Accident on vessels transporting liquid gases and the responders concerns: the Galerne project

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1. Introduction

The objective of the Galerne project, financed by the French ministry of Research (National Research Agency) is to provide responders at sea (Navy Evaluation Teams and Navy Fire Brigades) with relevant information on the hazards presented by the liquid gasses chemicals present on board vessels, disabled at sea. It is not a project that takes at first into consideration the civil Safety, although we are conscious that population might be affected by an open sea accident in straights for instance, or in traffic lanes close to a shore. Although this aspect is not ignored by Galerne, the main objective is to produce operational information for responders and head quarters. The Galerne project has started in 2006 and will end in September 2009. The consortium members 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 operationnals (French Navy, Ministry of Transport, Civil Safety).

To achieve this objectives, many simulations and experimentation have been done in Ineris (behaviour of liquid Gas in water), GdF-Suez (simulation if LNG when spilled in water using specific softwares), 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 taken.

Liquid gasses are defined as products that are gasses (Vapor Pressure over 100kPa) at normal temperature and pressure (20°C, 100kPa). For economical reasons these category of products are transported in a liquid form, either under pressure, in refrigerated form or under both conditions.

The IGC handbook edited by IMO defines the characteristics of the ships and proposes a definition of the products liable to be transported under liquid form. Thirty one chemicals are concerned by this regulation although some are also registered in the IBC code (bulk liquids).

These gasses are transported in a way depending on their physical characteristics (phase diagram) in order to be the easier to handle and therefore the less expensive on the transport point of view.
The temperature and the 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 gasses on the basis of their transport characteristics and their behaviour.

The following table shows the gasses selected and their properties (Gaz encyclopaedia, Air Liquide, Elsevier, Paris, 1151 p)

	Liquid Vol.mass Kg/m3)	Gaz density	Kg/Kmol	IIL (%)	TLV.TWA Ou VME ppm	Boiling Point °C(1atm)
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

Table 1: properties of the liquid gasses used in the Galerne project

* Vinyl Chloride Monomer

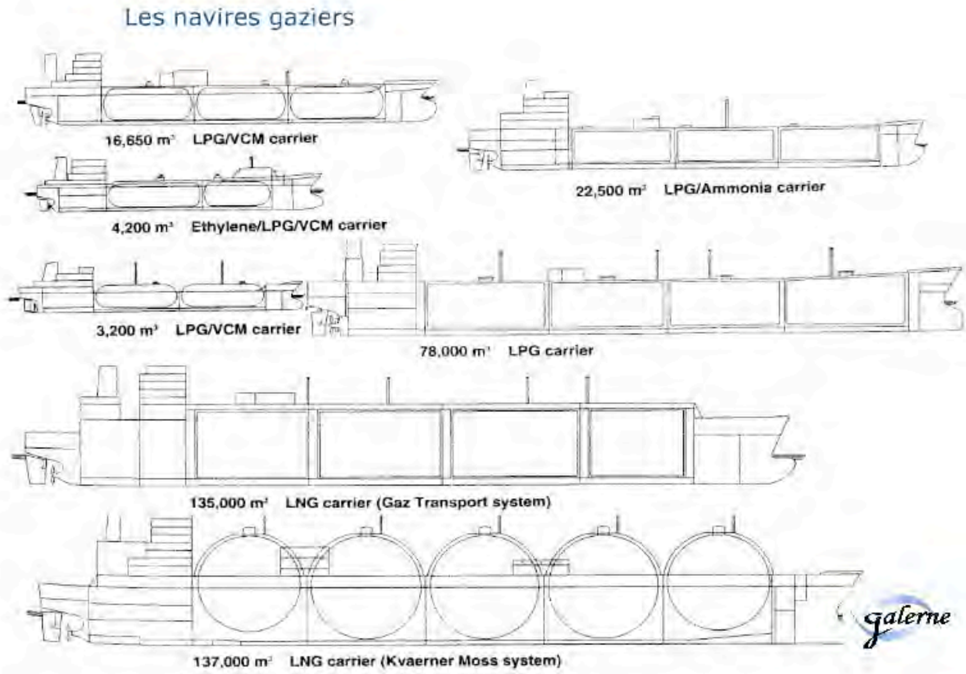
Physical characteristics of the transported products *versus* their volume at standard conditions (table 1)

The products transported in liquid forms, when submitted to standard conditions, develop the following volumes:

LNG: one litre of liquid is equivalent to 630 litres of gaz (15.1°C, 1 bar)
LPG: one litre of liquid is equivalent to 311 litres of gaz (15.1°C, 1 bar)
AMMONIA: one litre of liquid is equivalent to 947 litres of gaz (15°C, 1 bar)
VCM: one litre of liquid is equivalent to 365 litres of gaz

3. Type of ship dedicated to transport gasses in liquid form

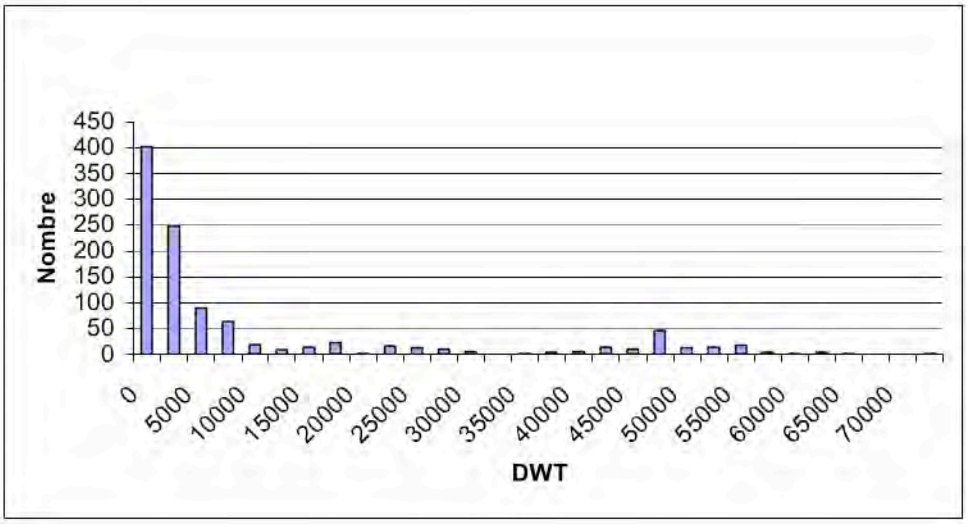
The ships dedicated to the transport of these liquid gases belong to specialised ship family call “gas carriers”. The design of these gas carriers responds to the requirements of the IGC code and depends on the transport conditions (Refrigerated, semi pressurised, pressurised..).



Picture 1: various types of Gas carriers selected in the Galerne Scenarios

The Bureau Veritas made a statistical analysis of the various types of gas carriers other than LNG carriers, on the tonnage point of view. Following the statistical distribution by size (tonnage), these ships can be divided into two categories (picture 2):

1: Less than 12 500 tons DWT for semi pressurised ships
2: More than 12 500 t DWT for refrigerated ships



Picture 2: distribution of the tonnage of the gas carriers (2005)
(1- Gas tankers dwt>12500 t => refrigerated. 2- Gas tankers dwt<12500 tonnes => /liq pressurised or semi-press).

3.1 The pressurised ships

The maximum service pressure is about 18-20 bars. The chemicals are transported at ambient temperature.

The capacity of the ships represents a maximum of 10 000 m3. Standards capacities allow the transport of 4 000 to 6 000 m3 into 2 or 3 tanks.

Ammonia and Propane are transported in these kind of ships.

3.2 The semi pressurised ships

The maximum service pressure is about 7 bars. These ships might be fully refrigerated (SP/FR) in which the gas may be transported at the atmospheric pressure (refrigerated) or under pressure.

Cargoes reach 3000 to 15 000 m3 of liquefied gases. A few of thes ships reach 30 000 m3. LPG, Ethylene, Propylene, CVM, butadiene… are transported in this kind of ships.

3.3 Transport of Ethylene.

Due to the level of the Critical Point, Ethylene must be refrigerated at -104°C. Capacities of ships range between 1 000 to 12 000 m3

3.4 Refrigerated ships

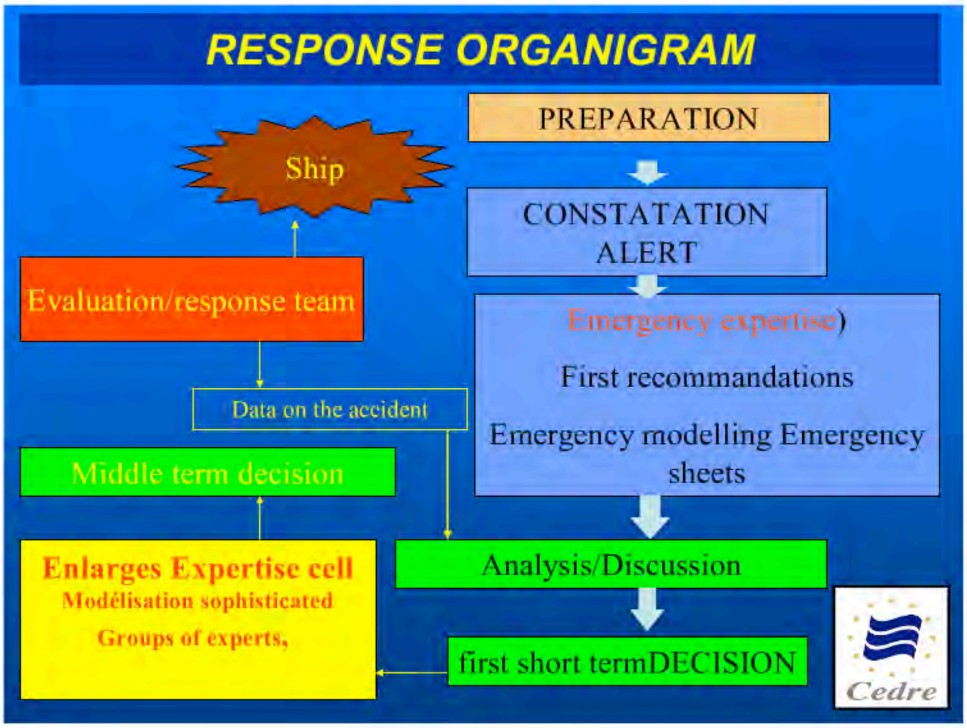
They transport chemicals at the atmospheric pressure, in 3 to 6 type A tanks. They are used for long distance transport of LPG up to 84 000 m3 and Ammonia. The transport of LNG is made by specific vessels. These vessels are refrigerated at -162° C slightly above atmospheric pressure. The number of these LNG transport reaches now (March 2009), 300 units. 89 LNG carriers are on orders, for delivery up to 2011.

4. The various response phases

Back to the emergency situations, the first "mayday" call from a ship is received by a MRCC (picture 3). A Data base called "Traffic 2000" immediately gives the characteristics of the ship and the owner name. So the authorities quickly know the type of chemical on board and the cargo details. The stowing plan will be on line in "Traffic 2000" in a close future. The MRCC calls the Navy Operation Centre (In France, the Navy acts as Coast Guards) who mobilises 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 the following days, by the mean of other experts who are specialised in a restricted aspect of the response problem.

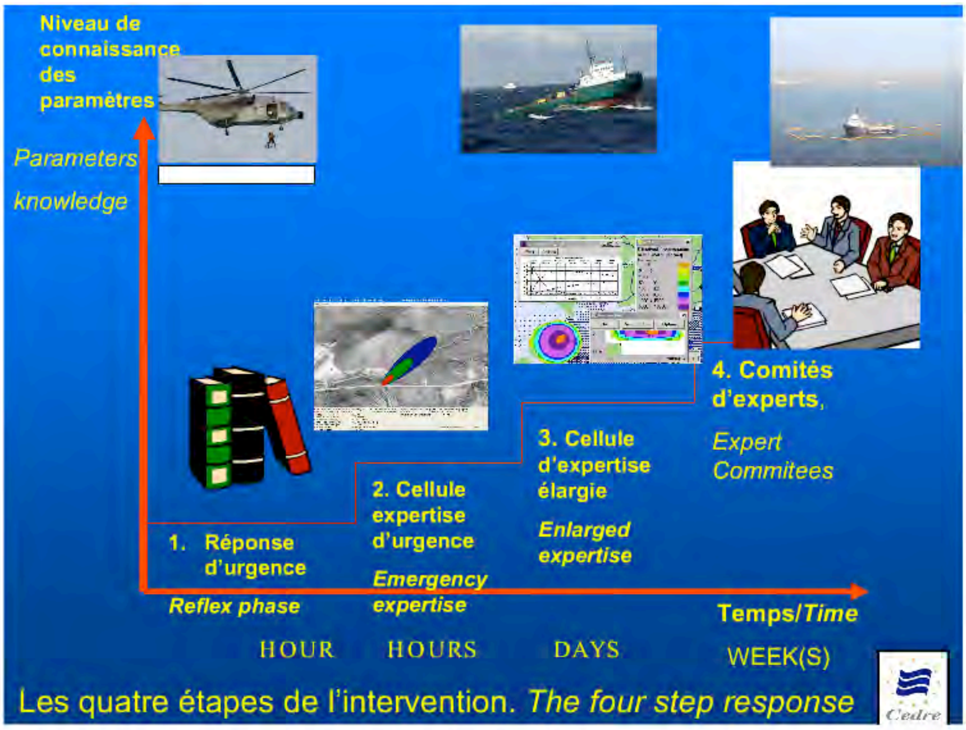
The following two hours following the emergency call, an Evaluation Team is sent on board the ship by helicopter (picture 1). There is no time to have a very accurate state of the situation on board and especially on the spill parametres (type of tank involved, hole size, volume already out of the tank…). But we have to take enough information in order to run emergency and simple models.

Pre-established action sheets must guide the very first responders.



Picture 3: response diagram

It must be underlined that during the first hours following the accident, it is almost not realistic to run sophisticated behaviour models (picture 4). The reflex phase must be achieved by the mean 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.



Picture 4: the four response phases.

5. The ship incidents

The Lloyd's Register Fairplay has been used. This database records the ships that have been subjected to enquiries after incidents.

Between 1999 an 2005, the Bureau Veritas made a list of 13 accidents with the T (Terminal = the ship has been destroyed) or S (Serious=the ship needed help).
The following table showed the result of the analysis of the Lloyd's Fairplay (1999-2005). The number in Italic indicates the probability of occurrence per year.

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

Table 2. Occurrence probability for various types of gas and liquid chemicals carriers. (T: Terminal , S: Serious) *Source Bureau Veritas*
(Note: the number of LNG carriers reaches now 300 in service around the world)

Despite the low number of total LNG and LPG refrigerated (>12 500 tons DWT), it may be possible to write the following probabilities.
Chemical tankers show an accident frequency equivalent to that of gas tanker <12 500 tons. On the other hand chemical/Oil tankers show twice more accident in terms of frequency.
A gas carrier (LNG/LPG) show less probability of occurence of accidents than Chemical tankers. 4 10-4 occ./year/ship vs 1.8.10-3 occ/year/ship

a)LNG carriers accidents
The SIGTO (Society of International Gas Tankers Terminal and operators Ltd) issued a paper "Safety Havens for disabled gas tankers" in 2003 where the following description of accidents is taken for the main part.

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"...

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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 there was repaired. 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 Rossenberg design LNG Carrier (2001)

A 125,000 Moss Rossenberg design LNG Carrier experienced an overfilling of a cargo tank, during cooldown operations, at a US 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…

b)The 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, she 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 central tanks refrigerated were surrounded by fire when the 32 000 m3 of naphta of cargo located in her lateral tanks took fire. The LPG escaped from the safety valves and burnt. Finally after 20 days burning the ship has been volontarly sunk. Excepted from the safety valve, no gas went out the tanks."

Regitze Tholstrup (1980)
The pressurised stranded vessel (400 M3 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 3m x 2m was blown in the roof of No.3 tank and much of the cargo pipe-work 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 2999 m3 semi – pressurised 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 000m3 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"*

5. The response scenarios

The consortium has selected 9 scenarios, taking into account the product, the size of hole, the impact level above the floating line or not, the type of incident (grounding, collision).

The following list describes the scenarios

LNG. Ship fullCollision above the floating line. Hole 20cm2. Flow 10kg/s
LNG. Ship almost empty.Collision. Impact under the floating line. Hole one m2. Sea water entering the tank.
LNG. Ship full.Collision. Impact above the floating line. Hole one m2.
LNG. Stranding.Hole 4.5 m2. Ship full. Flow 17 000kg/s.

LNG. Leak on the bridge (manifold)

5.6. Ammonia.Collision.Impact under the floating line. 8.4 bars, 5000 DWT
5.7.VCM. Collision. 5000 DWT.
5.8. Propane, Refrigerated, pressurised. 5000 DWT
5.9. Ethylene.5000DWT

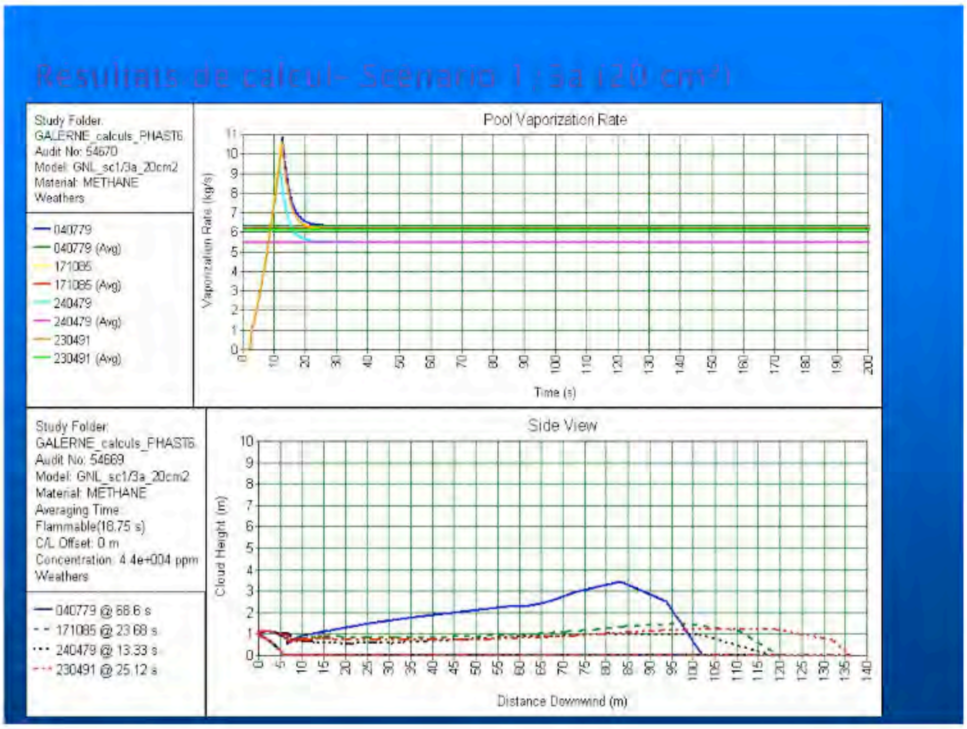
For each scenario, 5 response steps have been defined:

Step 1: description of the ship (type of ship)
Step 2: initiating event (collision, fire, grounding…)
Step 3: immediate consequence (failure; internal overpressure, Rapid Transition of Phase)
Step 4: aggravation factor (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

Date	Coefficient de marée	Vitesse du vent ($m.s^{-1}$)	Classe de stabilité (Pasquill)	Nébulosité	Température de surface (K)
24/04/1979	95	10,2	D	Peu nuageux à nuageux	282,9
18/10/1980	37	9,8	C	Très nuageux	287,5
04/07/1979	42	2,0	F	Ciel clair, brume possible	288,1
17/10/1985	89	4,5	B	Couvert	288,4
16/04/1984	112	6,6	C-D	Peu nuageux à nuageux	282,6
23/04/1991	50	5,6	E-D	Peu nuageux à nuageux	282,6

Table 2 . Types of atmospheric situation taken to simulate the behaviour of flammable/toxic gas clouds (*Meteo France).*

These simulations were run by the mean of Phast software, available at Ineris. We are giving hereunder a simulation result on a LNG incident. The atmospheric stability (wind, turbulence level, temperature) has a direct influence on the results.



Picture 5. Phast simulation describing the extension of a flammable zone of a LNG tanker with a 20cm2 hole.

The different lines are drawn depending on the type of atmospheric situation. (see table 2). *Source Ineris*

6. The Response Emergency Sheets

6.1 General info sheet

This sheet covers all the situations. It takes into consideration the gathering of information coming from the ship and the ship owner. These information are gathered by the MRCC, in direct contact with the ship and the Navy Operationnal Centre .
A general description of each type of ship is made.

6.2 Product sheets

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

Main danger: flammable, toxic, corrosive….
Danger code (Picture 6) edited in the Orange guide of the Geneve 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
A few data:

Odor 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, with air…)
Marpol category
Detection devices
Equipment list
First response (Fire, spill).

Picture 6: Danger code for chemicals following the Geneve 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 temperature
Yellow code Heat stability
White code Water reaction
Red and yellow Flammability with air4 is the maximum range in this case

6.3 Response sheets

These sheets take into consideration the scenarios and the simulations results with at least two type of atmospheric situation : stable and unstable

The diagrams show clearly the exclusion zones : flammability, toxic levels, including the elevation of the noxious cloud.

7. Conclusions

As far as the LNG carriers are concerned, a few accidents at sea have occurred since more than 28 years but no major accident involving the cargo has been notified. Handling LNG at terminals can lead to serious accident; Cleveland, (1944, 128 casualties), Cove Point (1979, One casualty), Skidda (2004, 27 casualties). Accident at sea have occurred but with no accidental spillage of cargo or involving the absolute necessity to release the cargo.

Concerning the other liquefied gases, some serious accidents have occurred during these last 40 years. But it has to be said that there has been no explosion of a tank following a fire or even after the tank was hit by a missile. We have noticed that a few ships sunk or have been deliberately sunk by the authorities.

The response teams on board disabled liquefied gas carriers need to know the main characteristics of the cargo together with the hazards to face. Decision makers, at the very beginning of the crisis must rely on facts described in scenarios.

These scenarios sheets have to respond to probable facts (not necessarily the worse case). The Emergency Response Sheets will be ready by September 2010 thanks to a multidisciplinary team gathered in the Galerne project.