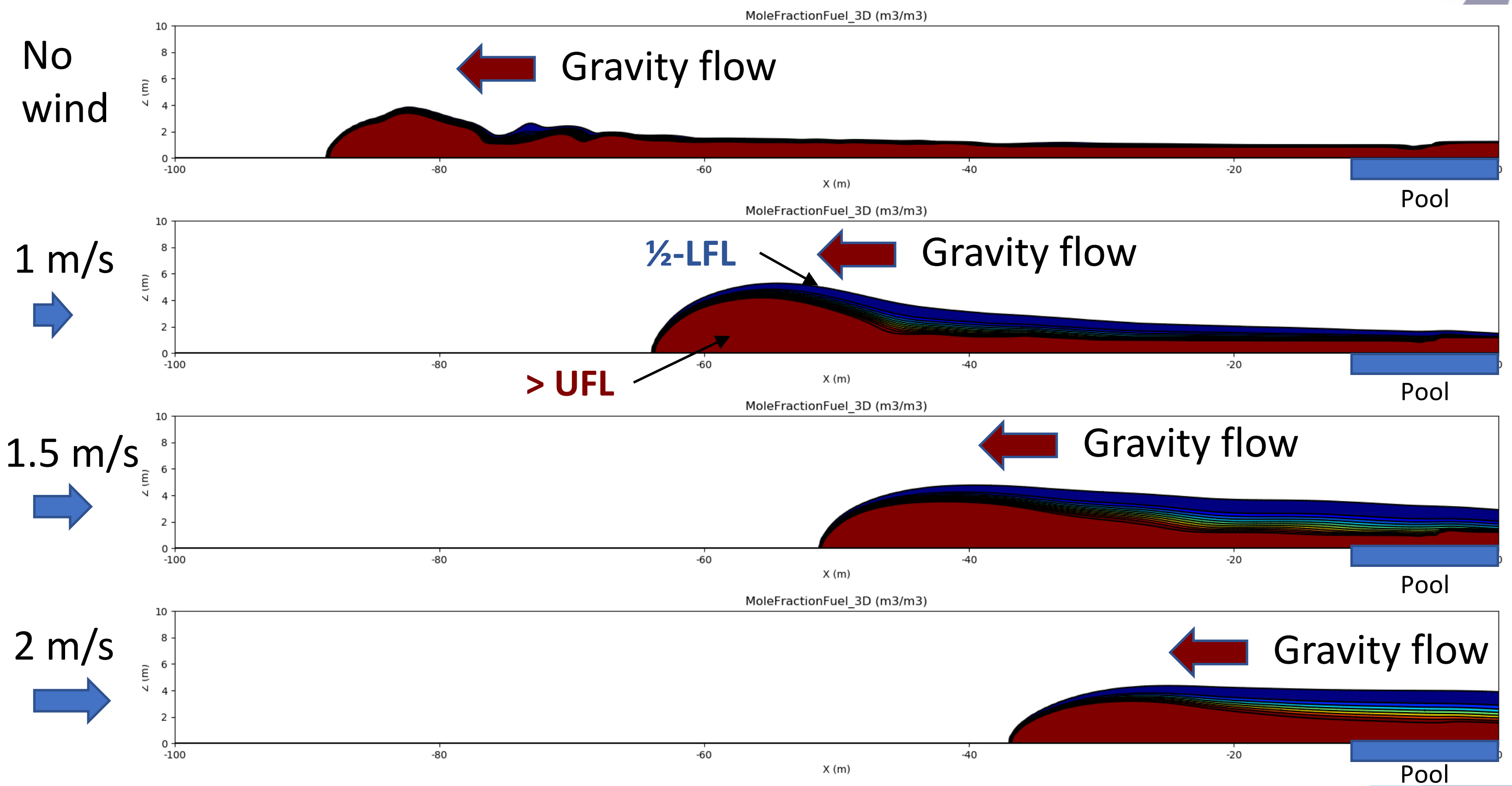
- Effect of wind vs. gravity:

$$Ri = \frac{\Delta\rho\, g\, h}{\rho_0\, U^2} = \frac{buoyancy}{shear}$$

- Laminarization of gravity flow depends on wind speed and initial cloud density
  - Threshold: Ri ≥ 0.25
  - Wind speeds below which gravity dominates were found to be generally higher than estimated by HSL
  - Wind speeds < 2 m/s nearly always correspond to Ri > 0.25

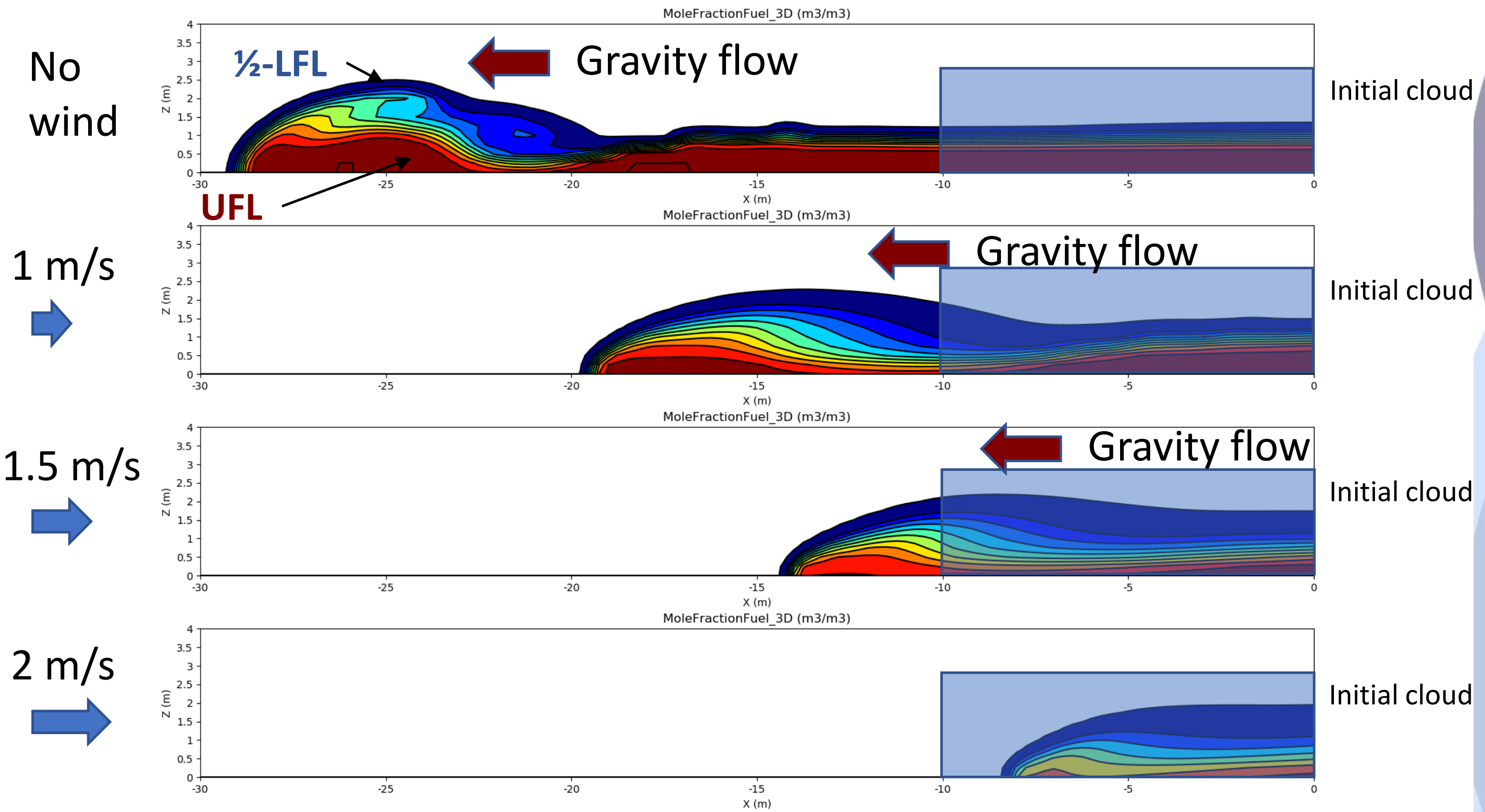
Gravity Slumping

- LNG vapors from evaporating pool ($\Delta\rho/\rho_0 = 0.46$)



Gravity Slumping

- Propane vapors from cloud @ UFL ($\Delta\rho/\rho_0$ = 0.09)



Nil Wind Definition

- Physics of dense cloud spreading do not change as U drops below current regulatory range
  - Change occurs for U > 1 m/s in most practical cases

- Modeling capabilities change drastically for U < 1 m/s
  - Integral model limitations

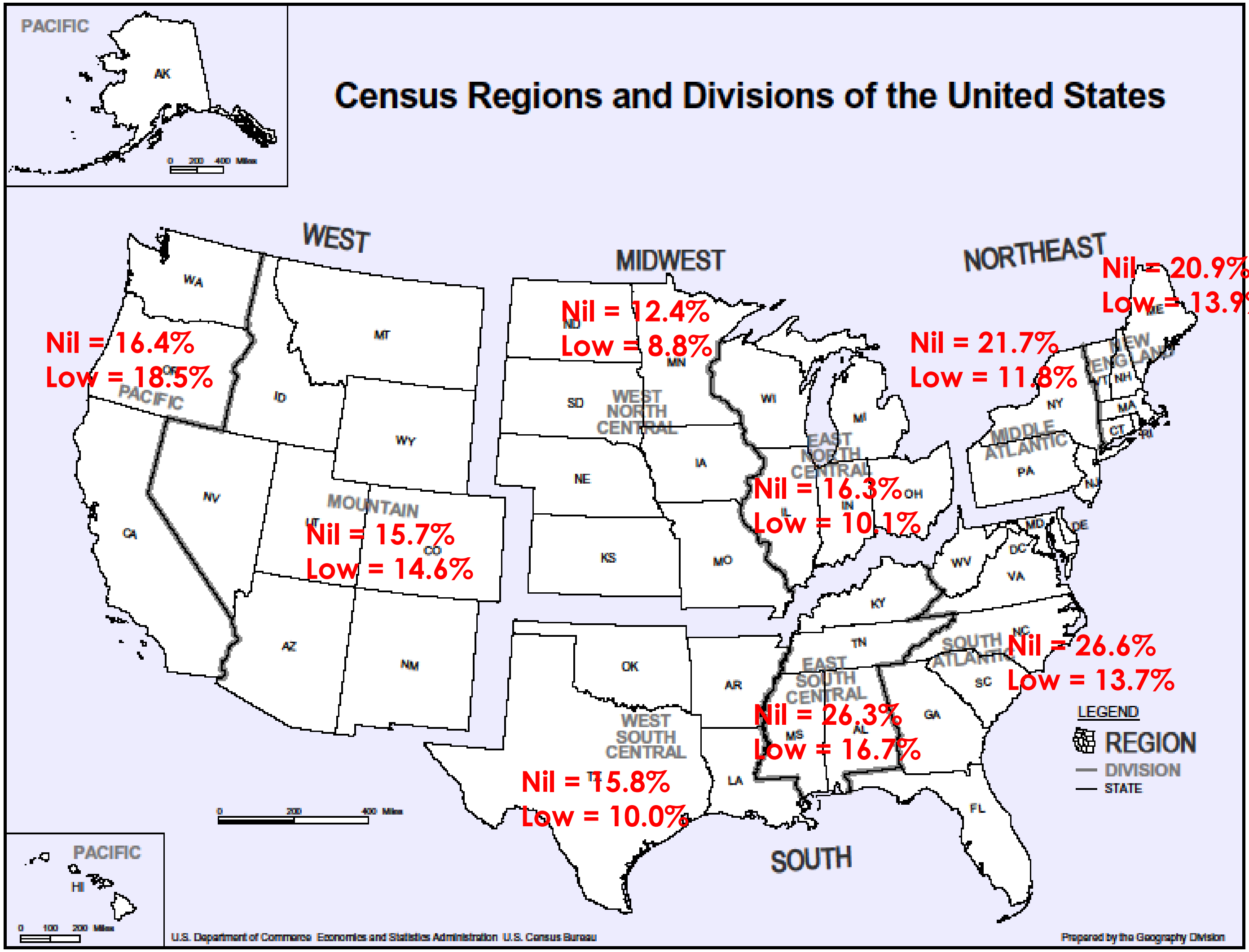
- Nil wind = U < 1 m/s (at 10 m elevation)
- Low wind = 1 ≤ U ≤ 2 m/s (at 10 m elevation)

Task 3: Weather Statistics

- Purpose:
  - Determine whether nil wind conditions occur frequently enough to warrant consideration

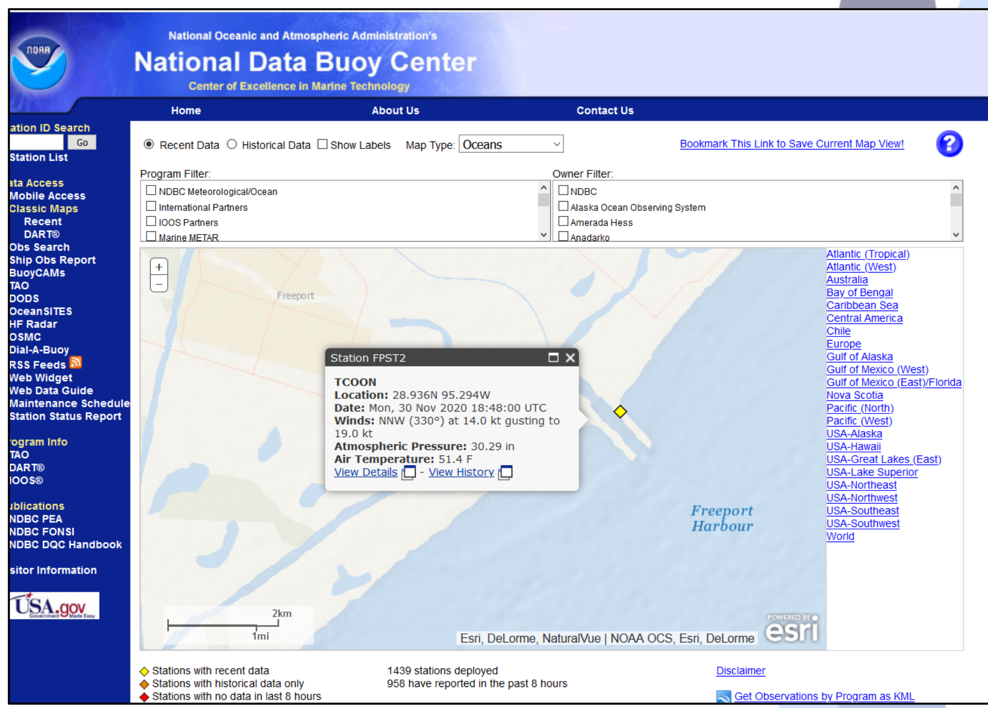
- Evaluated 10 years worth of hourly data (2010-19) for over 3,000 weather stations within the U.S.

Weather Data – Regional Results



Weather Data – Site-Specific

- Freeport LNG located in Quintana Island, Texas.
- West South Central Division data:
  - Nil = 15.8%
  - Low Wind = 10.0%
  - 10th %ile = 0 m/s
- Freeport Buoy data:
  - Nil = 0.4%
  - Low Wind = 7.5%
  - 10th %ile = 2 m/s



Weather Data Results

- Regional averages suggest that nil wind conditions can occur frequently enough to be considered
- However, regional averages can differ significantly from site-specific data, particularly for facilities near the coast
- Ultimately, site-specific data would determine the relevance of nil wind conditions for any given project

Task 4: Review 2017 HSE Report

- The 2017 HSE report (RR1113) included:
  - Evaluation of effect of nil wind on dense cloud dispersion
    - Already addressed in Task 2, Definition of Nil Wind
  - Review of historical incidents involving vapor cloud explosions at industrial installations
  - Hypothesis regarding a potential new and not well understood phenomenon (*episodic deflagration*) resulting in large vapor cloud explosions in nil wind conditions
- A critical review of RR1113 included available peer-reviewed literature

Historical Accidents

- Based on review of historical VCE accidents, RR1113 alleged that "*a wider range of smaller losses of containment (with much higher frequency) have the potential to cause a large cloud in [nil/low wind] conditions*"
- Most of the accidents in the review occurred at night or early morning, which is when nil/low wind conditions tend to be prevalent
- Night staffing is reduced, and darkness affects the operators' ability to detect a release
- These factors appear more reasonable to explain higher than expected frequency of large VCEs, than HSE's unsubstantiated allegation

Episodic Deflagration

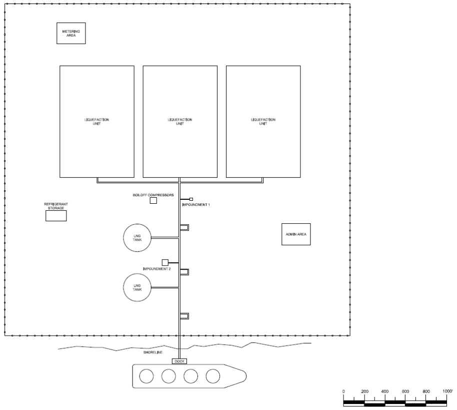
- Episodic deflagration: in very large clouds in the open, "*a target ahead of the flame would experience a series of separate blasts that increased in strength as the flame approached*". "*One possible mechanism that might allow such a burning pattern is the effect of preheating of unburned gas ahead of a flame by thermal radiation*"
- RR1113 claims that episodic deflagration is responsible for several large vapor cloud explosion accidents
- The concept of episodic deflagration has been sharply criticized and rebuked by several groups of explosion experts, both on the physical basis of the phenomenon and on the evaluation of forensic evidence.
- Based on the review of available literature on the topic, the current understanding of VCEs appears adequate to explain those accidents, and the hypothesis that episodic deflagration led to those events cannot be supported.

Regulatory Requirements

- Only one of the 24 accidents reviewed in RR1113 occurred at an LNG facility (Skikda) and wind conditions likely played a minimal role in that accident.
- RR1113 did not address the different regulatory requirements between accident facilities and PHMSA-jurisdictional LNG facilities, nor their effect on the likelihood of similar accidents occurring at LNG facilities.
- RR1113 did not provide reasonable justification for drawing a parallel between reviewed accidents and potential similar scenarios at PHMSA-jurisdictional LNG facilities

Task 5: Consequence Modeling

- Purpose: Evaluate quantitatively the hazard footprints for various design spills under low and nil wind conditions
- Export facility, consistent with other PHMSA R&D projects
  - Three MR trains
  - Two storage tanks
  - Auxiliary facilities

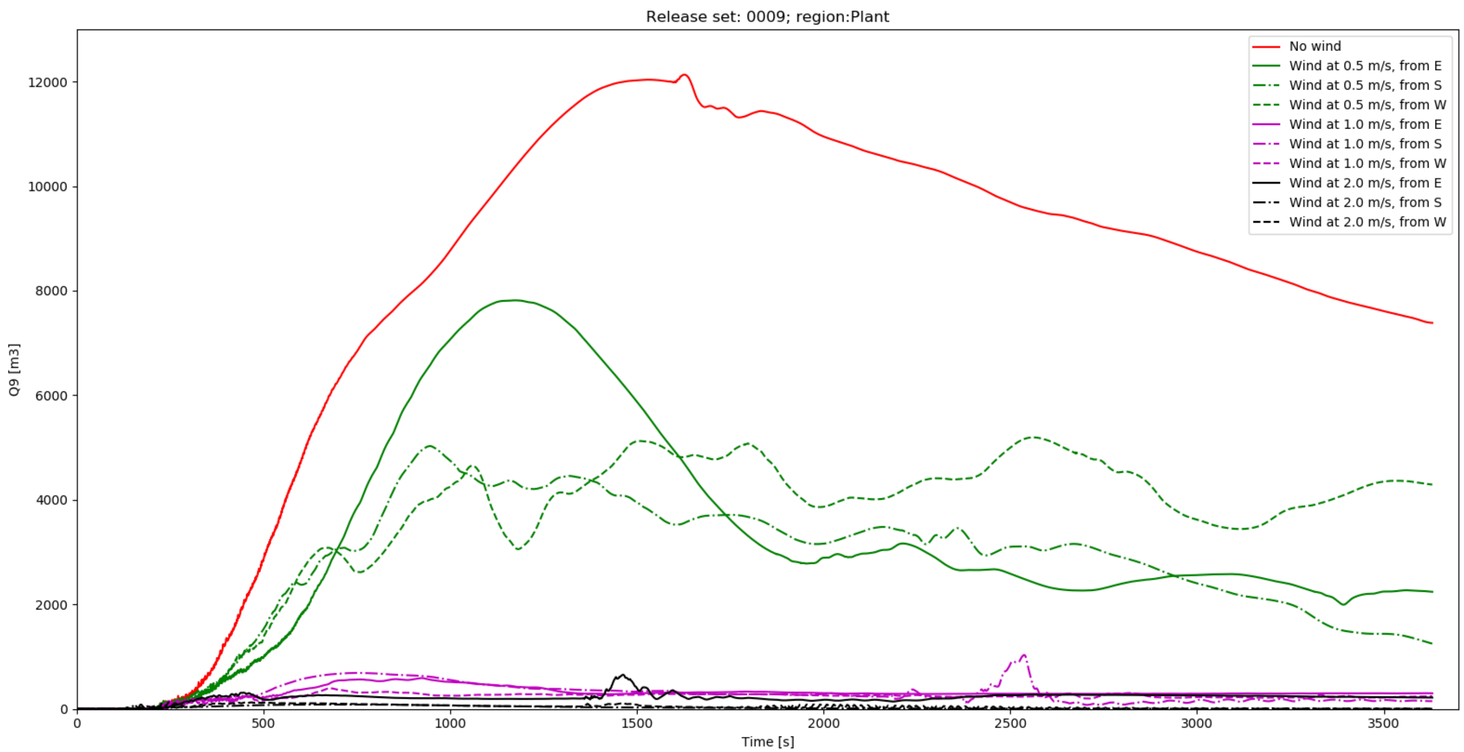


- Scenarios based on current PHMSA guidance (FAQ pages)
- Nil wind conditions require CFD modeling
  - All modeling was done with CFD

Modeling Results

LNG Spill, Plant-wide ESCs

- Strong effect of wind speed
- Nil-wind increases hazards over low wind



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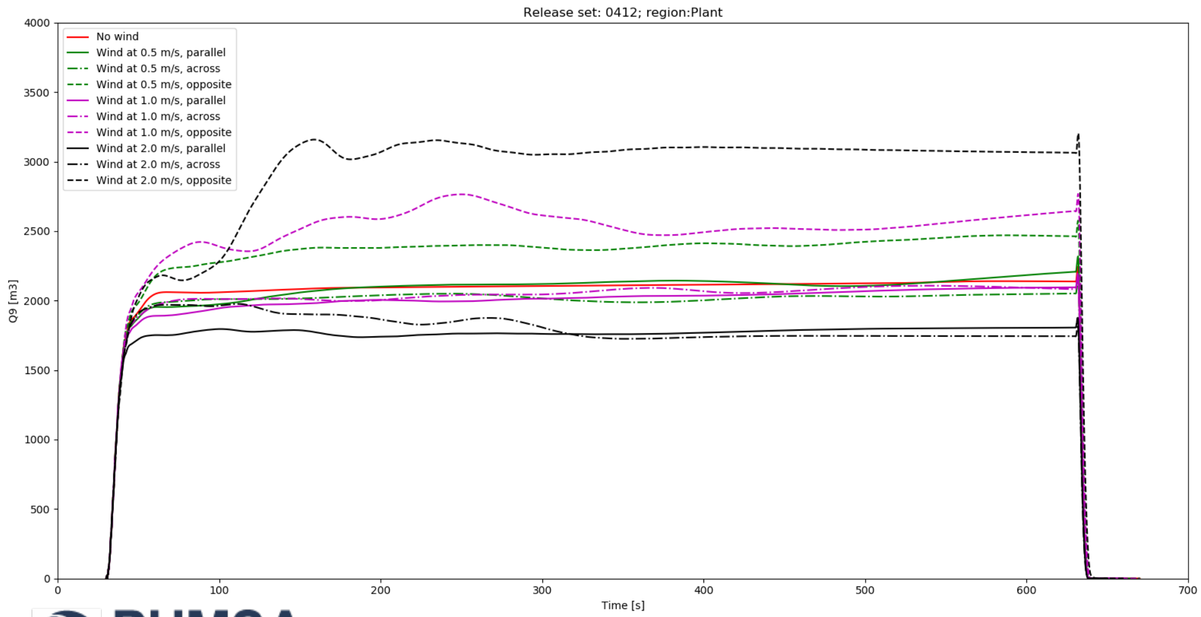
Modeling Results

LNG Flashing and Jetting, Plant-wide ESCs

- Effect of wind direction is stronger than effect of wind speed
  - 2 m/s, opposite wind direction is worst
- No evidence that nil-wind increases potential VCE hazards



Effects of Nil Wind on Prescriptive Siting

- Spills (and pressurized releases with significant rainout) can result in larger ESCs under nil wind
  - ESC volume contributing to VCE is capped by PES volume

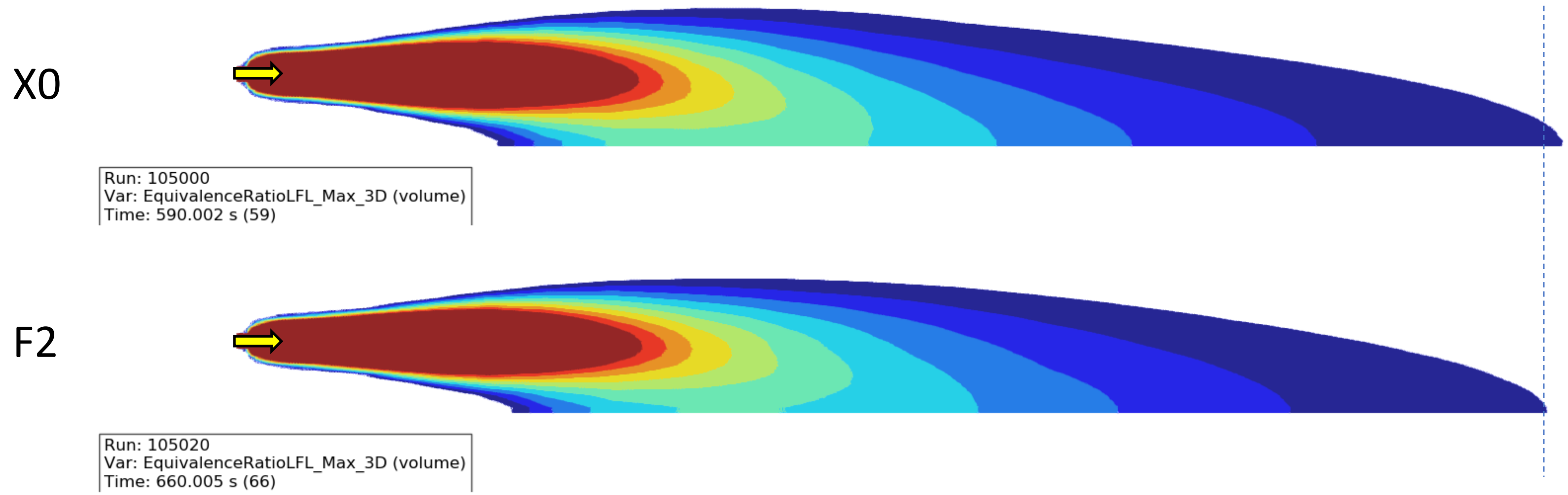
- ESCs from flashing and jetting releases are largely unaffected by low/nil wind conditions
  - F&Js are frequently the bounding cases for VCEs due to release location

Task 6: Quantitative Risk Assessment

- Purpose: Evaluate the impact of including nil-wind conditions in a facility siting QRA
  - Main purpose is to evaluate difference in QRA results with and without nil-wind
- Same facility as used in prescriptive task
  - Early design QRA
- Nil wind conditions require CFD modeling
  - Accounting for geometry = too many simulations
  - Used CFD as surrogate of Integral model

Modeling results

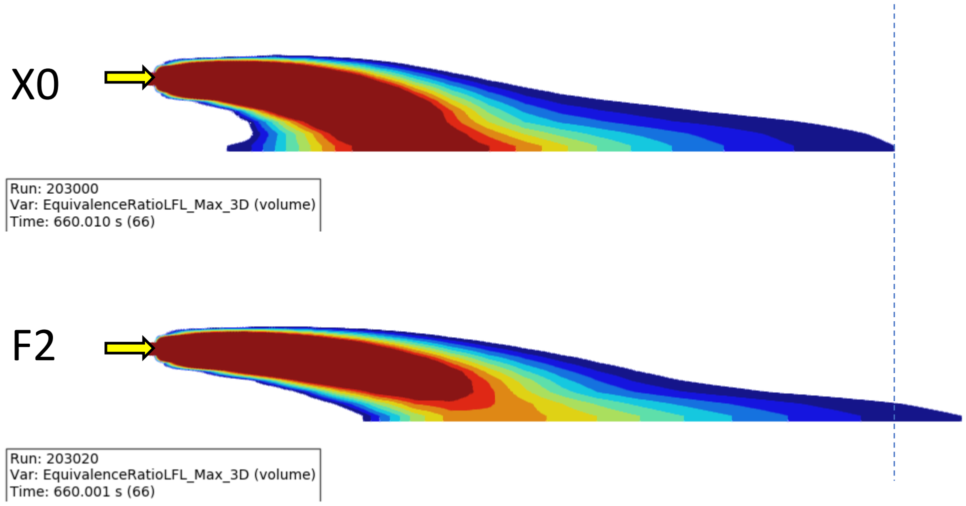
BOG to compressor, full rupture



High-momentum releases tend to be weakly dependent on wind speed

Modeling results

Propane makeup, 2” hole



Lower-momentum, ‘heavy’ releases can be affected by wind speed;

- Nil Wind does not generally increase dispersion distances
- Nil Wind does not generally increase ESCs

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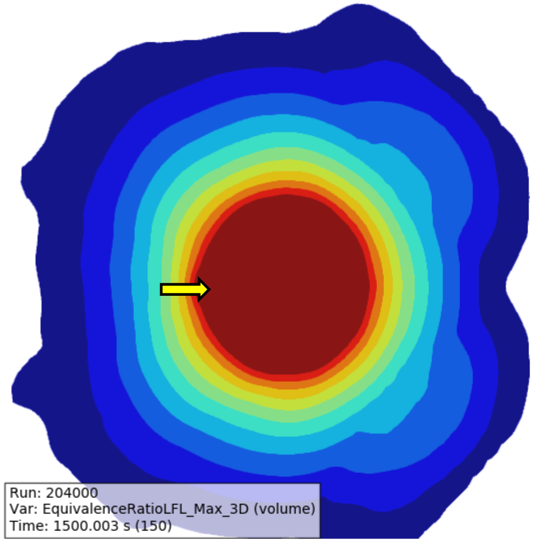
Modeling results

Propane makeup, 6" hole

X0



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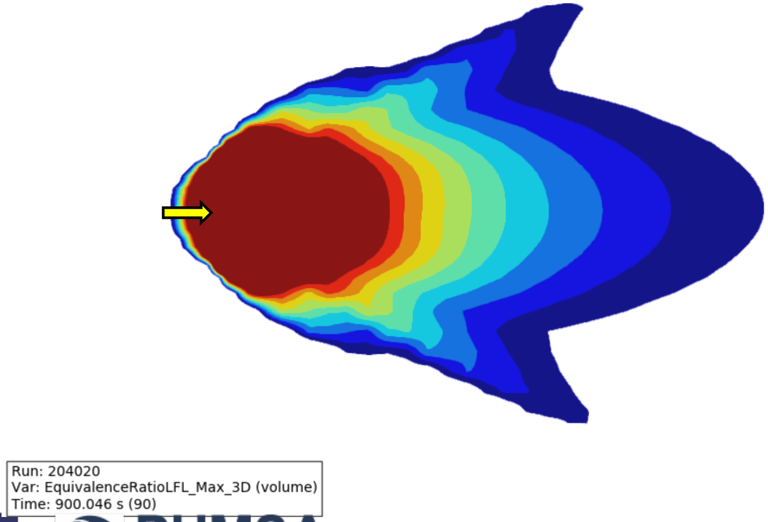
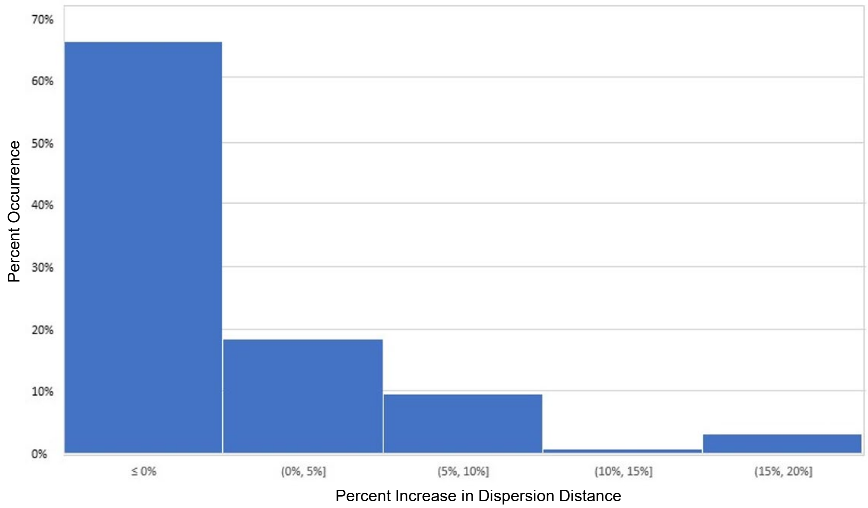
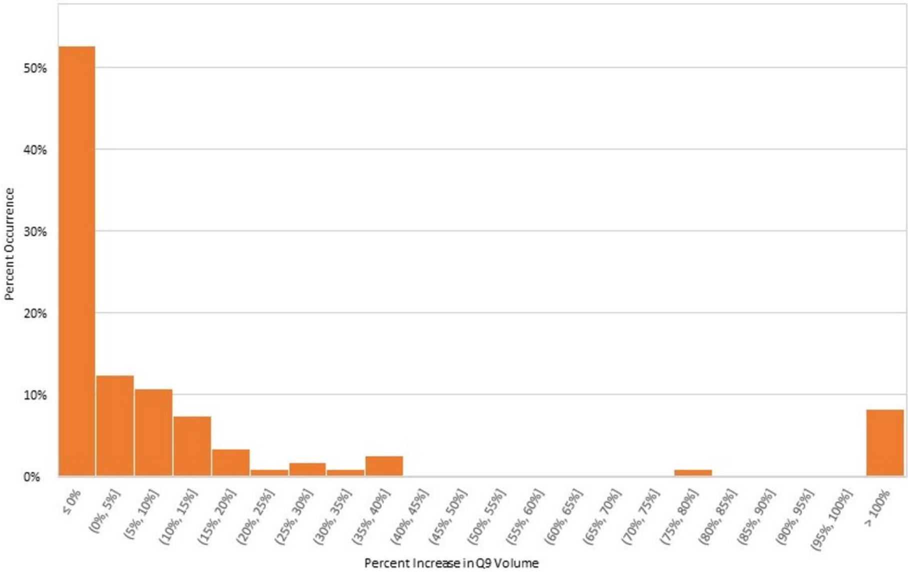


Lower-momentum releases with rainout tend to be more affected by wind speed;

- Nil Wind does not always increase dispersion distances
- Nil Wind generally increases ESCs

Hazard Modeling Results



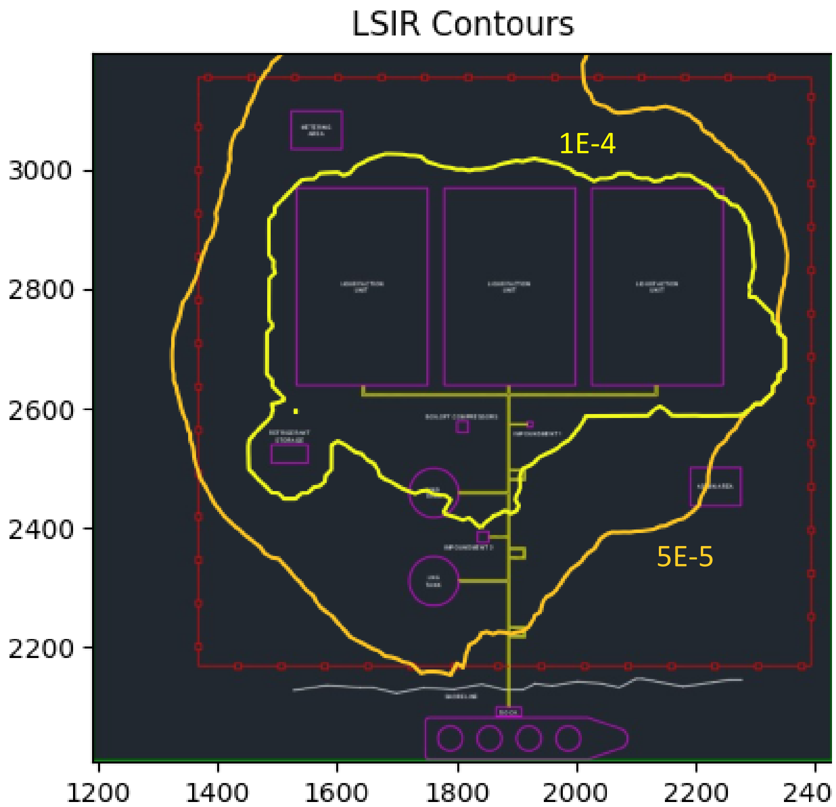


Modeling summary:

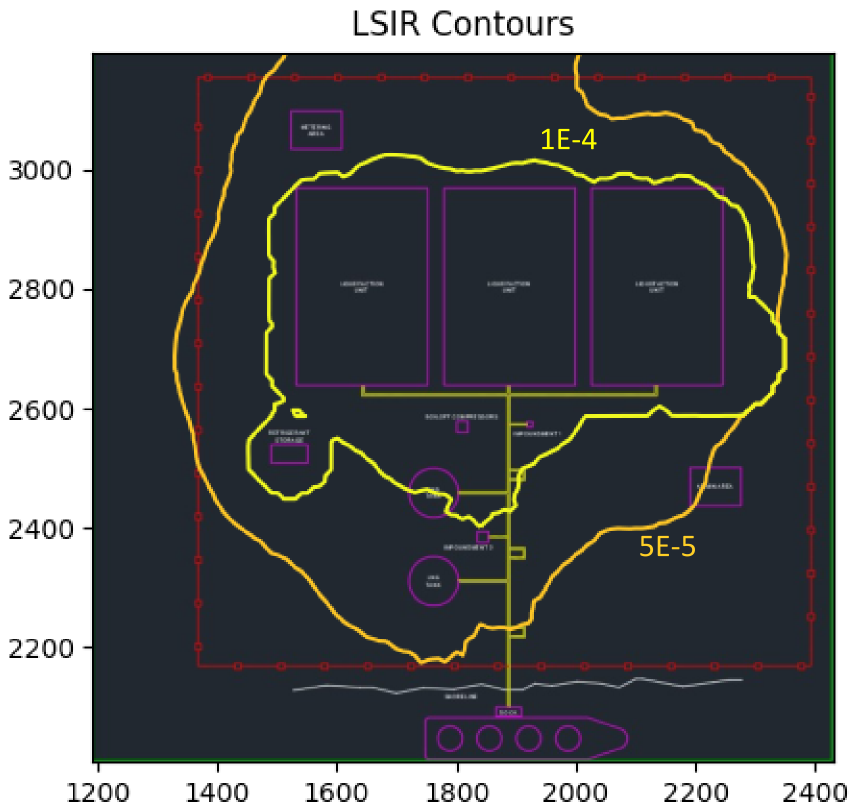
- Majority of scenarios result in no worsening of hazards
- Scenarios that result in worsening of hazards are predominantly large-bore releases (lower frequency)

Effects of Nil Wind on Risk-Based Siting

- Baseline



- Including Nil Wind



- Very limited difference
- Nil-Wind risk contours are smaller

Task 8: Project Management

- The project was completed on budget and with a slight delay (due to the computational effort required for Task 6)
- The TAP members remained involved and engaged throughout the project

Project Summary Conclusions

- Nil Wind definition: **U < 1 m/s**
  - Basis: non-CFD models are limited to U >= 1 m/s
- Episodic deflagration has been broadly discredited as a potential explosion mechanism
  - Current knowledge of VCEs is adequate
- Comparison of releases under Nil / Low wind shows:
  - Increase in ESC volumes (and sometimes dispersion distances) for high-rainout scenarios in Nil Wind
  - Decrease in ESC volumes and dispersion distances for high-momentum releases in Nil Wind
- QRA results with and without Nil Wind tend to be similar
  - Slightly smaller risk contours when Nil Wind is included

Recommendations and Next Steps

- The project team does not recommend any changes to the regulatory requirements regarding wind speeds to be included in an LNG facility siting study, as currently specified in 49 CFR 193.2059

- No further steps are required to address this topic

Closing

Project public webpage:
https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=922

- Public Final Report
- Project Debriefing Presentation

PM Contact Info:

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