Safety Analysis for LNG Terminal Focused on the Consequence Calculation of LNG Spills

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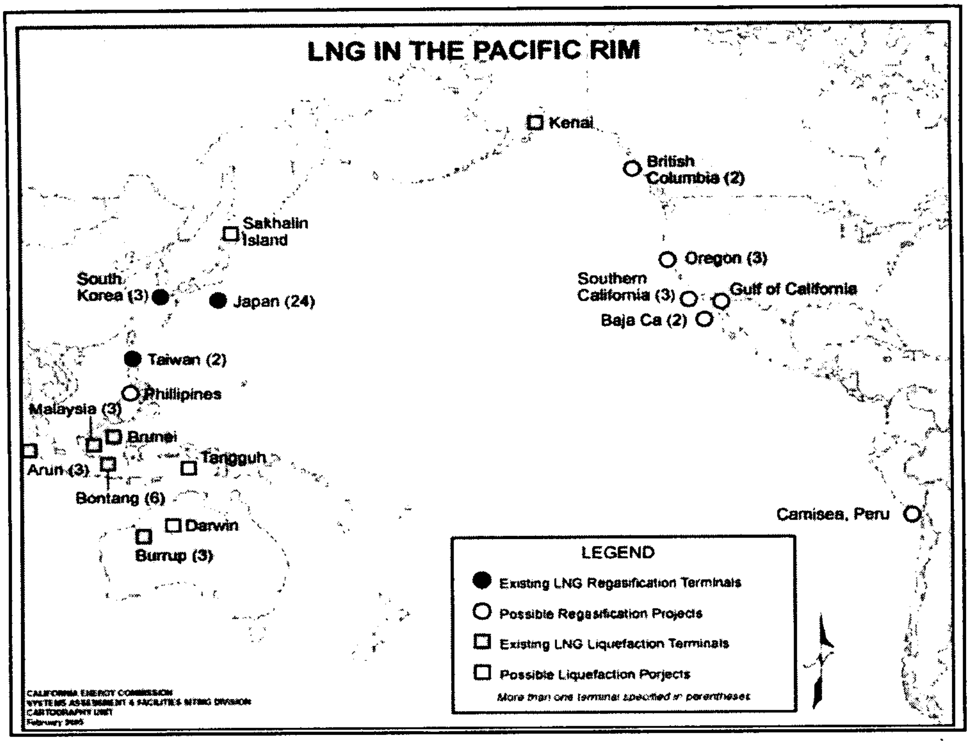
Contents

Objectives

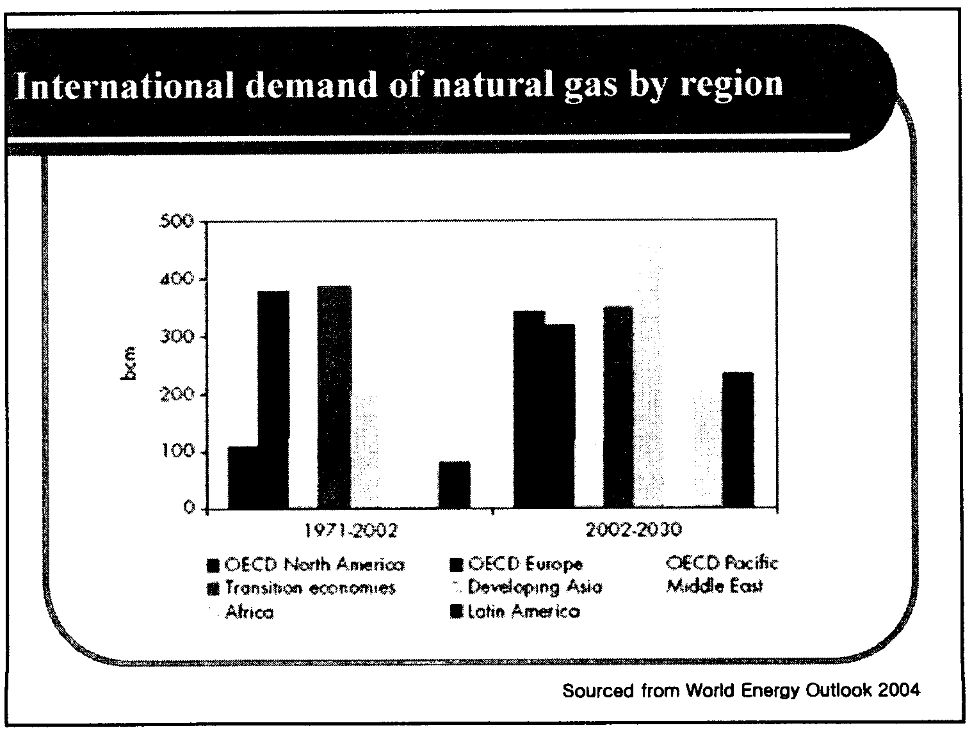
- To understand safety issue and hazard characteristic in LNG terminal
- To find out possible incident scenario for accidental and intentional release
  - Identifying potential hazard
  - Defining credible LNG incident
- To estimate consequence effect of LNG release in terminal
  - Calculating credible and worst case release and fire
- To suggest appropriate prevention and mitigation procedure
  - Constructing fire management system to prevent and mitigate incident

Overview

- Consumption of natural gas worldwide will almost double by 2030
  - The rate of increase is 2.3% per year
- Demand is projected to grow most rapidly in Africa, Latin America and developing Asia
  - Total world primary energy demand will increase from 21% in 2002 to 25% 2030
- Gas resource will increase in global demand
  - Proven reserves are now equal to about 66 years of production at current rates
- Cumulative investment needs for gas-supply infrastructure to 2030 will amount to $2.7trillion, or about $100billion per year

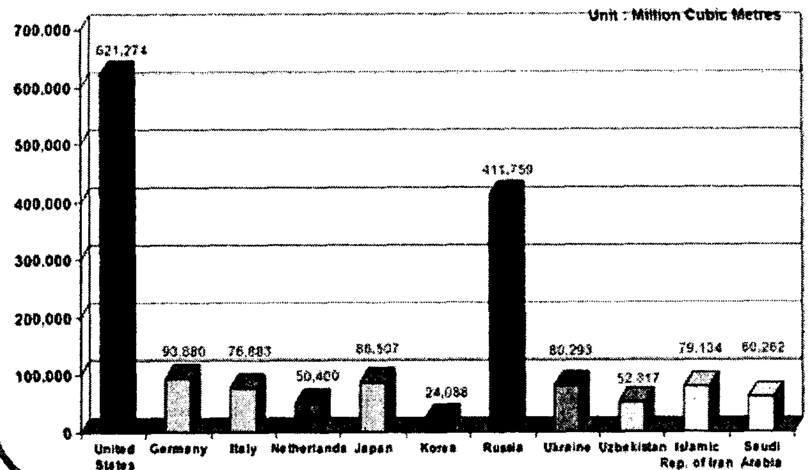


LNG IN THE PACIFIC RIM
Kenai
British Columbia (2)
Sakhalin Island
South Korea (3)
Japan (24)
Oregon (3)
Southern California (3)
Gulf of California
Baja Ca (2)
Taiwan (2)
Phillipines
Malaysia (3)
Brunei
Tangguh
Arun (3)
Bontang (6)
Darwin
Burrup (3)
Camisea, Peru
LEGEND
Existing LNG Regasification Terminals
Possible Regasification Projects
Existing LNG Liquefaction Terminals
Possible Liquefaction Porjects
More than one terminal specified in parentheses
CALIFORNIA ENERGY COMMISSION



International demand of natural gas by region
500
400
300
200
100
0
bcm
1971-2002
2002-2030
OECD North America
OECD Europe
OECD Pacific
Transition economies
Developing Asia
Middle East
Africa
Latin America
Sourced from World Energy Outlook 2004

World natural gas consumption(2003)



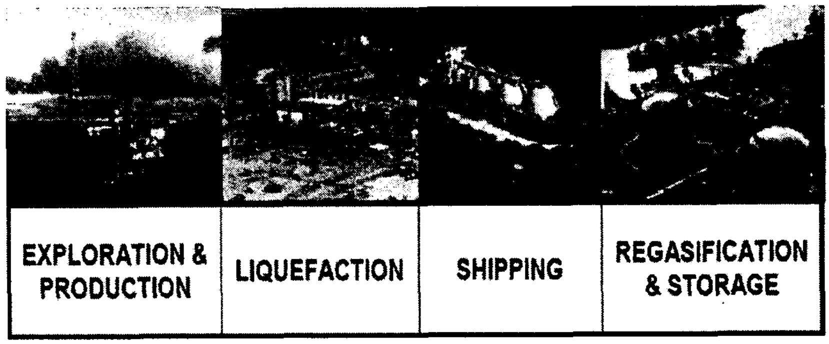
Sourced from Natural Gas Information 2004

Fire-related properties of LNG and other hydrocarbon fuel

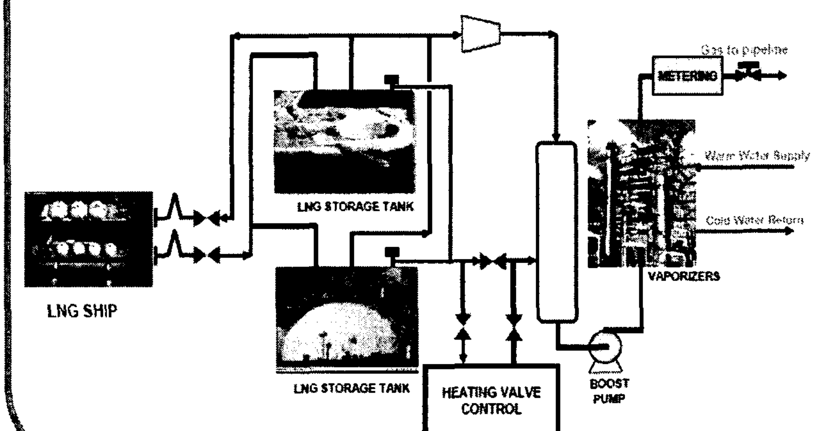
		Ethylene[1,2]	Gasoline[1,3]	LNG/Methan[1,2]	Propane(LPG)[1,2]
Flash point (°F)		-186	-40 to -49	< -259	< -155
Flammability Limit (% in air)	LFL	2.7	1.3	5	2.1
	UFL	36	7.1	15	9.5
Autoignition temperature (°F)		910	820	1,000	840
Minimum Ignition Energy (BTU)		6.6×10^{4}	Not reported	2.5×10^{-7}	2.4×10^{-7}
Fundamental Burning Velocity(ft/s)[4]		2.6	1.3	1.3	1.5
Vapor Specific Gravity		0.97	< 2	0.55	1.5

Source from 1.NFPA(1995), 2.Lees(1980), 3.NFPA(2001), 4.NFPA(2002)

LNG supply chain



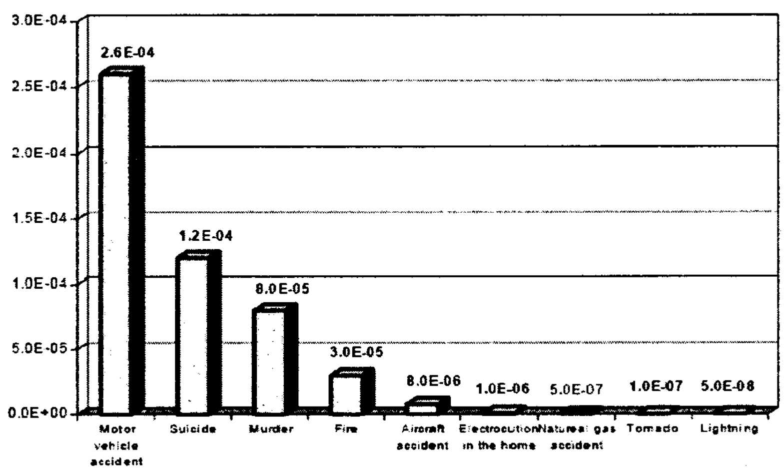
Process flow in LNG terminal



Feature of LNG terminal and incidents

- LNG Capacity is 21,530,000 m^3 in 241 storage tanks and 383 vaporizers in import terminal
- 61 storage tanks and it's capacity is 5,049,000m^3 in export terminal
- Usually consist of marine facility (berth), transfer facility from ship to storage tank, storage facility with double-hull or diked tanks and vaporization system
- LNG has a safety records
  1. Ships : no larger release
  2. Terminal : no public injuries in over 60 years
- Large amount of inventory but simple process
- Fire may result in the tremendous effect to the on and off site
- Big consequence potential but low possibility

Risk of fatality associated with commonly understood hazard



U.S. Nuclear Regulatory Commission, 1973

Major LNG incidents

- Major LNG ship and terminal accidents
  - Cleveland, USA (1944)
    - Peak shaving plant release to sewer
    - 128 killed & 225 wounded
  - Canvey Island, UK (1965)
    - LNG spill during transfer operation resulting in pool fire
    - 1 injury
  - Cove point, USA (1979)
    - Inadequately tightened LNG pump electrical seal
    - 1 killed and few wounded
  - Indonesia (1992)
    - Maintenance error resulting in releasing LNG vapor but no ignition
  - Seoul, Korea (1994)
    - Maintenance and operating error
    - 12 killed & 49 wounded
  - Skikda, Algeria (2004)
    - Large fire in liquefaction facility after explosion
    - 27 killed & 74 wounded

- Major LNG ship accidents
  - Three serious groundings of LNG ship-no loss of LNG cargo
    - El Paso Paul Kaiser(1979)
    - LNG Taurus (1979)
    - Malaysian membrane tanker (2004)
  - Many smaller collision, grounding and striking events and near miss but not more than for other type of vessel

Possible incidents type in LNG terminal

- Operational incidents
  Fire and explosion in terminal, structural failure, collision (Ship-to-Ship), ramming (Ship-to-Fixed object) and grounding
- Non-operational incidents
  Earthquakes, hurricanes, aircraft crashes, adjacent fires, sabotage and terror are events which could result in large amounts of LNG release in terminal

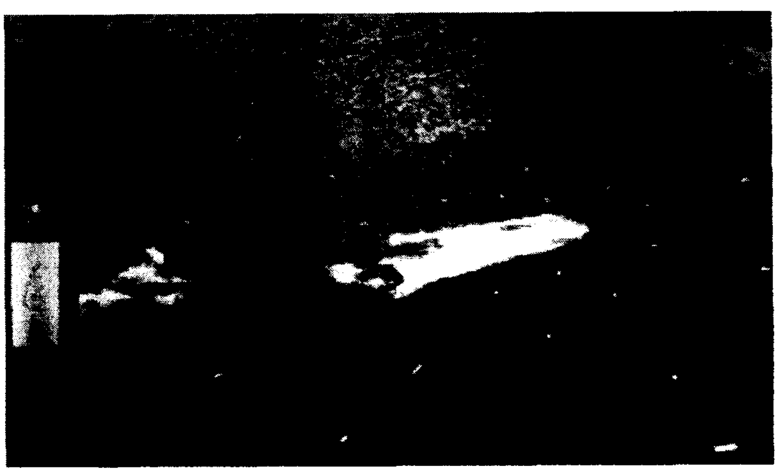
Possible scenarios of leak

- Storage tank area
  - Tank ruptures due to overfill
  - Design/construction failure
  - Inlet/exit line failure
  - Tank failure due to floor failure
  - Tank failure due to excess vacuum
- Tanker ship area
  - Tanker rupture due to boil-off pressure
  - Failure of vacuum relief in response to a failure in vacuum system during unloading
  - Valve rupture within ship's piping network
  - Rupture of tank due to extension of existing cracks when pressure each broken down

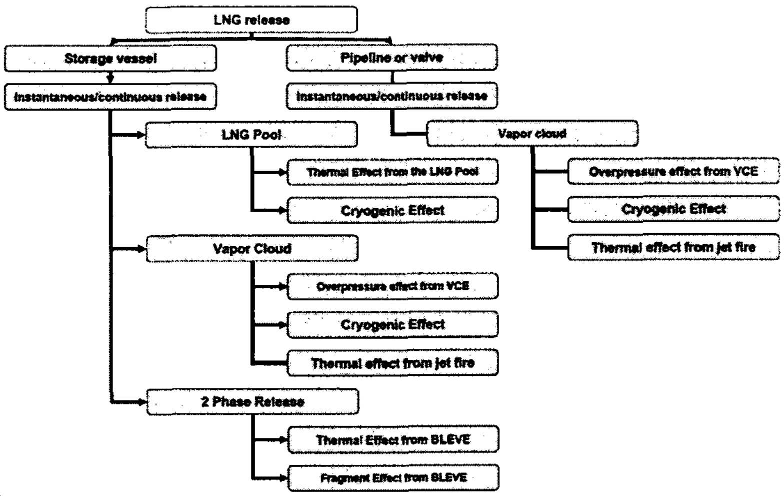
Characteristics of LNG release

- Rate of LNG released would be dependent on many factors, including the geometry of the penetration
- Flammable vapor cloud which can travel downwind until sufficient heating and mixing with turbulent atmosphere dilute the vapor concentration below the limits of flammability
- In order to estimate the downwind travel distance of the flammable cloud, several factors must be considered
  - Type of accidents
  - Characteristics of surrounding area
  - Local weather condition

LNG vapor cloud and fire



Incident tree for LNG release

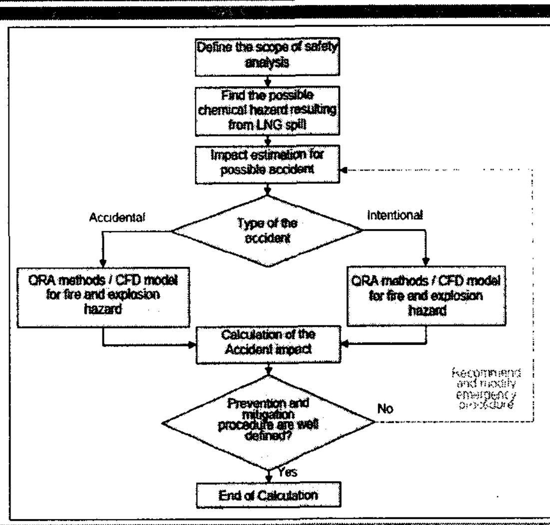


Types of LNG hazard

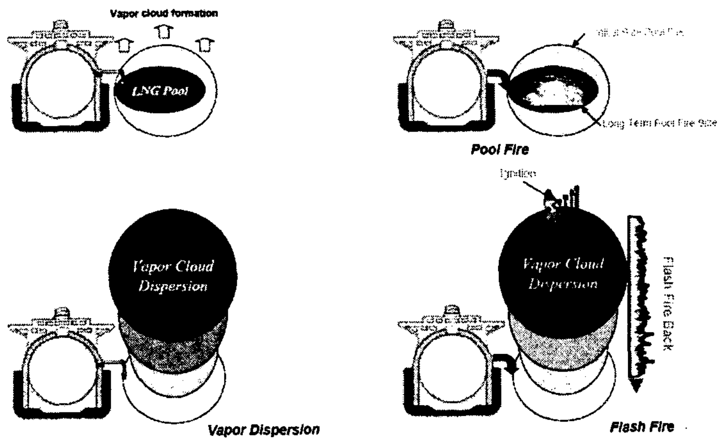
- Liquid pool fire
  - Evaporating gas in a combustible gas-air concentration can burn above the LNG pool
  - Thermal radiation may injure people and damage property a considerable distance from the fire itself
  - Magnitude of the heat radiation and the area subjected to the heat radiation are dependent on the coverage area and depth of the LNG spill
- Roll over
  - When LNG of multiple densities in a tank, strata may spontaneously roll over to stabilize liquid in tank
  - Liquid roll over would occur with sudden vaporization of LNG that may be too large to be released through the normal tank pressure release valves
  - At some point excess pressure can result in cracks or other structural failure

- Freezing liquid
  - When LNG is released, direct contact of LNG may cause cryogenic damage to human and structure
  - Cryogenic damage can result in steel failure by reducing the steel's temperature below its embrittlement temperature
- Rapid phase transition
  - If large volume of LNG are released on the water, it may vaporize too quickly causing Rapid Phase transition (RPT)
  - RPT can only occur if there is mixing between LNG and water
- Vapor cloud explosion
  - Confined fuel/air cloud might result in explosion when a rapid acceleration in burn rate may occur

Procedure to estimate hazard in LNG terminal

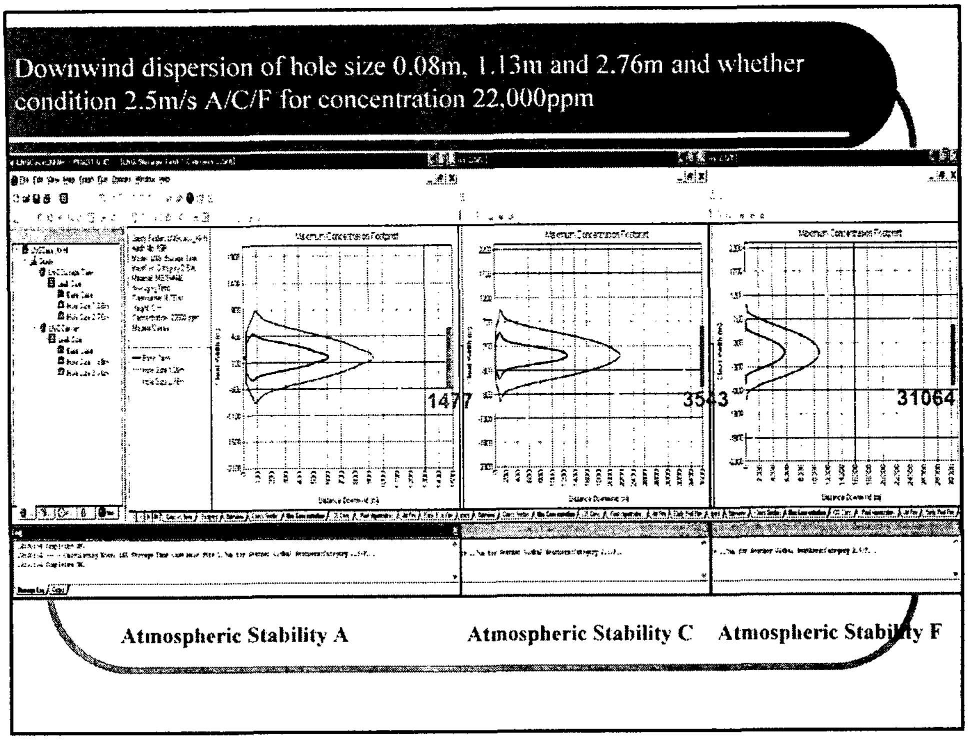


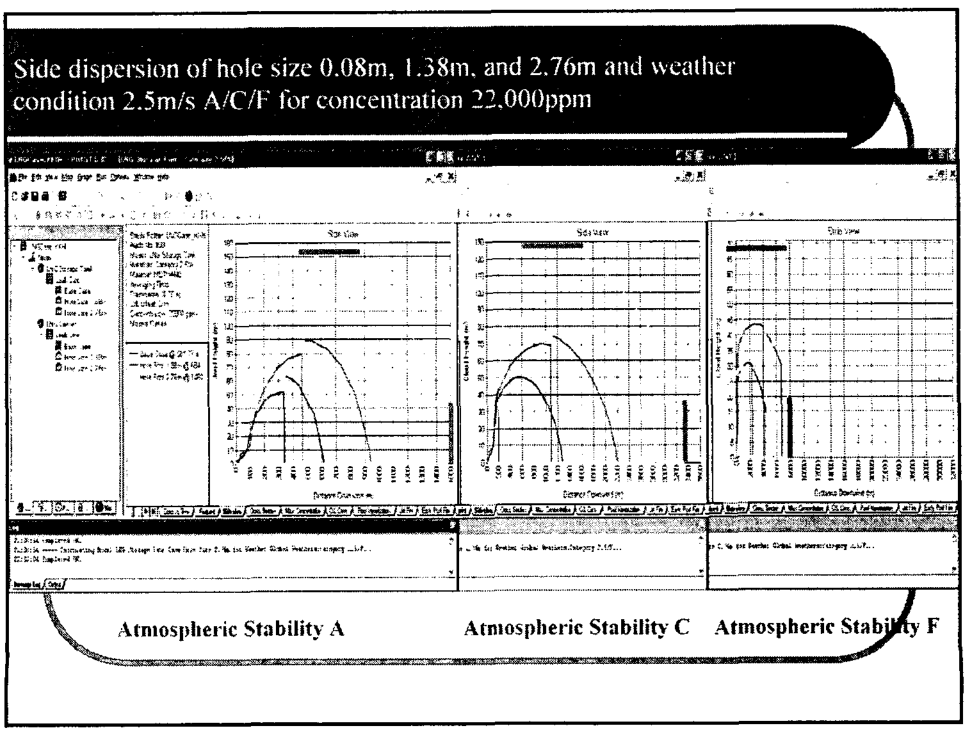
Possible accident scenarios on water



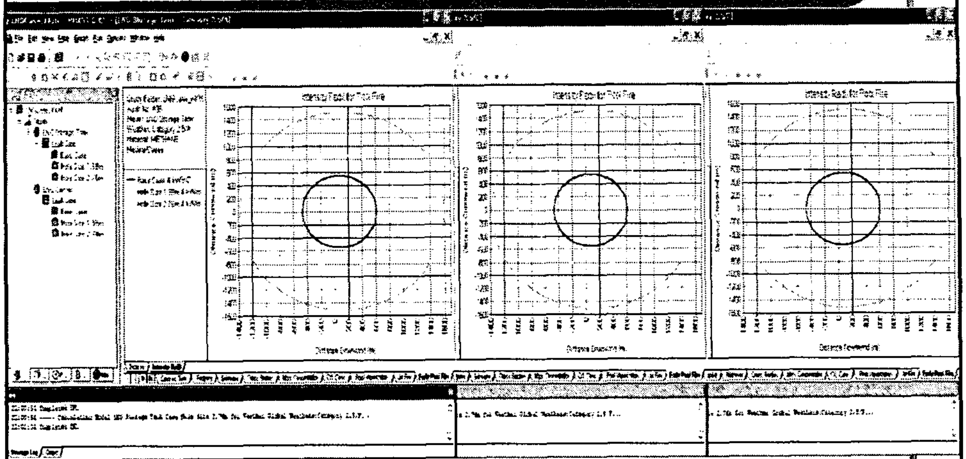
Accident scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Type of accident	Accidental	Accidental	Intentional	Accidental	Accidental	Intentional
Storage Temperature	-162 degC	-162 degC	-162 degC	-162 degC	-163 degC	-162 degC
Release position	Storage tank on the ground	Storage tank on the ground	Storage tank on the ground	Storage tank on the carrier	Storage tank on the carrier	Storage tank on the carrier
Hole size	$0.5m^2$ (D=0.8m)	$1.5m^2$ (D=1.38m)	$6.0m^2$ (D=2.76m)	$0.5m^2$ (D=0.8m)	$1.5m^2$ (D=1.38m)	$6.0m^2$ (D=2.76m)
Tank size	$140,000m^3$	$140,000m^3$	$140,000m^2$	$37,500m^3$	$37,500m^3$	$37,500m^3$
Dike	No	No	No	No	No	No
Wind speed and direction	2.5m/s SW	2.5m/s SW	2.5m/s SW	2.5m/s SW	2.5m/s SW	2.5m/s SW
Atmospheric stability	A (Unstable) C (Neutral) F (Stable)	A (Unstable) C (Neutral) F (Stable)	A (Unstable) C (Neutral) F (Stable)	A (Unstable) C (Neutral) F (Stable)	A (Unstable) C (Neutral) F (Stable)	A (Unstable) C (Neutral) F (Stable)
Interested concentration	44,000 ppm 22,000 ppm	44,000 ppm 22,000 ppm	44,000 ppm 22,000 ppm	44,000 ppm 22,000 ppm	44,000 ppm 22,000 ppm	44,000 ppm 22,000 ppm
Surface type	Concrete	Concrete	Concrete	Water	Water	Water
Relative humidity	70%	70%	70%	70%	70%	70%


Downwind dispersion of hole size 0.08m, 1.13m and 2.76m and whether condition 2.5m/s A/C/F for concentration 22,000ppm
1477
3543
31064
Atmospheric Stability A
Atmospheric Stability C
Atmospheric Stability F

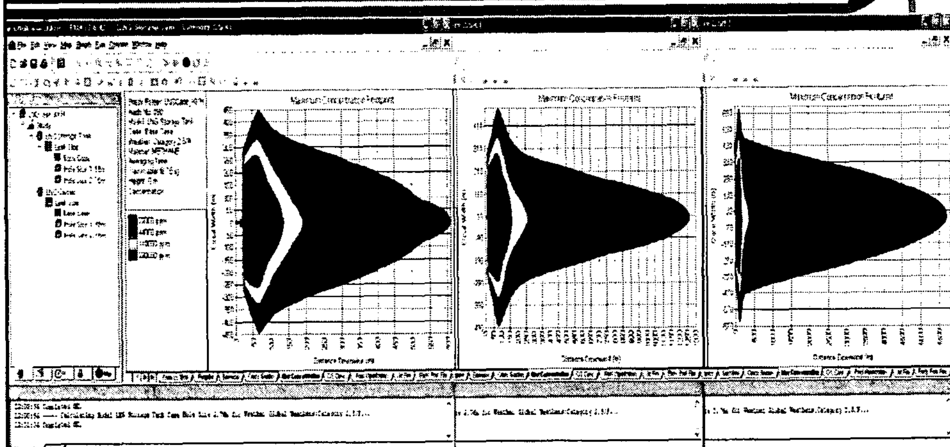

Side dispersion of hole size 0.08m, 1.38m, and 2.76m and weather condition 2.5m/s A/C/F for concentration 22,000ppm
Atmospheric Stability A
Atmospheric Stability C
Atmospheric Stability F

Intensity radius for pool fire of hole size 0.08m, 1.38m and 2.76m and weather condition 2.5m/s A/C/F for 4kW/m2

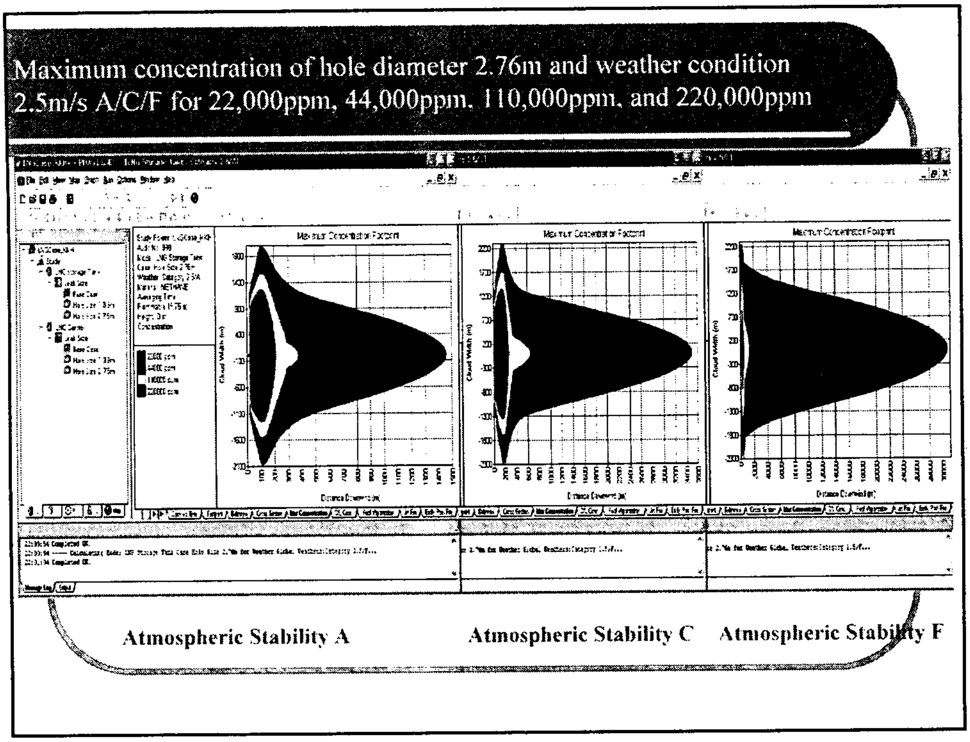


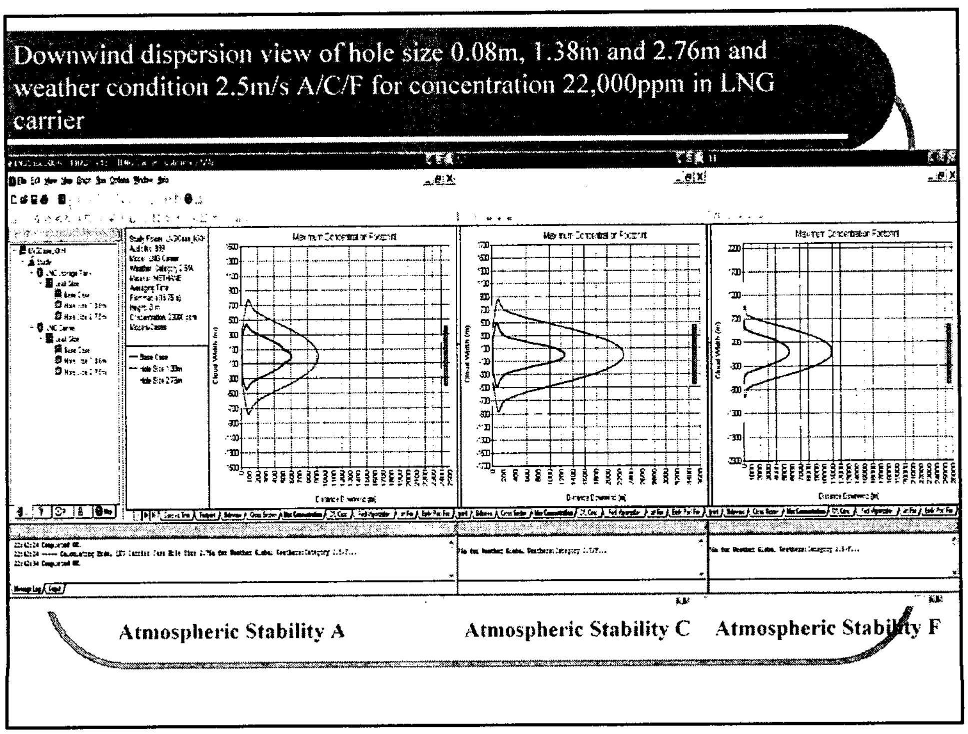
Atmospheric Stability A Atmospheric Stability C Atmospheric Stability F

Maximum concentration of hole diameter 0.80m and weather condition 2.5m/s A/C/F for 22,000ppm, 44,000ppm, 110,000ppm, and 220,000ppm

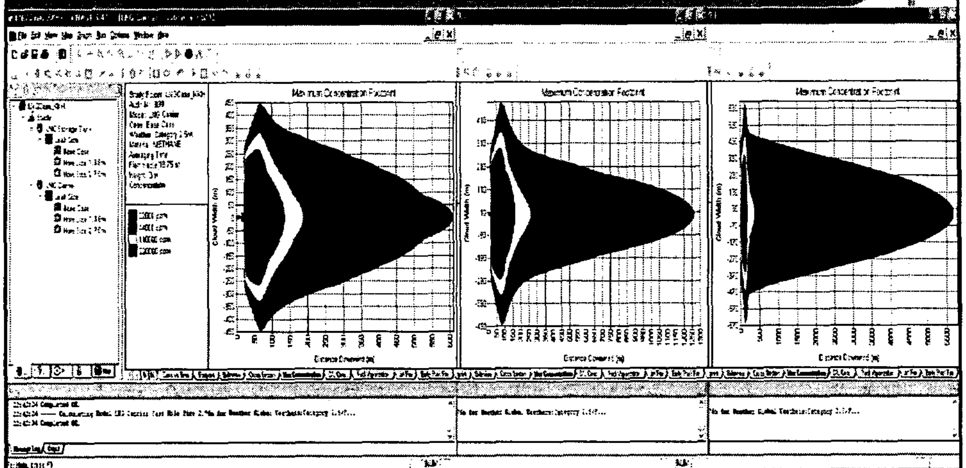


Atmospheric Stability A Atmospheric Stability C Atmospheric Stability F


Maximum concentration of hole diameter 2.76m and weather condition 2.5m/s A/C/F for 22,000ppm, 44,000ppm, 110,000ppm, and 220,000ppm
Atmospheric Stability A
Atmospheric Stability C
Atmospheric Stability F

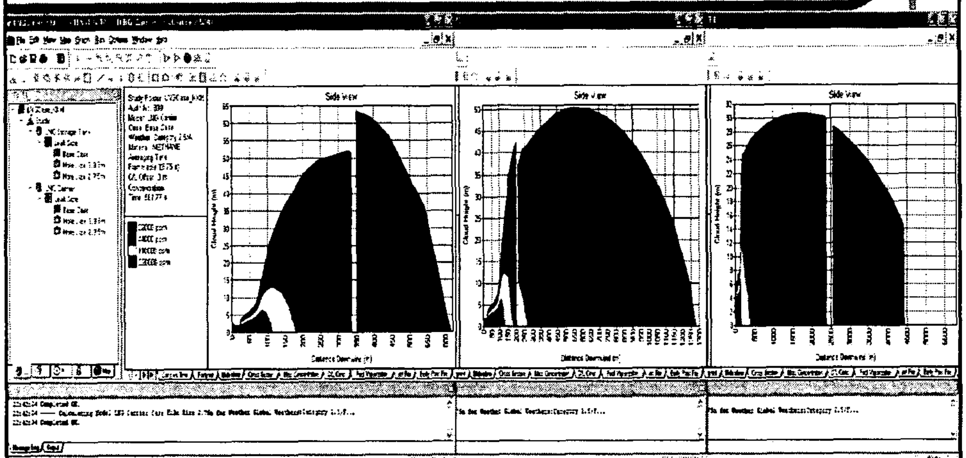

Downwind dispersion view of hole size 0.08m, 1.38m and 2.76m and weather condition 2.5m/s A/C/F for concentration 22,000ppm in LNG carrier
Atmospheric Stability A
Atmospheric Stability C
Atmospheric Stability F

Maximum concentration of hole diameter 0.80m and weather condition 2.5m/s A/C/F for 22,000ppm to 220,000ppm in LNG carrier



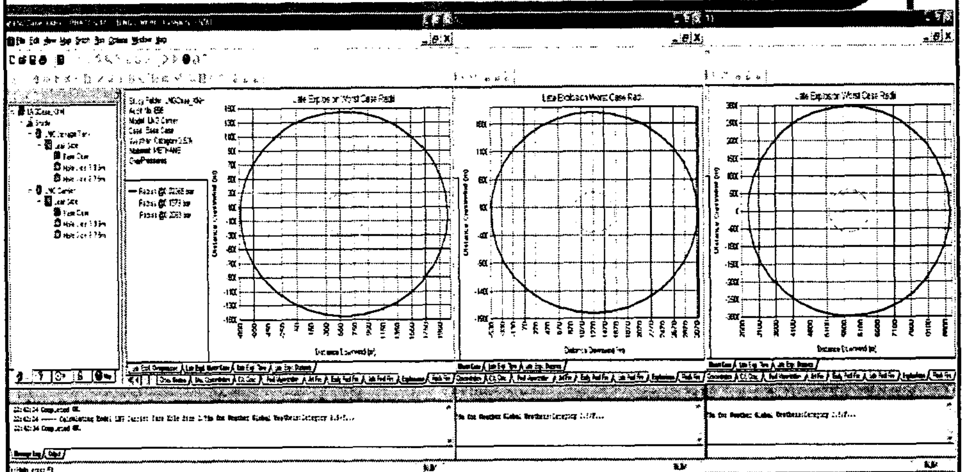
Atmospheric Stability A　　Atmospheric Stability C　　Atmospheric Stability F

Side concentration of hole diameter 0.80m and weather condition 2.5m/s A/C/F ranged from 22,000ppm to 220,000ppm in LNG carrier



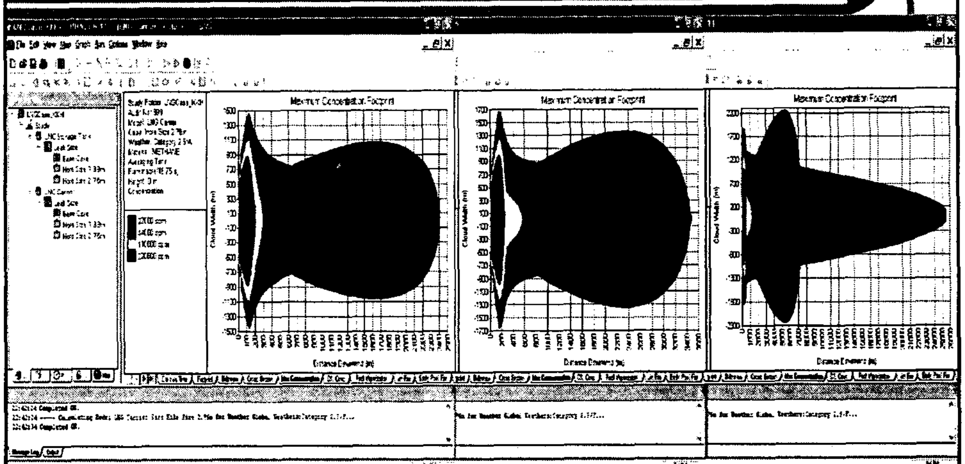
Atmospheric Stability A　　Atmospheric Stability C　　Atmospheric Stability F

Overpressure radius for late explosion of hole diameter 0.80m and weather condition 2.5m/s A/C/F for 0.02068bar, 0.1379bar, and 00.2068bar in LNG carrier



Atmospheric Stability A Atmospheric Stability C Atmospheric Stability F

Concentration of hole diameter 2.76m and weather condition 2.5m/s A/C/F ranged from 22,000ppm to 220,000ppm in LNG carrier



Atmospheric Stability A Atmospheric Stability C Atmospheric Stability F

LNG terminal safety strategy

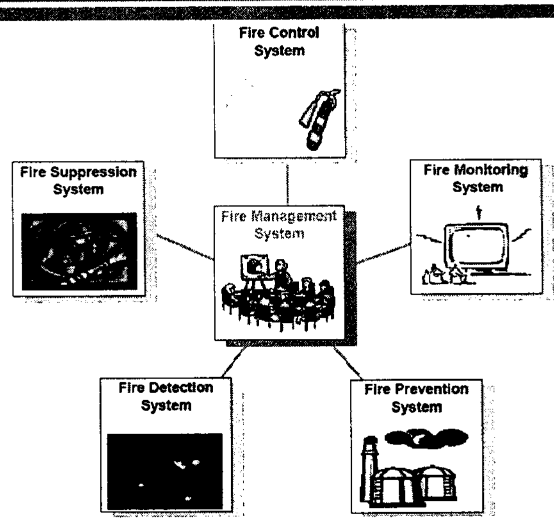
[redacted]

Preventive Effects Detection, Dispersal, Quenching
Separation Distance Setbacks, Operating Distances

LNG terminal safety system

- Considering factor to implement of safety system
  - Strength and suitability of materials that come in contact with LNG
  - Reliability of systems for preventing overpressurization, vacuum conditions of other malfunctions in vessels, piping and equipment containing LNG
  - Passive features incorporated into the terminal to limit the consequences of incident
  - Provision for emergency shutdown of the terminal
  - Active systems for the suppression of fires and reduction of vapor cloud hazard
  - Training of terminal personnel

Composition of fire management system



- Fire control system
  Water spray, hydrant, dike, emergency shut off
- Fire monitoring system
  CCTV, process control system
- Fire prevention system
  Process safe design (design criteria), safe operation procedure, Fire prevention device, patrol procedure, ship traffic control system
- Fire detection system
  Fire and material detecting sensor, alarm, spill detection system, smoke detector.
- Fire suppression system
  Hydrant, foam, dry chemical, inert gas system

Criteria to implement safety management system

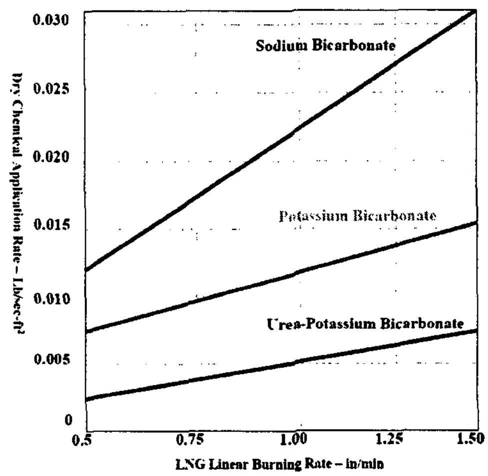
- Fire suppression system
  - Dry chemicals
    - Suppression of flammable liquid fires contains a combination of chemicals such as sodium bicarbonate, potassium bicarbonate and mono-ammonium phosphate
    - Depends on particle size, method of dispersion and the types of flammable Liquid hazard to suppression LNG fire
    - Extinguish times are function of LNG burning rates and dry chemical application
    - Dry chemical application rate is defined as the quantity of dry chemical applied to the fire per unit time divided by the surface area of the spill

- Wesson et al.(1973b) report work on the extinction of LNG fires using dry chemicals
  - Fire size was in the range 200 -1200ft^2
  - Dry chemical application rates and extinction times obtained for a 1200ft^2 fire are following table

	Threshold rate		Optimum rate	
	Application rate(lb/ft^{2}s)	Extinction time(s)	Application rate(lb/ft^{2}s)	Extinction time(s)
Sodium bicarbonate (SB)	0.012		0.0192	9.0
Potassium bicarbonate (PB)	0.007	30	0.0125	8.2
Urea-potassium bicarbonate (U-PBP)	0.00275	25	0.00417	10.9

Application rates for extinction of LNG fires by dry powders

Minimum dry chemical application rate to extinguish LNG fires as dependent on LNG burning rate



- Foam extinguish system

  Extinguishing agent for large flammable liquid spill fire such as LNG and LPG spills

  High performance foam is capable of reducing the intensity of LNG fires by about 90 percent

  High expansion foam is mixture of detergent and water expanded across an air blown screen

  - expansion ratio500 : 1 (500 volumes of foam per initial volume of water) can be applied directly to LNG spill
  - Most foam application standards for storage tanks call for a 3% foam solution and an expansion ratio in the range 5:1 to 10:1.
  - Kaura's comparison of application rates called for in fixed roof tank standards from five nations showed a range of 2.5 to 5liter/mim-m² (0.06-0.12 gpm/ft² of liquid surface area).
  - NFPA 11 calls for 0.10 gpm/ft² (4.1 liter/min-m²) for fixed roof tank and 0.16 – 0.50 gpm/ft² (6.5 – 20.3 liter/min-m²) of annular seal area in floating roof tanks.

- Fire water
  - Used to protect facilities within terminal from thermal radiation effects of hydrocarbon fires
  - Fire water hand line, monitor, hydrant can be used
  - Can not be applied directly to either an ignited or ignited LNG spill, since It would increase rate of LNG vaporization and size of vapor cloud
  - Will be used to aid dispersion of LNG vapor clouds
- Inert gas system
  - Useful for extinguish fires and preventing explosion in closed spaces.

Conclusions and remarks

- LNG is and has been an important and reliable part of the world energy infrastructure for almost 40 years.
- Possible accidents scenarios come from historical data and incident tree for LNG release
- Consequence estimation for various accident scenarios
  - Various weather condition, capacity of tank and released hole size
  - Effect distance for flash fire and pool fire does not changed by released hole size
  - Effect distance for late ignition vapor explosion depend on the weather condition and source of ignition source.
- Recommend proper fire management system
  - Consist of fire control system, fire fighting system, fire suppression system, fire monitoring system, fire prevention system and fire detecting system