SECRETARIAT D'ETAT AUX TRANSPORTS ET A LA MER
INSPECTION GÉNÉRALE DES SERVICES DES AFFAIRES MARITIMES
Bureau enquête — accidents / mer (*BEA*mer)

TECHNICAL REPORT OF THE INQUIRY INTO THE EXPLOSION

(one fatality)

ON BOARD THE OIL TANKER

CHASSIRON

ON 13TH JUNE 2003
OFF BAYONNE

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This report has been drawn up according to the provisions of Clause III of Act No.20023-3 passed by the French government on 3rd January 2002 relating notably to technical and administrative investigations after accidents at sea and the decree of enforcement No. 2004-85 of 26th January 2004 relating to technical investigations after marine casualties and terrestrial accidents or incidents, and in compliance with the "Code for the Investigation of Marine Casualties and Accidents" laid out in Resolutions A.849(20) and A.884(21) adopted by the International Maritime Organization (IMO) on 27/11/97 and 25/11/99. It sets out the conclusions reached by the investigators of the BEAmer on the circumstances and causes of the accident under investigation. In compliance with the above mentioned provisions, the analysis of this incident has not been carried out in order to determine or apportion criminal responsibility nor to assess individual or collective liability. Its sole purpose is to identify relevant safety issues and thereby prevent similar accidents in the future. The use of this report for other purposes could therefore lead to erroneous interpretations.

CONTENTS

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BUREAU ENQUETES ACCIDENTS MER

1* CIRCUMSTANCES

On 12th June 2003 the *CHASSIRON* called at Bayonne from Donges to unload the cargo of her 386th voyage consisting of 3 parcels distributed as follows :

- **Cargo tanks 1 (P & S) : domestic heating oil**
- **Cargo tanks 2, 3, 4, 5 (P & S) : gas oil**
- **Cargo tanks 6 (P & S) : unleaded mogas (98 octane)**

She left Bayonne for Donges at 0500 on 13th June 2003 to take on an identical but differently distributed cargo load.

- **Cargo tanks 1 (P & S) : unleaded mogas (98 octane)**
- **Cargo tanks 2, 3, 4, 5 (P & S) : gas oil**
- **Cargo tanks 6 (P& S) : domestic heating oil.**

After the vessel got under way, the pumpman and the boatswain began tank washing operations on Tank 1 (P & S) and 6 (P & S).

At 0709 they had just begun washing cargo Tanks 6 (P & S), which had previously contained mogas, when there was a very loud whistling sound immediately followed by an explosion and fire in Cargo tank 6. The boatswain who was standing by himself near the cargo manifold, was unhurt. The pumpman who was near Cargo tank 6 port was first reported missing and a search was carried out in the sea, but he was eventually found dead in the after part of Cargo tank 6 port. The deck of the vessel was ripped open from the bridgehouse to the manifold and the bulkheads of Cargo tanks 5 and 6 were severely damaged.

The fire was brought under control at 0800.

Considerable nautical and aeronautical resources were deployed by the CROSS-A to help in the search for the pumpman on the one hand, and to fight the fire on the other hand.

A 6-man assessment team comprising representatives of the Bayonne office of the Bordeaux Ship Safety Centre, and the Bayonne harbourmaster's office as well as the Bayonne pilot and tug services went on board at 1052. After the situation had been assessed, the vessel was granted permission to return to Bayonne where she berthed at 1348.

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2* THE VESSEL

2.1* Construction

The CHASSIRON is a double-hull IMO II combined petroleum products/chemical tanker.

She was built in 1999 by the NIESTERN SANDER shipyard in DELFZIJL (Netherlands) and was delivered on 5th January 2000 as a replacement for the SOMPORT which was time-chartered to Elf and registered in Saint Vincent and the Grenadines. She is one of a series of four similar ships built by the same yard for the same owner/operator, PETROMARINE whose head office is in BRUGES (Gironde) and who run a fleet of 9 ships of the same type and two small oil tankers.

She is owned by the consortium Dakar.

Her main particulars are as follows :

length overall	:	*119.00 m ;*
length between perpendiculars	:	*113.68 m ;*
moulded breadth	:	*17.80 m ;*
Depth to upper deck	:	*9.50 m ;*
Summer draught	:	*7.38 m ;*
Corresponding deadweight	:	*9995 t ;*
Gross tonnage	:	*5100 ;*
Net tonnage	:	*2700 ;*
Cargo capacity (at 98%)	:	*9926 m³ ;*
Cargo capacity (at 100%)	:	*10130 m³ ;*
Ballast capacity	:	*3860 m³ ;*
Speed	:	*14 knots.*

The cargo area is arranged with 12 cargo tanks and 6 segregations, plus a slop tank of 184 m^3. The cargo tanks are separated by vertically corrugated bulkheads which, combined with the fact that the deck stiffeners are outside the tanks, means that the tanks sides and top are flush and therefore easy to clean.

The inside surfaces of the cargo tanks are coated with epoxy phenolic paint .They are unloaded by 12 hydraulically driven Framo SD 125 centrifugal type deepwell pumps (one per tank) with a capacity of 230 m^3/h at 7 bar. The maximum discharge capacity is 1380 m^3/hr with 6 pumps in use simultaneously.

If one of the pumps breaks down, the tanks can be unloaded with a portable submersible emergency pump unit with a capacity of 70 m^3/hr.

Stripping of the cargo tanks is carried out through the cargo pumps by means of compressed air or inert gas at a pressure of 6 bar.

The tanks are equipped with a thermal fluid heat exchange system which enables the cargo to be maintained at a temperature of 65℃ for the carriage of products which require heating.

The vessel can carry up to 6 different cargoes simultaneously, whether they be petroleum products or IMO II listed chemicals.

The ballast tanks are arranged in the double hull and the double bottom.

The vessel is fitted with an inert gas system comprising a Smit Sinus nitrogen generator and a 5000 litres storage tank at 8 bar.

The main propulsion unit is an 8 cylinder in line MaK 8M32 medium speed diesel engine with an output 3840 kW at 600 rpm, driving a four blade KaMeWa controllable pitch propeller through a Valmet reduction gearbox.

Electricity is produced by three Caterpillar 3400/A generator sets fitted with Van Kaick 410 kW alternators or, at sea, by one 720 kW shaft generator which can be used as an electric emergency propulsion motor enabling the vessel to reach a speed of 7 knots with a draught of 6 metres.

The vessel is classed with Bureau Veritas with the following notation :

- **I 3/3 E * Oil Tanker / Chemical Tanker ESP Deep Sea IG * MACH * AUT PORT * BOILERS / CNC-1 V INT SBT F.**

She sails under the French flag on the TAAF register and is registered in Port aux Français for deep sea navigation.

2.2* Safety Equipment. Fire prevention and firefighting.

The equipment comprises :

- *fire detection using thermal sensors, ionizing smoke detectors and flame detectors in the accommodation, the forecastle store, the bow thruster room and the engine room;*
- *a fixed CO_2 smothering system in the engine room, separator room, boiler/incinerator room, heat exchanger room and galley;*
- *a drencher system using water under pressure;*
- *two main fire pumps each with a capacity of 62 m^3/hr ;*
- *a back-up fire pump with a capacity of 60 m_3/hr;*
- *a fixed foam installation comprising a 6000 litre foam tank, a mixer pump and 5 monitors on the main deck, two of which are just forward of the bridgehouse front port and starboard;*
- *a foam pump with a capacity of 197 m^3/hr ;*
- *gas detectors in the ballast spaces.*

The deck and cargo area are protected by foam monitors.

2.3* Cargo tank washing

2.3.1* WASHING EQUIPMENT

Each tank is equipped with two fixed TOFTEJORG TZ-82 tank cleaning machines, one in the forward part of the tank, the other in the after part, fitted 2 metres below the deck.

The cleaning fluid acts at the same time as prime mover, lubricant and coolant.

The fluid flow passes through a pipe making a turbine rotate. The rotation of the turbine is transformed into a combined horizontal rotation of the body and vertical rotation of the nozzles by a gearbox .

The combined movement enables the tank to be completely cleaned after 4 cycles each comprising 45 rotations of the nozzles.

The rotational speed of the turbine depends on flow rate of the fluid through the cleaning machine; the greater the flow rate, the higher the speed.

The tank cleaning machines are supplied by 2 tank washing pumps in the engine room, delivering 24 m^3/hr at 10 bar. Four tank cleaning machines can operate at the same time.

The slop tank can be washed with two portable washing machines (12 m^3/hr at 8 bar) which can also be used as back-ups for cargo tank cleaning.

Washing is either carried out with seawater (suction at the sea chest), or with fresh water (suction in the aft peak tank).

This water can be heated by a 1675 kW thermal fluid heat exchanger up to 60℃ for a flow rate of 24 m^3/hr, that is, with two cleaning machines in operation.

The working pressure varies from 2 to 12 bar. The recommended inlet pressure is 5 to 10 bar.

On board the *CHASSIRON* the working pressure is 8 bar and the flow rate 12 m^3/hr per cleaning machine.

The cleaning machines are manufactured of AISILS1316L stainless steel, PFTE, Tefzel and carbon.

To prevent static electricity from building up, the flexible hose supplying the cleaning fluid is a conductor of electricity and earthed.

2.3.2* TANK CLEANING PROCEDURE

On board the *CHASSIRON* tank cleaning was being carried out with cold seawater, each pair of tanks (P & S) being washed successively from fore to aft according to the procedure set out in the annexes (see Ship File).

The cargo pumps were discharging to the slop tank. They were set for local control on deck. The pressure of the hydraulic fluid was set to 80 bar to operate the pump at a reduced rate.

Only the aft cleaning machines were in use. The discharge pressure of the washing pump was set at 8 bar. It took 10 to 15 minutes to clean each pair of tanks. After cleaning, the tanks were dried.

2.4* Measuring levels, pressure and temperature in the cargo tanks

Each tank is fitted with a radar level gauge which measures the ullage and comprises a radar transmitter and antenna to which are connected the temperature probe and the vapour space pressure transmitter which is fitted with an alarm. The temperature probe is placed in a closed stainless steel sheath and insulated by magnesia. The pressure sensor is of the piezo-resistive type. The whole system is linked to a data acquisition unit in the cargo control room.

There is also a piezo-resistive transmitter for indicating the pressure in the cargo lines as well as a level gauge for protection against overfilling which consists of two probes with alarms set at 95% and 98%. This equipment is entirely static (no moving parts) in compliance with IMO Resolution A.686 (17) and US Coast Guard Rule 46 CFR 39-7.

All the equipment is intrinsically safe and complies with current ATEX standards, notably the 94/9/EC Directive which has been in force since 01/07/2003. It is noteworthy that equipment on board ships and mobile offshore units does not fall within the scope of this directive.

2.5* Hydraulic cargo discharge pumping system

The cargo pumps are hydraulically driven single stage submerged centifugal pumps with flow rate and speed controls, torque gauge and anti-rotation brake. The pump and motor are directly coupled at the bottom of the tank. The hydraulic fluid is pressurized by a hydraulic power plant. The hydraulic pressure pipe is placed inside the hydraulic return pipe, the whole unit being protected from the cargo by a cofferdam with a venting and purge system for detecting any leaks of cargo or oil. This cofferdam must be purged before and after unloading (see Ship File – technical description of cargo pumps)

The whole unit is made entirely of stainless steel.

The pumps are equipped with Teflon wear rings and the bearings are lubricated by the hydraulic fluid. There is no metal to metal contact between the fixed and moving parts. The design of the pump also permits dry running during stripping and tank cleaning operations.

2.6* Navigation and safety certificates

The vessel was built under the supervision of the Dunkirk Ship Safety Centre. The vessel is registered in Bordeaux and since being brought into service, has been regularly inspected by the Aquitaine Ship Safety Centre.

When the accident happened all her safety and pollution prevention certificates were valid. Her target factor in the context of the Memorandum of Paris was 20 and she had never been detained.

The last annual safety inspection was conducted on 8th January 2003 by the Bordeaux Ship Safety Centre.

The safety management certificate (ISM Code) was valid until 22nd June 2005.

The Bureau Veritas carried out an annual survey on 13/12/2002 in Bordeaux in compliance with the provisions of IMO Resolution A.746 (18) (Survey Guidelines under the Harmonized System of Survey and Certification). There was nothing to report, the vessel was in satisfactory condition and no reservations were made which could have had any bearing on the accident.

The insulation report of 5th November 2001 revealed no anomalies.

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3* THE CARGO

3.1* Physical and chemical properties of the products carried

3.1.1 DOMESTIC HEATING OIL*

Product used to produce heat in central heating systems and, under certain conditions of use, as fuel for internal combustion engines

Chemical nature

- *substance composed of paraffinic hydrocarbons, napthenic, aromatic and olefin hydrocarbons with mainly C9 to C20 hydrocarbons ;*
- *vegetable oil ethers such as methyl ether from rapeseed oil $\leq$5% volume (in certain cases $\leq$30% volume) ;*
- *in some cases, biocides ;*
- *dyes and tracer chemicals ;*
- *sulphur content $\leq$0,2% ;*
- *dye : scarlet red ortho-toluene- azo-ortho-toluene- azo-beta naphtol ...1g/l.*

Characteristics

- Red liquid at 20℃.
- Specific gravity : 830 to 880 kg/m3 at 15℃ (NF EN ISO 3675).
- Viscosity < 7mm2/s at 40℃.
- Temperatures at phase change : initial distillation point ≥ 150℃. Distillation range within 150 to 380℃.
- Flash point ≥ 55℃ (NF T 60-103).
- Auto-ignition temperature ≥ 250℃. (ASTM E 659).
- Flammability limits in air at ambient temperature : about 0,5 to 5% vapour by volume.
- Vapour pressure : < 100 hPa at 100℃, < 10 hPa at 4 0℃.
- Vapour density > 5 (air = 1).
- Solubility : practically immiscible in water, soluble in many common solvents.

Handling and storage. Precautions

Loading and unloading must be carried out at ambient temperature. To prevent risks related to the build-up of static electricity, ensure that the machinery, equipment and tanks are properly earthed, make sure that the product cannot splash or produce droplets during loading and ensure that the product is poured slowly, particularly at the beginning of the operation.

3.1.2* GASOIL

Fuel for diesel engines and combustion turbines.

Chemical nature

- *substance composed of paraffin hydrocarbons, naphtenic, aromatic and olefin hydrocarbons with mainly C9 to C20 hydrocarbons;*
- *vegetable oil ethers such as methyl ether from rapeseed oil $\leq$5% volume (in certain cases $\leq$30% volume) ;*
- *sulphur $\leq$350 mg/kg ;*
- *In some cases multipurpose additives to boost performance. Biocides.*

Characteristics

- Yellow liquid at 20°C.
- Specific gravity : between 820-845 kg/m3 at 15°C.
- Viscosity < 7 mm2/s at 40°C.
- Temperatures at phase change : initial distillation point ≥ 160°C. Distillation range within 150 to 380°C.
- Flash point : > 55°C (NF EN 22719).
- Auto-ignition temperature ≥ 250°C (ASTM E 659).
- Flammability limits in air at ambient temperature : about 0,5 to 5% vapour by volume.
- Vapour pressure < 100 hPa at 100°C ; < 10 hPa at 40°C.
- Vapour density > 5 (air = 1).
- Solubility : practically immiscible in water, soluble in many common solvents..

Handling and storage. Precautions

Loading and unloading must be carried out at ambient temperature. To prevent risks related to the build-up of static electricity, ensure that the machinery, equipment and tanks are properly earthed, make sure that the product cannot splash or produce droplets during loading and ensure that the product is poured slowly, particularly at the beginning of the operation.

3.1.3* UNLEADED MOTOR SPIRIT (GRADE 98)

To be used exclusively in spark-ignition engines.

Chemical nature

- *Substances composed of paraffin hydrocarbons, naphthenic, aromatic (=< 42%) and olefin hydrocarbons (=< 18%), with mainly C4 to C12 hydrocarbons, including benzene and n-hexane.*

- *Possibly the following oxygenate compounds: Methanol =< 3% volume, Ethanol =< 5% volume, Isopropyl alcohol =< 10% volume, Isobutyl alcohol =< 10% volume, Terbutyl alcohol =< 7% volume, Ethers (5 or more C atoms) including ETBE/MTBE =< 15% volume. Other oxygenate compounds =<10% volume. Multi-purpose additives to boost performance (MTBE : methyltertiobutylether – TBA : tertiobutyl alcohol – ETBE : ethyltertiobutylether).*

Characteristics

- Extremely flammable. As the vapours are heavier than air, they can spread along the ground giving a high risk of explosion. Friction generated at the discharge of the product can create static charges of sufficient magnitude to cause sparks which may lead to fire or explosion.
- Light yellow liquid at 20°C with a greenish yellow sheen.
- Specific gravity : between 720 - 775 kg/m3 at 15°C.
- Viscosity : 0,5 to 0,75 mm2/s at 20°C.
- Temperatures at phase change : distillation range within 30 to 210°C. Initial distillation point : typical value 27°C.
- Flash point : < -40°C (ASTM D 93).
- Auto-ignition temperature : > 300°C (ASTM E 659).
- Flammability limits in air at ambient temperature : about 1.4 to 7.6% vapour by volume.
- Vapour pressure : 45 - 90 kPA (NF EN 13016-1) at 37,8°C; < 100 kPA at 35°C.
- Vapour density : 3 to 4 (air = 1).
- Solubility : Practically immiscible in water, about 225 mg/l at 20°C, but this may depend on the nature and content of oxygenated organic compounds. Soluble in many common solvents.

- **Dangerous reactions : conditions to avoid : heat, sparks, ignition points, flames, static electricity, strong oxydizing agents.**

Handling and storage. Precautions

Use explosion-proof material. Handle away from any source of ignition (naked flame and sparks) and heat (hot manifold or casings). Do not use compressed air or oxygen when transferring or pouring the products..

Do not use mobile telephones during handling.

Loading and unloading must be carried out at ambient temperature. To prevent risks related to the build-up of static electricity, ensure that the machinery, equipment and tanks are properly earthed, make sure that the product cannot splash or produce droplets during loading and ensure that the product is poured slowly, particularly at the beginning of the operation.

Analysis of the motor spirit from the same shore tank as that loaded on the *CHASSIRON* on 16/06/03 :

volatility index K	:	794.00 ;
specific density at 15°C	:	0.7484 à 0.7493 ;
mon	:	87.100 ;
Reid vapour pressure bar abs	:	0.5880 ;
% distillation at 100°C	:	49.000 to 50.000 ;
% distillation at 150°C	:	88.000 ;
benzene chloride % volume	:	0.7400 to 0.7700 ;
olefins % volume	:	12.000 to 12.300 ;
aromatics % volume	:	37.200 to 37.300 ;
total sulphur content mg/kg	:	64.100 to 66.000 ;

Conductivity measurements made on samples from the grade 98 mogas shore tanks at the Donges oil refinery in July gave the following results :

date	shore tank	conductivity at 20°C in pS/m (picoSiemens per metre)
01/07	P504	390
03/07	P891	150
04/07	P801	137
05/07	P505	210
07/07	P801	175
11/07	P801	210
21/07	P505	215
29/07	P504	190

At the request of the *BEA*mer, electrical conductivity tests were carried out by the INERIS (Institut national de l'environnement industriel et des risques) on samples of grade 98 unleaded motor spirit, one taken from the product which was loaded at the Donges refinery, the other from what was unloaded in Bayonne. These test and their results are described in the annexes to this report. The two samples showed an electrical conductivity well below 50 pS per metre and a discharge time of several minutes to dissipate 90% of the initial electric charge.

The grade 98 unleaded motor spirit thus has a fairly high resistivity to the dissipation of electric charges and can therefore be classed as an insulating fluid.

The two series of tests were carried out with different frames of reference and at different times which explains why the results differed. They nevertheless showed that this product has low conductivity.

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4* MANNING – ORGANIZATION OF WORK ON BOARD

The vessel was manned by a crew of 14 persons most of whom were French or Senegalese :

- **5 Frenchmen : 4 officers plus one cadet : master, chief engineer, chief mate and third mate;**
- **7 Senegalese including : second engineer, second mate, boatswain and pumpman;**
- **1 person from the Ivory Coast;**
- **1 Togolese.**

The minimum complement for safe manning requirements was 10 persons.

Bridge watchkeeping at sea was organized in 4 hour watches :

- **Middle watch from 00.00 to 04.00 and Afternoon watch from 12.00 to 16.00 : 3rd mate , rating 1 ;**
- **Morning watch from 04.00 to 08.00 and Dog watches 16.00 à 20.00 : Chief mate, pumpman;**
- **Forenoon watch from 08.00 to 12.00 and First night watch from 20.00 à 00.00 : 2nd mate, boatswain.**

As the vessel was classed AUT, work in the engine room was organized on a daywork system.

On the day of the accident, the complement of the vessel was greater than the minimum safe manning requirements ; the master, officers and ratings all had the requisite qualifications as prescribed by the STCW Convention.

The master held a French 2nd class master's ticket (C2NM) as well as oil tanker, chemical tanker and liquefied gas tanker certificates. He had sailed regularly on the *CHASSIRON* as master since May 2000.

The Chief mate held the French 2nd class master's diploma (C2NM) and also held a tanker certificate. He had acquired most of his qualifying sea time in the engine room where he had served as Second engineer and Chief engineer, on board the *CHASSIRON* in particular.

He had been Chief mate for a month and was making his first voyage in this capacity.

The Chief engineer was a qualified engineer officer and also held oil tanker, chemical tanker and liquefied gas tanker certificates as well as a tanker familiarization certificate.

He had worked in this capacity since 1990. He had been on board the *CHASSIRON* since 1st May 2003 and had followed her construction in the shipyard.

The 3rd mate who was a qualified merchant marine officer, had first sailed as a cadet on the *CHASSIRON* in October 2001 and then as multi-purpose officer from November 2002.

As for the pumpman, he had a solid experience of vessels used for transporting petroleum products.

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5* THE SEQUENCE OF EVENTS

5.1* Arrival and unloading at Bayonne

The vessel arrived in Bayonne on 12th June 2003 and was made fast alongside, port side to, at 0518. All the ballast tanks were empty except for the fore peak tank and the anti-heeling tanks (No.4).

Cargo characteristics on arrival

- DOMESTIC HEATING OIL : d. = 0.8568 ; Temp. °C = 23.6 ; Vol. = 938.378 m³ ; Vol. 15°C = 931.716 m³ ; wt. = 796.269 tonnes, loaded in Tank 1 (P & S) ;
- GASOIL : d. = 0.8437 ; Temp. °C = 29.5 ; Vol. = 7729.932 m³ ; Vol. 15°C = 7635.645 m³ ; wt. = 6433.794 tonnes, loaded in Tanks 2, 3, 4 et 5 (P & S);
- UNLEADED GRADE 98 MOGAS: d. = 0.7502 ; Temp. °C = 25,2 ; Vol. = 1228.234 m³ ; V 15°C = 1213.127 m³ ; P = 908.753 tonnes, loaded in Tank 6 (P & S).

Unloading began on 12th June and was completed on 13th June in the following order :

- 0530 : connection ;
- 0536 to 0554 : cargo identification, calculations ;
- unloading of unleaded grade 98 mogas from Tank 6 port and starboard from 0600 to 0900 ;
- unloading of domestic heating oil from Tank 1 port and starboard from 1006 to 1224 ;
- unloading of gasoil from Tanks 2, 3, 4, 5 port and starboard from 1312 to 0106 ;

- **0130 : inspection ;**
- **0136 : disconnection.**

The unloading rate was as follows :

- **Unleaded grade 98 mogas : 303 m³ per hour ;**
- **Domestic heating oil : 347 m³ per hour ;**
- **Gasoil : 541 m³ per hour ;**

Pumps used

- **Unleaded grade 98 mogas : 2 cargo pumps / 1 hydraulic pump (Ph = 180 bar) discharge pressure = 3,8 bar**
- **Domestic heating oil : 2 cargo pumps / 1 hydraulic pump (Ph = 180 bar) discharge pressure = 3,9 bar**
- **Gasoil : 4 cargo pumps / 2 hydraulic pumps (Ph = 160 bar) discharge pressure = 6,1 bar.**

After unloading, when the vessel left Bayonne, the ballast situation was as follows : all the ballast tanks were full except for the fore peak tank, the deep tank, the anti-heeling tanks and ballast Tank 6 port and starboard.

5-2* Departure from Bayonne on 13th June 2003

Times are given in local time (UTC + 2)

0500, after completely discharging her cargo the *CHASSIRON* set sail from the oil berth at the Raffinerie du midi at Boucau (port of Bayonne) bound for the oil refinery at Donges. The vessel was in ballast.

0530, the pilot disembarked.

0536, the vessel was full away on passage, electricity was being produced by the shaft-driven alternator. The vessel's speed was steady on 14.7 knots.

0600, the master left the bridge and handed over the watch to the Chief mate.

At about **0630**, the pumpman began washing the pair of tanks which had previously contained domestic heating oil (Tank No.1 P & S).

Around **0640**, washing of Tank No.1 was completed and the pumpman went to wake up the boatswain so that he could help him with the work.

At about **0700**, the washing machines in Tank No.6 port and starboard were in operation as well as the pumps in both of these tanks.

The vessel was in position : 43°53'.9 N – 001°30' .8 W.

0709, there was a violent explosion followed by fire in way of Tank No.6 which has previously been loaded with unleaded grade 98 mogas. The general alarm was sounded immediately.

0710, the master came on to the bridge. The engine was slowed down and brought to zero pitch, the second steering motor was started and the wide angle rudder engaged. The helm was set to manual steering.

Contact was established with the SOCOA signal station.

As soon as he had confirmed that there were no other vessels in the immediate vicinity, the master put on helm and increased the propeller pitch in order to maintain the flames and smoke at right angles to the ship and keep a clear view from the wheelhouse. The course was stabilized and speed established at three knots.

0711, the Chief engineer went down to the engine room. The engine spaces seemed to be intact. He activated the firefighting foam system.

0712, the foam system was operational.

0715, a 65 mm fire hose was installed on the poop deck but could not be used because the fire main had been severed by the explosion forward of the bridgehouse. So the Chief engineer decided to blank off the engine-room fire main so that the engine–room fire lines would be usable and available to protect the engine spaces.

0720, the crew was mustered at the stern. After several roll calls and head counts, it was confirmed that the pumpman was missing.

The boatswain was cut off from the rest of the ship and by himself on the forecastle.

0724, the third mate, who was in charge of communications, called the SOCOA signal station and asked for assistance from the *AQUITAINE EXPLORER.* The Chief mate reported that the hull was apparently intact.

0730, observing that the intensity of the fire had decreased, the master decided to stop the foam pump to keep some foam in reserve. At that time the fire was confined to the area around the port manifold drip dray, the crane on the main deck and the part of the catwalk that had been destroyed. The master then decided to follow a course which would take him closer to the coast while minimizing the effects of the fire and then another course to take him safely to Bayonne.

0739, contact was made with the CROSS (*Regional Centre for Surveillance and Rescue Operations)* and the fishing boats in the area to search for a possible man overboard.

0742, there was a call from PETROMARINE, the vessel was in position : 43° 53'.1 N – 001°37'.3 W.

0750, the CROSS called to report that the *AQUITAINE EXPLORER* was proceeding from Bayonne as well as a large tug from Bilbao.

0756, two lifeboats, SNS 79 from Bayonne and SNS 243 from Cap Breton, got under way.

0800, the fire was almost out. The fire pump was stopped to limit the consequences on the vessel's stability and structure. The vessel was on course 180°. Her speed was increased to 8 knots.

0808, the CROSSA authorized the vessel to proceed to Bayonne.

0825, the vessel was informed by the CROSSA that a helicopter was proceeding with a team of firemen to assess the situation and pick up the boatswain.

0832, the maritime service at Donges was informed of the situation.

0848, lifeboat SNS 79 arrived on scene.

0851, the intervention of the tug from Bilbao was cancelled.

0900, the position of the vessel was : 43°44'.5 N – 00 1°37'.7 W

0913, contact was made by VHF with the *AQUITAINE EXPLORER* to keep her informed of the situation and decide how she should intervene on the port side to cool down the manifold. The speed of the vessel was reduced to 3 knots to facilitate the operation.

0920, the *AQUITAINE EXPLORER* commenced her intervention.

0942, two inspectors from the Ship Safety Centre and the maritime gendarmerie arrived on board.

1026, a call was received from the Bayonne pilot sevices to decide on the approach to the port.

1030, the *AQUITAINE EXPLORER* completed her intervention and accompanied the vessel to Bayonne.

1037 , the vessel slowed down so that the Maritime Gendarmerie could pass a portable VHF set to the boatswain.

1054, arrival of the pilot launch with two pilots, a linesman and three representatives of the Affaires maritimes (French maritime administration).

1057, the helicopter arrived with the firemen who were to examine the area the crew could not reach.

1106, pilots on board.

1120, the pumpman's body was found.

1142, the préfecture granted permission for the vessel to berth at Bayonne.

1145, a manoeuvring team was winched down to the forecastle by helicopter.

1154, the production of electricity was transferred to a genset.

1216, the vessel passed the outer harbour jetties.

1234, the ship's towing line was taken by the tug ATTURI.

1244 , the vessel was turned.

1348, All fast.

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6* DETERMINING AND COMMENTING ON THE CAUSES OF THE ACCIDENT

The method used for determining the causes of the accident was that used by the *BEA*mer in all of its enquiries in compliance with Resolution A.849-20 of the IMO as amended.

The contributory factors were placed in the following categories :

- **natural causes;**
- **equipment failure;**
- **the human element.**

The *BEA*mer investigators listed the possible factors of each category and attempted to define their nature ; were they :

- **certain, probable or hypothetical,**
- **decisive or contributory,**
- **incidental or structural?**

Their goal, after careful examination of the factors, was to rule out those which had no bearing on the events and retain only those which, with some degree of probability, could be considered as having participated in the course of events.

They are aware that this means they may have left aside some of the questions raised by the accident

As their aim is to prevent this type of accident from happening again, they have favoured an impartial inductive analysis of those factors which, by their structural nature, could lead to the same thing happening again.

The *BEA*mer asked the INERIS (Institut National de l'Environnement Industriel et des Risques) to carry out the damage survey after the explosion.

The aim of the survey was :

- **to define, on the basis of the damage, the characteristics of the type and number of explosions which took place and to estimate by extrapolation from the breaking strain of the steel values for the parameters of an equivalent explosion which would cause the same damage as that observed;**
- **to identify the ignition source which caused the explosion as well as the position of the locus of the ignition according to the type and spread of the combustion ;**
- **to calculate the ignition energy necessary to generate this type of combustion.**

And from the results obtained :

- **to list the situations and locations in which explosive atmospheres may be formed during unloading and tank cleaning operations ;**
- **to assess how likely it is that these explosive atmospheres would ignite ;**
- **to analyse present safety instructions and operational procedures in order to determine whether they are sufficient to prevent an explosive atmosphere from forming and whether they offer sufficient protection for personnel in the event of an explosion ;**
- **to define what technical and organizational measures need to be taken to reduce the risk of explosion and ensure the safety of the vessel and her crew.**

6.1 * EXTERNAL FACTORS

The weather conditions as reported by MétéoFrance for the areas where the CHASSIRON was on 12th and 13th June 2003 were as follows :

12th June 2003 for the area « Port de Bayonne » between 0400 and 0700 UTC

General synopsis ***:***

The area was in the zone of relatively high pressure (around 1018/1019 hPa) situated between the anticyclone 1024 hPa lying west-south-west of the point of Brittany and the depression 1008 hPa near the western coast of Marroco.

High altitude cold Atlantic air moving in a south-westerly airstream brought instability, creating rain-bearing storm systems in the near-Atlantic, France and Spain which moved slowly eastwards. Ahead of these systems, in the warm air of the lower layers, convergence generated storms and scattered thundery showers.

Wind :

The mean wind was light, west force 2 to 3 Beaufort without significant gusting.

Temperatures ***:***

Air temperatures were fairly high around 18.5°C to 20°C.

The sea surface temperature was 18.5°C.

Humidity :

Humidity was high with values around 91% at 04 and 0500 UTC, followed by a slight decrease to 86% at 06 and 0700 UTC.

Significant weather summary :

Although some convective precipitation was observed on the Bordeaux Merignac radar, no other precipitation, thunderbolts or other electrical phenomena (lightning) were observed in the area during the period in question.

13th June 2003 between 04 and 0600 UTC in the area near 43°53.9’ north – 001°30.8’ west.

General synopsis :

There was little change and the area remained in the zone of relatively high pressure (around 1018/1019 hPa) situated between the anticyclone 1026 hPa (slight strengthening) centered over the southern Irish Sea and the depression 1012 hPa (slight filling) now centered in the region of Lisbon (Portugal).

Wind :

The mean wind remained light at force 2 Beaufort, without gusting, but backed east-south-east during the night of 12^{th}/13^{th}.

Temperatures :

Air temperatures in the area during the period in question remained relatively high around 17.5°C to 19.5°C. The sea surface temperature was 20°C and significantly higher than on the 12^{th} (1.5° difference in 24 hours).

Humidity :

Humidity was again rather high around 92 to 97% at 06 and 0700 UTC.

Significant weather summary :

Although some convective precipitation was observed on the Bordeaux Mérignac radar, no other precipitation, thunderbolts or other electrical phenomena (lightning) were observed in the area during the period in question. Nor was any intra-cloud lightning observed on the 13th between 04 and 0700 UTC.

Sea :

The sea was slight and the significant wave height (H1/3) was about 1.2 metres with the highest waves recorded not exceeding 2.3 metres.

Taking into account the low flash point of the unleaded grade 98 mogas (-40℃) and its temperature before unloading began (2 5.2℃), the outside temperature did not contribute to the formation of an air/unleaded grade 98 mogas explosive atmosphere during unloading operations.

It was not possible to obtain information about the electric charge of the atmosphere because measurements of electricity in the air are not made systematically. However, the high humidity of the air would not have favoured the build up of static electricity outside.

6.2* Damage observed

6.2.1 ON BOARD THE VESSEL*

The *BEA*mer investigators first went on board on 18th June and returned for a second visit on 1st July accompanied by a group of specialists from the INERIS.

The damage caused by the explosion was confined mainly to Tanks 5 and 6 with Tank 6 sustaining the most severe damage.

The longitudinal bulkheads separating Tank 4 port from Tank 4 starboard and Tank 5 port from Tank 5 starboard were torn from their fittings but remained in place.

The longitudinal bulkhead between Tank 6 port and Tank 6 starboard was buckled from starboard to port.

The bulkheads of Tank 6 port as well as the deck in way of the tanks were less damaged than the starboard side.

The starboard side

Tank 6 starboard was the most badly damaged.

The deck covering this tank and part of the deck of Tank 5 were completely blown away, including the part welded to the double hull which was itself buckled. It was thrown into the sea, no doubt by the blast of the explosion (it weighed something like 15 tonnes). The access trunk to Tank 6 no longer exists, the only thing left is the small inspection hatch cover.

The slop tank transverse bulkhead was buckled.

The cargo pump in Tank 6 was found in bits and pieces, one part in Tank 5 port (the lower part), the bearing housing in Tank 5 starboard (but the hydraulic motor and shaft were missing). The pump from Tank 5 starboard was found in Tank 5 port, broken into two pieces near the bottom of the access ladder.

The port side

The deck of Tank 6 port had lifted right off including the section above the double hull. It was not blown into the sea but folded outwards across the deck. The access trunk and inspection hatch cover are both in place. All the deck plating above Tank 5 bulged outwards and the outside stiffeners were buckled and broken. The deck was cut in way of Tank 4.

The transverse bulkhead between Tanks 4 and 5 was forced in towards the inside of Tank 4.

The transverse bulkhead between Tanks 5 and 6 had been violently projected into the after part of Tank 6 port. In view of the way it had buckled, this bulkhead had more than likely been projected twice : first towards the inside of Tank 5 port and then towards the after part of Tank 6 port.

The slop tank transverse bulkhead was buckled.

The cover of the opening giving access to Tank 5 had been blown away.

The cargo pump of Tank 5 was found at the bottom of the tank.

The drip pans under the manifold had burned.

The cargo pump of Tank 6 port had been bodily lifted up by the explosion.

The after tank washing machine was still in place.

The inner wall of the double hull on the tank side was pierced and the side shell plating distorted.

Amidships

The catwalk and all the pipes and cables had been lifted and bent.

The preceding facts confirm that Tanks 5 and 6 were the most affected by the explosion. The way the various elements of the inner structure of these tanks had buckled and deformed leads us to conclude that the explosion had very probably occurred in one of the two tanks making up Tank 6 while it was being washed.

6.2.2 EXAMINATION OF THE EQUIPEMENT IN SERVICE AT THE TIME OF THE ACCIDENT*

The equipment in Tank 6 port and starboard being used at the time of the accident was dismantled and sent to the CETIM (Centre Technique des Industries Mécaniques / *Technical Centre for the Engineering Industries*) in Nantes for examination and mechanical analysis.

The following pieces of equipment were examined :

- **the cargo pump from Tank 6 port,**
- **the cargo pump from Tank 6 starboard,**
- **the after washing machine from Tank 6 port,**
- **the after washing machine from Tank 5 starboard,**
- **the tank pressure venting (PV) valves.**

The *BEA*mer investigators went to the CETIM in Nantes on 4th December 2003 with representatives of the INERIS for an open meeting in the presence of the parties involved and representatives of the pump manufacturer. The aim of the meeting was to evaluate whether one of the moving parts of the pumps could have caused hot spots or sparks likely to have triggered off the explosion.

After these pieces of equipment had been dismantled and examined the following observations were made.

Pump 6 port

On the impeller side the pump flange was scored by several rows of small shallow marks (1 to 2 mm in width).

There were marks on the two lips near the discharge orifices on the pump volute. They had probably been made by foreign bodies and showed signs of slight erosion.

The inside surface of the volute showed a number of fairly faint circular scratches as well as several rows of fine circular marks. A number of small impacts were also noted which were rough to the touch (they might have been embedded fine foreign particles).

The splines on the pump impeller drive shaft seemed to bear traces of contact on both of their sides.

The lower part of the cofferdam check pipe (connected to the shaft seal) showed signs of grinding or intense friction against another part. Attention was drawn to the fact that the securing screws were not identical.

This pipe had been crushed in places against the body of the hydraulic motor and its fixing lug was broken. There were signs of friction between the pipe and the body of the hydraulic motor.

At the level of the part corresponding to the anti-rotation brake, the presence of oil was observed and the shaft turned freely in one direction only.

The shaft of the hydraulic motor rotated freely in both directions.

The housing of the hydraulic motor was deformed and severely dented near the central piping (upper part of the housing).

Shaft : some signs of seizure were observed on the shaft just below the ceramic sleeve. These marks were not circular and seemed to have been made by a tool, presumably by someone trying to turn the shaft against the anti-rotation brake when it had been dismantled on some previous occasion.

Impeller : Three of the 6 impeller blades were marked on their leading edges. A hexagonal bolt was found wedged in one of the passages between the blades. The bolt was of the same type and size as those securing the impeller to the hub. According to the CETIM none of these bolts was missing when the pump was dismantled. As a result, it is not difficult to imagine that the bolt was already inside the impeller when it was repaired in spring 2003. As the bolt was completely inside the passage between the blades, no contact was possible between the bolt and the volute while the impeller was rotating. There were, however, several dents in the tongue, probably from impacts during a previous incident

The imbalance due to the bolt in the impeller could have caused vibrations which might eventually have resulted in substantial damage to the pump.

The upper wear ring showed excessive wear, its outside diameter was reduced. Wear on the lower wear ring and the impeller was normal.

When the pump was dismantled all the securing bolts between the volute and diffuser flanges were seen to be correctly tightened and there was no play between the flanges.

The upper surface of the impeller hub showed signs of wear, but for contact to be possible in this area, the volute casing would have had to move axially relative to the impeller hub. When the examination took place, the volute had already been dismantled, but it was confirmed that the bolts holding the volute to the diffuser flange were present and tight.

When the pump was removed from the cargo tank on 3rd July 2003, photographs were taken which show that at least two of the bolts (reference 16) holding the volute against the pump head were missing. In this case, the volute casing could have moved axially and contact between the wear ring support and the upper side of the impeller hub was possible.

Thus contact between the impeller hub and the wear ring support could have occurred while the impeller was rotating. The rotation would continue until the inertia torque became nil and/or the supply of hydraulic fluid was cut off.

The possibility exists that the bolts had not been replaced or correctly tightened during a previous maintenance operation, or again that they had been blown off in the explosion. These bolts are essential for the correct positioning of the volute casing relative to the impeller.

During the visual inspection of the 4th December, it was not possible to conclude whether there had been direct metal to metal contact in this area while the pump was in service during tank washing on 13th June 2003. The contact could have occurred during unloading or tank washing on previous voyages.

It must be emphasized that, since the vessel's maiden voyage, the maintenance records for this pump show that it had been dismantled and/or inspected three times because of malfunction or breakdown :

- on 16th December 2001, the crew discovered that the "upper wear ring" (reference 20) was broken and that part of the "lower wear ring" (reference 61) had disappeared. All the tightening bolts of the "upper wear ring" (ref.19) were missing and only one of them was found. The securing bolts (ref.17) were also missing and the whole assembly had sagged.

- on 14th October 2002, following a drop in the discharge rate and loss of head, when the pump was dismantled three bolts (ref.16) were seen to be missing two of which were found in the impeller and the "wear rings" were unserviceable.

- on 29th December 2002, the pump malfunctioned during unloading operations at Bayonne, making a lot of noise and being ineffective for stripping operations.

- between 22nd and 28th May 2003 the pump was completely overhauled. Some wear was observed on the shaft where the ceramic sleeve bears. The shaft was re-assembled as it was. The mechanical seals and packing were replaced as were the roller bearings.

Pump 6 starboard

This pump was in fragments as it had been severely damaged by the explosion.

The parts still remaining were removed from the cargo tank and taken down by the CETIM.

The two discharge flanges were heavily deformed. On one side the discharge pipe had broken off flush with the flange (a brutal rupture probably due to shear stresses). On the other side the pipe was severed at a distance of 240 mm from the flange.

A positioning stud had sheared off one of the two flanges. On the edge of the same flange there was a well-defined mark similar to a hammer blow (probably caused by a shock).

There were no marks caused by friction or any scoring worthy of note in the pump (whether on the flange, impeller or volute).

No marks were observed on the leading edges of the blades nor on the two discharge lips in the pump body.

The centre bolt between the spindle and the impeller was broken (brutal rupture due to tensile stress) and the splines on the impeller hub were deformed in places.

The casing of the anti-rotation brake was badly distorted. Its securing bolts were broken.

Examination of the five bolts and the stud which were recovered showed that they were all cases of brutal rupture.

None of the parts examined : the volute, the impeller, the hub, the wear rings, the packing or the suction pipe showed any signs of abnormal wear or overheating.

None of the parts of pump 6 starboard which remained after the explosion gave any indication that the pump had failed.

After tank washing machine No.6 port

No traces of any shock or friction were observed.

The state of the other tank washing machines did not enable any meanigful conclusions to be drawn

Port and starboard pressure venting valves

The PV valves were all seen to be operating perfectly well.

Nota :

The purges of the pump cofferdams carried out immediately after unloading (002/06/03) contained no traces of cargo or hydraulic fluid.

While repairs were being carried out to the ship, the tank washing machine in service at the time of the accident was inspected. There was nothing to indicate that a foreign body had been present in the pump nor that there had been any mechanical failure.

6.3* Possible causes of the accident

Risk analysis shows that an explosion could not have occurred without the formation of an explosive atmosphere (ATEX) and the presence of an ignition source within the said atmosphere.

Indeed, for an explosion to take place, the following conditions must be fulfilled :

- **the presence of a flammable mixture of fuel and oxidizer;**
- **the concentration of the mixture must lie within the flammable range;**
- **confinement ;**
- **the presence of ignition energy : an electrically- or mechanically-produced spark providing the minimum ignition energy of the explosive atmosphere and/or the formation of a hot spot which heats the fuel mixture to its auto-ignition temperature. The minimum temperature depends on the pressure, nature and composition of the mixture (how rich or lean it is).**

For a given mixture, we can therefore consider that there is an auto-ignition temperature limit (for a given pressure) and an auto-ignition pressure limit (for a given temperature).

6.3.1 THE PRESENCE OF AN EXPLOSIVE ATMOSPHERE (ATEX)*

A mixture of hydrocarbon gas and air cannot ignite and burn unless its composition lies within the scale of gas/air concentrations known as the flammable range or explosive range.

The lower limit on this scale or Lower Explosive/Flammable Limit (LEL / LFL) is the concentration of hydrocarbon gas in air below which the mixture of air and vapour is too lean to maintain and propagate combustion.

The upper limit or Upper Explosive/Flammable Limit (UEL/UFL) is the concentration of hydrocarbon gas above which there is not sufficient air to maintain and propagate combustion.

The mixture must therefore be flammable and its concentration within the flammable range.

The danger of flammable products igniting also depends on their volatility or propensity to give off vapour by evaporation. This volatility is characterized by the product's vapour tension at different temperatures.

The flammability limits vary slightly for different pure hydrocarbon gases and for mixtures of gases combining different petroleum liquids.

Roughly speaking, the mixtures of crude oil gases, motor or aviation spirit gases and typical natural product gases could be represented respectively by the pure hydrocarbon gases such as propane, butane and pentane.

The following table gives the flammable ranges of these three gases. It also shows, for each of the three gases, how much dilution by air is necessary to reduce the concentration of a volume of the mixture by 50 % towards its LEL. This type of information is useful as an indication of how quickly the vapours will disperse in the atmosphere at non-flammable concentrations.

Gas	Explosive limits of hydrocarbons % by volume in air		Number of dilutions by air to reduce a volume of the mixture by 50% towards its LEL
	Upper	Lower	
Propane	9,5	2,2	23
Butane	8,5	1,9	26
Pentane	7,8	1,5	33

In practice, the lower and upper flammable limits of petroleum cargoes are generally taken to be 1% and 10% by volume respectively.

As cargo tanks 6 (P & S) had contained unleaded grade 98 mogas, they were full of vapour after unloading.

The normal operation of the pressure venting valves during unloading and the opening of the small inspection hatch for inspection of the tanks after unloading meant that air was able to enter the tanks. Not enough air entered the tank to bring the air/mogas mixture below the lower flammable limit, but sufficient for there to be a very flammable mixture in the tank when the tank was cleaned.

Moreover, as the mogas vapour is heavier than air, it tends to build up at the bottom of the tanks. This difference in density resulted in a gradient of unleaded grade 98 vapours with concentrations decreasing progressively from the bottom to the top of the tanks.

The following table summarizes the possibility of there being an air/unleaded grade 98 mogas ATEX and an air/gas oil ATEX after tanks 5 and 6 had been loaded and unloaded.

	Volume (V1) of the vapour space after tank loading (m3).	Presence of an ATEX in the vapour space after the tanks are loaded.	Presence of an ATEX in the vapour space after the tanks are unloaded.
Tank 6 port	16	No, because the concentration of mogas vapour in the vapour space was 44% well above the UEL (7.6%).	Unloading the tank results in dilution of the air in the tank. Volume V1 increases and as a result dilutes the mogas vapours (by a dilution factor of about 40%). The average mogas vapour content is around the LEL after unloading and it can be concluded that there was an ATEX during tank cleaning operations.
Tank 6 starboard	20	Idem above.	Idem above.
Tank 5 port	20	No, because the temperature of the gas oil (31.7℃) was lower than the flash point (>55℃). The vapour space contained gas oil vapour which could ignite if heat was applied.	No, but the tank was not degassed and the gas oil vapours could auto-ignite in the event of an external source of ignition being present.
Tank 5 starboard	24	Idem above.	Idem above.

We can therefore positively assert that there was an air/unleaded grade 98 mogas ATEX in tank 6 port and starboard and that its varying concentration (higher towards the bottom of the tank) fell within the flammable range.

6.3.2* PROVIDING IGNITION ENERGY

When fuel vapours and air are mixed in proportions corresponding to the flammable/explosive range, the provision of even a small amount of energy can trigger off the combustion process. For the simpler hydrocarbons like methane, ethane, propane and butane the minimum ignition energy is about 0.5 millijoules.

The energy can be provided by :

- thunderbolts,
- pyrophoric compounds,
- a flame,
- an increase in temperature,
- sparks.

By thunderbolts, pyrophoric compounds or an object falling

As the tank acted as a Faraday cage there was no risk of an electromagnetic field entering the tank.

In the present case, thunderbolts and pyrophoric compounds such as iron sulfide were not retained as possible ignition sources.

Similarly, the hypothesis :

- of an explosion caused by an outside object falling on to the deck (a missile from the Landes Test Centre) was ruled out as no missile was launched during the period in which the CHASSIRON was in the area;

- of a metal object being dropped into one of the tanks (a tool, for example) was considered but not retained as it was impossible to prove.

By a flame

No welding was being carried out and no naked flame was present during the tank cleaning operations. This source of ignition was therefore eliminated.

By an increase in temperature bringing the mixture to its auto-ignition temperature

In this case, the mixture ignites spontaneously, there is no flame or spark present.

The rise in temperature can be due to local, mechanically-generated hot spots caused by friction or the seizure of moving parts. The friction can be the result of :

- mechanical defects (imbalance of the pump or tank washing machine impellers, component wear, faulty fastenings etc.);

- or the presence of foreign bodies in the pumps (nuts, bolts) or tank washing machines.

At the time of the tank cleaning, the only moving parts in tanks No.6 were in the after tank washing machines and the cargo pumps.

Overheating of one of the tank washing machines does not seem possible bearing in mind the quantity of water used.

An increase in temperature due to friction between moving parts caused by a malfunction or failure of one of the two pumps in service is a hypothesis which can be retained. This hypothesis is all the more likely because of the whistling sound or screech heard by some crew members just before the explosion.

Be that as it may, the analysis of the parts concerned carried out by the CETIM, coupled with the fact that the tank washing machine and some components of the pump in Tank 6 starboard were missing, did not enable this hypothesis to be either confirmed or rejected.

By a mechanically-produced spark

Such a spark could have been produced by metal to metal shocks in way of the cargo pumps in use or by foreign bodies thrown out by the tank washing machines. But according to the statements taken, this hypothesis does not seem plausible.

By an electrically-produced spark

The absence of electrical equipment in use near the tanks at the time of the explosion means an electrically-produced spark cannot be retained as the ignition source. The voltages and current of the measuring instruments in the tanks were not high enough to cause this type of spark either.

By an electrostatically-produced spark

This type of spark could have been produced by an electrostatic discharge in one of the tanks during tank cleaning.

Could the presence of mogas vapours and a salty water mist have contributed to the build up of static electricity and the electrostatic discharge?

It has been shown that tank washing could lead to the build up of static electricity which can be abruptly released as an electric discharge having sufficient energy to ignite mixtures of air and hydrocarbon gases.

When water is sprayed static electricity is formed. The water spray is charged as it passes through the nozzle and is projected; this amplifies the charge separation process and thus electrifies the nozzle if it is not earthed.

The mist formed by spraying the water can itself produce an electrostatic field throughout the tanks characterized by the distribution of a potential in space. The inner surfaces of the tanks are earthed, the mist, on the other hand, will absorb positive charges until equilibrium is reached.

Electrostatic discharges occur when the intensity of the electric field near a charged object exceeds the breakdown field of the surrounding gas. According to the circumstances, they take on different forms depending as much on the shape of the equipment and the conductivity of the media separating the charged surfaces as on the conductivity of the surfaces themselves and the operational process.

The electrostatic charges of the droplets sprayed into the tanks depend, in turn, on the characteristics of the water used for washing, on the pressure of the spray jet and the volume of the tank.

The electrostatic potential of the water mist increases with the pressure at which the water is sprayed and the volume of the tank. Even if the water used for washing is a conductive liquid (seawater), when it is sprayed by the tank washing machines a charged water mist will be formed.

Generally speaking, the discharges which occur during tank washing are not sufficient to ignite a mixture of hydrocarbon gas and air. However, experiments have demonstrated that fixed tank cleaning machines with simple nozzles can produce water droplets which, according to their size, trajectory and life-span before bursting, are likely to produce electrostatic discharges with enough energy to ignite a mixture.

The surface coating of the tank inner surfaces may also play a part in the generation of electrostatic sparks depending on whether it is conductive or insulating.

As a matter of fact, if there is an insulating layer, this can lead to extremely high energy discharges (several joules); this type of situation is found when a thin insulating layer is pressed against a conductor (as is the case when a metal pipe is painted or covered with a layer of insulating material). A coat of paint can also act as a barrier against the release of the electrostatic charges of fluids (fuel, residues of washing etc.) towards the earthed metal surface of the tank.

The tanks of the *CHASSIRON* are coated with non-conductive phenolic epoxy paint. This type of paint has been used for several years on carriers of chemicals and petroleum products.

It cannot be ruled out that the accumulated charge at the surface of this coat of paint may have given rise to a brush discharge, capable of releasing sufficient energy (a few millijoules) to ignite an ATEX.

Tank cleaning on the *CHASSIRON* was carried out at low pressure (8 bar) and low flow rate (12 m^3/hr) producing low charge densities (about 20 nC/m^3). But at such rates, with a tank volume of around 600 m3 and taking into account what has been said above, it is possible that the water mist may have become charged.

An electrostatic spark (brush discharge with a maximum energy of 5 mJ) likely to ignite an air/unleaded grade 98 mogas ATEX could be produced if this water mist neutralized itself on equipment (notably tank surfaces, tank washing machines and cargo pumps) which was not connected to the same electric potential (lack of equipotentiality). The conductive equipment not connected to the same potential should be sought at a short distance from the tank washing machine.

The appearance of an electrostatic spark due the projection of a water mist thus seems possible in so far as the cargo pump, tank washing machine and tank surfaces(in the event that the protective coat of paint was locally deteriorated) could unfavourably modify the equipotentiality.

Thus, a source of ignition of this type cannot be ruled out, neither can the pump be ruled out as a source of ignition if it lacked equipotentiality and there was an air/unleaded grade 98 mogas ATEX in the pump body after it was started.

It seems highly unlikely that a spark could have been produced at a greater distance (at the tank surfaces or between the tank washing machines).

In conclusion, the BEAmer investigators and the specialists from the INERIS have retained three possible sources of ignition which could have caused the explosion :

- one source of mechanical origin connected to the mechanical malfunction of one of the cargo pumps or one of the tank washing machines;

- one source of electrostatic origin linked to the generation of electric charges by the spraying of water from the tank washing machine accompanied by the lack of equipotentiality of the tank washing machine in use;

- another source of electrostatic origin linked to the lack of equipotentiality of one of the pump components while it was running.

During the tank cleaning operation, the presence of a liquid residue of unleaded grade 98 mogas at the bottom of the tank (which would have had an insulating effect) did not affect the generation of the electrostatic charge nor the appearance of an ignition source of electrostatic origin, because the liquid was not in movement.

6.4* How the explosion developed

The observations made by the BEAmer investigators, the analysis of the explosion made by the INERIS specialists, as well as the statements taken from the crew, led them to the conclusion that the most likely scenario for the explosion was as follows :

- **phase 1 :** The presence in Tank 6 port and starboard, during tank cleaning operations, of an air/unleaded grade 98 mogas ATEX the fuel concentration of which was variable (higher towards the bottom of the tank) but within the flammable range.

- **phase 2 :** An initial explosion of the air/unleaded grade 98 mogas ATEX, which, taking into account the extremely serious damage observed, must have occurred in Tank 6 starboard, the ignition source being of mechanical or electrostatic origin. The explosion blasted the deck plating over Tank 6 starboard into the sea, breached the transverse bulkhead between Tank 6 starboard and Tank 5 starboard and the longitudinal bulkhead between Tank 6 starboard and Tank 6 port. The explosion propagated into Tank 6 port; Tank 5 starboard apparently did not explode, but judging by the damage incurred, suffered blast damage from the explosion in Tank 6 starboard

- **phase 3 :** A second explosion of the air/unleaded grade 98 mogas ATEX in Tank 6 port caused by the heat of the first explosion. The explosion then propagated into Tank 5 port. The plating over Tank 6 port was torn from the deck (it was not thrown into the sea but remained hanging over the port side of the vessel against the sideshell plating). The transverse bulkhead between Tank 6 port and Tank 5 port was breached.

- **phase 4 :** A third explosion caused by auto-ignition of the gas oil vapours in Tank 5 port. The blast of the explosion projected the bulkhead separating Tank 5 port from Tank 6 port into the after part of Tank 6 port.

Most of the transverse bulkhead between Tank 5 starboard and Tank 6 starboard was pushed into Tank 5 starboard by the force of the explosion but part of it remained in place.

Tanks 5 and 6 bore the brunt of the explosion, although Tank 4 port was slightly perforated (due to the breaking up of Tank 5 port) and Tank 4 starboard was slightly buckled (because of the damage to Tank 5 starboard).

After studying the damage, notably the way in which the bulkheads separating the tanks buckled, it is possible to assert that the explosion in Tank 6 starboard was more powerful than that in Tank 6 port, which was, in turn, more powerful than the one in Tank 5 port.

All three explosions followed the deflagration regime (where combustion of the mixture propagates through a subsonic wave)

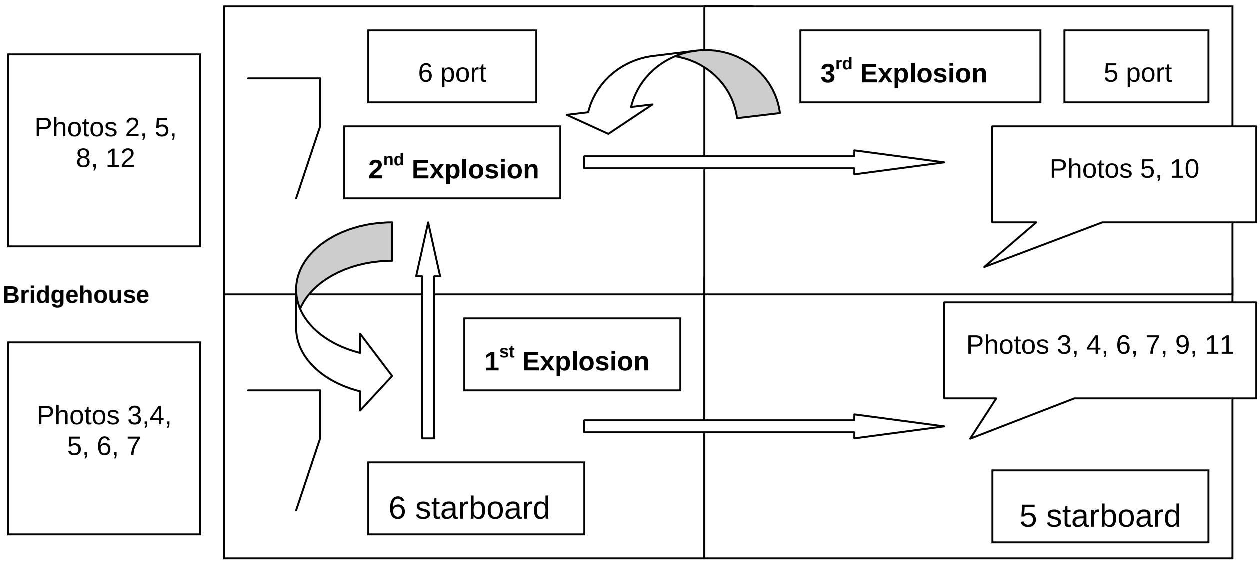
Tank 5 starboard is not thought to have exploded but to have been damaged by the blast of the explosion in Tank 6 starboard.

In a closed space, the propagation of a deflagration releases high temperature, high pressure gases. Taking into account the mechanical strength of the structures, the pressure necessary to break the deck plating over Tank 6 starboard, as calculated by digital simulation (EFFEX modelisation software) is about 1.5 to 2 bar

The following table gives the approximate overpressure values in Tanks 5 and 6.

Tank	**Overpressure (bar)**
Tank 6 starboard	1.5 – 2
Tank 6 port	1 à 1.5
Tank 5 starboard	# 1
Tank 5 port	# 0.5

The following diagram shows the sequence of the series of explosions and the associated causal trees.



Simplified description of the explosion scenario and references of the photographs showing damage (source INERIS).

7* CONCLUSIONS

Up to now it has not been possible to determine unequivocally the origin of the ignition source which caused the explosion. Nevertheless, two possibilities have been retained :

- a source of mechanical origin due to the malfunction of the cargo pump,

- a source of electrostatic origin which could have been produced by a lack of equipotentiality of the cargo pump or tank washing machine, or (but this is less likely) by deterioration of the coating of the tank surfaces (spots of rust were observed at the bottom of the tank).

The air/unleaded grade 98 mogas ATEX in Tank 6 starboard only needed a few microjoules energy to ignite.

Four sequences were considered :

- **a deflagration detonation transition;**
- **a "bang box" phenomenon (high-pitched whistling sound) followed by a generalized explosion;**
- **the rapid propagation of a deflagration from one tank to another;**
- **an explosion in one tank resulting in combustion phenomena (multiple explosions) in other tanks.**

According to the analysis of the accident, the damage sustained was the result of the domino effect of a series of successive explosions (three in all) in a deflagration regime.

The observations made by the BEAmer investigators and the INERIS specialists favour the hypothesis that the first explosion took place somewhere near the bottom of Tank 6 starboard (in all likelihood near the cargo pump), followed by a second explosion in Tank 6 port caused by the propagation of the heat of the first explosion and a third and final explosion due to the ignition of the gas oil vapour in Tank 5 port.

The noise heard just before the explosion, which was described as a whistling sound, could have been the noise made by turbulent combustion in a small confined space and, as such, would have been the "initial" event characteristic of the explosion. It could also have been due to a rise in pressure inside in the tank, the noise being made by gases escaping through the small inspection hatch just before the explosion, or again, it could have been due to friction between moving parts.

Among the factors which may have helped to trigger the explosion :

- **the operation of the pressure venting valves during unloading, opening the small inspection hatches for tank inspection and tank cleaning, the technique of injecting compressed air to strip the submerged pumps all led to the ingress of air which provided the oxidizer making it possible for an explosive mixture to form;**
- **the unleaded grade 98 mogas carried was of the "summer", less volatile variety; its vapour pressure was therefore lower than that of the "winter" product. This reduction of the vapour pressure brought it closer to the flammable range;**
- **tank washing operations set up turbulence zones within the tanks.**

Bearing in mind the low flash point of the unleaded grade 98 mogas and its temperature (25.2℃) before unloading commenced, it can be affirmed that the weather conditions had no influence on the formation of an air/unleaded grade 98 mogas ATEX during unloading.

Tank cleaning was carried in the usual way. The pumpman was very experienced as regards tank cleaning but human error cannot be excluded. Dropping a tool, for example.

As regards firefighting, the destruction of the fire line on deck and the absence of sectioning valves on the engine-room fire main meant that the firefighting system was not immediately available (it was necessary to wait for the damaged section to sectioned off by means of a plug). Further sectioning valves should be installed so that the fire main in the engine room remains available for use in the event that other sections of the system become unserviceable.

Finally, as a preventive measure, the use of electrostatically non-insulating paints or coatings for tank surfaces should be preferred

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8* RECOMMENDATIONS

These are aimed, for the most, part at revising certain operational practices and adapting technical regulations to take account of developments in the construction of tanker ships and their operation.

8.1* Reduce the risk of an explosive atmosphere forming in the tanks

The risk is high for volatile petroleum products with a flash point below 60℃.

It is therefore advisable to prevent air from entering the tanks during discharging and tank washing. It would seem difficult, however, in practice, to keep the vapour concentrations in the tank atmospheres permanently above the upper explosive limit.

Thus, opening the small tank inspection hatches for visual inspection after discharging as well as during tank washing operations are practices which need to be reappraised. Loading, discharging and washing operations should be carried out in closed operation mode (*closed loading, closed discharging, closed washing*), the only air entering the tanks being due to the normal operation of the pressure venting valves.

Furthermore, modern petroleum product tankers not only have accurate instruments for remote ullage measurements but are also equipped with small capacity pump suction wells (submerged pumps) which enable practically total stripping. As a result, there is no longer any need to open the inspection hatches for visual inspection after discharging. Further development of the technique which consists in stripping the pump suction wells by plunging a small vacuum tube into the suction wells should enable stripping to become even more efficient.

Whatever stripping technique is adopted, the use of compressed air must be prohibited.

The ISGOTT recommendations regarding operational procedures for tank inspection and cleaning should therefore be followed to the letter. They should be included in the vessel's operational instructions. Safety managements (ISM) audits should verify whether they are in fact actually applied during everyday operations.

8.2* Reduce the possibility of ignition sources appearing

8-2-1 AT THE OPERATIONAL LEVEL*

There is a risk of sparks being produced by discharge of static electricity or of an increase in temperature (creation of hot spots) due to friction between moving parts during tank washing operations.

Tank cleaning operations should be kept to a strict minimum insofar as, on modern ships, the quantity of residual cargo in the tanks after discharging and stripping is very small (a few tens of litres at the most).

Arrangements could be sought between owners and charterers, within the framework of charter-parties, to limit the numbers of tank washings according to the type of product carried or to merely rinse out the tanks.

Explosivity measurements should be taken before any operation is undertaken in the tanks.

Whatever measures are adopted, any operation to be carried out in the tanks should comply with ISGOTT recommendations and be preceded by measurements of the concentrations of oxygen and flammable products.

If the vessel is equipped for loading and discharging in the closed operation mode and has fixed tank washing machines, the ISGOTT now recommends that the washing of tanks with atmospheres that may lie within the flammable range, should be effected in closed operation mode so that, on the one hand, the quantity of air entering the tanks is reduced, and on the other hand, the risk of an object falling into the tank is eliminated.

8-2-2* AT THE EQUIPEMENT LEVEL

a) Installations should be permanently monitored to ensure that their electrical continuity and equipotentiality is maintained. Sounding pipes should go right down to the bottom of the tanks, particularly where ships not equipped with inert gas systems are concerned.

Inspection and checks of mechanical installations should be reinforced and particular care should be taken with tightening and locking the assembly and fixing nuts on submerged pumps and their drive units, as well as any other equipment in the tanks

b) At the European level, it seems advisable to consider widening the scope of Directive 94/9/EC of the European parliament and the Council of 23rd March 1994 "on the approximation of the laws of the Member States concerning equipment and protective systems intended for use in potentially explosive atmospheres" which, as it stands, does not apply to sea-going vessels and mobile offshore units as regards cargo pumps and tank washing machines :

- where tank inerting does not exist : equipment corresponding to equipment Group II category 1 G

- where tank inerting exists : equipment corresponding to equipment Group II category 3 G

8.3* Inerting of tanks loaded with volatile petroleum products with a flash point below 60°C

International regulations (SOLAS Chapter II-2, Regulation 5.5) impose inert gas systems only on tankers of 20 000 tonnes deadweight and upwards.

Tankers of less than 20 000 tonnes deadweight, including chemical tankers, should be required to be fitted with inert gas systems for the protection of cargo tanks, in light of recent accidents and improvements in ship technology and operational procedures. Consequently, Regulation 5.5 of Chapter II-2 of the SOLAS Convention (FSS Code) should be amended to take account of this.