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LNG Safety Excellence: A Decade of Efforts by the Mary Kay O'Connor Process Safety Center

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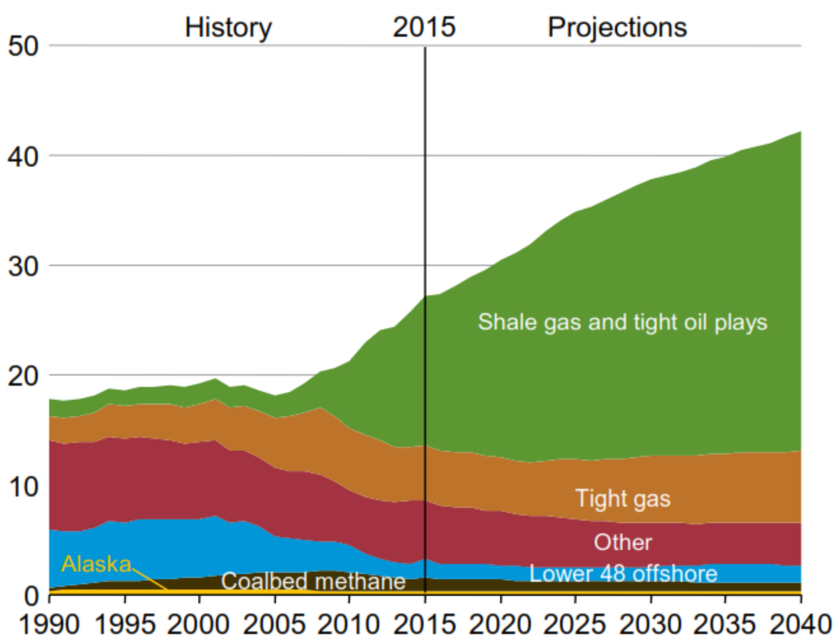
PHMSA Government & Industry R&D Forum
Cleveland, Ohio, November 16-17, 2016

Outline

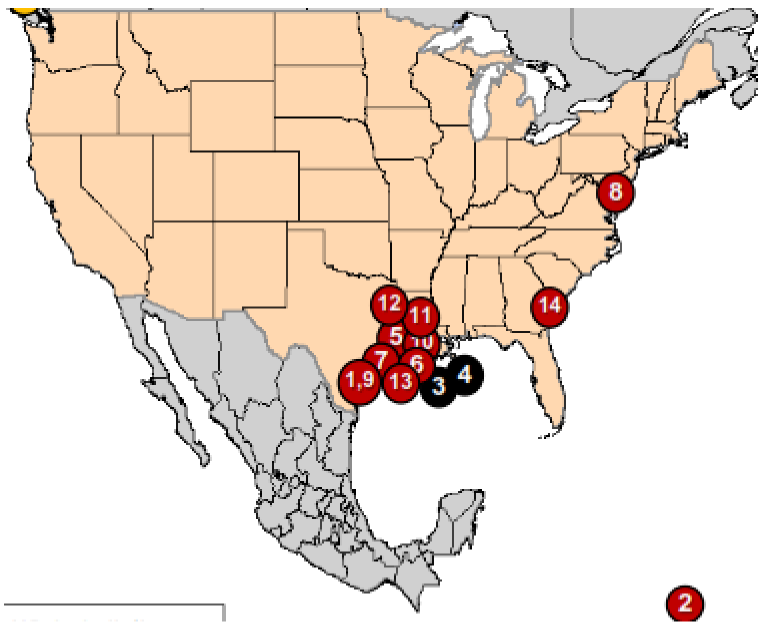
- Introduction
- LNG Safety Concerns
- LNG Safety Research Overview
- Areas of Study
  - LNG Vapor Dispersion and Pool Fire Modeling with CFD
  - LNG Vapor Cloud Control using Water Curtain
  - LNG Vapor and Fire Mitigation using Expansion Foam
  - Experimental Study and CFD Simulation of Bund Overtopping
  - Source-Term and Pool Spreading of Spill on Land and Water
- Conclusions

Introduction

- Liquefied natural gas (LNG): provides flexibility in natural gas industry for storage and inter-regional trade
  - New emerging natural gas market will accelerate LNG trade globally
- Growing concerns on potential LNG spill and consequence around facilities
  - Further research on LNG safety is required to ensure public safety and safe operation



U.S. natural gas production by source (trillion cubic feet) (source: EIA)



LNG import and export terminals approved in the U.S. (source: FERC)

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LNG Safety Concerns

LNG Properties

- Flammable as a fuel
  - Flammable limit ranges approximately 5-15 v/v % in air
- Cryogenic liquid for ease of storage and transportation
  - Extremely cold, boiling point is -162˚C (-263˚F)
  - Expands 600 times in volume during vaporization
  - Difficult to disperse due to heavier-than-air behavior below -114˚C (-173˚F)

Hazards and Regulations

- Main hazards
  - Flammable vapor cloud
  - Pool fire
- Standards and regulations
  - 49 CFR Part 193
    - Define "exclusion zones" in terms of vapor dispersion (1/2 LFL) and fire thermal radiation (5 kW/m^2)
  - NFPA 59A (2013)
    - Require mitigation measures to reduce risks to a tolerable level

LNG Safety Research at MKOPSC

- Involved in research for the improvements of LNG safety, security and spill response since 2005
- Research program, sponsored by BP Global Gas SPU, Qatar National Research Foundation, and others includes
  - LNG vapor dispersion and pool fire
    - LNG vapor dispersion and pool fire CFD modeling and validation
  - Safety measures for dispersion and fire control
    - Application of water curtain to disperse LNG vapor cloud
    - Application of expansion foam and alternate systems to control LNG vapor and fire
  - Risk analysis of bund overtopping
  - Source-term and pool spreading of spill on land and water
- Combination of theoretical understanding with field/lab tests to make the research applicable to the current industry needs

الصندوق القطري لرعاية البحث العلمي
Qatar National Research Fund

bp

TRAIN • SERVE • RESPOND

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LNG Facility at TEEX

- Seven series of LNG outdoor spill tests have been performed since 2005 at LNG test facility at the Brayton Fire Training Field (BFTF) of Texas A&M Engineering Extension Service (TEEX), College Station, Texas

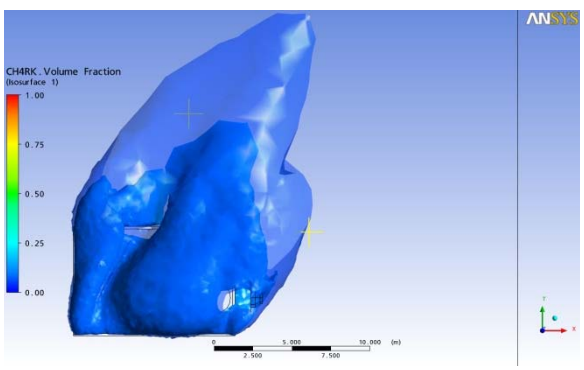
- Pit 1: Small Pit - 3m x 3m x 1.22 m
- Pit 2: Large Pit - 10m x 6.7m x 1.22m
- Pit 3: L-shaped trench
- Pit 4: Marine Pit - 2.44 m x 6.7 m x 6.7 m

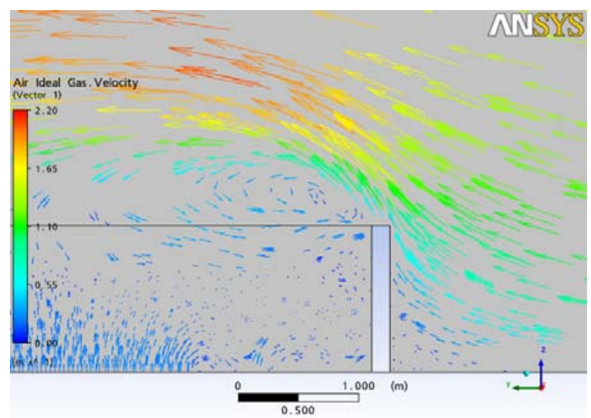
- Average total vol. of LNG used: 41 m^3
- Average spill rate: 0.36 ~ 1 m^3/min
- Data measured
  - Wind speed, direction, temperature, humidity, atmospheric heat flux
  - LNG flow, level, temperature
  - LNG vapor turbulence, speed, concentration, temperature
  - LNG fire temperature, heat flux

LNG Vapor Dispersion and Pool Fire Modeling with CFD

LNG Vapor Dispersion and Pool Fire

- High demand exists for performing site-specific risk analysis of complex scenarios in LNG facilities and terminals
- No specific guideline on how to address complex scenarios with CFD
- Improve the understanding of physical process of LNG vapor dispersion and pool fire
- Study key parameters of modeling LNG vapor dispersion and pool fire with CFD codes





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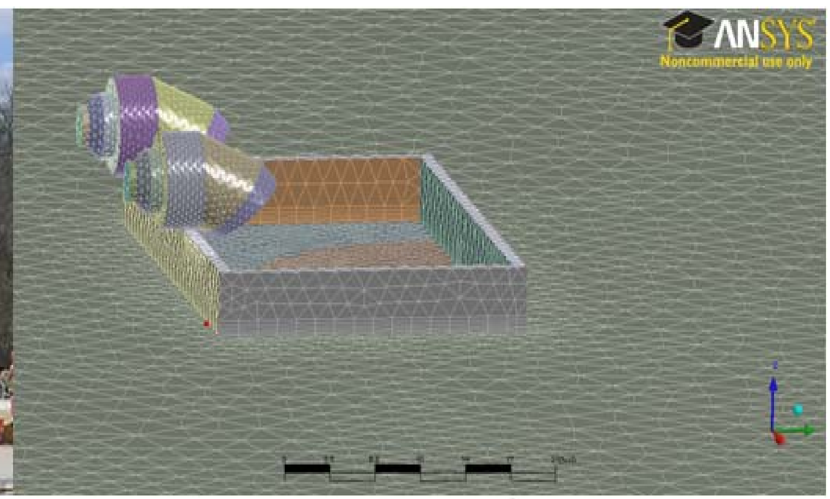
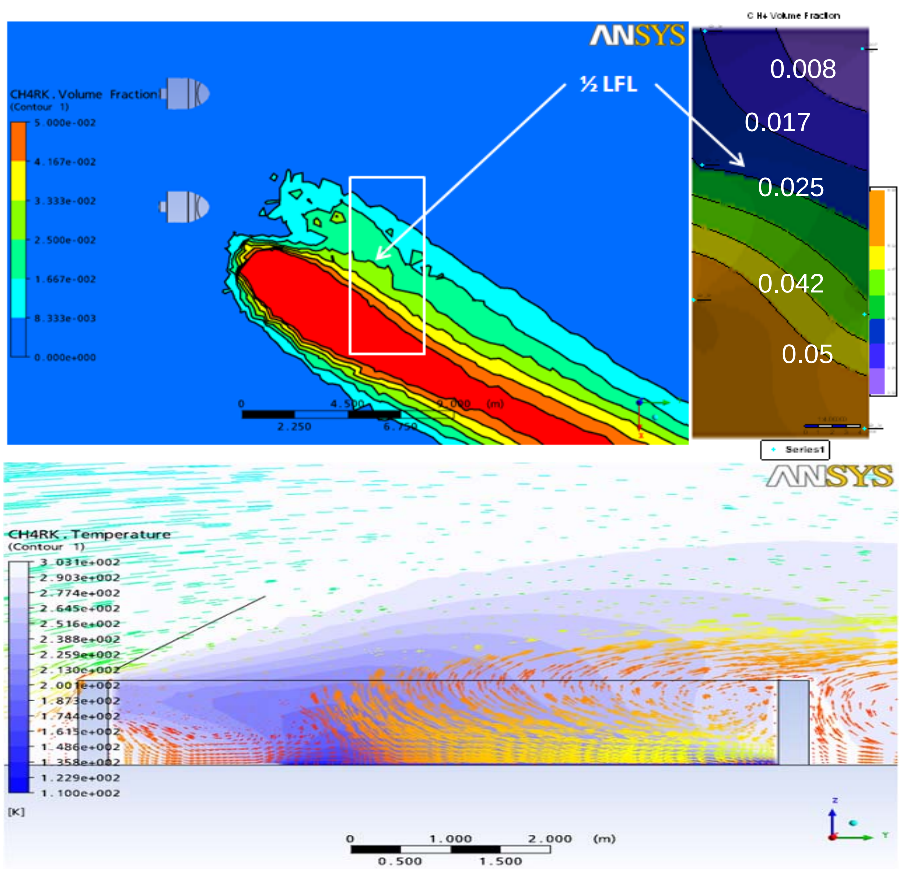
LNG Vapor Dispersion and Pool Fire

- **Field test setup**

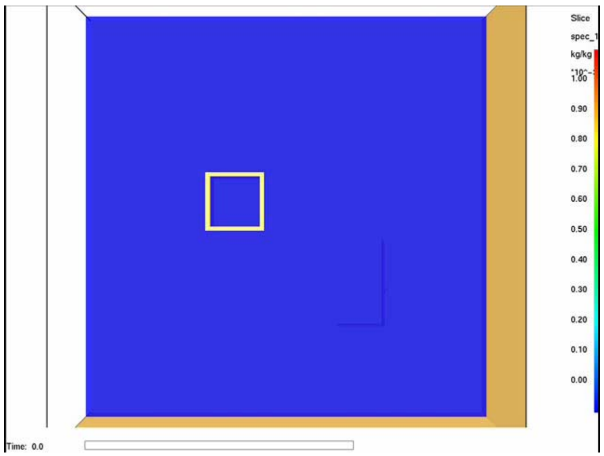


LNG Vapor Dispersion and Pool Fire

LNG Vapor Dispersion and Pool Fire



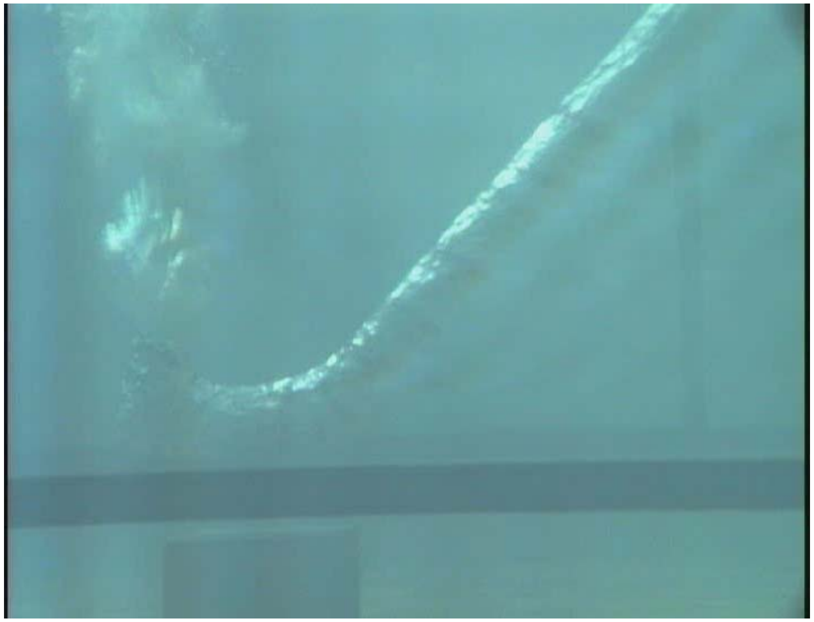
Comparison of gas concentration contours and effect of turbulence induced by the dike



LNG Vapor Dispersion and Pool Fire

- **LNG underwater release**

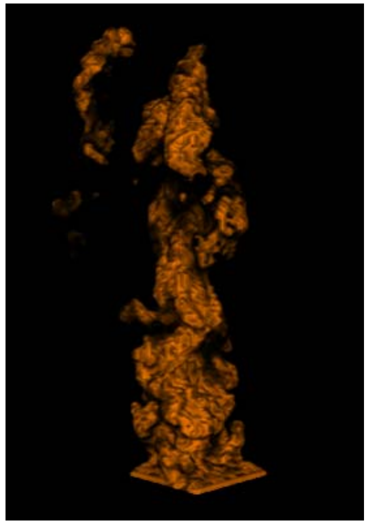
Over-the-land video camera



Underwater video camera

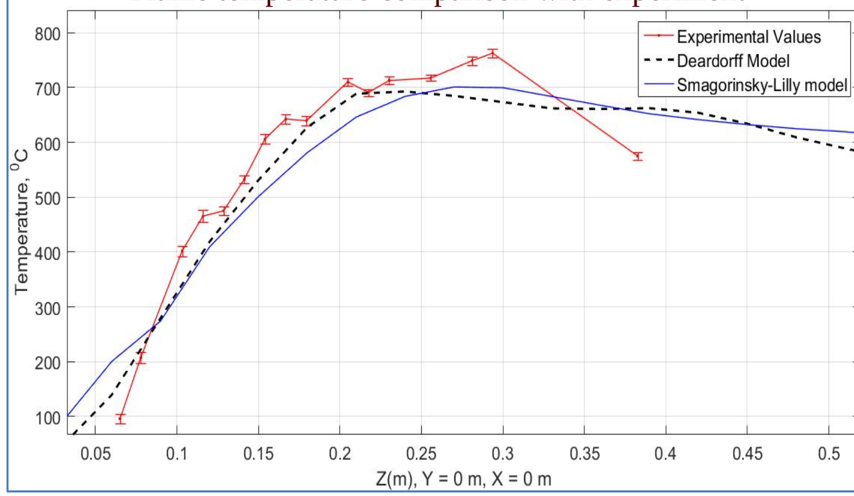
LNG Vapor Dispersion and Pool Fire

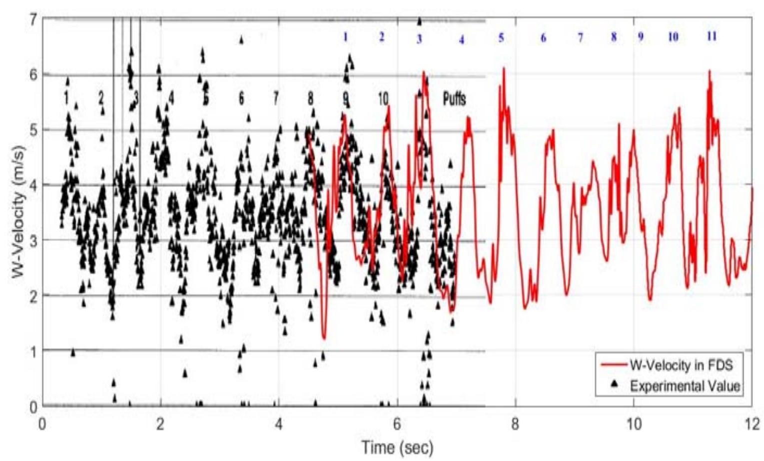
Experiment



FDS

Flame temperature comparison with experiment





Pulsation behavior of the fire compared with experiment

R3 (-2, -2, 0.9) m R4 (-2.2, -0.1, 0.9) m

Source	R3 (kW/m^2)	R4 (kW/m^2)
Experiment	2.5	5.0
FDS-Deardorff	3.1 (+22%)	5.5 (+11%)
FDS-Smagorinsky	3.5 (+39%)	6.4 (+28%)

Deardorff turbulence model results in better accuracy of radiation prediction

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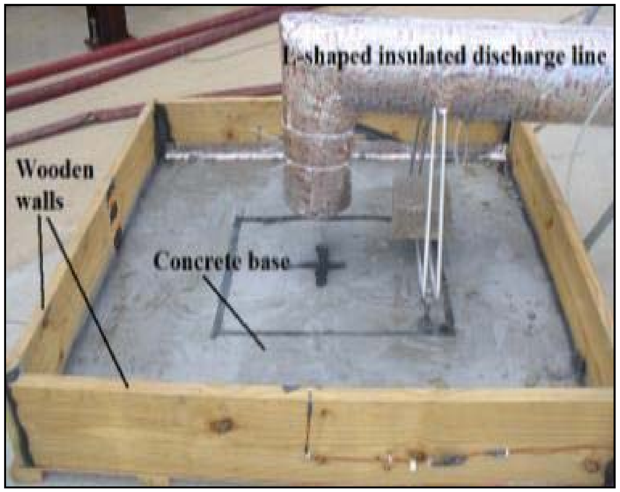
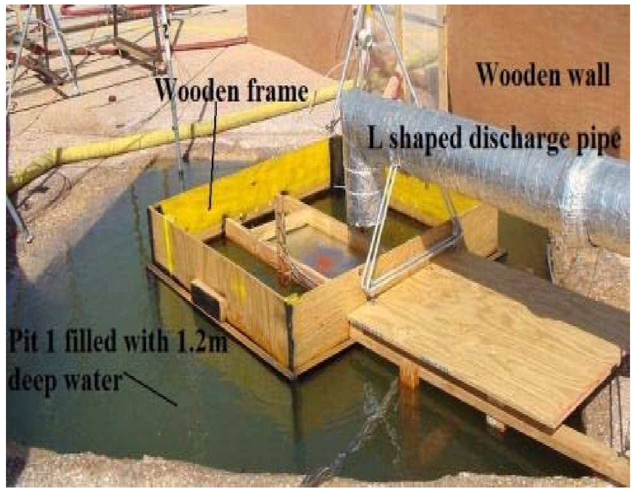
LNG Vapor Cloud Control using Water Curtain

Controlling LNG Vapor Cloud using Water Curtain

- Water curtain is considered one of the most effective engineering methods in mitigating various types of hazards
- No definitive and comprehensive guideline for water curtain design in LNG vapor control
- Determine the key parametric dependence of different water curtains in controlling the LNG vapor cloud
- Develop an effective engineering guideline for water curtain application

Experiment design





- **Facility: Brayton Fire Training Field**

Pit 1 (3m x 3m x 1.22m) filled with water up to 1.2m

Wooden confinement (1.52m x 1.52m x 0.31m)

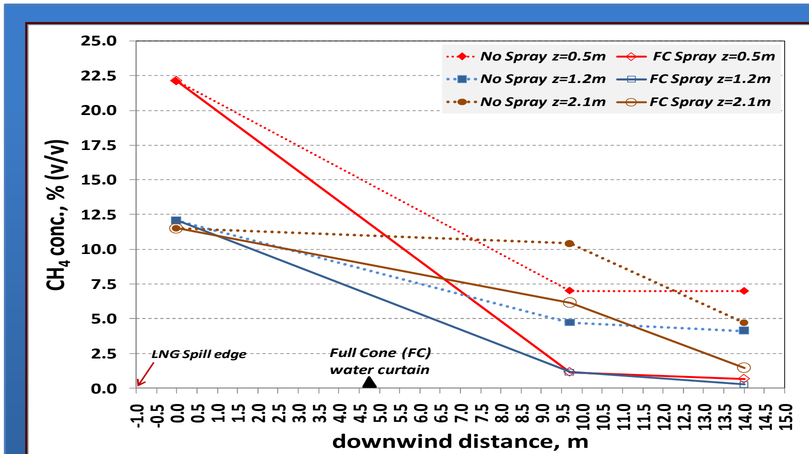
3 types spray: Fan, Conical and Fog

Fan type

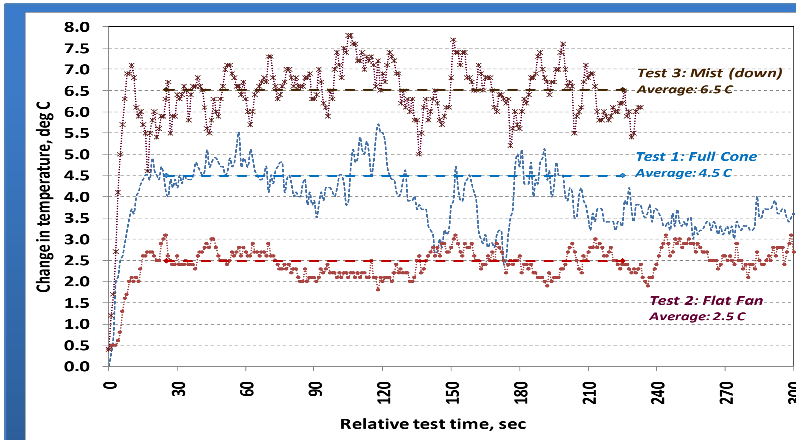
Conical type

Fog type

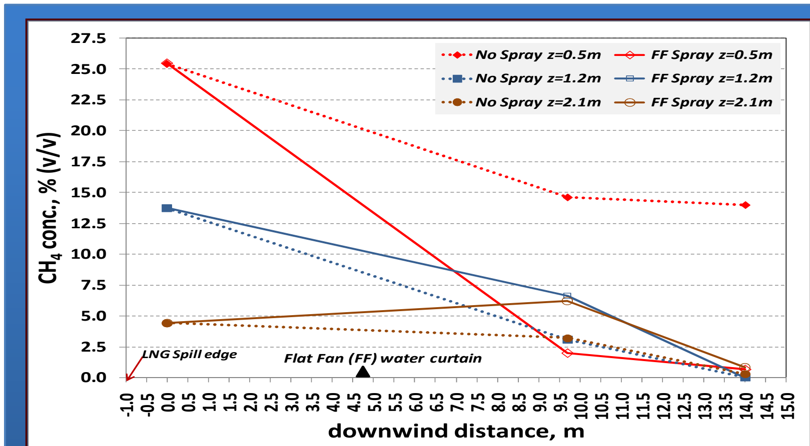
Controlling LNG Vapor Cloud using Water Curtain



Conc. at 3 different height with/wo full cone type



Change in water spray temperature reading



Conc. at 3 different height with/wo flat-fan type

Droplet Size: Mist Cone < Full Cone < Flat Fan

Heat Transfer Rate :

Flat Fan < Full Cone < Mist Cone

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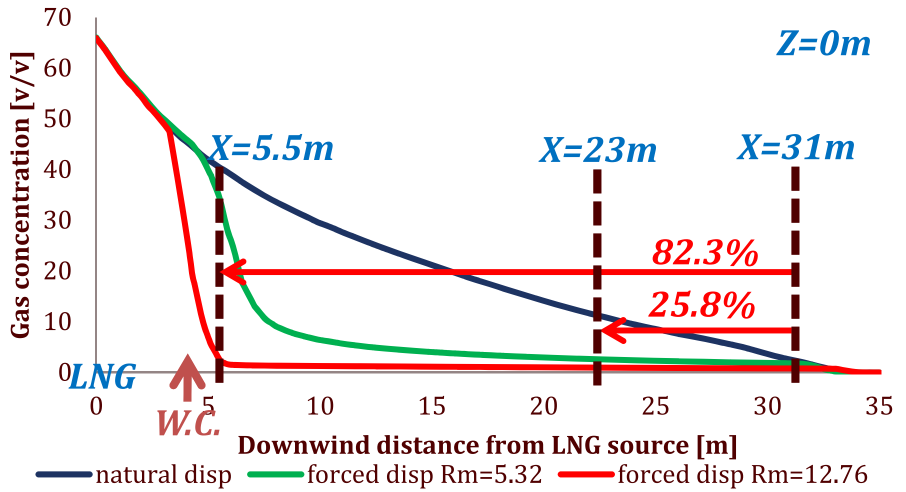
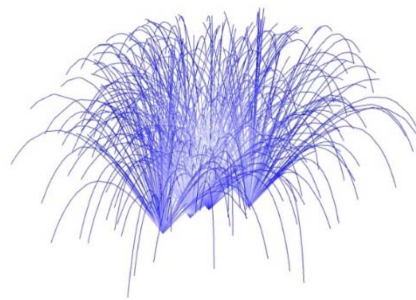
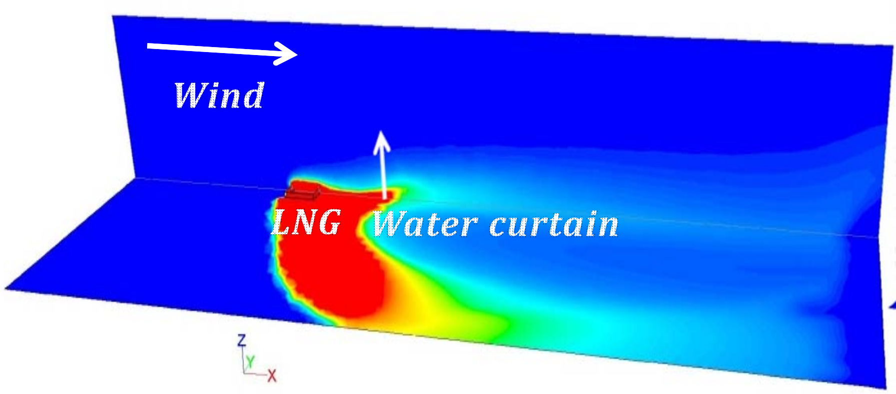
Controlling LNG Vapor Cloud using Water Curtain

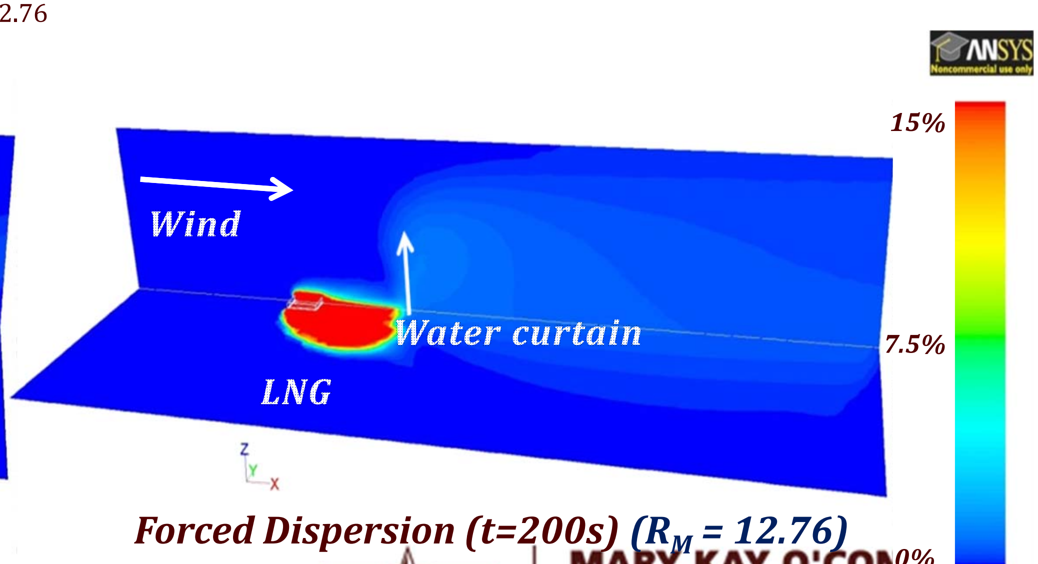
- **Forced Dispersion at R_M=5.32 & 12.76**







Forced Dispersion (t=200s) (R_M = 5.32)



Forced Dispersion (t=200s) (R_M = 12.76)

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LNG Vapor and Fire Mitigation using Expansion Foam

High Expansion Foam

Low expansion	• up to 20
Medium expansion	• 20 to 200
High expansion	• 200 to 1000

NFPA 11: Standard for Low-, Medium-, and High-Expansion Foam

Foam= Foam solution+ Air

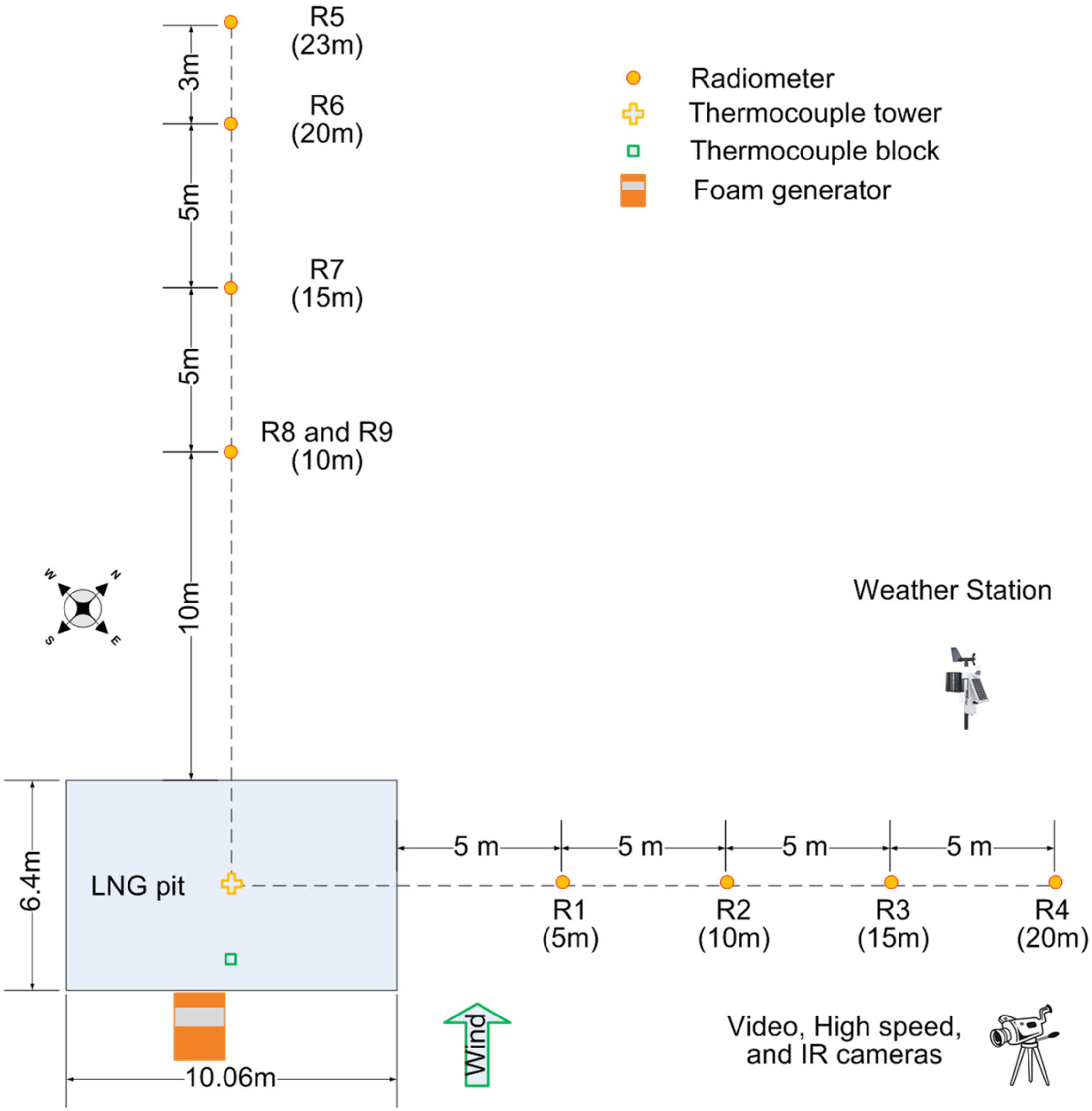
- **Vapor hazard mitigation**
- **Pool fire control**

- Study required to understand the physical phenomena and develop specific guidelines for foam system design

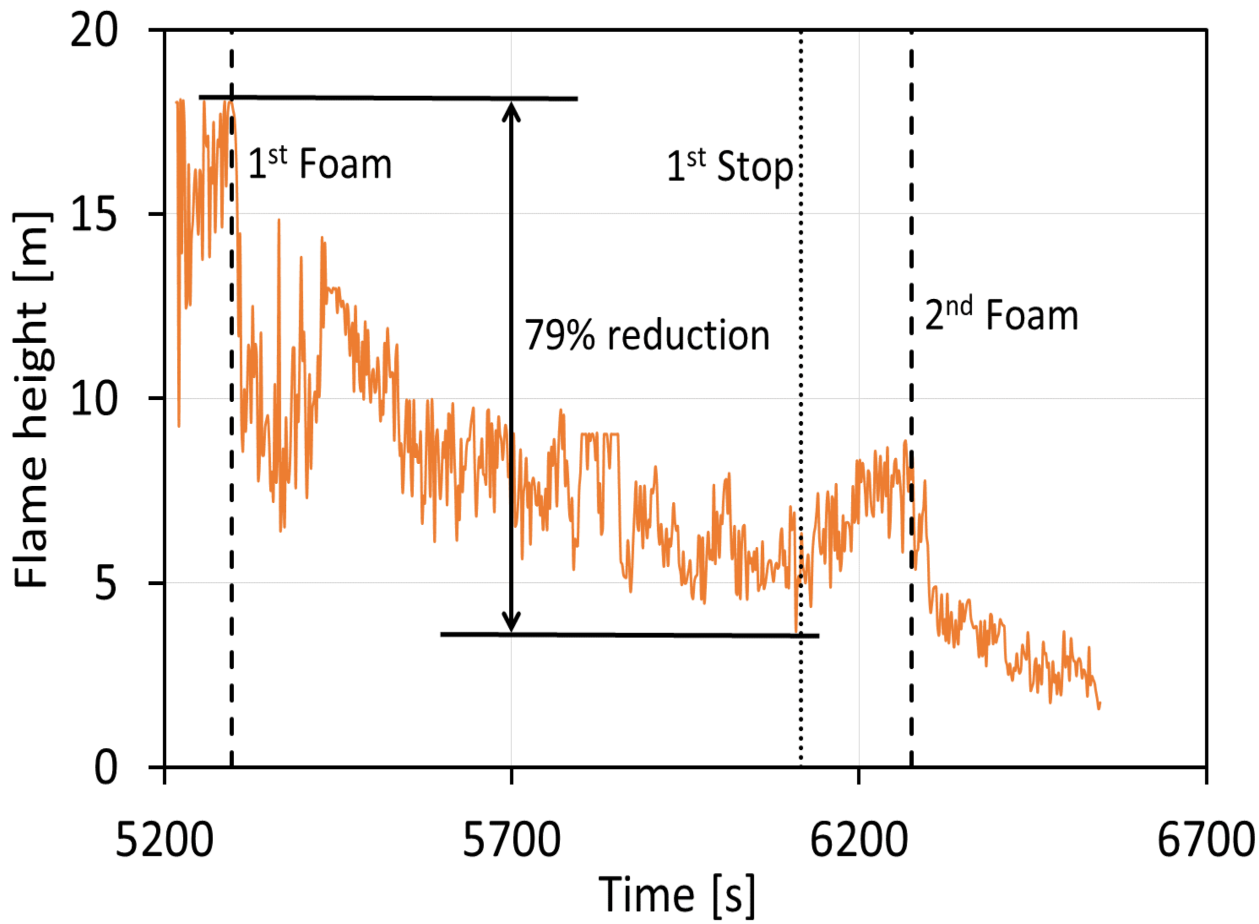
LNG Vapor and Fire Mitigation using Foam

LNG Vapor and Fire Mitigation using Foam

LNG Vapor and Fire Mitigation using Foam



LNG Vapor and Fire Mitigation using Foam



The idea of intermittency *I(L)* was used to determine average flame length

The average flame length was 16.34 m for the fire without foam application, which is the flame length with an intermittency of 0.5

Experimental Study and CFD Simulation of Bund Overtopping

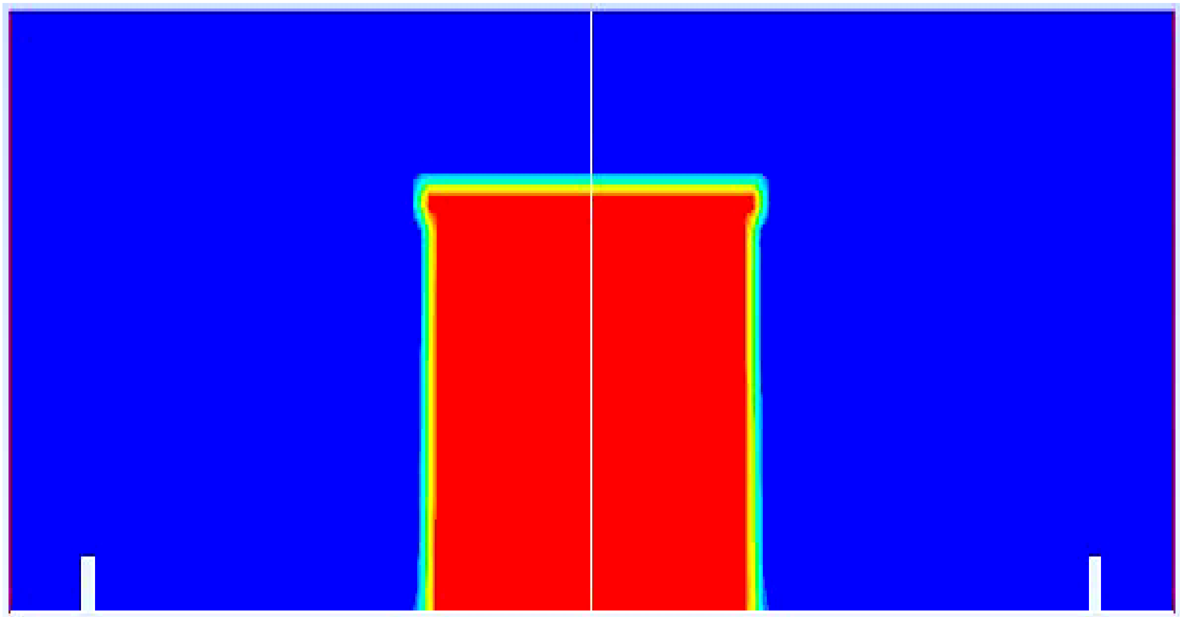
Bund Overtopping

- Roles of Bund
  - Secondary containment
  - Limit contamination
  - Reduce vaporization
  - Control pool fire impact

- Capacity of Bund
  - **≥ 110% * tank capacity**

Bund Overtopping

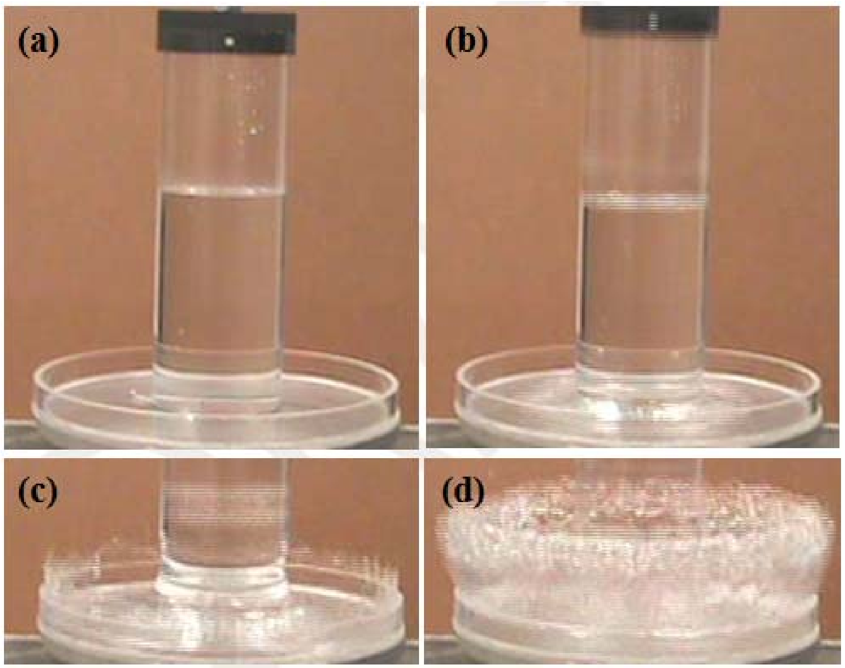
Scenario - Catastrophic Tank Failure



Video – CFD Simulation on Bund Overtopping in case of catastrophic tank failure.

Bund Overtopping

- Lab test



Snap of the overtopping process: (a) 0.0 s; (b) 0.1 s; (c) 0.2 s; (d) 0.3 s.

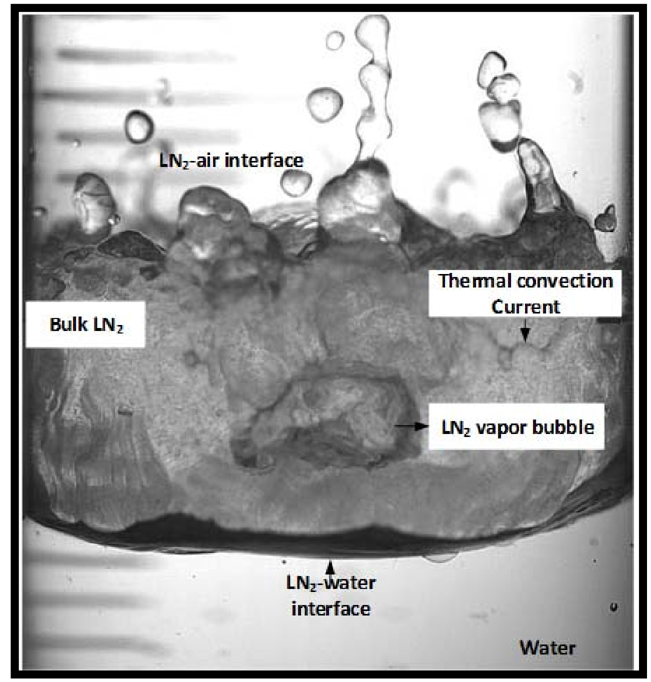
- Field test

Setup of bund overtopping test at Brayton Fire Training Field

Source-Term and Pool Spreading of Spill on Land and Water

LNG Spill on Water

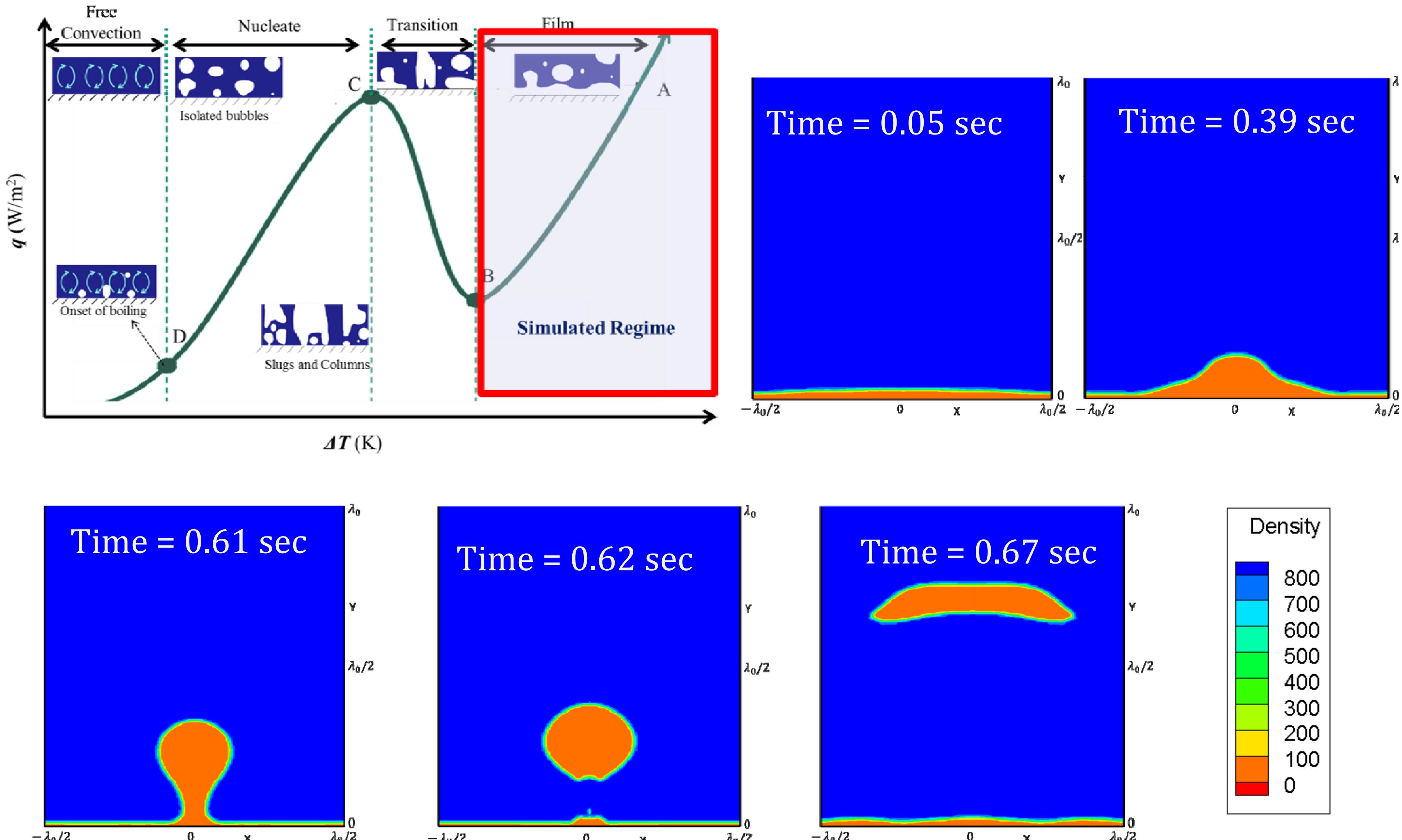
Experimental setup for release of LN_2 on water



High-speed Image from flow visualization experiment

LNG release in L-Shaped Trench, Release duration – 1200 s

LNG Spill on Land



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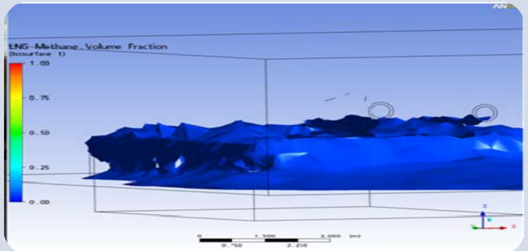
Conclusions



Understand complex phenomena of LNG vapor dispersion and pool fire

Understand water curtain mechanisms to disperse the LNG cloud

Understand the mitigation effect of foam on LNG vapor and fire scenarios

Assess the risk of LNG overtopping and provide recommendations for dike design

Understand the LNG spill phenomena and develop accurate source term and pool spreading model

Acknowledgements

- Dr. Bin Zhang
- LNG Safety Team of MKOPSC

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Thank you!

Questions and Comments?

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