Enabling a better working world

HEALTH & SAFETY LABORATORY

Update to the LNG Dispersion Model Validation Database

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PHMSA Public Workshop on Liquefied Natural Gas (LNG) Regulations, Washington DC, 19 May 2016

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- Timeline
- Possible future work

Background

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2007 ← LNG Model Evaluation Protocol (Ivings *et al*., 2007)

2008 ← LNG Model Validation Database, Version 1 (Coldrick *et al*., 2008)

2009 ← Review of LNG Source Models (Webber *et al*., 2009)

2010 ← LNG Model Validation Database, Version 11 (Coldrick *et al*., 2010)
PHMSA Advisory Bulletin PHMSA-2010-0226

2011 ← Evaluation of DEGADIS 2.1, PHAST v6.6/6.7 and FLACS v9.1r2 by FERC & PHMSA

2012

…

2016 ← LNG Model Validation Database, Version 12 (Stewart *et al*., 2016)
LNG Model Evaluation Protocol (Ivings *et al*., 2016)

Background

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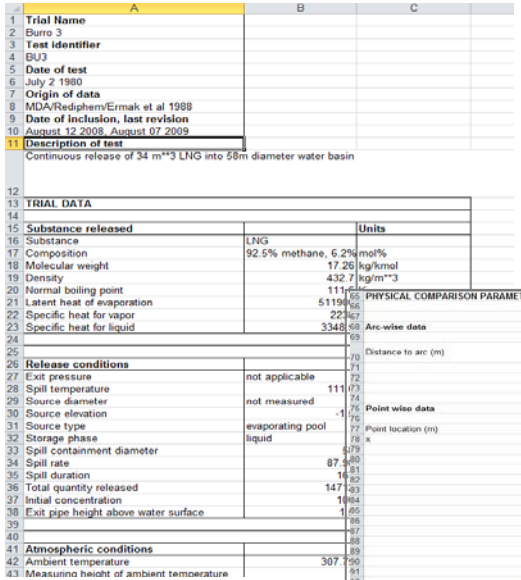
Content of the NFPA Database:

Trial Name	Sheet number in the Database	Trial number	Field (F) or Wind tunnel (WT)	Obstructed (O) or unobstructed (U)	Atmospheric stability	Substance released	Dispersion over water (W) or land (L)
Maplin Sands, 1980	1	27	F	U	C-D	LNG	W
	2	34			D		
	3	35			D		
Burro, 1980	4	3	F	U	B	LNG	L
	5	7			D		
	6	8			E		
	7	9			D		
Coyote, 1981	8	3	F	U	B-C	LNG	L
	9	5			C-D		
	10	6			D		
Falcon, 1987	11	1	F	O	G	LNG	L
	12	3			D		
	13	4			D-E		
Thorney Island 1982-4	14	45	F	U	E-F	Freon 12 & Nitrogen	L
	15	47			F		
CHRC, 2006	16	A	WT	U	D	Carbon Dioxide	L
	17	B		O	D		
	18	C		O	D		
BA-Hamburg	19	Unobstructed (DA0120)	WT	U	D	Sulfur Hexafluoride	L
	20	Unobstructed		U	D		



	A	B	C
1	**Trial Name**		
2	Burro 3		
3	**Test identifier**		
4	BU3		
5	**Date of test**		
6	July 2 1980		
7	**Origin of data**		
8	MDA/Rediphem/Ermak et al 1988		
9	**Date of inclusion, last revision**		
10	August 12 2008, August 07 2009		
11	**Description of test**		
	Continuous release of 34 m**3 LNG into 58m diameter water basin		
12			
13	**TRIAL DATA**		
14			
15	**Substance released**		**Units**
16	Substance	LNG	
17	Composition	92.5% methane, 6.2%	mol%
18	Molecular weight	17.26	kg/kmol
19	Density	432.7	kg/m**3
20	Normal boiling point	111	
21	Latent heat of evaporation	511	
22	Specific heat for vapor	22	
23	Specific heat for liquid	3348	
24			
25			
26	**Release conditions**		
27	Exit pressure	not applicable	
28	Spill temperature	111	
29	Source diameter	not measured	
30	Source elevation	-1	
31	Source type	evaporating pool	
32	Storage phase	liquid	
33	Spill containment diameter		
34	Spill rate	87.3	
35	Spill duration	1	
36	Total quantity released	147	
37	Initial concentration	1	
38	Exit pipe height above water surface	1	
39			
40			
41	**Atmospheric conditions**		
42	Ambient temperature	307	
43	Measuring height of ambient temperature		

	PHYSICAL COMPARISON PARAMETERS				
	Arc-wise data				
	Distance to arc (m)	Averaging window (s)	Averaging time (s)	Maximum arc-wise concentration (%)	Cloud width (m)
	57		1	22.4	
	140		1	9.0	
	57	30-130	100	7.9	20.86
	140	26-125	100	6.1	n/a
	Point wise data				
	Point location (m)				
	x	y	z	Averaging time (s)	Concentration (%)
	40	-40.6	1	1	8.6
	49	-28.7	1	1	11.2
	55.6	-14.9	1	1	22.4
	55.6	14.9	1	1	20.3
	49	28.7	1	1	22.4
	127	-58	1	1	6.8
	140	0	1	1	9.0
	40	-40.6	1	100	0.4
	49	-28.7	1	100	3.7
	55.6	-14.9	1	100	6.9
	55.6	14.9	1	100	7.9
	49	28.7	1	100	3.1
	127	58	1	100	0.9
	140	0	1	100	6.1

Aims of the Update

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- To add new features into the database to meet the requirements of PHMSA Advisory Bulletin PHMSA-2010-0226
  - Maximum arc-wise concentrations
  - Point-wise data for Maplin Sands and Thorney Island
  - Concentration Safety Factor, Concentration Safety Factor to LFL, Distance Safety Factor to LFL
  - Experimental uncertainty
- To correct errors
  - BA-Hamburg: incorrect geometry
  - Other small mistakes
- To provide more extensive documentation and guidance

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Max. Arc-wise Concentration

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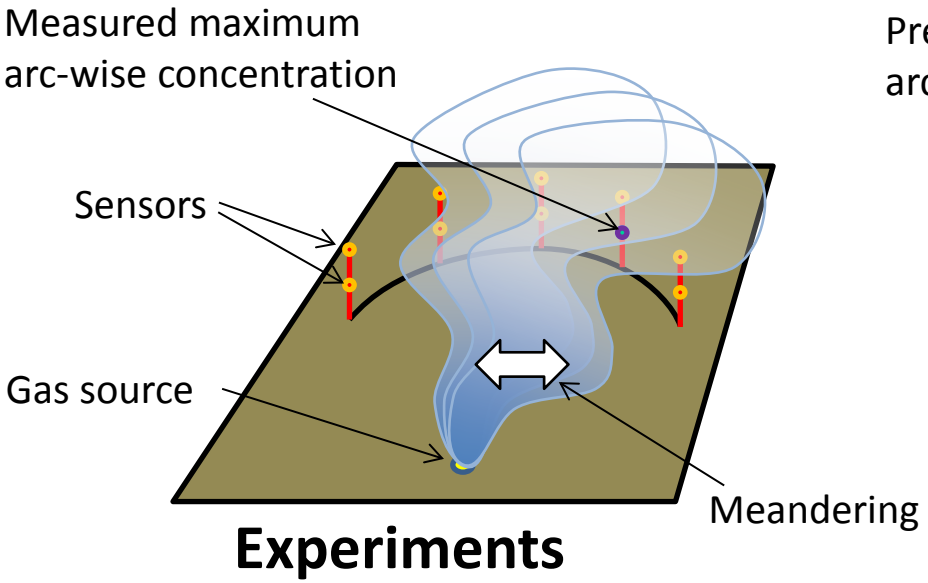
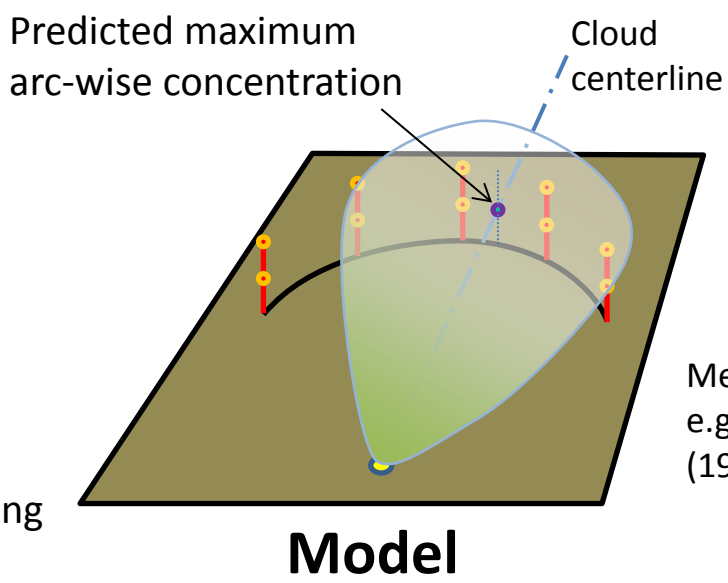


Experiments



Model

Method used by e.g. Hanna *et al*. (1993)

Max. Arc-wise Concentration

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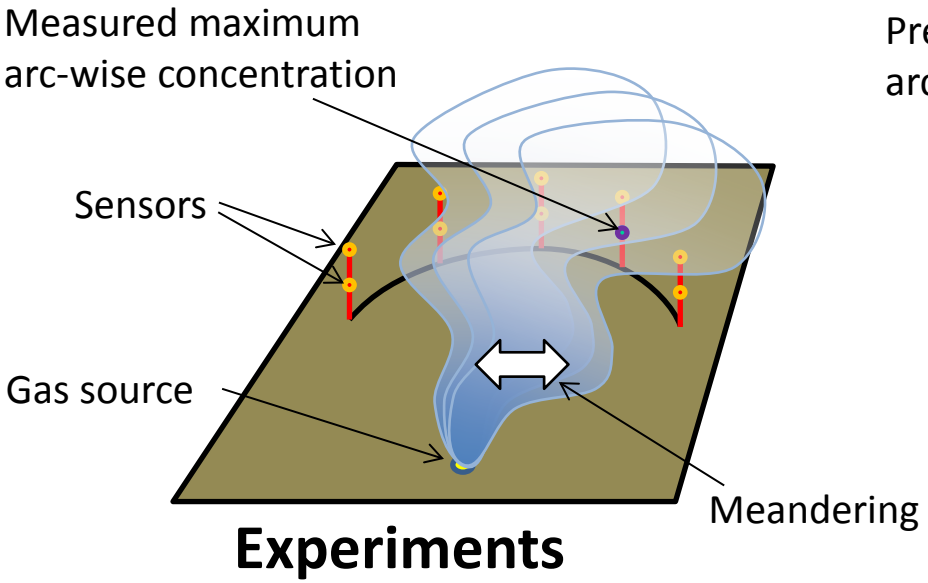
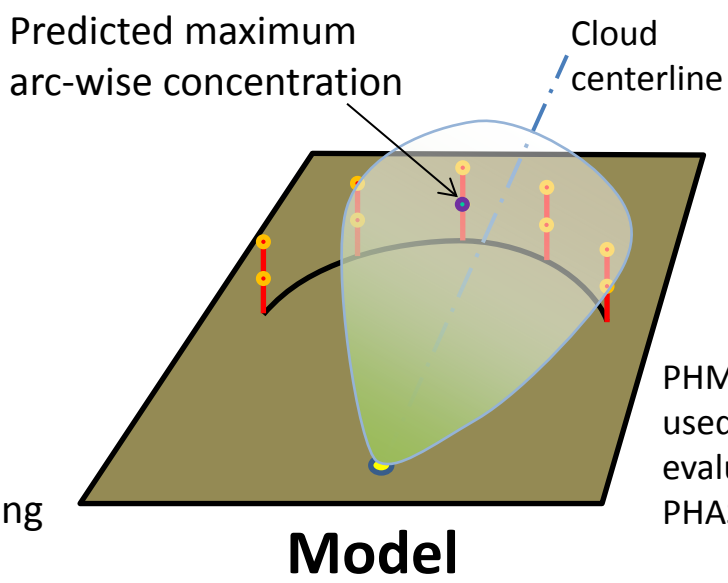


Experiments



Model

PHMSA method: used previously to evaluate DEGADIS, PHAST, and FLACS

Max. Arc-wise Concentration

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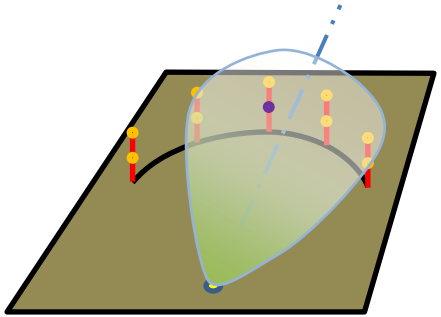

PHMSA method for max. arc-wise concentrations

PHMSA-2010-0226 Advisory Bulletin states: “The maximum arc wise concentration should be based on the location of the experimental sensor data that produced the maximum arc wise concentration relative to the cloud centerline”

- Precautionary, given uncertainties in ensemble mean concentrations (it will tend to make the ½ LFL exclusion zone larger)
- It accounts for the strong vertical gradient in concentration near the ground
- It accounts for sensors not being aligned to arcs in some experiments
- It encourages development of plume meandering models

Max. Arc-wise Concentration

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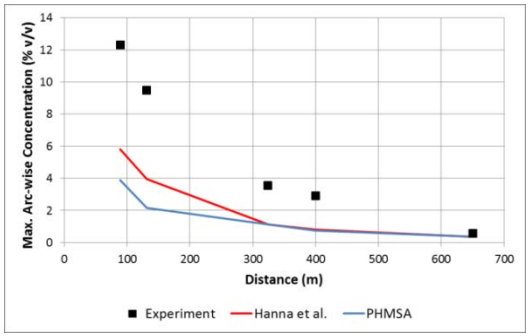
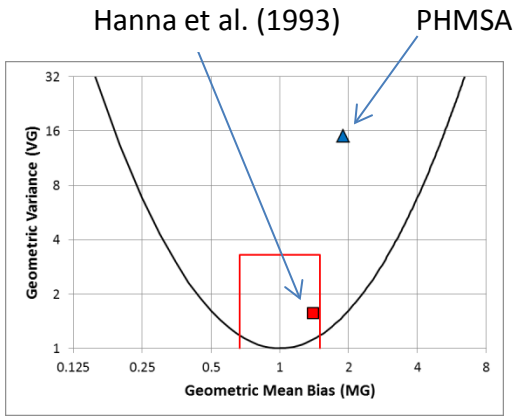
Does it matter which method is used for maximum arc-wise concentration?

Example:
Maplin Sands 27 experiment



Results for DRIFT model



Results summary for Maplin Sands, Burro, Coyote & Falcon:

Method	Mean Relative Bias (MRB)	Mean Relative Square Error (MRSE)	Geometric Mean (MG)	Geometric Variance (VG)	Factor of Two (FAC2)
Hanna et al.	0.31	0.38	1.4	1.6	61%
PHMSA	**0.41**	0.59	**1.9**	**15**	56%
Acceptable	-0.4 < MRB < 0.4	MRSE < 2.3	0.67 < MG < 1.5	VG < 3.3	FAC2 > 50%

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Additional Experimental Data

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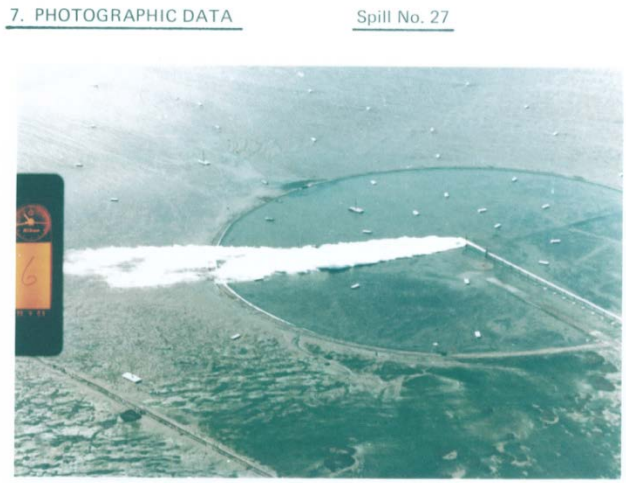
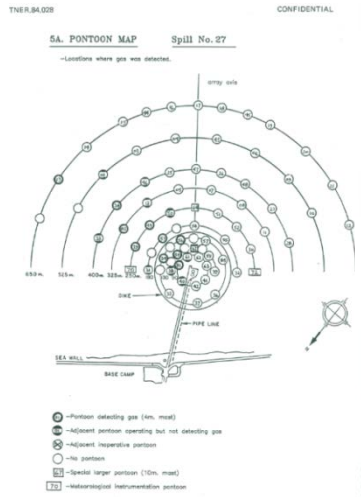
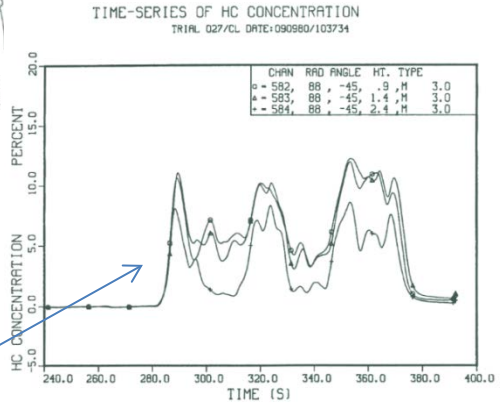
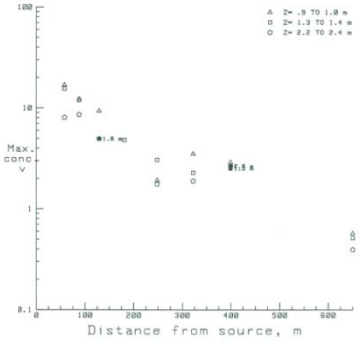
Maplin Sands (1980) experiments









Time-series data processed for point-wise concentrations

Additional Experimental Data

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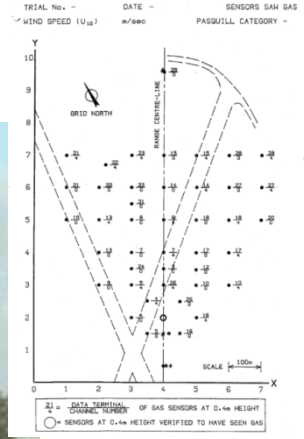
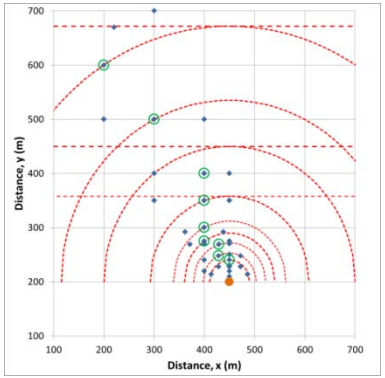
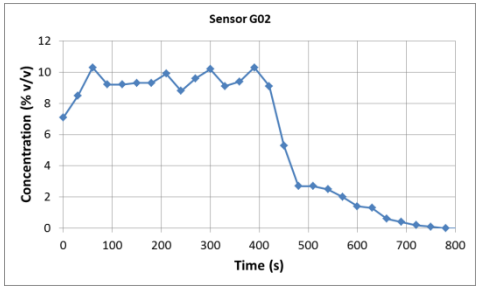
Thorney Island (1982) experiments





Time-series data processed for point-wise concentrations



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Errors in Experimental Data

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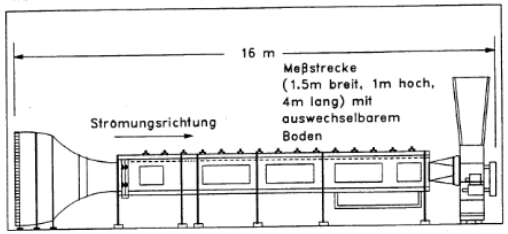
BA-Hamburg experiments



REDIPHEM (1996)

Table 15. Hamburg experiments with a semi-circular fence downwind of the release, see figure 4e.

Instantaneous release				Continuous release			
File	fence height $[L_{ci}]$	fence diameter $[L_{ci}]$	velocity @ L_{ci} $[U_{ci}]$	File	fence height $[L_{cc}]$	fence diameter $[L_{cc}]$	velocity @ L_{ci} $[U_{cc}]$
DA0502	0.4	4	1	DA0501	2.24	22.4	1
DA0517	0.4	4	1	DA0532	2.24	22.4	1

Schatzmann *et al.* (1991)

Continuous Release.
Obstacle: Semi–circular wall of Height: 2.2 Lcc and Radius 23 Lcc.
Ground–level Concentrations measured downstream from the Source.

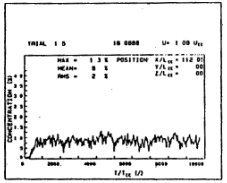
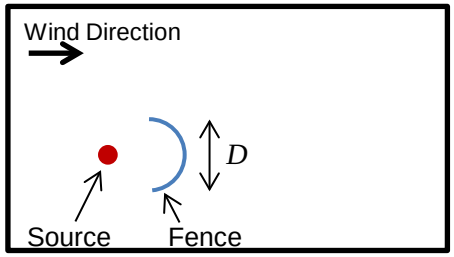
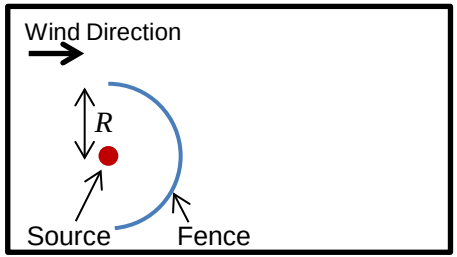


Fig. 26: Concentration versus time traces at different locations for a continuous heavy gas release into flat terrain obstructed by a semi-circular wall.

Incorrect: NFPA database, version 11



Correct: NFPA database, version 12



Marotzke(1993)

Ein solcher halbkreisförmiger Schutzzaun kann zum Beispiel dann zur Anwendung kommen, wenn sich nur in einer Richtung von einer potentiellen Schwergasquelle zu schützende Einrichtungen befinden. Es wurden zwei Zäune mit unterschiedlichen Radien verwendet:

- quellnaher Zaun: Radius 2.5 L_{ci} bzw. 14 L_{cc} und Zaunhöhe 0.4 L_{ci} bzw. 2.2 L_{cc}
- quellferner Zaun: Radius 4 L_{ci} bzw. 22.4 L_{cc} und Zaunhöhe 0.4 L_{ci} bzw. 2.2 L_{cc}

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Deliverables

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1. NFPA Model Validation Database **version 12**
   a) Microsoft Excel 2010 spreadsheet
   b) ASCII data files (plain text version of spreadsheet)
   c) Database Guide (125 pages)

2. Revised LNG Model Evaluation Protocol
   – Relatively minor changes from version 11

Deliverables

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Excel 2010 Spreadsheet version 12, e.g. Burro 3

Exit pipe height above water surface	1.5	m
Atmospheric conditions	**Value**	**Units**
Ambient temperature	307.75	K
Measuring height of ambient temperature	1	m
Ambient pressure	0.936	atm
Wind speed	5.58	m/s
Measuring height of wind speed	3	m
Domain-avg wind speed	5.4	m/s
Domain-avg sigma wind speed	1.19	m/s
Domain-avg sigma wind direction	13.3	degrees
Measurement ht for domain-avg wind data	2	m
Averaging time for domain-avg data	360	s
Array centerline	225	degrees from true North, p-ve from SW to NE
Wind direction	224	wind from this angle, in degrees from true North
Pasquill-Gifford stability class	C	N/A
Monin-Obukhov length	-9.057	m
Friction velocity	0.25	m/s
Relative humidity	5.2	%
Terrain and obstacles	**Value**	**Units**
Surface roughness	0.0002	m
Groundwater temperature	not available	N/A

PHYSICAL COMPARISON PARAMETERS

Point wise data

Point location					Maximum Concentration (% v/v)				
X (m)	Y (m)	Z (m)	Averaging window (s	Averaging time (s	Fixed-Averaging Window	Absolute Max.r Rolling Average **	Model Output (Max. at ang Z)	Temp. (K) *	Notes
40	-40.5	1, 3, 8	30-130	1	8.6	16.7			Data from 1 m
49	-28.7	1, 3, 8	30-130	1	11.2	20.6			**Data from 3 m**
55.6	-14.9	1, 3, 8	30-130	1	22.4	22.4			**Data from 8 m**
57	*6*	*N/D*	*30-130*	*1*	*N/D*	*N/D*	*N/D*		*N/D - No recorded data at sensor*
55.6	14.9	1, 3, 8	30-130	1	20.3	20.3			**Data excluded from SPM calculations**
49	28.7	1, 3, 8	30-130	1	22.4	28.2			**N/A as data excluded after cloud bifurcation**
37	38	1, 3, 8	30-130	1	**0.0**	16.9			* Temperature included for reference only, data is not used as part of LNG MEP assessment
112	-84	1, 3, 8	30-130	1	**0.0**	**0.0**			
127	-58	1, 3, 8	30-130	1	6.8	6.8			** Absolute max. or 100 s moving average calculated across full experiment duration
137	*-38*	*N/D*	*30-130*	*1*	*N/D*	*N/D*	*N/D*		
149	0	1, 3, 8	30-130	1	9.0	9.0			*** Cloud width calculated using data from sensors at 1 m only
137	*38*	*N/D*	*30-130*	*1*	*N/D*	*N/D*	*N/D*		
127	*58*	*N/D*	*30-130*	*1*	*N/D*	*N/D*	*N/D*		# Transformed sensor locations for use where models are only capable of using grid-aligned wind
112	84	1, 3, 8	30-130	1	**0.0**	**0.0**			
360	-174	1, 3, 8	50-150	1	**0.0**	**0.0**			
382	-118	1, 3, 8	50-150	1	**0.6**	**0.6**			
395.5	-59.8	1, 3, 8	50-150	1	**1.2**	**1.2**			
468	*6*	*N/D*	*50-150*	*1*	*N/D*	*N/D*	*N/D*		
395.5	*59.8*	*N/D*	*50-150*	*1*	*N/D*	*N/D*	*N/D*		
382	118	1, 3, 8	50-150	1	**0.0**	0.3			
360	174	1, 3, 8	50-150	1	**0.0**	**0.0**			
737	*-312*	*N/D*	*170-270*	*1*	*N/D*	*N/D*	*N/D*		
784	*-236.5*	*N/D*	*170-270*	*1*	*N/D*	*N/D*	*N/D*		
784	*-155*	*N/D*	*170-270*	*1*	*N/D*	*N/D*	*N/D*		
796	*-75.5*	*N/D*	*170-270*	*1*	*N/D*	*N/D*	*N/D*		
668	*6*	*N/D*	*170-270*	*1*	*N/D*	*N/D*	*N/D*		
796	79.9	1, 3, 8	170-270	1	**N/A**	**0.9**			
784	159	1, 3, 8	170-270	1	**N/A**	**0.7**			

Deliverables

Database Guide

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Validation Database for Evaluating Vapor Dispersion Models for Safety Analysis of LNG Facilities

Guide to the LNG Model Validation Database

Version 12, 29 April 2016

MSU/2016/12

DRAFT Version 1

Report Approved for Issue By:	**Charles Oakley, CEng FIMechE**
Date of Issue:	**29/04/2016**
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HSL Project Number:	**PE06387**

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Timeline

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- 1 May 2016 — Draft database spreadsheet and guide circulated for review
- 27 May 2016 — Comments due on database and guide
- End of June 2016 — Revised MEP report circulated for review
- End of July 2016 — Comments due on MEP report
- End of Aug 2016 — Final NFPA Database version 12 issued

Tentative dates

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Possible Future Work

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- LNG MEP focuses on spills of LNG (import terminals)
  - Source terms: evaporating pools of cryogenic liquids
- For LNG export terminals, range of other source terms:
  - Flashing jets of pressure-liquefied refrigerant gases, e.g. propane, mixed refrigerants
  - Spills of condensates
- Experimental data could be added to LNG MEP, e.g.:
  - Flashing jets: Lathen (propane releases with obstacles), Desert Tortoise and FLADIS (ammonia), Jack Rabbit (chlorine) etc.

References

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