

Accidents on Vessels Transporting Liquid Gases and Responders' Concerns: The Galerne Project

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1 Introduction

The objective of the Galerne project, which was financed by the French Ministry of Research (National Research Agency), is to provide responders at sea (Navy evaluation teams and fire brigades) with relevant information on the hazards presented by liquid gas chemicals on vessels disabled at sea. Civil safety is not a primary concern in the project, although we are aware that people might be affected by open-sea accidents that occur in a strait or in traffic lanes close to shore. Although this aspect is not ignored by Galerne, the main objective is to produce operational information for responders and headquarters. The Galerne project began in 2006 and will end in September 2009. Members of the consortium are experts in atmospheric modelling (Meteo France), ship structure and risk assessment (Bureau Veritas), producers and handlers (GdF- Suez, Total), hazards assessment and source terms (Ineris, Cedre), and operations (French Navy, Ministry of Transport, Civil Safety).

To achieve this objective, many simulations and experiments have been carried out in Ineris (behaviour of liquid gas in water), GdF-Suez (simulation of LNG when spilled in water using specific software), and Meteo France (validation of Perle, a long-range dispersion model and twinning of a surface drifting model, Mothy, to Perle).

2 Liquid Gases

2.1 Chemicals Used

Liquid gases are defined as products that are gases (with a vapor pressure of more than 100 kPa) at normal temperature and pressure (20°C, 100 kPa). For economic reasons, this category of products is transported in a liquid form, either under pressure, in refrigerated form, or under both conditions.

The IGC handbook edited by the International Maritime Organisation (IMO) defines the characteristics of the ships and proposes a definition of the products likely to be transported in a liquid form. Thirty-one chemicals are covered by this regulation although some are also registered in the IBC code (bulk liquids). These gases are transported as liquids in order to be easier to handle and therefore less expensive to transport. Temperature and pressure are the parameters to play with in order to generate the liquefaction of the gases.

For practical and financial reasons, it was not possible to consider all the 31 chemicals described in the IGC code. For Galerne, we chose four liquid gases on the basis of their transport characteristics and behaviour. The selected gases and their properties are listed in Table 1 (Gaz encyclopaedia, Air Liquide, Elsevier, Paris, 1151 p.)

Table 1 Properties of Liquid Gases used in the Galerne Project

	Liquid Volume Mass (kg/m³)	Gas Density	Kg/Kmol	IIL (%)	TLV.TWA or VME (ppm)	Boiling Point °C (1 atm)
LNG/methane	422	0.71	18	5	-	-162
LPG/Propane	582	2	44	2.2	-	-42
Ammonia	682	0.770	17	16	20	-33
VCM*	970	2.75	62.5	3.6	1	-13.7

* Vinyl chloride monomer

2.2 Physical Characteristics of the Transported Products Versus their Volume in Standard Conditions

When subjected to standard conditions, products transported in liquid form develop the following volumes.

LNG: one litre of liquid is equivalent to 630 L of gas (15.1°C, 1 bar)

LPG: one litre of liquid is equivalent to 311 L of gas (15.1°C, 1 bar)

Ammonia: one litre of liquid is equivalent to 947 L of gas (15°C, 1 bar)

VCM: one litre of liquid is equivalent to 365 L of gas

3 Type of Ship Dedicated to Transporting Gases in Liquid Form

Ships dedicated to transporting these liquid gases belong to a specialized family of vessels called “gas carriers”. These gas carriers are designed to meet the requirements of the IGC code and vary with the transportation conditions, e.g., refrigerated, semi-pressurized, pressurized.

The Bureau Veritas statistically analyzed the various types of gas carriers other than LNG carriers from the point of view of tonnage. Following the statistical distribution by size (tonnage), these ships can be divided into two categories as shown in Figure 2:

1. less than 12,500 tons DWT for semi-pressurized ships; and
2. more than 12,500 t DWT for refrigerated ships.

3.1 Pressurized Ships

The maximum service pressure is about 18 to 20 bars. The chemicals are transported at ambient temperature. The capacity of the ships represents a maximum of 10,000 m³. Standard capacities allow the transport of 4,000 to 6,000 m³ in 2 or 3 tanks. These types of ships are used to transport ammonia and propane.

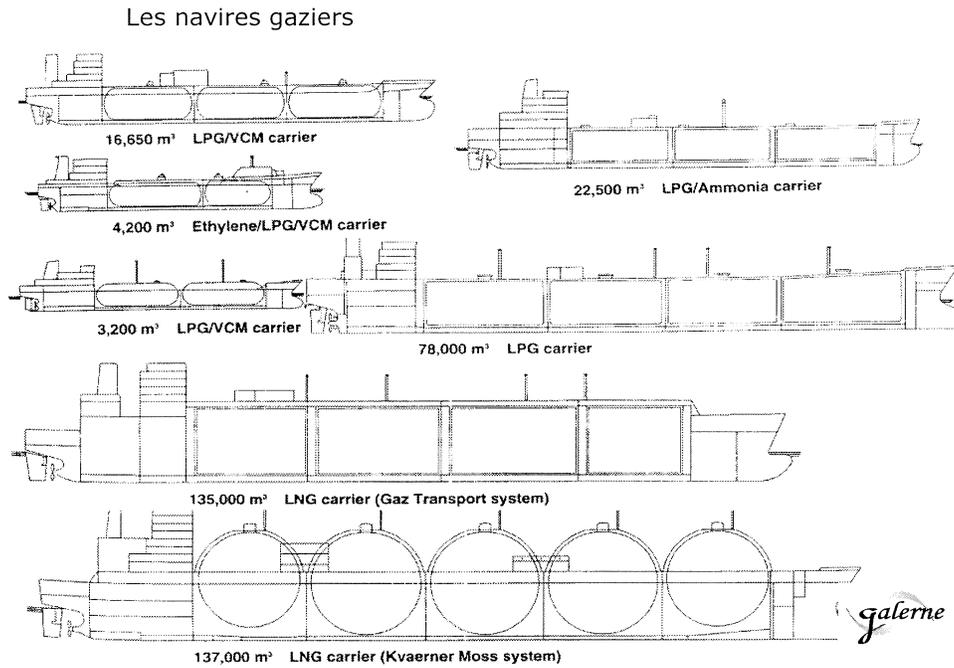


Figure 1 Types of Gas Carriers Selected for the Galerne Scenarios

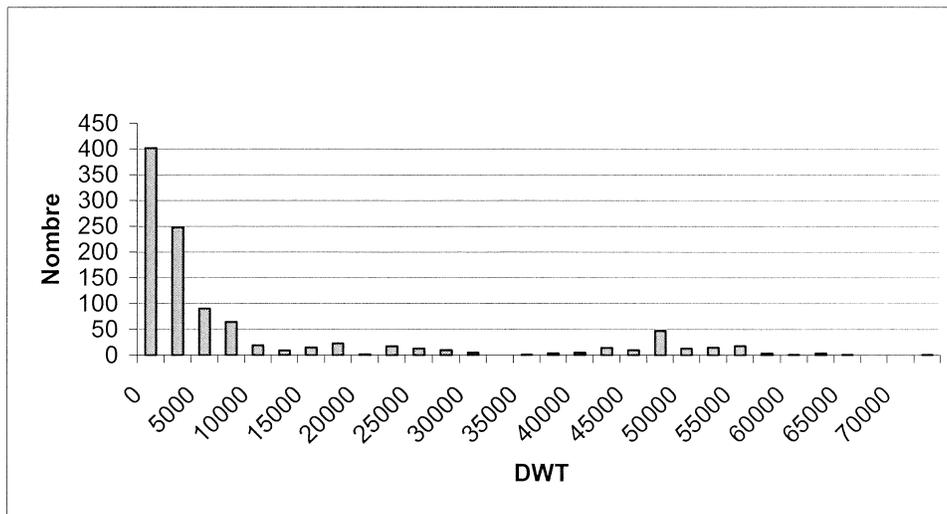


Figure 2 Distribution of Tonnage of Gas Carriers (2005)

- (1. Gas tankers DWT >12,500 t = >refrigerated.
2. Gas tankers DWT <12,500 t = >/liq pressurized or semi-pressurized).

3.2 Semi-pressurized Ships

The maximum service pressure is about 7 bars. These ships can be fully refrigerated (SP/FR) and the gas can be transported at atmospheric pressure (refrigerated) or under pressure. Cargoes can be as large as 3000 to 15,000 m³ of liquefied gases. A few of these ships reach 30,000 m³. LPG, ethylene, propylene, CVM, and butadiene are transported in this type of ship.

3.3 Transport of Ethylene

Due to its critical point, ethylene must be refrigerated at -104°C. These ships range from 1,000 to 12,000 m³ in capacity.

3.4 Refrigerated Ships

Refrigerated ships transport chemicals at atmospheric pressure in 3 to 6 type-A tanks. They are used for long distance transport of up to 84,000 m³ of liquefied petroleum gas (LPG) and ammonia. Liquefied natural gas (LNG) is transported in specific vessels that are refrigerated at -162°C and slightly above atmospheric pressure. There are now 300 of these ships for transporting LNG (March 2009). Eighty-nine LNG carriers are on order for delivery up to 2011.

4 Various Response Phases

In an emergency situation, the first “mayday” call from a ship is received by a Maritime Rescue Coordination Centre (MRCC), as shown in Figure 3. A database called “Traffic 2000” immediately gives the characteristics of the ship and the owner’s name so authorities quickly know the type of chemical on board and the cargo details. The stowing plan will be on line in “Traffic 2000” in the near future. The MRCC calls the Navy Operation Centre (in France, the Navy acts as Coast Guard) which mobilizes the emergency response experts (Navy fire brigades, Ceppol, Navy chemists and Cedre duty engineer). Simple models are run with the limited data available. More sophisticated data are run over the following days by other experts who are specialized in a restricted aspect of the response problem.

In the two hours following the emergency call, an evaluation team is sent on board the ship by helicopter. There is no time to have a totally accurate picture of the situation on board and especially of the spill parameters, i.e., type of tank involved, size of hole, and volume already spilled from the tank. But enough information is obtained to run emergency and simple models. Pre-established action sheets must guide the very first responders.

It must be emphasized that during the first hours after an accident, it is almost not realistic to run sophisticated behaviour models as shown in Figure 4. The reflex phase must be achieved by means of emergency and reflex data sheets. The entry data are not very precise and the objective is to define rough exclusion zones using a good safety margin coefficient.

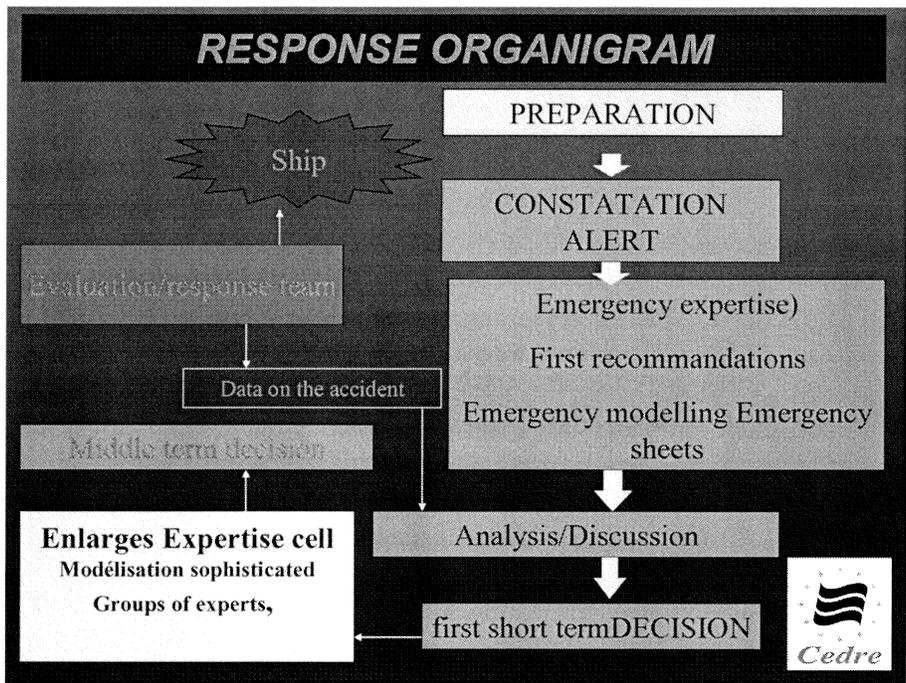


Figure 3 Response Diagram

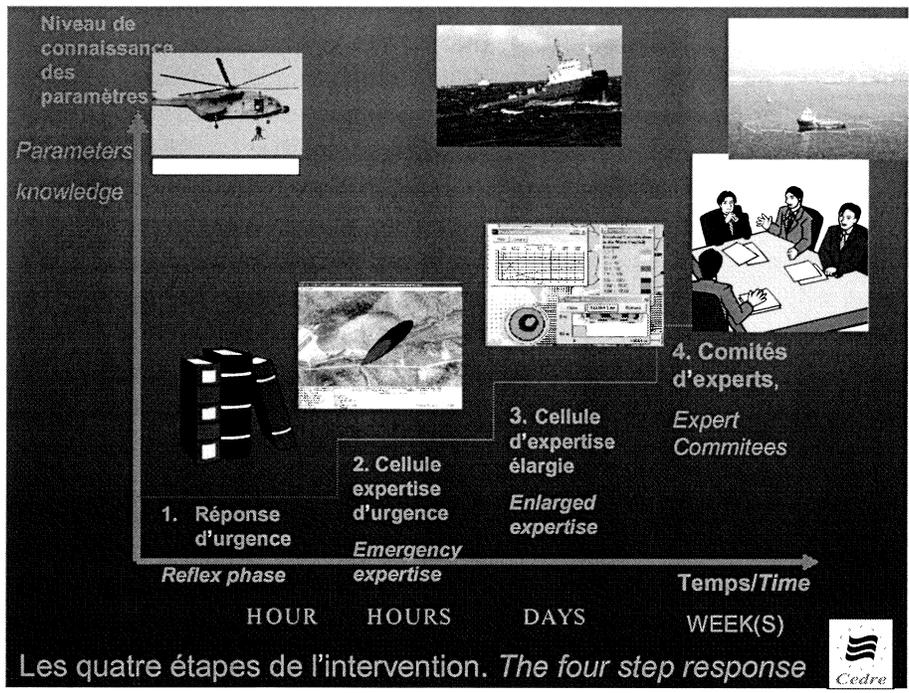


Figure 4 The Four Response Phases

5 Ship Incidents

Lloyd's Register Fairplay has been used. This database records the ships that were the subject of enquiries after incidents. From 1999 to 2005, the Bureau Veritas listed 13 accidents as "T" (Terminal = the ship has been destroyed) or "S" (Serious = the ship needed help). The results of the analysis of Lloyd's Fairplay (1999 to 2005) are shown in Table 2. The numbers in italics indicate the probability of occurrence per year.

Table 2 Occurrence Probability for Various Types of Gas and Liquid Chemical Carriers

	T or S	T or S No Leak No Cargo Failure	T or S Leak Probable or Real	Number of Ships (2006)
LNG	13 (<i>1.23E-2</i>)	4 (<i>3.79E-3</i>)	0	176
Other Gas Tankers>12,500 t	24 (<i>1.70E-2</i>)	5 (<i>3.55E-3</i>)	0	235
Other gas tankers<12,500 t	70 (<i>1.42E-2</i>)	24 (<i>4.88E-3</i>)	2 (<i>4.07E-4</i>)	819
Chemical tankers	142 (<i>1.68E-2</i>)	50 (<i>5.93E-3</i>)	15 (<i>1.78E-3</i>)	1406
Chemical/oil tankers	217 (<i>2.34E-2</i>)	99 (<i>1.07E-2</i>)	20 (<i>2.16E-3</i>)	1543

(T: Terminal, S: Serious) Source: Bureau Veritas

Note: There are now 300 LNG carriers in service around the world.

Despite the low number of total LNG and LPG refrigerated ships (>12,500 tons DWT), it is possible to make the following generalizations. Chemical tankers show an accident frequency equivalent to that of gas tankers <12,500 tons. On the other hand, chemical/oil tankers have twice as many accidents. A gas carrier (LNG/LPG) is less likely to be involved in an accident than chemical tankers. (4 10^{-4} occ./year/ship vs 1.8 10^{-3} occ/year/ship).

5.1 LNG Carriers Accidents

The following description of accident is taken primarily from a paper issued by SIGTO (Society of International Gas Tankers Terminal and Operators Ltd.) titled "Safety Havens for Disabled Gas Tankers" in 2003.

El Paso Paul Kayser (1979)

"While loaded with 99,500 m³ of LNG, the ship ran at speed onto rocks and grounded in the Straits of Gibraltar. She suffered heavy bottom damage over almost the whole length of the cargo spaces resulting in flooding of her starboard double bottom and wing ballast tanks. Despite this extensive damage, the inner bottom and the membrane cargo containment maintained their integrity. Five days after grounding, the ship was refloated on a rising tide by discharge of ballast by the ship's own pumps and by air pressurisation of the flooded ballast spaces. With the permission and co-operation of the Spanish Authorities, the ship was towed to an anchorage in the shelter of Algeciras Bay where shortly afterwards she was relieved of her full cargo by ship-to-ship transfer to a sister LNG carrier moored alongside."

LNG Libra (1980)

“While on passage from Indonesia to Japan, the propeller tail shaft fractured, leaving the ship without propulsion. The Philippine authorities granted a safe haven in Davao Gulf to which the ship was towed. Here, with the ship at anchor in sheltered water, the cargo was transferred in 32 hours of uneventful pumping to a sister ship moored alongside. The LNG Libra was then towed to Singapore, gas-freeing itself on the way and was repaired there. In this casualty, there was, of course, no damage to the ship's hull and no immediate risk to the cargo containment.”

LNG Taurus (1980)

Approaching Tobata Port, Japan to discharge, the ship grounded in heavy weather with extensive bottom damage and flooding of some ballast tanks. After off-loading some bunkers and air pressurising the ruptured ballast spaces, the ship was refloated four days after grounding. Despite the extent of bottom damage, the inner hull remained intact and the spherical cargo containment was undisturbed. After a diving inspection at a safe anchorage, the ship proceeded under its own power to the adjacent LNG reception terminal and discharged its cargo normally.

Moss Rosenberg Design LNG Carrier (2001)

A 125,000 Moss Rosenberg design LNG Carrier experienced an overfilling of a cargo tank, during cooldown operations, at a U.S. LNG Terminal. The spillage of LNG resulted in cracks appearing in one tank cover. The cargo containment system was not damaged nor was there any structural damage to the vessel.

5.2 Main Liquefied Gas Accidents other than LNG (LPG, Ammonia, Propylene)**Mundogas Oslo (1966)**

“Loaded with ammonia and on voyage from Fredericia, Denmark to Nystad, Sweden, she was in collision in dense fog. The colliding ship struck the LPG carrier at right angles and penetrated her hull in way of No.2 (aftermost) cargo hold which flooded. The ship listed heavily and, four hours after the collision, part submerged with her stern resting on the sea bottom. Salvage attempts were frustrated by almost continuous bad weather and by the onset of ice conditions. Finally, after three and a half months of battering, the forepart of the ship also submerged. During the salvage attempts, some cargo gas escaped through the cargo tank relief valves and some liquid cargo was discharged by the Salvors. During the initial submergence of the aft part and the final floundering of the whole ship, no cargo was released...”

World Bridgestone (1973)

“A 74,000 m³ fully refrigerated LPG carrier, loaded with butane and propane for Japan was in collision with an oil tanker in the Malacca Straits. The hold around No. 1 cargo tank flooded but with no immediate threat to the cargo containment. The ship was accepted into Singapore waters where temporary repairs were carried out.”

Yuyo Maru 10 (1974)

“A combination LPG/oil products carrier with four fully refrigerated LPG centre tanks of about 47,500 m³ total capacity and with wing tanks of normal oil tanker construction capable of carrying 32,000 m³ of oil products. While loaded with a full cargo of butane and propane in the centre tanks and of naphtha in the wing tanks, she was in collision with a bulk carrier, Pacific Ares, in Tokyo Bay. Naphtha spilled from an opening of 24 metres in length and extending to below the water line in No. 1 Starboard Wing Tank. The naphtha immediately caught fire and flames enveloped the whole of the Pacific Ares and the starboard side of the Yuyo Maru. Twenty-nine of the crew of the bulk carrier and five men on the gas carrier were killed. LPG vapour escaping from the safety valves and ullage fittings of Nos. 1, 2 and 3 LPG tanks ignited and burnt continuously at the points of emission. The Yuyo Maru continued to burn and fire spread to Nos. 2 and 3 Starboard Wing Naphtha Tanks with sporadic eruptions of flame. Despite major efforts by firefighting tugs, it was not possible to extinguish the fires. Finally, after 19 days, the ship, still burning and having been towed far out to sea, was sunk by torpedo and gunfire.

It is noteworthy that despite the considerable initial collision damage, the fierce and protracted burning of the naphtha cargo in and around the ship and the ignition of the gas escaping on deck from the LPG tanks, no rupture or explosion of the LPG cargo tanks took place and there was no release of the liquefied gas cargo either into the hull or to the sea until the final bombardment and sinking. The 47,000 m³ of LPG in her refrigerated central tanks were surrounded by fire when the 32,000 m³ of naphtha of cargo located in her lateral tanks took fire. The LPG escaped from the safety valves and burnt. Finally, after 20 days of burning the ship has been voluntarily sunk. Except from the safety valve, no gas went out the tanks.”

Regitze Tholstrup (1980)

The pressurized stranded vessel (400 m³ of butane) was lightered from the coast.

Gaz East (1980)

This ship capsized in bad weather off Fos sur mer (Southern France). She was carrying 1000 tons of butane and was towed offshore and sunk by Navy divers.

Gaz Fontaine (1984)

“This vessel of 40,232 m³ was built in 1969 and can be considered to be one of the first generation of fully refrigerated LPG carriers. She had loaded 18,440 tons of propane and butane in three prismatic tanks. She was on passage from Ras Tanura to Fujairah when she was attacked by Iranian aircraft with air to ground missiles, three of which hit the vessel, causing severe damage. A hole 3 x 2 m was blown in the roof of No. 3 tank and much of the cargo pipework and electrical cabling on deck was severely damaged.

As would be expected, a serious fire developed on deck and subsequently spread to the accommodation, but luckily not to the engine room. The crew abandoned ship and two days later, a salvage team arrived on the scene and extinguished the fires with powerful water jets and foam from a salvage tug. The vessel was then towed to a safe anchorage some 15 miles off Dubai and during this period work started on securing the vessel’s gas-tight integrity. Services were

supplied by barge until the vessel's engine room could be recommissioned and six weeks later, 17,204 tonnes of the original cargo had been discharged by ship-to-ship transfer to the LPGC Ribagorca, using Gaz Fountain's own pumps. The vessel was then gas freed prior to repairs.

(Captain J. Carter of P&O Marine Safety Services presented the full story of this incident at the 1985 Gastech Conference, at Nice.)”

Val Rosandra (1990)

“The vessel, a 2,999 m³ semi-pressurized LPG carrier with cylindrical tanks was discharging propylene at Brindisi when a fire started between the compressor house and No. 3 tank. The vessel was towed out to sea with No. 3 tank dome burning. This continued to burn for a further 22 days after which explosive charges were laid to breach the domes of the four remaining tanks and allow the gas to burn off. This situation continued for a further 16 days until the vessel was scuttled.”

Gas Luck (1996)

“She was carrying 1,500 tons of butane gas and sank in bad weather in the East China Sea”.

Igloo Moon (1997)

“The Igloo Moon was carrying 6,600 tons of butadiene when she ran aground on rocks off Florida. No leak was noticed. After a few days, the cargo was off-loaded and the ship freed and towed up to a port after inspection.”

Gaz Poem (2002)

“This 75,000 m³ refrigerated LPG tanker was loaded with 10,000 m³ propane and 10,000 m³ butane. A fire broke out in the machine room (ship on anchor) and the fire extinguished after 3 days. Due to the lack of refrigeration, the pressure increased in the tanks but the off-loading operations were successful”

6 The Response Scenarios

The consortium selected 9 scenarios, taking into account the product, the size of hole, whether the impact level is above the floating line, and the type of incident, such as grounding or collision. The following lists the scenarios.

- LNG. Ship full. Collision above the floating line. Hole 20 cm². Flow 10 kg/s
- LNG. Ship almost empty. Collision. Impact under the floating line. Hole 1 m². Sea water entering the tank.
- LNG. Ship full. Collision. Impact above the floating line. Hole 1 m².
- LNG. Stranding. Hole 4.5 m². Ship full. Flow 17,000 kg/s.
- LNG. Leak on the bridge (manifold).
- 5.6. Ammonia. Collision. Impact under the floating line. 8.4 bars, 5000 DWT.
- VCM. Collision. 5000 DWT.
- Propane. Refrigerated. Pressurized. 5000 DWT.
- Ethylene. 5000 DWT

For each scenario, 5 response steps have been defined.

Step 1: description of the ship (type of ship)

Step 2: initiating event (collision, fire, grounding, etc.)

Step 3: immediate consequence (failure; internal overpressure, Rapid Transition of Phase)

Step 4: aggravating factors (ignition, flow rate, Meteo-oceanic condition, type of fire, possible effect).

Step 5: medium time hazard (impact on the other tanks, structure breakdown, population hazards)

These simulations were run by the means of Phast software, available at Ineris. Figure 5 provides a simulation result on a LNG incident. The atmospheric stability (wind, turbulence level, temperature) has a direct influence on the results

Table 3 Types of Atmospheric Conditions to Simulate the Behaviour of Flammable/Toxic Gas Clouds (Meteo France)

Date (dd/mm/yyyy)	Tidal Coefficient	Wind Speed (m.s ⁻¹)	Stability Class (Pasquill)	Cloudiness	Surface Temperature (K)
24/04/1979	95	10.2	D	Partly cloudy to cloudy	282.9
18/10/1980	37	9.8	C	Mostly cloudy	287.5
04/07/1979	42	2.0	F	Sunny, chances of mist	288.1
17/10/1985	89	4.5	B	Cloudy	288.4
16/04/1984	112	6.6	C-D	Partly cloudy to cloudy	282.6
23/04/1991	50	5.6	E-D	Partly cloudy to cloudy	282.6

6 The Response Emergency Sheets

6.1 General Info Sheet

The general information sheet covers all situations. It takes into consideration the gathering of information from the ship and the ship owner. This information is compiled by the MRCC, in direct contact with the ship and the Navy Operational Centre. A general description of each type of ship is provided.

6.2 Product Sheets

The response emergency sheets need to be very simple to use support papers. Only the main characteristics of the chemical are noted.

- Main danger: flammable, toxic, corrosive, etc.
- Danger code (Figure 6) edited in the Orange guide of the Geneva Fire brigades (2003 edition). This is a requirement of the Navy Fire Brigade. This code is known as a reference by the Navy Fire Brigade.
- Behaviour at sea (floats, dissolves in water) using the SEBC code (Standard European Behaviour Classification)
- Fire decomposition products if any

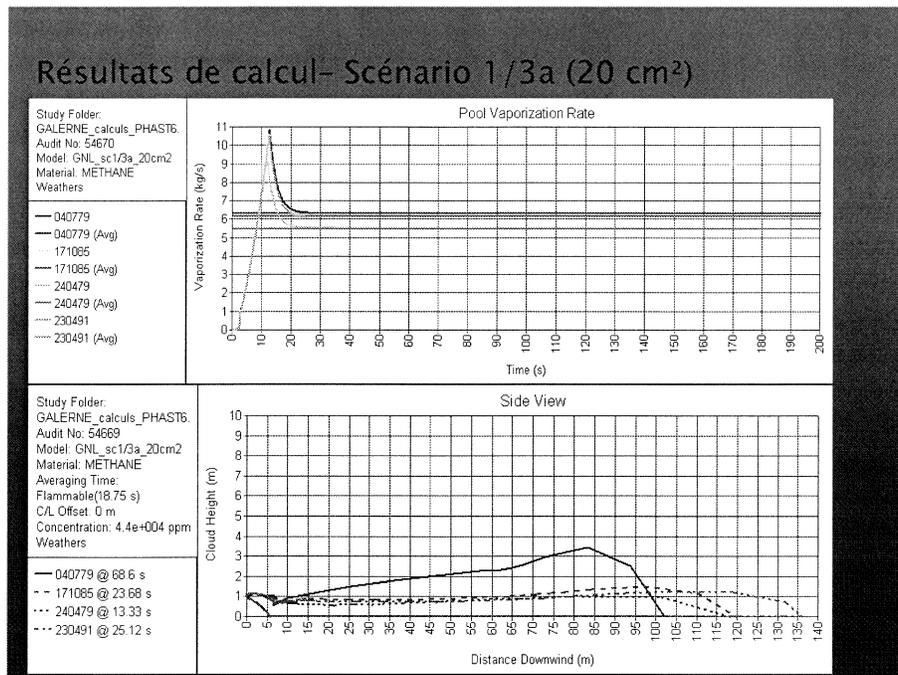


Figure 5 Phast Simulation Describing the Extension of a Flammable Zone of an LNG Tanker with a 20-cm² Hole (Different lines are drawn depending on the type of atmospheric conditions (See Table 3). Source: Ineris

The following data are also provided.

- Odour limit
- Colour
- Density of gas and of the liquid product
- Vapour density
- Vapour pressure
- Toxicity and fire limits
- Conversion factor (mg/m³ vs ppm (v))
- Special care (reaction with water, air, etc.)
- Marpol category
- Detection devices
- Equipment list
- First response (fire, spill)

6.3 Response Sheets

These sheets take into consideration the scenarios and the results of simulations with at least two types of atmospheric situations: stable and unstable. The diagrams clearly show the exclusion zones and flammability and toxic levels, including the elevation of the noxious cloud.

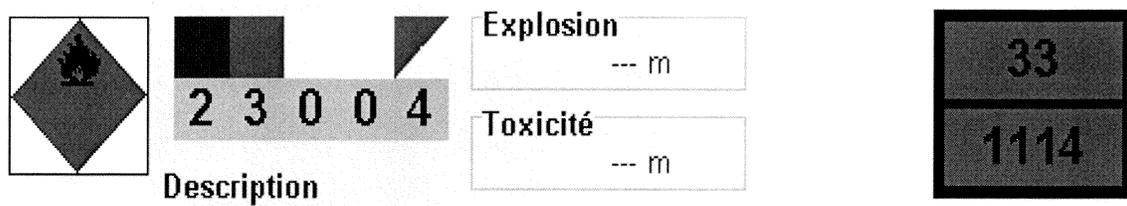


Figure 6 Danger Code for Chemicals following the Geneva Fire Brigade Orange Code

Pictogram: flammable

Blue code: Health. 2 means that BA are indispensable

Red code: Fire. 3 means that the chemical is flammable at ambient temperatures

Yellow code: Heat stability

White code: Water reaction

Red and yellow code: Flammability with air 4 is the maximum range in this case

7 Conclusions

As far as the LNG carriers are concerned, a few accidents at sea have occurred in more than 28 years but no major accidents involving the cargo have been reported. Handling LNG at terminals can lead to serious accidents, e.g., Cleveland, Ohio (1944, 128 casualties), Cove Point, Maryland (1979, 1 casualty), and Skikda, Algeria (2004, 27 casualties). Accidents have occurred at sea but with no accidental spillage of cargo or with the absolute necessity to release the cargo.

With regard to other liquefied gases, some serious accidents have occurred over the last 40 years, but there has been no explosion of a tank following a fire or even after the tank was hit by a missile. A few ships have sunk on their own or been deliberately sunk by the authorities as a result of such accidents.

Response teams on board disabled liquefied gas carriers need to know the main characteristics of the cargo as well as the potential hazards. At the very beginning of the crisis, decision-makers must rely on facts described in scenario sheets. These scenario sheets have to respond to probable facts (not necessarily the worse case). Emergency Response Sheets will be available to the response community by September 2010 thanks to the multidisciplinary team brought together in the Galerne project.