



INSTITUT NATIONAL DE L'ENVIRONNEMENT INDUSTRIEL ET DES RISQUES

Explosion of a grain silo BLAYE (France)

Summary Report

Ministry for National and Regional Development
and the Environment

F. MASSON

july 1998

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INTRODUCTION

On Wednesday August 20th 1997, an accident occurred at the grain storage facilities of the Société d'Exploitation Maritime Blayaise (SEMABLA) at Blaye (in the Gironde department). The accident mainly affected a vertical grain storage silo. The collapse of a major part of this facility, notably on the administrative and technical buildings, caused 12 victims (11 deaths and 1 injury).

As part of the administrative inquiry that is held concerning any accident of this type, INERIS (National Institute for Environmental protection and Industrial Risks Management) was requested by the Ministry for National and Regional Development and the Environment to conduct an expert appraisal in support of the DRIRE Aquitaine (Regional Directorate for Industry, Research and the Environment for the region of Aquitaine).

For reference purposes, the INERIS report on this expert appraisal, entitled « Explosion d'un silo de céréales – Blaye (33) », is dated april 1998.

The present document is a summary of the analysis of that accident. It is subdivided as follows:

- Principal characteristics of the SEMABLA facilities
- Damage and observations
- Conceivable scenarios and search for causes
- Lessons learned from the analysis of the accident

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1. PRINCIPAL CHARACTERISTICS OF THE SEMABLA FACILITIES

1.1. THE SEMABLA SITE AND ITS SURROUNDINGS

The SEMABLA installations are located in the port area of the commune of Blaye, on the right bank of the Gironde estuary, about 50 kilometres to the north-west of Bordeaux. They constituted one of the biggest grain storage complexes in the Gironde department. The total storage capacity was about 130,000 tonnes of grain, with 90,000 tonnes stored on the ground in warehouses and 40,000 tonnes in vertical cells.

In the same port area, the Société Chimique Routière et d'Entreprise Générale (SCREG) has storage tanks notably containing caustic soda, aromatic oils and molasses. In terms of distance from the vertical silo, the boundary of the SCREG property, marked by a low wall, was 25 m from the storage units, the nearest tank about 40 m and the administrative buildings some 210 m away.

The closest dwellings were about 230 m from the silo.

1.2. DESCRIPTION OF THE SEMABLA INSTALLATIONS

The principal business of the SEMABLA company is the handling and storage of grain intended for export by sea (using two jetties), grain being brought in almost exclusively by truck. For this purpose the SEMABLA had one vertical silo and a number of storage warehouses (metal-framed buildings).

The vertical silo was of compact design consisting of 3 rows of reinforced concrete cells of circular cross-section, totalling 44 in number. The total storage capacity of this assembly was 47,240 cubic metres that is to say about 37,200 tonnes of wheat.

There were two vertical concrete towers, culminating about 53 m above ground level, at each end of the silo. The northern tower was the top of the handling tower of the silo. The southern tower was situated at the top of the cells at the southern end of the silo, and mainly housed a grading system and a set of two cleaner-separators. These two towers were connected by a gallery running above the cells, with concrete walls the over-cell gallery). At the bottom of the silo, all the cell barrels under their conical bottom formed the under-cell space.

A metal-framed tower containing maize dryers was located to the south of the vertical silo, a few metres from the nearest cells.

Grain could also be stored in a number of different metal-framed warehouses across the SEMABLA site. One of these warehouses (denoted FGH) was linked to the vertical silo. The link had been mechanised notably with the introduction of two belt conveyors (identified as TB5 and TB6) operating in both directions.

A shelter built at the foot of the vertical cells of the silo on the Gironde side housed the bagging operations which were a speciality of this site (including shipments for humanitarian projects).

The administrative and technical buildings, which notably housed the control room, were located to the north, mainly in line with the storage cells and the northern handling tower.

The layout of the different buildings and installations mentioned above (vertical silo, warehouses, etc) is shown on figure 2.

SEMABLA had a workforce of 21 people at the Blaye site to operate the facilities.

Figure 1 shows the vertical silo before the accident.



Figure 1 : View of the vertical silo before the accident

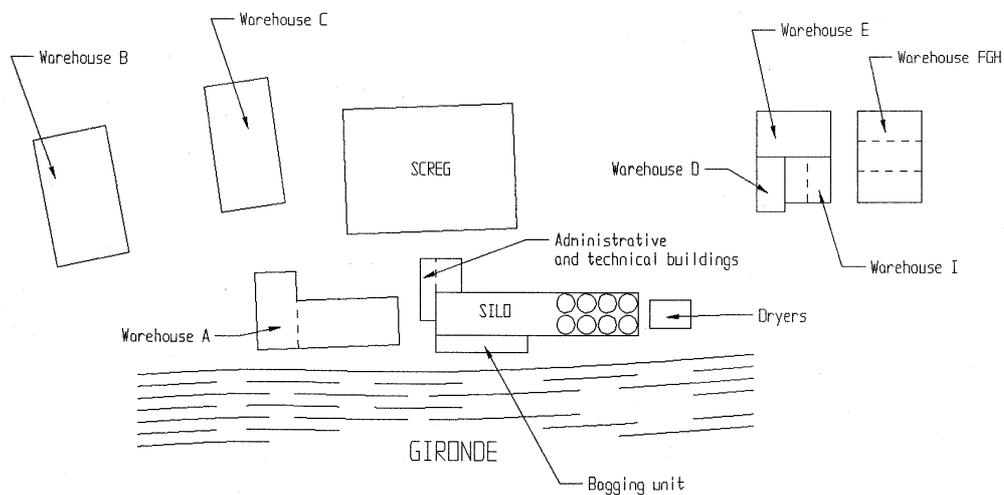


Figure 2 : Diagram showing the layout of buildings and installations (not to scale)

1.3. DESCRIPTION OF THE VERTICAL SILO

This silo consisted of two groups of vertical storage units, built one after the other with an interval of four years in the 1970s. The two groups formed a compact volume about 100 m long, 20 m wide and 40 m high.

Each group of storage units consisted of contiguous vertical concrete cells of circular cross-section in three rows. They had an inside diameter of 6.20 m with a total average storage height of the order of 33 m. The two rows of spaces between the cell walls formed storage units. These interspace chambers offered a total storage height of about 32 m on the average, the biggest inside diameter being about 4.20 m.

The first group of storage units consisted of 20 cells and 12 interspace chambers. This offered a total storage volume of 20,904 m³. The second group had 24 cells and 14 interspace chambers giving a total storage volume of 26,336 m³.

The two interspace chambers at the junction of the two groups of storage units were not used for grain storage ; they opened at the bottom into the under-cell space but were closed at the top by the floor of the over-cell gallery.

The diagram in figure 3 gives a sectional view of the entire vertical silo and shows in particular how SEMABLA identified the cells and interspace chambers.

The cells in the second groups of storage units differed from those in the first group in that they could be ventilated by injecting some air into the bottoms of the cells, they were fitted with an air extractor at the top (except for three cells at the southern end of the silo) and also had a pneumatically operated emptying valve in addition to the one controlled manually.

Grain was received through two adjoining pits. An underground gallery containing chain conveyors linked these reception pits to the underground elevators pit in the northern handling tower.

The northern handling tower was in line with the vertical cells and its structure was partly supported by them. This tower notably housed the vertical grain handling facilities (bucket elevators) and some elements of the central dust removal circuit (fan, filter system and dust chamber). It may be noted that the equipment openings made in the different floors of the tower allowed these floors to communicate with one another and that the tower communicated directly with the over-cell gallery at the top, and with the under-cell space underneath.

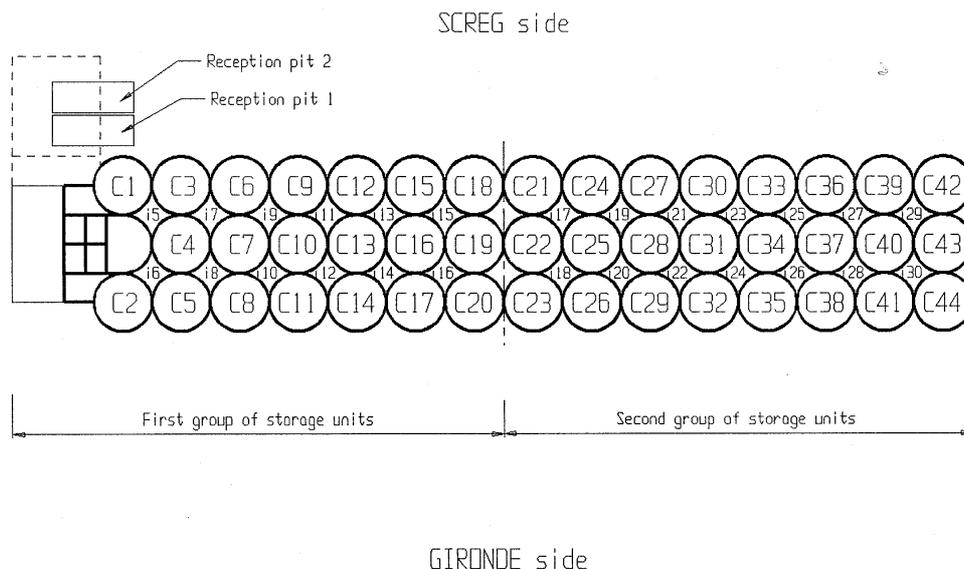


Figure 3 : SEMABLA identification of storage units

The southern tower housed a set of two cleaner-separators and a grading system, used respectively for « green » maize and barley.

The gallery running across the top of the cells connected the southern tower to the northern handling tower. It mainly housed horizontal grain handling facilities, i.e., 4 conveyor belts including 3 belts conveying grain into the silo and one handling belt linking the vertical silo to the FGH warehouse.

The under-cell space (not underground), consisted of all the cell barrels below their conical bottom. This space mainly contained the conical bottom of the cells, horizontal grain handling facilities (reclaim chain conveyors) and the component parts of the air blowing system at the cells bottom of the second group of storage units.

The diagram in figure 4 shows the layout of the main systems dedicated to grain handling. Thus the following are shown :

- the reclaim chain conveyors located in the under-cell space (identified TR1 to TR10),
- three of the four bucket elevators situated in the handling tower (identified E1 to E3),
- the bucket elevators located outside the silo, at the southern end, notably connecting the vertical silo to the drying facilities and the FGH warehouse (identified E5, E6, E7 and E9),
- the conveyor belts forming part of the mechanised link to the FGH warehouse (identified TB5 and TB6).

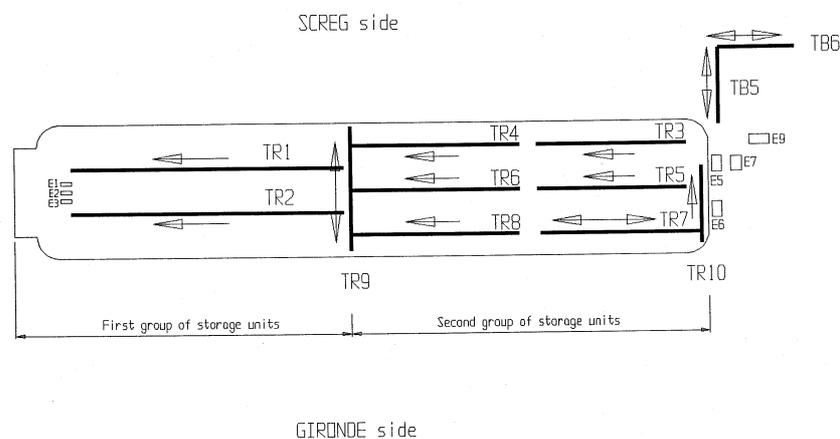


Figure 4 : Diagram showing the layout of the main grain handling systems

Inside the silo, dust was removed in a number of different ways and particularly through a centralised system. This system sucked out air from several points in the grain circuit by means of a fan at the top of the northern handling tower. Filtration involved an open bag filter, the dust being recovered in a dust chamber. The fan was located upstream of the bag filter.

An automatic scanning system monitored the temperature in all the cells. This system did not include the interspace chambers.

In general, the silo was not fitted with protection devices such as fire detectors or explosion vents. Similarly, there was no system to detect and collect foreign bodies, at product reception, or any magnetic system for trapping metal items in the grain circuit regardless of origin.

De façon générale, le silo n'était pas équipé de moyens de protection tels que des détecteurs d'incendie ou des événements d'explosion. De la même façon, il n'y avait pas de dispositif de

2. DAMAGE AND OBSERVATIONS

2.1. HUMAN COST

As a result of the accident, 11 persons were killed and one injured.

The persons killed included seven SEMABLA employees, three persons whose activity was connected with those of SEMABLA and a fisherman.

The bodies of ten victims were found in the administrative and technical buildings at the foot of the silo, or in the immediate vicinity. The persons in the administrative and technical buildings were found at their workplace, apparently not having had the time to react to the incident. This demonstrates the sudden nature of the accident and the probable lack of any precursor event or identifiable worsening situation. The bodies found outside the administrative and technical buildings at the time of the accident, with the exception of the fisherman, showed traces of slight burns.

The eleventh victim, the fisherman, was found several days after the other victims, buried under the debris, on the bank of the Gironde.

2.2. MATERIAL DAMAGE

2.2.1. Damage to the SEMABLA installations

Generally speaking, the vertical silo collapsed in the centre and at the northern end. Of the 44 cells, only 16 appeared to be still largely in place after the incident, 9 of them in the southern part of the silo and 7 in the northern part (these figures refer to the number of cells that retained their cylindrical geometry over at least two-thirds of their original height). Accordingly one feature of this accident is that two groups of cells collapsed : a first set of cells to the north and linked to the handling tower ; a second set of cells from the central part of the silo.

The northern handling tower and the cells immediately adjacent were practically completely destroyed. All that remains, from half of its original height, is part of the curved half-shell of the structure of this tower, the sides of which – forming the walls of the adjacent interspace chambers (I5 and I6) – were pressed back on the barrel of cell C4. This situation suggests an explosion inside the handling tower, apparently taking place after possible explosions inside the neighbouring storage units.

The over-cell gallery was completely destroyed.

The southern tower seems to have fallen on top of the cells. Parts of the cleaner-separators (rubber balls from the screens) found with burned surfaces show that a flame or expanding burned gases passed through this tower.

In the northern part of the silo, the under-cell space (consisting mainly of the barrels of the central cells) shows few traces suggesting the passage of a flame or expanding burned gases. On the other hand, under the compact block of 9 cells still in position in the southern part of the silo, numerous traces of combustion were found (melted plastic components, deposits of calcined dust, etc), especially underneath the central cells (C34, C37 and C42). Also in this part of the installation, the air ducts at the bottom of the cells were mostly found smashed, with elements thrown in the north-south direction. This demonstrated that dust accumulated in the circuit.

No trace of combustion was found inside the elevators pit, the grain reception pits or the underground connecting gallery between these pits.

Regarding the grain handling facilities, the elevator drive drums located in the handling tower showed no traces of slipping ; the shafts of these elevators did not appear to be jammed in their bearings ; pieces of metallic sleeves found were neither swollen nor shattered, and the lengths of bucket belt recovered showed no traces of combustion. The reclaim conveyors located in the under-cell space, particularly conveyors TR4, TR6, TR8 and TR9, were damaged by the collapse of the storage units. A number of covers of the compartments containing the reclaim conveyors were blown off. In the northern part of the silo (first group of storage units), conveyor TR2 showed signs of rubbing at the top (driving portion) and a number of fins were missing from the conveyor chain.

In general, parts of the installation, notably components of the centralised dust removal circuit,



Figure 5 : View of the vertical silo after the explosion

some of which were of large size, were never found despite the search carried out at the locality known as “Naviplane” (where debris removed in the first few hours after the accident were dumped) and the operations of dragging the Gironde.

Also, certain facilities in the vicinity of the silo (warehouses and drying installations) were damaged to varying extents, mainly by the fall or projection of parts of the silo.

2.2.2. Damage to other parties

As far as damage to other parties is concerned, SCREG suffered the most damage. Various projectiles struck different storage tanks and the transfer pipes between the tanks and the public jetty were broken.

Regarding damage outside the port area, generally speaking, it may be noted that there was damage to dwellings up to a distance of about 500 m from the silo, especially broken windows.

2.2.3. Other damage

The fires noted in the storage units just after the accident were located around the units that were still partly in place. No amount of incandescent, hot or burned grain, that might have indicated the presence of self-heating before the accident, was found in the debris.

Immediately after the accident, a smouldering fire was detected (emission of smoke) in a cracked cell in the south-east part of the silo (cell C42). Inspection with a thermal camera showed the presence of a hot zone at a depth of a few metres from the top of the cell, which was full of barley. Subsequently, smouldering fires were also detected in two other cells.

2.3. PROJECTILES

In general, projectiles (metal, concrete and glass) of significant size were found up to about 100 metres from the silo, that is to say twice the height of the handling tower.

During the investigation, pieces of concrete about a metre in size were found up to about 50 m from the silo, and small lumps of debris (weighing less than a kilogram) were projected up to about 140 m from the cells.

2.4. OBSERVATIONS CONCERNING THE ACTIVITIES AT THE TIME OF THE ACCIDENT

During the removal of debris, a tipper truck and trailer was found on the reception pits. It appeared to have been unloading maize. The presence of this grain at the bottom of a conveyor connecting to the elevators pit suggests that the truck had begun to empty its load into reception pit No. 1 (the pit closest to the administrative and technical buildings).

Also the previous truck had unloaded wheat into reception pit No. 2 and had just left the SEMABLA site. The presence of a mixture of barley and wheat in a conveyor connecting to the elevators pit suggests that this was empty at the time of the accident and that the operation of receiving wheat had been completed.

Inspection of the reclaim conveyors in the under-cell space, involving making regularly spaced holes in the bottom of the compartments when these were full of grain, shows that possibly only the chain conveyors TR1 and TR2 were operating, with barley. As regards TR1, the operation in progress was probably an emptying of cell C15 for transferring barley to the FGH warehouse, and as regards TR2, it was probably an internal transfer for the same purpose.

In addition, inspection of conveyor belts TB5 and TB6 by SEMABLA personnel appears to indicate that barley had been taken from the vertical silo to the FGH warehouse.

The status of the contents of the silo was reconstituted on the basis of various observations. It seems therefore that the silo was practically full and that most of the empty storage units were the interspace chambers.

3. CONCEIVABLE SCENARIOS AND SEARCH FOR CAUSES

3.1. OPERATING SITUATION OF THE SILO

It appears from the examinations and analysis carried out that elevator E2 was being used with maize, although the destination storage unit is unknown. It could equally well have been in the first or second group of storage units. Because maize was being handled, this first storage unit was open to the over-cell gallery. Since this was the first truck to be unloaded (with this type of quality), it could legitimately be regarded as practically empty. Also, it is likely that the storage unit used was an interspace chamber.

Elevator E3 was being used at the time of the accident to empty C11. This emptying operation would appear justified only for transferring barley from the silo to the FGH warehouse. In these circumstances it would be plausible and logical to pass through the cell C1 which would also therefore be open to the over-cell gallery.

Elevator E1 served for transferring grain from the vertical silo to the FGH warehouse. It seems plausible that it was being supplied by emptying C15 and directly from C1.

Finally, it seems legitimate to conclude that the operation of emptying wheat had only just been completed. In such a case it seems possible that the hatch giving access to the storage unit being loaded would still be open to the over-cell gallery. It is not possible to specify the identity of the destination cell. However it would be two-thirds empty.

In other words it may be concluded that two - and possibly three - cells allowed communication between the top of the storage units and the over-cell gallery, including in particular cell C1 (barley). The other two storage units would be practically empty or two-thirds empty of maize and wheat respectively.

3.2. THE EXPLOSION SEQUENCE

From the statements by witnesses it is possible to determine the space where the explosion initially began as the upper part of the northern handling tower. It propagated through the over-cell gallery as far as its southern end, probably owing to the fact that settled dust had been stirred up.

The explosion flames, probably in the form of a jet, were able to enter some storage units that were open. These were probably 2 in number, possibly 3.

The entry of the jet of flames into these storage units, which were extremely dusty owing to the loading operations, generated a violent explosion. The geometry of these storage units and, in particular, their elongated shape, would certainly have contributed to the development of the pressure effects. This applies particularly to the interspace chamber in which maize could be stored. It is recalled that since the height/hydraulic diameter ratio was close to 10, it is possible that this fact, together with the reactivity of the maize, largely explains the damage that occurred in the central part of the silo.

In addition, destruction of the over-cell gallery, and its floor in particular, enabled communication between that gallery and the under-cell space through the interspace chambers located at the junction of the two groups of storage units.

It seems that propagation of the explosion via this route was possible, since this space had never been specifically cleaned. It is therefore likely that dust was deposited on the walls of this space.

In the northern handling tower, the explosion expanded downwards. In this case too, the pressure could not be limited since there were no vent surfaces. As a result, the northern handling tower was destroyed. The propagation vector is neither the elevator ducts, nor those of the centralised dust removal circuit. It appears reasonable to conclude that propagation took place through the structure of the handling tower itself. This partial conclusion assumes the presence of a flammable cloud in that space. The presence of deposits can reasonably be excluded since regular cleaning was carried out. Accordingly, only an accidental mechanism resulting in the spreading of dust would be capable of placing this dust in suspension throughout the handling tower. The only conceivable process capable of spreading a significant quantity of dust from the top to the bottom of the handling tower would be a failure downstream of the fan

sucking out the dust. This spreading mechanism is significant, particularly if the dust chamber is assumed to have failed.

The explosion entered the space underneath the cells either from the bottom of the handling tower or, and this is more likely in our view, through the interspace chambers situated at the boundary between the two groups of storage units. According to this second assumption, propagation of the explosion through the interspace chambers would be such as to allow the flame to accelerate significantly, owing to the geometrical configuration, resulting in substantial pressure effects. In these circumstances the pressure waves emerging from the bottom of the interspace chambers would easily be of sufficient intensity to destroy the adjoining storage units and, to a large extent, the concrete shell separating the under-cell space from the outside. These openings in the under-cell space shortly before the arrival of the flame acted as vent areas, thus limiting the overpressure reached inside the under-cell space.

The destruction of the concrete shells of the under-cell space could therefore be the result of the pressure waves generated by the downward propagation of the explosion or the actual collapse of the structures. This sequence is coherent with the fact that the destruction of the concrete shells of the under-cell space took place rather late in the explosion process, as reported by witnesses.

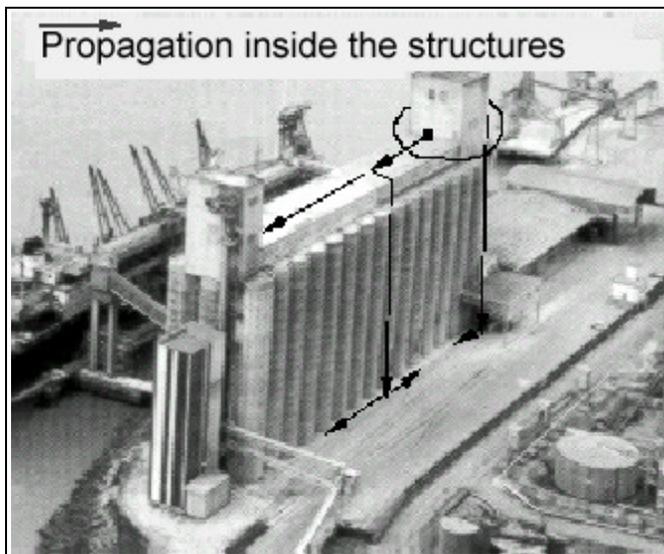


Figure 6 : Assumed progress of the explosion

It is possible that the collapse of the structures was facilitated by structural weaknesses. The collapse itself and falling items of equipment inevitably caused short circuits, particularly in the transformer room in the administrative and technical buildings. These short circuits may have been the cause of the localised fires that followed the explosion.

Similarly, propagation of the flame and the expanding burned gases may in particular have caused the ignition of combustible materials and thermal effects on plastic materials.

The fires in the cells noted after the explosion were located particularly on the top surface of the stored grain. They may have been caused by the fall of combustible materials ignited by the passing flame.

3.3. THE SEARCH FOR CAUSES OF THE ACCIDENT

The two key points in determining the conditions governing this accident were the search for the conditions in which an explosive atmosphere could form, and the identification of the ignition source.

As regards the formation of an explosive atmosphere, two possibilities were considered. The first concerns the formation of combustible gases in the top of the storage units, arising from a degraded situation such as, for example, self-heating, fermentation, or an incipient fire. The second possibility involves a flammable mixture of dust and air. In the light of the facts and the witness statements, it seems reasonable to exclude the former possibility. The second

possibility concerns the explosion of a dust-air mixture that may have existed in parts of the installation. This type of explosion has frequently been encountered in other accidents. On the basis of the witness statements and the observations made, it is possible to conclude that the explosion began either in the centralised dust removal circuit, or actually inside the silo structure, since a source in the product circuit can reasonably be excluded. Consideration of the possible ignition sources, given hereafter, has led to the choice of plausible ignition sources inside the dust removal circuit. Accordingly, only the former of the above alternatives will be considered.

The search for the ignition source was more difficult since the consideration of hot spots was excluded relatively quickly. The following types of ignition source remained conceivable : sparks or mechanical heating effects, static electricity, electrical sparks, or the self-ignition of a deposit of dust. For example, owing in particular to the relatively high minimum ignition energy required, sparks of electrostatic origin were not considered as an ignition source for the explosion,

Following analysis of the various possibilities, and bearing in mind that no component parts of the centralised dust removal circuit were found, it appears plausible that the ignition causing the explosion arose either from mechanical impacts or friction in the fan of the centralised dust removal circuit, or from an incipient fire caused by self-heating in the dust chamber.

4. LESSONS LEARNED FROM THE ANALYSIS OF THE ACCIDENT

The review of the sequence of this accident, and the uncertainties involved, suggest that the principal lessons for a silo with a structure similar to that at Blaye affect a number of fields that we may arrange in the same order as an explosion process. They are listed below by topic.

- Preventing an explosive atmosphere from forming:
 - monitor the temperature in the interspace chambers,
 - use video surveillance systems, possibly linked to detectors,
 - determine the operating limits of the dust removal suction system, especially in centralised systems,
 - continuously monitor the suction efficiency of a centralised dust removal system, for example by vacuum measurements,
 - ensure that filter bags are enclosed, or install some equivalent system to prevent any risk of spreading dust in installations that are largely enclosed. The most appropriate step would be to install these systems outside any such largely enclosed installation, in other words in the open air,
 - as far as possible, isolate the different parts of the silo from one another (the term “parts of the silo” refers for example to the handling tower, the over-cell gallery or the under-cell space).
- Eliminating ignition sources:
 - on all the main systems, install spark detectors or equivalent devices with a capability of shutting down the installation,

- install a system to detect any unusual increase in the temperature of certain systems (for example, the bearings of the fan in the centralised dust removal system),
- Propagation of the explosion:
 - separate the various structures so as to limit propagation of an explosion (with the concomitant result of limiting its effects),
 - install the centralised dust removal systems, as far as possible, outside any enclosed installation ; in other words, in the open air.
- Limiting the effects:
 - introduce dust explosion vents on the structures containing grain handling systems, and on the storage units,
 - determine the procedures and limitations on the design of explosion vents for elongated structures in the event of ignition by a jet of flame,
 - avoid or limit the use of storage units whose length/diameter ratio is high (i.e., over 5), particularly the interspace chambers.
- Limiting the consequences:
 - investigate, on a case-by-case basis, the distance to buildings occupied by other parties¹, with a value of 1.5 times the height of the silo being seen as a minimum distance,
 - keep away from the silo all persons whose activities do not contribute to the direct operation of it.
- Other lessons:
 - install fire detectors in areas where there is a risk of fire due to combustible materials other than grain,
 - regularly clean the pipes of the air blast circuit at the bottom of the storage units,
 - adapt the storage temperature alarm threshold to the external climatic conditions, subject to technical justification taking into account notably the kinetics of the phenomenon of self-heating.

Note: In the framework of the hazard study, each silo should be the subject of a risk analysis.

¹ Other (third) party: extract from the Ministry of Environment (DPPR/SEI) circular dated October 16th 1997 (not published in the Official Journal): “For the purposes of the government, excluding the spouse, the children of the operator and his employees for whom he provides housing, any person not connected with the factory is regarded as an other (third) party with respect to the installation”.