Explosion in the AZF fertilizer plant

September 21st, 2001

Toulouse

France

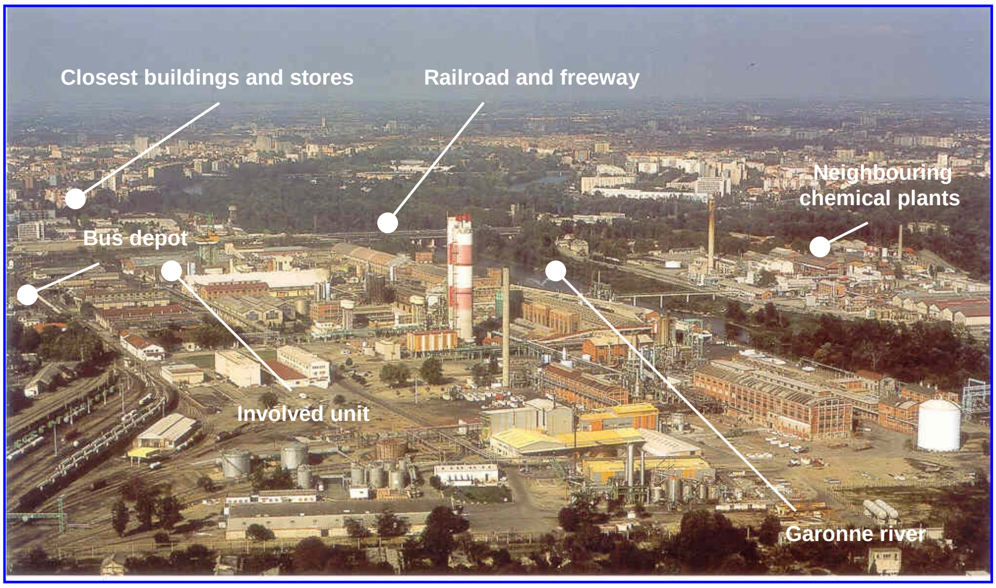
Chemical plant
Industrial disaster
Ammonium nitrate
Detonation
Casualties
Physical and psychological traumas
Material damages
Risk assessment / Danger studies
Urban planning

Between 20 and 120 tons of ammonium nitrate residue (equivalent to 20 to 40 tons of TNT) detonated on September 21, 2001 in the **AZ**ote **F**ertilisant (AZF) fertilizer plant in Toulouse, causing devastating effects at the site and far beyond.

THE FACILITIES INVOLVED

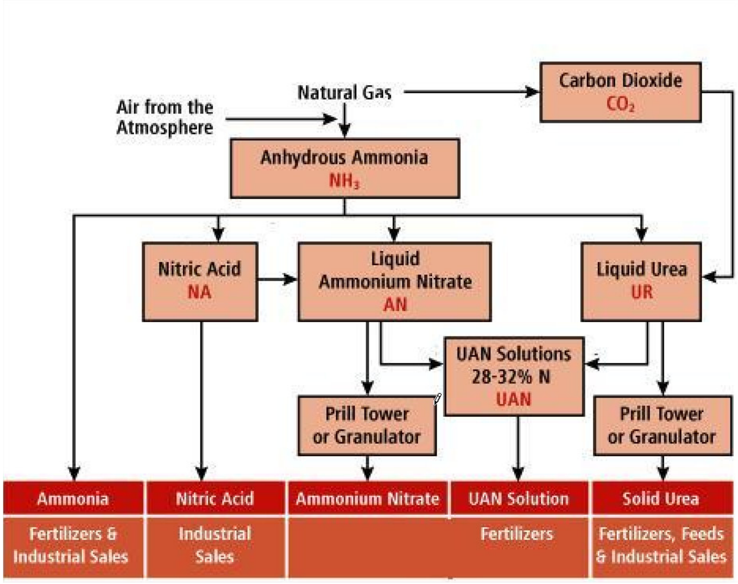
The site:

The plant is located in an industrial zone to the south of Toulouse, at a distance of approximately 3 km from town centre. Created in 1924 as ONIA, it belongs to the GRANDE PAROISSE group since 1991. The company, with majority shares held by ATOFINA, a branch of the TOTAL FINA ELF chemical group, is the leading French producer of fertilizers and ranked 3rd in Europe.



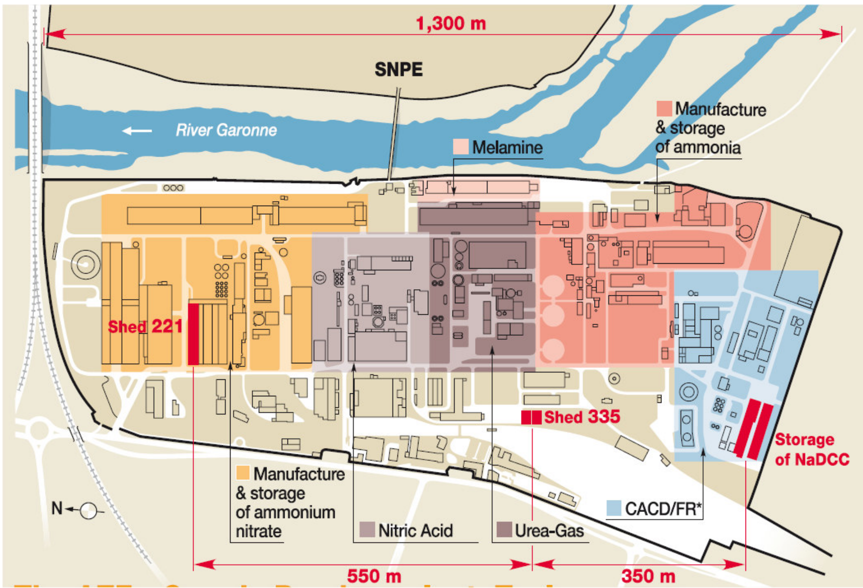
View of the plant before the accident (source : Grande Paroisse)

The Toulouse plant employs 469 people and has an annual turnover in the order of 100 million Euros. The plant has two main activities: the fabrication of nitrogen fertilizer and industrial nitrates, and the synthesis of chlorine-containing compounds. The plant synthesises ammonia that it transforms into ammonium nitrate, a part of which is then used to manufacture fertilizer, the rest being marketed directly in the form of industrial nitrates. The establishment also manufactures melamine (a raw material used in the manufactures of resins), as well as adhesives and chlorinated products used for water treatment applications.



Nitrogenous fertilizers manufacturing process (Source: PotashCorp, all rights reserved)

The site includes several large dangerous material storage facilities: two cryogenic ammonia tanks (5,000 and 1,000 tons), a 315-ton pressurised ammonia storage tank, two 56-ton liquid chlorine tankers, 1,500 tons of oxidants, 15,000 tons of solid ammonium nitrate in bulk form, 15,000 tons in sacks and 1,200 tons of ammonium nitrate in hot liquor solution, as well as 2,500 tons of methanol.



AZF plant map (Source: Grande Paroisse)

The site is governed by the SEVESO 2 directive owing to the presence of ammonia, chlorine, toxic or combustive substances, ammonium nitrate, and nitrate-based fertilizers… Within the scope of French legislation regarding classified facilities, the site is subject to authorisation (AS) and must abide by the requirements of the authorisation order dated October 18, 2000 that governs it. In addition, the exact quantities of dangerous substances were regularly declared prior to February 2001 and a safety management system was in place in compliance with the 2001 deadline stipulated by the Ministerial Order of May 10, 2000.

The plant maintains an internal contingency plan and has formed part of an external special intervention plan since 1989, including the 3 plants in Toulouse's southern chemical zone (AZF, SNPE and TOLOCHIMIE). Finally, a system aimed at controlling urbanisation was implemented in 1989. A Prefectoral order based on a general interest project required communes to observe certain restrictions relative to new constructions or extensions near production facilities.

The AZF plant is operated under authorisation required under the terms of legislation governing classified facilities. Finally, several danger studies have been conducted since 1982. Updated every 5 years, some of them were conducted in 2000 and the most recent was conducted in 2001. In these studies, dozens of accidental scenarios were analysed, although the detonation of ammonium nitrate was disregarded based on the available feedback; the contingency plan did thus not foresee a scenario of this type.

The site is inspected periodically (approximately twice / year). The last inspection, conducted May 17, 2001 by the classified facilities inspectorate (DRIRE), focused on several elements of the safety management system.

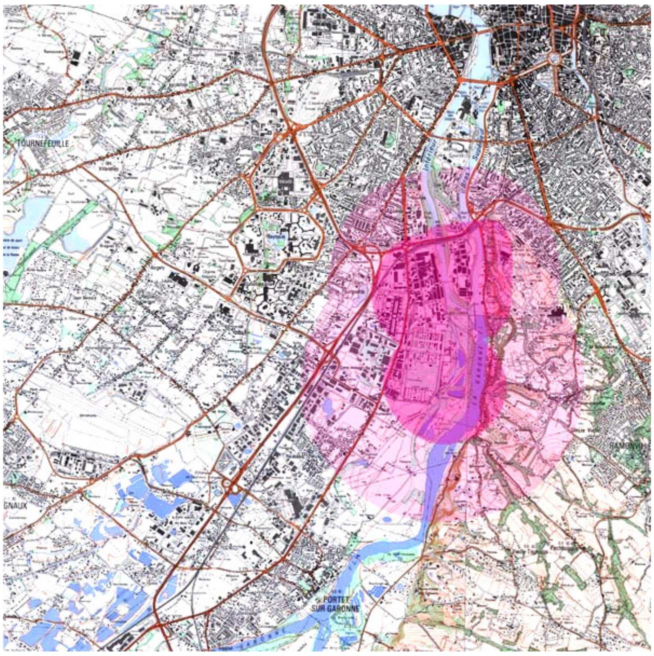
The specific unit involved:

Shed 221 belongs to a group of buildings located in the northern part of the plant, an area dedicated to the manufacturing and storage of ammonium nitrate. The logistic service, 4 employees and 3 subcontractors, is in charge of these sheds. The sheds, built between 1920 and 1938, were used to store bulk fertilizers and package ammonium nitrate until 1981. Since 1981, shed 221 stores agricultural or industrial nitrate considered "below grade" owing to their grain size and off-spec chemical composition. The others neighbouring sheds are still used for packaging. From the various workshops, this rejected material is brought to an inlet area by three subcontractors. It is then pushed by transport equipment into the building to be bulk stored. This scrap material is removed periodically and oriented to the SOFERTI plants (ATO Group) in Toulouse and Bordeaux to be recycled to be used the manufacture of complex fertilizers [1].

View of the storage sheds n°221-225

THE ACCIDENT, ITS CHRONOLOGY, EFFECTS AND CONSEQUENCES

The accident:



Map of the overpressure areas caused by the detonation (50 mbar in light pink and 140 mbar in dark pink)

At 10.17 am, a severe explosion (detonation) occurred in shed 221. The detonation, felt several kilometres away, corresponded to a magnitude of 3.4 on the Richter scale. Significant dust fallout from the installations and a crater were observed outside the plant.

A large cloud of dust from the detonation and red smoke drifted to the north-west. The appearance of the smoke is linked to the emergency shutdown of the nitric acid manufacturing installation. Before rapidly dissipating, the cloud containing ammonia and nitrogen oxides sickened witnesses who complained of eye and throat irritations. The atmospheric pollutants released after the detonation lead to the formation of nitric acid (HNO_3), ammonia (NH_3), nitrogen dioxide (NO_2) and nitrous oxide (N_2O) from ammonium nitrate. As a precautionary measure, the local governmental authority (“*Préfecture”*) requested that the population of Toulouse confine themselves to their homes. This measure, the efficiency of which was limited owing to the damage to numerous homes, nevertheless reduced the number of traffic problems after the accident.

From a strictly technical point of view, and according to the measures and observations made by the experts [1], it should be noted that the detonation gave rise to an overpressure in the order of 140 mbar (threshold retained to characterise the lethal effects in the danger studies) at a distance between 280 and 350 m and 50 mbar (threshold retained to characterise the irreversible effects on human health in the danger studies) at a distance between 680 and 860 m. This observation can be constructively compared to the fact that there were victims resulting from indirect effects up to 500 m away on the one hand, and injuries caused by broken glass at distances of a few kilometres away, on the other hand.

Evacuation of an injured employee

Human and social consequences:

At the time of the explosion, 266 plant employees and 100 agents from sub-contracting companies were present at the site.

The accident resulted in many casualties: 21 at the AZF site, 1 at SNPE and 9 people outside the site (2 of which were in hospital) who were killed by the explosion or deceased in the days that followed, more than 30 people were seriously injured of which 21 remained hospitalised for more than one month (300 more than 6 days). A student at the *Gallieni* professional college, located 500 m from the epicentre, was killed and several other injured when a concrete structure collapsed. Two people also died in a vehicle maintenance establishment located 380 m away and one person died in the EDF (Electricity company) building located 450 m from the epicentre.

Thousands of people were hospitalised; the local authority (*Préfecture de Haute-Garonne*) counted a total of 2,442 people as of October 17, 2001; 8042 peoples are submitted to a legal medical investigation.

The INVS (health national institute) and the *Midi-Pyrénées* DRASS (local health authority) published a progress report in July 2002 and a final report in September 2006 on the sanitary consequences of the explosion [2]. The information gathered during this epidemiological study allowed the short term impact of the catastrophe to be assessed by clearly identifying the sanitary effects of the environmental exposures and by describing the physical and psychological traumas.

First aid at the entrance of the plant
(source : Encyclopédie Larousse, all rights reserved)

Numerous physical traumas are registered: wounds, fractures, amputations, contusions… Auditory troubles resulting from the double effect of the blast and to the acoustic trauma due to the explosion were extensive: partial or total deafness, pierced eardrums, hypoacousia, tinnitus, otalgia…

Among the nearly 6,000 students located in a radius of 2 km around the site who underwent testing 8 to 10 weeks after the explosion, 5.5% of the secondary school children and 6.3% of the primary school/kindergarten children suffer from hearing deficiencies (> 25 dB). Health professionals were recommended to conduct hearing deficiency examinations on the individuals who were within a radius of 1.7 km at the time of the explosion.

The NO_2, the NH_3 and the particles released by the explosion were responsible for transitory ocular (conjunctivitis, vision disabilities…) and respiratory irritations (tracheobronchitis…) in the population living near the site. These problems appeared to decrease within 5 weeks after the accident. However, the collected data allow to establish the absence of significant health effects potentially associated with these substances in the short and long term.

According to the heath services and considering toxicological and epidemiological knowledge on the exposure-hazard relationship, it appears that there are no disquieting consequences concerning the health risk associated with the release of asbestos (cancers, fibrosis). However, labour protection regulations must be carefully applied for individuals working on site cleanup operations. The water monitoring system allows any alteration in raw water quality and the water distributed in the hours following the catastrophe to be detected. The occasional overshoot of quality limit values for NH_4^+, NO_3^- and NO_2^- do not represent a health risk for consumers. The risks associated with soil contamination (soil thrown from the crater), both direct and indirect (food) have been disregarded.

Psychological traumas are also registered: more than 8,000 people consulted their general practitioner for acute post-traumatic stress in the weeks following the explosion. Five thousand people began a psychotropic treatment (anxiolytic, antidepressant, hypnotic). According to the experts, these numbers are underestimated as they only take into account the individuals who sought medical care. The explosion had a major impact on psychological problems (depression, anxiety…). In addition, two studies conducted jointly with the French National Educational Service show that one year after the accident, one out of seven students still displays clear signs of post-traumatic stress.

Continued monitoring of the medium and long-term health effects will be conducted via various elements of the epidemiological system: a cross-section study (a descriptive epidemiological study at time t) concerning approximately 50,000 salaried employees of the greater Toulouse community and 5,000 rescue personnel, on the one hand, and monitoring of a cohort of 5,000 salaried employees derived from this study (biological examinations), on the other hand. Finally, long-term analysis is planned to identify the causes of death (changes in the mortality rate) of the employees who agreed to give their addresses during the initial study.

The information systems of the heath care structures which supplied the data are independent from one another and the existing databases cannot be interconnected when they exist. A person may be recorded in several of these systems without it being possible to detect the error and may be counted more than once. Also, the results do not allow precise quantitative estimates to be made regarding the overall number of different troubles observed.

In addition to the physical and psychological traumas suffered by the population of Toulouse, there are significant social disturbances notably linked to the destruction and damage to homes, community equipment, buildings, technical unemployment, and to the loss of work… Associations and a collective have been organised to combat industrial hazards and to defend the interests of the populations concerned.

Environnemental consequences:

The explosion destroyed storage tanks containing ammonium nitrate solutions and caused nitric acid leaks. However, no leakage on a damaged hot ammonium nitrate solution (95%) tank was observed. On the day of the explosion, the fire and rescue services noted the release of nitric acid into the *Garonne* River. These releases of nitrogen-containing solutions from the AZF site polluted the river.

Of the 120 parameters measured on the raw water, only an increase in NH_4, NO_3 and COT was observed. The highest values were measured in the *Garonne* oxbow. The passage of the pollution was identified between September 22 and 27, 2001 with maximum concentrations from the 22nd to the 24th: for the NH_4, 331 mg/l in the oxbow and 16 mg/l in the *Garonne*; for the NO_3, 1,277 mg/l in the oxbow and 63 mg/l in the *Garonne*; for the COT, 23 mg/l in the oxbow and 8.7 mg/l in the *Garonne*.

A few days later, on October 17 and 18, the release of ammonia into the *Garonne* exceeded the values authorised by prefectoral order. As the ammonia network was no longer pressurised after the explosion, the release of gas into the atmosphere caused the residents discomfort. A water-borne ammonia collection device with the release of ammonia-containing effluent into the *Garonne* was set up. An incorrect estimation of this release of ammoniated water resulted in the authorised values being exceeded; approximately 9 tons of ammoniated solution thus significantly polluted the *Garonne* which killed off the aquatic fauna (dozens of kg of fish killed). The mortality noted is essentially associated with the ammonia contents associated with a high pH (up to 8.6), thus promoting a shift in the chemical balance towards a non-ionised form of ammonia (free NH_3), which is very toxic to fish.

Atmospheric measurements conducted by the ORAMIP (local air quality laboratory) allow the chemical pollutants released into the atmosphere to be determined. For the most part, the gaseous releases contained NH_3, NO_2, N_2O, and dust… For the NO_2, the estimated exposures on the neighbourhoods nearest the site and within the trajectory of the cloud, are short of the guideline values for one hour recommended by the WHO (200 µg/m³).

Economic consequences:

A large part of the AZF plant's 70 ha is devastated and debris of all kind littered the site:

Crater resulting from the detonation (ground zero)

- ✓ The detonation of the depot dug an oval crater measuring 65 x 45 meters and 7 m deep, causing considerable destruction in the northern part of the plant,
- ✓ Brick and concrete buildings of roughly one hundred meters in length were partly collapsed,
- ✓ For certain buildings of lighter construction, only the completely deformed metal framework remains,
- ✓ Certain storage tanks containing ammonium nitrate solution were destroyed causing the *Garonne* to be polluted,
- ✓ Nitric acid leaks were observed,
- ✓ A hot solution of ammonium nitrate at 95% was damaged but no leak was observed,
- ✓ 2 of the site's stacks collapsed,
- ✓ Several structures were leaning after the explosion...

The explosion also caused significant damage in the chemical companies located on the chemical platform outside the AZF plant, on the other side of the *Garonne* and which are also governed by the SEVESO 2 directive: SNPE and ISOCHEM, a subsidiary of SNPE. Two establishments located on the grounds of the SNPE plant were subjected to very heavy damage (RAISIO and AIR LIQUIDE). The TOLOCHIMIE plant (part of the SNPE group), also governed by the SEVESO 2 directive and located to the south of the AZF plant was only slightly damaged. The activities of these establishments were suspended by a local governmental authority injunction to secure the sites. More than 1,100 employees were concerned.

Impact made by flying debris on a water pipe

The consequences of the accident could have been much worse owing to a "domino effect" namely due to the many chemical storage tanks located nearby: chlorine, ammonia and fertilizer at AZF, phosgene units and piping belonging to SNPE and TOLOCHIMIE… Quite thankfully, no notable "domino" effect occurred, except for leaks on nitric acid tanks which were rapidly brought under control.

The experts offer various explanations as to why the "domino" effect did not occur:

Superficial damages suffered by a NH_3 tank

- For AZF, the pressurised ammonia storage tanks located 300 m from the explosion were relatively protected by a building which suffered extensive damage but which acted as a screen. The liquid ammonia storage tank located more than 600 m suffered no direct damage. The building sheltering the chlorine storage tank more than 500 m was damaged, although the railcars located inside were not touched. Finally, the railcars containing chlorine and ammonia located to the south of the site and at more than 400 m, were protected by buildings whose structure resisted the shock.
- The explosion did not spread to the other ammonium nitrate storage tanks located within the zone, although the integrity of other locations designated for the storage of dangerous substances was seriously damaged however (namely the collapse of a building housing ammonium nitrate) thus creating a situation at risk requiring additional operations to secure the site.

- For SNPE and TOLOCHIMIE, owing to the precautions applied to the powders and explosives based on 3 principles: fractioning, partitioning and the overabundance of safety features.
- For the ISOCHEM plant which is relatively near ground zero of the explosion, owing to the distance which lowers the secondary effects of an accident, as well as the small quantity of products stored or undergoing preparation, which allows them to be held in protected areas.

Warehouse destroyed by the blast

Six months after the catastrophe, the *Préfecture* published a report of the establishments that were directly affected by the explosion. Nearly 1,300 companies, representing approximately 20,000 employees, claimed losses to various degrees. The French government released 10.4 million Euros in help to companies and proposed 1.7 million Euros in tax exemption.

	Significant impact		**Limited impact**	
	Nbr of establishments	**Nbr of employees**	**Nbr of establishments**	**Nbr of employees**
Industry	58 (including 30 small/medium sized industries and 28 groups)	5,408	54 (including 25 small/medium sized industries and 29 groups)	6,358
Service	33	511	285	4,368
Retail	81	767	461	2,775
Total	**172**	**6,686**	**800**	**13,501**

Source : « Toulouse, six mois après la catastrophe « (Six months after the catastrophe) – *Governmental brochure*

Residents in towns 75 km away (*Castres*) and 45 km away (*Montauban*) claim to have heard the explosion.

Significant property damage was also observed around the industrial zone in an extensive oval-shaped perimeter oriented toward the south of the city: a nearby urban boulevard, several public buildings which can no longer be used, windows broken up to 7 km away according to several sources.

The shock wave and various projectiles damaged 82 schools, 19 middle schools and 15 high schools (36,000 students), as well as 4 establishments of higher education and 3 university dormitories. In front of the factory, a depot containing roughly one hundred busses was destroyed (30,5 M€) and numerous other store were damaged. A household appliance store located 320 m from the explosion's epicentre, as well as a vehicle maintenance facility at 380 m, collapsed also claiming victims.

Bus depot destroyed

Many other constructions were also damaged, some of which had to be evacuated given the extent of the damage or the risk of collapse (psychiatric hospital, schools, homes…). A total of 25,550 homes were damaged to various degrees, 11,180 of which were seriously damaged. More than one thousand homes were completely destroyed and more than 1,200 had to be relocated immediately. Certain people were housed in private homes under a specially implemented temporary housing program. Relocation efforts were set up in both the council housing and private sector to find shelter for numerous individuals. Hundreds of homeless families were relocated to mobile homes. The last emergency housing centre was closed October 30, 2001. The French government released 24 million Euros for support measures dealing with housing and the construction of new public equipment began in the months that followed.

Finally, telecommunication was disturbed in a 100 km radius and the cellular telephone networks were completely saturated for several hours after the explosion.

According to information provided by insurance companies, the damage is estimated between 1,5 and 2,3 billion Euros. Dozens of accident victims whose homes had their windows shattered and still not replaced were forced to endure the winter weather conditions several months after the accident.

The European scale of industrial accidents:

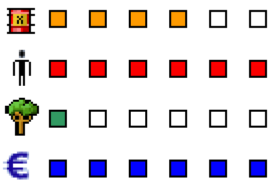
By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States' Competent Authority Committee for implementing the '*SEVESO*' directive on handling hazardous substances, and in light of information available, this accident can be characterised by the four following indices:

Dangerous materials released

Human and social consequences

Environmental consequences

Economic consequences



The parameters composing these indices and their corresponding rating protocol are available from the following Website: http://www.aria.developpement-durable.gouv.fr.

✓ The "hazardous substances released" index was scored a level "4" as the detonation involved more than 5 t of explosive substance and less than 50 t (in TNT equivalent).

✓ The "human and social consequences" index was scored a level "6" given the number of people killed (31, 10 of them outside the plant), wounded, having lost their homes or job after the accident.

✓ The "environmental consequences" index was scored a level "1" due to the pollution of the *Garonne* river by nitrogenous compounds.

✓ The "economic consequences" index was scored a level "6" due to the extensive property damage and production losses for the plant operator, neighbouring plants, retails and individuals, cost of clean-up and rehabilitation measures of the area (total cost estimated above 2 billions euros).

THE ORIGIN, CAUSES AND CIRCUMSTANCES SURROUNDING THE ACCIDENT

On the eve of the explosion, 15 to 20 tons of ammonium nitrates with an additive in qualification phase was brought into shed 221. On the morning of the explosion, products derived from the packaging of the ammonium nitrates and the manufacturing shops were also transferred into the shed. The last addition of material by bin coming from another storage zone was made less than 30 min before the explosion

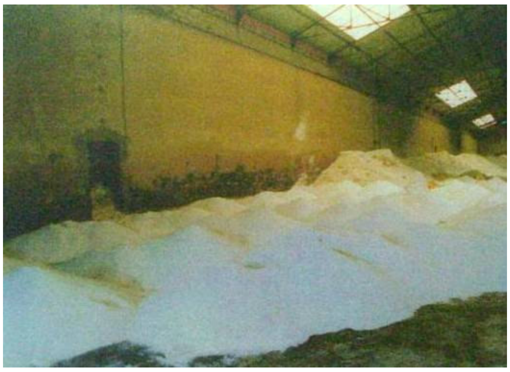
Several inquiries and expert evaluations were conducted:

✓ judicial inquiry,

✓ administrative inquiry conducted by the French Ministry of the Environment with the participation of industrial hazard experts [3],

✓ ATOFINA internal inquiry,

✓ inquiry by the CHSCT (the plant committee for hygiene, safety and working conditions).



Bulk storage of ammonium nitrate

Many hypotheses were formulated to explain the explosion:

✓ Unintentional external causes associated with accidental technological or natural phenomena (methane due to underground bacterial activity, lightning, meteorite, falling aircraft parts, explosion of a bomb or nitrocellulose underground following previous site activity); all of these hypotheses proved to be unfounded.

✓ Intentional external causes (attack, malicious mischief, missile) conjured up and spread by public opinion in the same context as the "Twin Towers" terrorist attack in New York, on September 11, 2001. From a legal standpoint, this hypothesis is not supported by any tangible facts.

✓ A process incident (an internal electrical fault at the plant, electric arc, missile effect from a part projected at high speed…). An examination of manufacturing parameters at the time of accident would not however explain this type of incident. Concerning the possible high speed projection of a piece of metal causing a primary explosion in a filter at the top of a tower near the site of the explosion, experts feel that the kinetic energy developed by the projection of debris from the filter would be insufficient to cause the nitrate contained in shed 221 to explode.

✓ As far as an accidental chemical reaction is concerned, the nitrates used were polluted by iron oxides, sulphur and in contact with bitumen used to pave the floor of shed 221 or following the mixture of incompatible chemical substances, such as ammonium nitrate with sodium dichlorocyanurate (NaDCC, a product used in treating swimming pools); the incompatibility of these substances was highlighted during court-ordered laboratory tests.

Favoured differently by the entities concerned, none of these hypotheses have lead to a consensus.

In may 2006, the final report presented by the expert investigators to the plaintiffs supports the theory of a chemical accident, attributing the causes of the disaster to an unfortunate combination of a few dozen kilos of sodium dichlorocyanurate with 500 kg of ammonium nitrate spilled on the main nitrate pile 20 minutes before the detonation.

It is worth noticing that, since the very beginning of the industrial manufacturing of nitrogenous fertilisers early in the 20th century, ammonium nitrate have been involved in several major industrial accidents while being stored or dispatched [4]. On July 26, 1921 in *Kriewald* (formerly German Silesia), the "dislodging" of wagons filled with ammonium nitrate using explosives caused a detonation killing 19. Less than 2 months later, on September 21st, in Germany's *Oppau* plant, blasting work on a pile of aggregated fertiliser mix containing ammonium nitrate and ammonium sulphate produced a detonation responsible for 561 deaths, 1,952 injured and the near total destruction of the town. Twenty years after that, in Belgium, explosives were still being used to disaggregate a pile of ammonium nitrate, resulting in another several hundred deaths at Tessenderlo.

Despite the production of coated nitrate to subsequently avoid nitrate aggregation, several detonations of ammonium nitrate still occurred either in France or abroad, thus confirming the complex characteristics (e.g. chemical composition, particle distribution, density, humidity) associated with these categories of products and their detonation potential under circumstances promoting their instability: mixing, hazardous outcome when reacting with other materials or pollutants, temperature, containment…

ACTIONS TAKEN

Immediate firefighting and rescue measures:

The local authorities and several governmental departments activated emergency centres, the municipality set up a support centre for the population and the operator installed a crisis centre within the establishment.

The PPI (special administrative accident response plan) and the plant's emergency plan were put into action; reinforcements were requested to assist the departmental firemen, the civil protection mobilised a chemical hazard evaluation cell and technological catastrophe specialists. During the first 6 days,1,430 people were thus mobilised, including 460 firemen from the region, 620 firemen from other districts and 350 military personnel of the UIISC (civil security units). Roughly fifty doctors, 32 nurses or health care practitioners and more than 80 ambulance drivers were also mobilised.

The monitoring of access routes, looting protection and guarding required 500 to 600 policemen and 13 companies of special CRS (riot control) policemen rotating between September 21 to October 3, 2001. Crisis management operations also mobilised 350 police officers plus 80 belonging to a mobile squad; primarily for traffic control, reinforcement and sanitary convoys.

Considering the extent of the collateral damage and the inherent risks, numerous buildings and schools were evacuated. A security perimeter was set up in a radius of 500 m around the site. Thoroughfares around the site were closed. Traffic on the freeway, the southern ring road, the *A62* and *A64* motorways, the *RN 20* highway, the metro, the railway station and *Blagnac* airport were interrupted.

The numerous injured are admitted to local hospitals.

The population was ordered to remain confined as a precautionary measure and masks were distributed around the site. In late morning, the Prefecture announced that the toxic risk was under control and that all danger of atmospheric pollution had been dismissed. The precautionary confinement order was lifted around 4.00 pm, and rail and air traffic was reestablished. Nevertheless, the population was asked not to consume the tap water. The pollution of the *Garonne* was also brought under control.

The PPI was lifted September 28, 1.00 pm.

Securing of the site:

At the request of the classified facilities inspectorate and according to an emergency procedure, on September 21, 2001 the *Préfet* issued an order suspending the activity of 6 companies operating within the chemical zone (AZF, SNPE, TOLOCHIMIE, ISOCHEM, AIR LIQUIDE and RAISIO) requiring them to secure their sites. One company, SOFERTI in *Fenouillet*, which recycles off-spec products coming from the storage facility that exploded, was also the subject of an emergency prefectoral order requesting it to secure its chemical substances; inerting operations were set up for this purpose.

Dilution of NH_3 by water curtains

The crisis centre of the inspectorate remained active for 3 weeks after the accident in order to ensure that the various sites were secure.

The securing of AZF site included several delicate operations: recovery and removal of stocks of ammonium nitrate in hot solution, industrial nitrates buried near the crater, liquefied ammonia, nitric acid… Expert evaluation and validation of the procedures were requested prior to certain operations.

During the drainage of a liquefied ammonia storage tank, an uncontrolled release of approximately 9 tons of ammoniated solution resulted in pollution of the *Garonne* and fish mortality.

It took several months to secure the AZF site and the other plants concerned, which namely involved the evacuation of dangerous substances. At the request of the *Préfet*, the corresponding operations were carried out by the operators under the control of the inspectorate. In this manner, according to the latter's estimates and for the AZF plant alone, 4,000 tons of agricultural nitrates (fertilizer) and 800 tons of industrial nitrates buried under the gravel and rubble of buildings destroyed by the explosion, were to be cleared out and removed in the 4 months following the explosion.

SNPE, ISOCHEM and TOLOCHIMIE were required to conduct an audit of the property damage and conduct analysis of the safety conditions. Based on a proposal by the inspectorate, the *Préfet* also required that a third-party expert evaluation be conducted, as defined in article 3-6 of the order dated 09/21/77.

In addition to this,150 agricultural or industrial nitrate storage installations are monitored throughout France.

Clean-up and rehabilitation measures:

The remediation of the site led by the operator aimed essentially at reducing the concentrations of hydrocarbons, lead, arsenic and mercury in soil. In July 2006, after two years of work, more than 750,000 cubic meters of earth had been excavated, nearly 90% of the contaminated earth and concrete had been depolluted through on-site washing and heat treatment at 850 °C. Depollution work is completed in early 2008. The operator estimates the cost of clean up measures at 100 million Euros.

In autumn 2006, the construction of a cancerology center is announced on the site of the former AZF plant. The center will ultimately house 4,000 people, mostly researchers, on a campus of 220 ha. The *Pierre Potier* research Institute is inaugurated in late 2009, joined in 2010 by pharmaceutical companies. Finally, the University Hospital of Cancer, whose construction began in late 2009, will open in 2013

The cancerology center under construction (source : Oncopôle Toulouse)

Legal action:

Judicial action

The public prosecutor's office in Toulouse opened a judicial inquiry for "involuntary homicide and injuries". The inquiry conducted in this framework mobilised up to 140 policemen (regional judiciary police) and forensic and technical police laboratories for long-term investigations. According to the press, 1,500 reports and 800 to 900 statements had already been entered in the case file one month after the accident.

At the end of the judicial investigation in September 20, 2006, the AZF mother group GRANDE PAROISSE and the plant manager were prosecuted for "involuntary homicide and injuries".

The civil trial took place between February 23 and June 30, 2009 with a significant technical support and was entirely filmed for the first time in French history. The court required a 225,000 Euros fine against the GRANDE PAROISSE group and 45,000 Euros fine plus a three year suspensive imprisonment order against the manager. The criminal court of *Toulouse* pronounced the discharge of the accused who were given the benefit of the doubt, leading to strong reactions from victims' associations.

As the public prosecutor appealed the sentence, a new trial begun November 3rd, 2011 in *Toulouse*. The Court of Appeal pronounced its verdict on September 24th, 2012, recognizing the Grande Paroisse company and its former director guilty of involuntary homicide and injuries due to "clumsiness, carelessness, negligence, recklessness or breach of a duty of safety." The fines are confirmed for the Grande Paroisse group and its director, as well as the prison sentence : 2 years with suspension and one year with partial release. However, the Court considers once again the prosecution against the Total group and its former CEO are "inadmissible". The verdict known, the defense lodged an appeal (to the cassation court) September 27, 2012.

Administrative action

In September 2010, the Administrative Court of Toulouse dismissed 3 persons who wanted to involve the responsibility of the State. In its judgment of 24 January 2013, the Administrative Court of Appeal of Bordeaux acknowledged partial responsibility of the State and allocated 2,500 euros in damages to the 3 plaintiffs. The State lodged an appeal.

Emergency financial aid:

In addition to the housing support provided, emergency relief funds for the accident victims (> 18 M€) was released by the government, the regional authorities, the departments and communes… The assistance provided to accident victims was not considered compensation but allowed them to deal with primary needs for the individuals whose homes had been destroyed or significantly damaged.

The reconstruction of damaged public and private buildings outside the chemical sites was launched in the month following the accident. In the *Midi-Pyrénées* region, the "*Direction générale de la concurrence, de la consommation et de la répression des fraudes*" (the French general directorate for competition, consumption and the prevention of fraud) set up a monitoring system to detect possible abuse by companies performing repair operations.

Proposals and national measures:

An inquiry by the Parliamentary Commission was opened October 24, 2001 relative to the safety of industrial installations and research centres, and relative to the protection of persons and the environment in the case of a major industrial accident. As of January 29, 2002, this commission had formulated 90 proposals along six major themes: reducing the risk at the source, the human factor notably with the employees playing a role in the prevention of accidents, the implementation of greater openness and pluralistic expertise with regard to disasters, urban planning questions, the adaptation of judicial procedures and the compensation of the victims of industrial catastrophes [5].

Within a few months, the French public authorities undertook different reflective thinking and actions:

- In the field of prevention, in order to:
    - ✓ Broaden the field of application of the SEVESO 2 directive by lowering the ammonium nitrate threshold,
    - ✓ Limit the risk presented by ammonium nitrate-based fertilizers by adapting their technical specifications to make them intrinsically less explosive,
    - ✓ Improve the prevention of major accident risks in ports and railroad yards,
    - ✓ Ensure the continuity of the security between fixed installations and the transport of dangerous substances,
    - ✓ Reinforce the exchanges between member States relative to the hazards associated with ammonium nitrates (fertilizer and industrial nitrates),
    - ✓ Reinforce the exchanges between member States relative to the cohabitation of activities at risk with other economic activities, residential housing and thoroughfares,
    - ✓ Harmonise the risk evaluation methods between France and the member States,
    - ✓ Access to improved harmonisation of methods and inspection means of establishments at risk by the public authorities,
    - ✓ Reinforce cooperation between research and expert assessment organisations in the European Union,
    - ✓ Re-examine the safety conditions of high-level SEVESO facilities,

- In the field of inspection, in order to:
    - ✓ Reinforce significantly the staff of the inspectorate,
    - ✓ Reinforce the inspectorate through technical support for the examination of danger studies,
    - ✓ Check the fertilizer storage and ammonium nitrate storage facilities governed by the environmental legislation.

- In the field of openness and information to:
    - ✓ Create more than 200 experimental local information and joint action committees (circular of July 12, 2002),
    - ✓ Publish (via Internet) the new operating authorisation orders accompanied with the inspection reports.

The actions conducted between September 2001 and September 2002 concern the organisation of national and regional debates on risk evaluation and management, the organisation of a European seminar on urban planning control (12-14/02/2002 in *Lille*, France), the installation of several theme - and sector - based workgroups on the risk control and evaluation, as well as the preparation of a legislation on major hazards that led to the enactment of the law of July 30, 2003.

LESSONS LEARNED

The scenario of detonation had not been selected in the risk analysis of the plant either by the operator, the inspectorate or by third experts, because the existing feedback led to consider as unlikely the detonation of ammonium nitrate when compliant with manufacturing standards.

This disaster clearly shows that the contingency plans must consider a series of scenarios of the type, severity and kinetics representative of possible accidents even if their probability is considered extremely low.

The method for evaluating the risk proved to be insufficient. The danger study must consider the danger potential of installations, examine possible scenarios and their consequences including the most dramatic or improbable, estimate probabilities and characterize the modes of occurrence. Reducing risks at the source must aim at reducing the potential for danger, the probability of accidents occurring and limiting the consequences through appropriate organisational and technical systems.

The legal system did not enable sufficient control in terms of urban planning, particularly for the existing industrial sites whose surrounding area had already been urbanised [6 and 7]. This point was brought up in the bill concerning the introduction of a technological risk protection plan foreseeing pre-emption, abandonment and expropriation mechanisms.

Growth of urbanization around the plant between 1930 and 2001 (Source: Grande Paroisse/ IGN)

This bill also emphasises information and joint action on the risks, in terms of both employees and the surrounding area. It broadens the role of the CHSCTs (Committees for hygiene, safety and working conditions) and creates local information and joint action committees. The implementation of the law concerning the prevention of technological risks will enable the various actors intervening on the site to be implicated, the release of information to the public, and urban planning control around installations at risk. It will also improve the compensation paid to victims of industrial accidents.

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