MINISTRY OF ECOLOGY, SUSTAINABLE DEVELOPMENT AND ENERGY

Bases for an accident study on the inerting process practiced in silos

- July 2015 -

ARIA
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Scope of this study

This study has been based on an analysis of accidents involving grain silo or dryer installations that require an inerting process.
The ARIA database contains slightly fewer than 500 accidents featuring silos or dryers responsible for causing a fire or explosion. Among these entries, only 23 indicate some reliance on the inerting process as the preferred type of response, thus accounting for less than 5% of this category of accidents.

Out of these 23 examples of accidents, only one mentions the implementation of an inerting system following an explosion, more specifically as a means of protecting the other cells (ARIA 42815).

Description of the inerting system employed

In our sample of 23 accidents, the most commonly used inerting system consists of nitrogen injection.
Only four accidents involve an alternative system that introduces carbon dioxide (ARIA 11618, 14380, 21694, 32060).

The accidents where an inerting system was used are classed by product in the table below.

Accident no.	Product used for the inerting operation	Products found in the silo
2429	nitrogen	barley
20979	nitrogen	barley
22898	nitrogen	barley
33331	nitrogen	barley
11983	nitrogen	alfalfa
15499	nitrogen	alfalfa
20378	nitrogen	alfalfa
35414	nitrogen	alfalfa
12627	nitrogen	sunflower
21694	carbon dioxide	sunflower
23247	nitrogen	sunflower
44541	nitrogen	sunflower husk
32060	nitrogen + carbon dioxide	sunflower meal
11618	carbon dioxide	grains
18825	nitrogen	grains
17816	nitrogen	corn
37426	nitrogen	corn
14380	nitrogen + carbon dioxide	malt
42815	nitrogen	malt
32464	nitrogen	pellets
35051	nitrogen	wheat
11659	nitrogen	cocoa cake
14625	nitrogen	bran

Conditions surrounding the use of inerting

This chapter is intended to describe the set of use conditions under which the inerting systems have been implemented with respect to the accidents included in our sample.

➢ Inerting offers a long-lasting response technique

Inerting is often carried out over a several-day period. The following table indicates the inerting periods for accident records containing such information.

Accident no.	Duration
14380	12 days and 3 hours
2429	20 hours
11983	5 days
12627	2.5 days (60 hours)
20378	2 days (48 hours)
20979	29 hours
21694	10 hours
33331	several days
37426	2 days (48 hours)
44541	3.5 days

➢ Large volumes of gas needed

The gas volumes required to conduct inerting operations reach into the thousands of m^3 in the majority of accidents whose recording lists this volume figure.

The following table indicates the various gas volumes introduced during accidents with a record of this information:

Accident no.	Volume	Duration
14380	10900 m3	12 days, 3 hours
2429	48 m3	20 hours
11983	6000 m3	5 days
32464	1000 m3	/
33331	200 m3/h	several days
42815	16880 m3	several days

➢ Nitrogen taps located relative to their efficiency

By closely studying the accidents contained in our sample, it becomes quite apparent that the choice of where to inject inerting product can be situated just as easily in the lower part or upper part of the cell under combustion. In some instances, the inerting site can even be positioned on the cell ventilation system.
The taps initially installed inside the cells for nitrogen injection are therefore not necessarily being used. Other taps are sometimes made to improve the distribution of gaz in the cell.

➢ Silo and dryer operators prefer an external supply line

For the vast majority of accidents included in our sample, maintenance and repair technicians were recipients of a special nitrogen delivery. The next chapter will expose the benefits of anticipating the arrival of all such deliveries.

The following table serves to illustrate the two previous points, namely: inerting product supply mode and inerting location.

Accident no.	Product	Location of the implemented inerting system within the cell	In-house supply	Subcontracted supplier
2429	nitrogen	Inerting through ventilation ducts	--	Injection by fire-fighters
11983	nitrogen	Inerting via the top of the silo		
17816	nitrogen		--	Injection by fire-fighters
20378	nitrogen		Use of the internal nitrogen reserve	--
20979	nitrogen		--	Delivery of a cistern
21694	carbon dioxide	Inerting via the top of the silo	--	Injection by fire-fighters
22898	nitrogen		--	
23247	nitrogen	Inerting via the bottom of the silo	--	Delivery of a 20-m³ cistern
32060	nitrogen + carbon dioxide	Nitrogen is injected through the bottom of the cell, and the carbon dioxide is injected via the tank roof		
32464	nitrogen		--	Injection by fire-fighters
33331	nitrogen	Injection by dedicated taps proves to be inefficient due to a location that's too high. Two other lower orifices will be created.	--	Requisition of a nitrogen supplier
35051	nitrogen	Inerting via the bottom of the silo	--	Delivery of a cistern
35414	nitrogen		Use of the internal nitrogen reserve at first	Delivery of a cistern afterwards
37426	nitrogen	Inerting by tapping on the ventilation duct	--	Delivery of a cistern

Difficulties encountered during repairs

An analysis of our sample has highlighted a number of difficulties capable of arising when implementing an inerting system.

➢ Supply and pipe connection difficulties to be anticipated

Several accidents make mention of nitrogen supply shortages slowing response times (ARIA 33331, 44541) and, in some cases, forcing technicians to abandon this inerting technique (ARIA 10185, 21694). Such difficulties may be of several types :
- suppliers contacted but unable to deliver cisterns,
- a ban applicable to materials transport on certain weekends, thus preventing product delivery via tanker lorry,

The compatibility of nitrogen injection nozzles with fire-fighter hose connections needs to be checked in order to avoid delays during technician intervention, as was the case for accident ARIA 2429.

It must also be verified that the cistern has been fitted with a heater so as to avoid injecting liquid nitrogen into the cell. The absence of such a heater would slow implementation of the inerting system, as was the case during accident ARIA 44541.

➢ The obstacles to inerting efficiency

Tap placement may indeed hinder inerting efficiency, especially if the zone undergoing combustion is far from the injection zone.
In some cases, the taps installed on cells were not used due to their placement. The considerable distance of taps from a combustion zone could cause technicians to set up other taps inside the cell during their repair work (ARIA 33331).

Discussions held regarding the placement of stationary taps:

The placement of stationary taps is subject to debate: experts assigned to the National "Silo" working group tend to favor taps located on ventilation ducts rather than on hatches and manholes.
During an inerting operation, nitrogen actually flows via preferential paths through the mass of grains in accordance with the size of intergranular spaces.

Hence, if an injection point lies on a hatch or manhole, the nitrogen may not fully sweep all cell contents. Consequently, if the combustion chamber is located far away, it might prove necessary to add other injection points during the fire outbreak or explosion.

The lack of sealant around the cells has also been cited as an obstacle to the efficiency of the inerting processes introduced (ARIA 42815).
In some cases, this lack of a cell seal has led repair technicians to opt out of using the inerting technique (ARIA 39116).

➢ Inerting procedures not operational in all circumstances

The inerting procedures adopted at silo sites are not always highly operational (ARIA 33331).
This procedure must, at the very least, enable answering the following question: how are the inerting resources to be implemented, given the steps of :
- defining the cistern location;
- drawing up a list of nitrogen suppliers capable of providing service, and updating this list on a regular basis;
- planning for the installation of a heater to avoid having to inject liquid nitrogen;
- identifying the location of nitrogen hose routes;
- specifying the characteristics of coupling devices.

APPENDIX

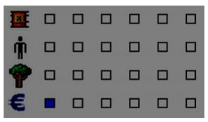
List of the 23 accidents involving an inerting system

French accidents

ARIA 14380 - 10th January 1983- ROUBAIX
NAF code 11.05: Beer production
Inside a brewery, slow combustion followed by fire occurred at a silo containing 110 tonnes of malt. Twelve days and 3 hours were needed to neutralise this outbreak along with the use of 10,900 m³ of gaseous phase nitrogen and 3.2 tonnes of dry ice. Coordination between the various public and private response services ensured the success of this intervention procedure and facilitated the transfer of silo contents.

ARIA 2429 - 10th October 1990 - LE HAVRE
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
Around 5 pm, a port silo employee noticed the smell of burnt grain. The unloading of a ship was suspended while employees inspected the various conveyor belts. They discovered a fire outbreak at the top of a bucket elevator caused by hot metal chips falling onto the grains. The blaze was put out using fire extinguishers. Upon inspection of the 2 barley silos being filled at the time (2,000 and 6,000 tonnes, respectively), employees observed some faint smoke along with a burnt odour. They called the fire-fighters, whose measurements confirmed the presence of combustion in both cells. A 300-m safety perimeter was cordoned off. The preferred solution for fighting this blaze consisted of inerting with nitrogen the 2 tanks via the ventilation vents. The nitrogen was to be conveyed at 13 bar and 0°C by the dry standpipe and fire hoses. Injection began at 11 pm once the incompatibility between fire-fighters' connections (100 mm) and nitrogen supply pipes (50 mm) could be resolved. Silo drainage was initiated the next day. The standard system was not used so as to prevent the fire from spreading. It was decided to place openings in both cells. This intervention lasted until 7 pm on 13th October. In all, 48 m³ of liquid nitrogen were applied. Only 10 tonnes of barley were lost out of the 8,000 drained.
A facility employee forwarded a hypothesis to explain this accident. The conveyor belt system was bonded to a metal roof frame. The dilatation of this structural frame caused by daytime/night-time temperature differences offset the alignment of the conveyor belt shaft at the end of the line. The friction of mechanical parts would have subsequently triggered the heating.

ARIA 11659 - 18th September 1997 - LA CAPELLE
NAF code 10.91: Production of farm animal feed
In a plant manufacturing animal feed, a smouldering fire appeared in a 140-tonne cocoa cake silo. Pyrolysis gases (methane), present at a concentration above the lower explosive limit, were detected in the upper part of the cell. The combustion chamber was flushed by an injection of liquid nitrogen. Some 20 individuals had to be evacuated within a 140-m radius.



ARIA 11983 - 12th February 1998 - SAINT-OUEN-L'AUMONE
NAF code 52.10: Warehousing and storage
Fire appeared inside a concrete silo cell containing 2,000 tonnes of dehydrated alfalfa. It was decided to drain the cell. Five days later, the outbreak worsened, making it necessary to notify public emergency services. Nitrogen and then foam were injected into the upper part of the cell in order to inert and prevent dust from becoming airborne. Afterwards, nitrogen was injected for 5 consecutive days at a rate of 50 m³/hour in the lower part to smother the fire. The product was drained after being completely cooled. Traffic on the waterway was suspended throughout this intervention. A number of conservation measures were also mandated.

ARIA 12627 - 12th March 1998 - BASSENS
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
During a monitoring round, an abnormal odour followed by smoke led to discovering a smouldering fire in a vertical cylindrical cell (58 m high, 12 m in diameter) at a silo containing 2,600 tonnes of sunflower seeds. Nitrogen was injected into the cell prior to proceeding with removal of all silo contents. This operation was completed 60 hours after fire was first detected. Several tens of kg of seeds were burned. The temperature probes had failed to signal any anomaly. An expert appraisal indicated that this accident was caused by a spark originating at a grinder and, in traversing a very narrow passage, initiated a smouldering fire of dust that had accumulated on a metal structural member. A small incandescent mass fell igniting the seed 10 m away.

ARIA 14625 - 30th December 1998 - LOUVIERS
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
Fire broke out at a silo containing 60 tonnes of fermenting bran. A safety perimeter was set up and 7 workers had to be evacuated. Both nitrogen inerting and cell drainage were carried out.

ARIA 15499 - 30th March 1999 - MESGRIGNY
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
In a dehydrated alfalfa storage silo, while initiating a drainage operation, the technician noticed an abnormal smell along with a product shortage. He immediately stopped the operation and the temperature probe alarm sounded. A nitrogen inerting step was triggered. After 2 hours without any improvement, fire-fighters were called to the scene. They installed a 300-m safety perimeter and suspended rail traffic on the Paris-Basel line due to smoke and methane releases (at 80% of the lower explosive limit). A 5% foam mix was injected at the top of the silo. With temperature remaining stable and methane content decreasing, the safety perimeter was scaled back to 100 m. The silo drainage step resumed under supervision 11 hours after the initial shutdown. The hotspot consisted of 10 tonnes of alfalfa. The suspected causes of this incident were: specific product characteristics, a very gradual drainage operation (lasting one week) to promote oxygenation and fermentation, and a late temperature probe detection (due to the inter-probe distance and thermal insulation of the alfalfa).

ARIA 17816 - 28th May 2000 - ROZAY-EN-BRIE
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
Fire broke out inside a cell containing 2,500 tonnes of corn at an agricultural cooperative silo, whose roof wound up collapsing. The blaze extended to the conveyor belt running along the upper gallery. Fire-fighters deployed 2 teams, one equipped with thermal cameras to control the spreading of hotspots while the other injected nitrogen in order to smother the fire raging in the cell. By the next morning, pieces of incandescent belt had conveyed the fire to another cell. At that point, fire-fighters decided to empty all the cells. 10 individuals in the vicinity were evacuated during this operation. The silo was not available

for several months. The cause of this accident gave rise to 3 hypotheses: an electrical short-circuit, heating of the grain, and repair work carried out the day before on an antenna positioned on the silo roof.

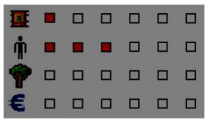
ARIA 18825 - 28th September 2000 - BIENVILLERS-AU-BOIS
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
Fire broke out in a silo; it was brought under control by means of nitrogen inerting and cooling with water hoses

ARIA 20378 - 28th March 2001 - PONTFAVERGER-MORONVILLIERS
NAF code 10.91: Production of farm animal feed
Self-heating occurred inside a metal cell containing 500 tonnes of dehydrated alfalfa pellets. Once temperature probes had detected the anomaly, the site operator introduced nitrogen into the storage unit to slow the self-combustion phenomenon. Fire-fighters poured foam over this unit via a hatch located on top of the cell; this hatch was drained within the next 48 hours, though 200 tonnes of pellets were lost. The observed self-heating may have been due to humidity entering the cell via an opening, resulting from the rupture of a weld between a footbridge and the cell housing.

ARIA 20979 - 3rd July 2001 - LUYERES
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
A burning smell in a silo alerted site employees, who subsequently detected smoke in a cell containing 400 tonnes of barley. They noticed that one of the cell's ventilation hoods had fallen onto the pile of grain. Upon arriving on the scene, fire-fighters racked the grain, thus generating a funnel that pulled the hood down, submerging it in the grain. To prevent the fire from spreading, the racking operation was halted and foam was injected. Despite this step, the temperature of the nearest heat probe rose by 0.25°C/hour. A nitrogen cistern was ordered to inert the cell. This step got underway 12 hours after the incident began and lasted another 29 hours. The temperature kept increasing by 0.15°C an hour. The inerting procedure was continued, and the cell could be drained by setting up a shorter circuit (without conveying grain to the handling tower) so as to contain the fire. The extracted grain was hot and moist; after 3 hours, totally burnt yet still cold blocks began to appear. The inerting process appeared to have extinguished the smouldering fire.
This temperature rise was due to the fermentation of barley once foam had been sprinkled. The motor on the recovered hood was not compliant with the purchase order dated 29th July 1998. All identical motors in this silo were disconnected and in the operator's other silos as well. Facility activity was suspended until a centralised dust suction system could be installed and made operational. A verification of all electrical installations by a certified body was also mandated.

ARIA 21694 - 15th January 2002 - VILLAGE-NEUF
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
In a silo, 25 tonnes of sunflower seeds burned within a concrete cell (height: 55 m, Ø: 10.5 m) filled to half its 2,000-tonne capacity. At the time, the other silo cells were full of sunflower and soybean. While unloading a lorry, a technician detected a fire outbreak at the foot of an elevator. Silo staff immediately snuffed out this blaze with an extinguisher and sounded the alert after observing that grain combustion in the elevator had spread into the cell being filled and had tripped the thermal probe alarm. First responders set up a 100-m safety perimeter and ordered the cessation of activities at the 3 neighbouring companies, with emphasis on the transfer of flammable liquids at an oil depot. Waterway navigation was limited on the Rhine River. Given the proximity of their borders, both Swiss and German authorities were notified. Fire-fighters created a foam blanket at the top of the grain pile inside the cell. This operation lasted 5 hours. The extinction strategy called for introducing carbon dioxide via the top of the

silo lasted for more than 10 hours. The use of nitrogen had been planned, but its introduction via the bottom of a cell lacking the proper equipment was deemed too complicated.
The origin of this fire, initially attributed to a welding operation conducted a few days prior without a hot work permit, was in fact due to heating by friction of the elevator strap, which was not taut enough following its replacement. The Classified Facilities Inspectorate undertook, at the departmental level, an information campaign directed at the operators of similar silos in order to both verify the tension of straps and conveyor belts after replacement and stipulate within their fire recommendations an intervention that inerts those cells where such straps and belts need to be equipped with proper installation fittings.

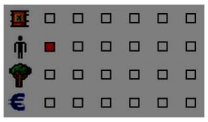


ARIA 22898 - 21st August 2002 - PONT-SAINTE-MAXENCE
NAF code 52.10: Warehousing and storage
Combustion was detected at 8:30 am in one of the 24 cells of a vertical concrete silo containing 1,500 tonnes of barley from the 2002 harvest. Fire-fighters recorded temperatures of up to 300°C and decided to empty the cell. A strong increase in carbon monoxide concentration (> 1,200 ppm of CO) led to fears of a gas explosion, causing the drainage operation to be halted. A 400-m radius safety perimeter was cordoned off and 400 people were evacuated. The cell was inerted with nitrogen before the resumption of drainage, which ended 5 days later (26th Aug. at 4 am).
This event was triggered when an inspection lamp turned on was inadvertently left in the cell prior to filling, on 12th August during a cleaning operation; the lamp had remained on for 24 hours before switching off. From 12th August to the day of the accident, the cell was ventilated every night. With the thermometer idle, combustion could only be detected once smoke could be seen by the staff.
Subsequent to this incident, a Prefectural decree ordered a series of emergency measures, namely: resumption of the temperature measurement campaign compliant with current regulations, verification of the affected cell's condition, and an update of the safety report for all installations. The total cost of damages was estimated at €900,000, including €300,000 in operating losses.

ARIA 23247 - 9th October 2002 - ARZEMBOUY
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
At a silo facility comprising 4 storage cells, fire began to smoulder at 9:15 am in the upper part of a concrete cell containing 900 tonnes of sunflower (8.8 m diameter, 29 m high). The accident occurred shortly after the cell was filled with sunflower that had been dried and then cooled by ventilation. Without any detectors in place, an employee noticed a smoke release and alerted first responders and the Group's head of safety. Local gendarmes set up a safety perimeter. Responders feared not only that contact between incandescent particles and dust (stuck to walls in the empty space above the grain pile) would cause a primary explosion leaving dust in suspension (to be followed by a more powerful explosion), but also that ignition of the smouldering fire, facilitated by the oleaginous nature of sunflower, would spread throughout the storage zone. The silo temperature recordings and fire-fighters' thermal camera exposures confirmed that this fire had remained confined to the upper part of the grain pile, with cell drainage amplifying the loss by spraying incandescent particles across the entire storage height, both on the conveyor chain and in the elevator. Given all these elements and upon the advice of the safety manager, fire-fighters covered the grain pile with a foam blanket and, using a small hose, flooded the chain conveyor and elevator base, where incandescent particles had been located. The lack of appropriate on-site equipment slowed the inerting process via the cell bottom (at 11 pm), with a subcontractor having earlier delivered a 20-m³ cistern of liquid nitrogen and installed an evaporation station. Following a final examination at 4 am using a thermal camera, site employees drained the cell.
According to the operator, a mound of sunflower dust stuck between the dryer ducts had heated before loosening and was conveyed towards the cell. Initially fanned by the ventilation, combustion then spread to the grain cluster.

ARIA 32060 - 21st July 2006 - SAINT-NAZAIRE
NAF code 10.41: Production of oils and fats
Self-heating took place in a closed metal cell containing 550 tonnes of sunflower cake in pellet form (an agglomerated and dry by-product) inside a vertical silo at a vegetable oil factory. A nitrogen inerting process was undertaken. Since the heating effect seemed to be well under control, the cell was scheduled for a drainage operation 4 days hence. During this drainage, a sunflower cake combustion was discovered. The operation was halted so that nitrogen could be injected by the cell bottom and carbon dioxide into the top of the tank. Classified Facilities inspectors, informed the next day (26th July), requested the operator to alert emergency services and the fire department and then implement the precautionary measures stipulated in the silo state-of-the-art guide. After its 27th July site visit, the inspectorate also issued the following requests: establish an intervention protocol before conducting any operations on the cell, delimit a safety perimeter for technicians, and strengthen the monitoring of extracted sunflower cakes with the potential to reignite. The attempts at drainage over the subsequent 8-day period were fruitless due to either product clogging or a resumption of combustion; 250 tonnes of sunflower cakes still needed to be extracted. The cell would not be completely drained until 6th October.

ARIA 32464 - 20th October 2006 - ROUEN
NAF code 10.61: Grain processing
In a pasta product factory, heating occurred in a 350-m³ cell containing 200 tonnes of pellets; several probes displayed temperatures above 100°C. The clustered products, at least those at the bottom of the silo, formed an arch at the base of the cone, thereby preventing material removal. Classified Facilities inspectors, with the site operator's agreement, called on external responders to inert the cell. A chemical emergency squad measured the levels of both CO and explosive gases (in terms of hexane equivalent), which revealed the presence of combustion in the cell. Fire-fighters applied a highly expanding foam blanket at the top of the cell and then, around 8 pm, injected nitrogen. The operator commissioned a silo drilling specialist to perforate the plug blocking product removal. After inerting, a slight temperature decrease was observed on the sensors, along with the presence of 1% to 10% oxygen (O_2) depending on the injected nitrogen pressure. The next day, the specialist firm bored through the entire material quantity and installed a weigh beam on top of the cell in order to evacuate the material by means of gravity flow. During this phase, a 20-m safety perimeter was set up around the cell in recognition of the risk of cell collapse. Over 1,000 m³ of nitrogen were injected and 200 tonnes of product could be eliminated.



ARIA 33331 - 9th July 2007 - MOUY-SUR-SEINE
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed
Around 1:30 pm, the head of a silo detected heating inside a concrete cell (diameter: 8 m, height: 33 m) containing 1,400 tonnes of barley after observing a brown-coloured discharge oozing from a crack in the cell wall. The week prior, facility personnel had noticed an abnormal smell without being able to identify its cause. In an attempt to cool the grain, the decision was made to transfer silo contents into another cell with precautions (reduced transfer speed, water nozzle easily available, permanent human supervision, inspections carried out with a thermal camera). On the morning of 10th July, even though the transfer had taken place the previous night without any problem, a temperature rise was recorded with the thermal camera, and the grain quality was found to be below commercial grade. It was thus decided to drain the barley by the side hatch and dispose of it with a dumper lorry at another company site. Around 4 pm, a sudden temperature rise (T°=110°C) was recorded by both the silo thermometer and thermal camera on the 300 tonnes of barley left to be extracted. The silo was secured, energy supply lines turned off and public emergency services notified. Fire-fighters cooled the cell from the outside and sprinkled the inside to contain the blaze. In light of the temperature

instability (successive dips and spikes), a foam blanket was installed inside the cell, by inerting with the nitrogen delivered by a subcontractor at 6 am on 11th July. Since injection by means of dedicated taps proved inefficient due to tap location, 2 other orifices were created. As of 12th July, drainage could take place using a vacuum lorry via a 40-cm borehole in the cell envelope, following approval by a concrete specialist. The extraction of grains in bulk required expanding the orifice after another favourable opinion from the concrete expert. The emergency response was wrapped up during the night of 13th July as the incident seemed under control; 120 tonnes however still needed to be drained. The next day upon arriving at the site, where the operator had not instituted round-the-clock monitoring the previous night, employees found the fire continuing to burn in the initially damaged tank along with heating in the adjoining cells containing barley and rapeseed. Public responders once again arrived on the scene. Some cells were cooled from the outside and inerted with nitrogen. Moreover, grain supplies were covered with a foam blanket over the top of the storage pile, and all silo tanks were drained from 14th to 27th July. A 1-m² borehole was drilled on one of the newly compromised cells to complete its drainage. Four people, including 3 fire-fighters, were slightly injured during the emergency response. Silo operations, suspended by virtue of administrative edict issued on 13th July 2007, would resume on 27th June 2008.
According to the facility operator, dust accumulation on the motor of the air extractor installed under the cell roof had generated a hotspot and then a smouldering fire after falling onto the grains during tank filling carried out between 19th June and 8th July 2007.
Several lessons can be drawn from this accident:
- avoid installing motors in the cells (ATEX designated zones) and, should this be impossible, verify their compliance and ensure their periodic maintenance (i.e. cleaning);
- plan for appropriate organisational and technical measures (especially nitrogen "availability") that allow inerting cells whenever necessary; favour the placement of injection taps on ventilation ducts;
- be sure to notify public emergency personnel as quickly as possible (notably in instances when the event is likely to worsen);
- incorporate the heating risks in neighbouring cells (fermentation due to extinction water intake, thermal conduction, etc.);
- assign round-the-clock staff monitoring (in particular at night or on weekends) of all affected or potentially affected installations as long as the incident has not been fully controlled.

ARIA 35051 - 17th June 2008 - ARCIS-SUR-AUBE
Naf code 11.06 : Malt production.
Around 2 pm, employees at a malt house noticed that faint smoke was being released from a wheat cell in a silo. All handling facilities were shut down, the site evacuated and fire-fighters notified. The plant's internal crisis management and nitrogen search procedures were activated. Temperature monitoring of the 350-m³ cell was initiated. The response to contain the incident started up around midnight by both pouring highly-expanding foam at the top of the tank in order to cover the grain pile and inerting the cell from the bottom. Its drainage via a screw system towards the outside was launched around 5 am and continued throughout the morning. During this response effort, cell temperature was closely tracked; then after drainage, the grain circuits were verified to ensure all hotspots had been removed. The situation returned to normal by the beginning of the afternoon, or about 25 hours from the time the alarm was first sounded. In all, 50 tonnes of wheat had sustained damage.
The use of a blowtorch by a subcontractor during sealing works carried out on the silo roof caused this accident. A hot work permit had actually been delivered for this job. Subsequently, the facility operator reminded the subcontractor of all pertinent safety recommendations and planned to instruct all subcontracted personnel in the risks related to work performed on these installations. The accident was also cited internally, within the industrial group, for the purpose of recalling the importance of implementing effective controls when conducting such repairs and maintenance.

ARIA 35414 - 31st October 2008 - BAZANCOURT

Naf code 10.81 : Sugar manufacturing

An operator noticed, when making his rounds around 7:15 am, smoke being released from a vertical 1,200-tonne concrete silo filled to one-third capacity with alfalfa pellets. He then sounded the alarm. The cell was isolated and nitrogen inerting initiated at 7:35 am using the gas reserve available on-site. The silo temperature reading did not indicate that the alarm trigger threshold had been surpassed. At 11 that morning, emergency response services were alerted as a precaution, as was the Classified Facilities Inspectorate and the rail agency since a high-speed train line ran nearby. An additional lorry load of nitrogen was supplied to the company at 4 pm. Fire-fighters set up 2 variable-speed hoses capable of delivering 500 l/min, for purposes of fire protection and extinction, throughout the cell drainage operation lasting from 4:45 to 8 pm; 300 tonnes of pellets were slightly darkened and subjected to temperatures at times reaching 40°C. The products were still prepared for market and stored in a hangar and another cell. The emergency response concluded at 8:30 pm. The operator proceeded with cleaning and instituted a night watch. The next morning around 9, fire-fighters inspected the particular cell and found no anomaly. Following this incident, the malt house operator increased the frequency of inspection rounds.

ARIA 37426 - 2nd November 2009 - GRIGNY

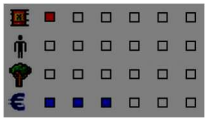
NAF code 46.21: Wholesale trading of cereals, non-manufactured tobacco, seeds and livestock feed

Heating was detected by silo temperature readings around noon in a metal cell (12 m in both height and diameter) with a flat bottom containing 680 tonnes of corn. A temperature of 80°C was recorded. First responders placed a 50-m safety perimeter around the silo, which was located in the vicinity of 2 SEVESO-rated hydrocarbon storage facilities and, as such, subjected to restricted road access. The LPG depot operator suspended all gas transport and activated the stationary cooling apparatus for railcars parked on the site's internal track.

A foam blanket was deployed on the grains and nitrogen inerting initiated as of 8:15 pm. Temperature was monitored every 30 min. The next morning around 7:30, these values were varying between 75° and 90°C. Two 20-cm orifices were cut into the cell wall at a height of 5 m in order to extract the corn by gravity under the protection of 2 variable-speed hoses, one of which was used to cool the extracted cereals; drainage took place at a 30-m³/hour flow rate. By the end of the morning, the 2 perforations no longer allowed the grain to be extracted, as its level in the storage vessel had become too low. In fearing cell collapse due to the "arch" phenomenon and holes in the wall, first responders set up a 30-m safety perimeter circling the tank. Around 5:30 pm, upon receiving the approval of the manufacturer and experts, 2 new orifices were drilled in order to resume corn extraction. The gravity flow was suspended about 8:30 pm and a night watch was organised. Drainage using an extraction screw started back up on 4th Nov at 1 pm, although fire-fighters had to extinguish renewed combustion around 8 pm that night. The cereal transfer and emergency response were completed during the day of 5th Nov.

According to the operator, heating near the scraper screw motor, positioned at the centre of the cell, might have caused this accident. 2 days earlier, it had mistakenly been installed and kept running when the intention was to turn on the motor of another silo.

Subsequent to this accident, the operator laid out several measures, namely: identifying cells adjacent to electrical circuit-breakers and drainage screws; upgrading electrical installations to meet code; verifying fuse calibration on the scraper screws; adjusting thermal relays; gradually replacing motors located in metal cells that use "ATEX" designated devices; increasing thermometer reading frequency (to twice a week), visually inspecting screw motors each time the tank is emptied, drafting an internal emergency plan in conjunction with fire-fighters, and improving the site's water resources. The operator also studied: installation of an automatic shutoff on the scraper screws after 2 hours of operations and a continuous "on" indicator light in the silo office; and a specific metal cell drainage procedure once an incident arises.



ARIA 42815 - 28th September 2012 - NOGENT-SUR-SEINE
Naf code 11.06 : Malt production
An explosion occurred around 2:30 am in a 60-tonne malt cell at a 40-m high silo while it was being drained via a hatch (i.e. no use of the lower gallery conveyor belt) subsequent to the emanation of a burnt smell. Pieces of the cell roof and of an adjacent tank were strewn over 70 m. The cell's drainage cone was cracked. Polypropylene vents in the upper gallery were destroyed, yet the roof remained intact. The neighbouring handling tower was not damaged (continued operations of the decoupling mechanism). The internal emergency plan was activated and a 100-m safety perimeter cordoned off. Fire-fighters measured the temperature in the other tanks using a thermal camera. The continuing transfer of the targeted cell was slowed by a plug composed of burnt matter as well as by concrete debris. In the morning, smoke releases were detected at the level of 3 cells and 2 adjacent interstices. The site operator commissioned a silo specialist to assess these risks and devise a strategy for emptying the tanks. Foam injection at the top of the cells began that afternoon, but insufficient water pressure that far above ground prevented good accumulation. Nitrogen inerting began at 10:30 pm. The cells' compromised seal limited the efficiency of this step. The targeted cells were drained over the ensuing days using a suction vehicle, while maintaining in place all foam extinction functions at the top of the silo, a water extinction set-up for the residual smouldering spots, and nitrogen inerting and ventilation of the basements to assist responders' in their tasks. Boreholes were necessary in the lower part of 2 cells to suction contents. The emergency intervention was completed, with operator approval, on 2nd Oct around 7 pm. Both the Mayor and Deputy Prefect visited the site. A specialist consultant conducted an expert appraisal to determine the causes of this explosion, as well as to evaluate pressure surges in the cell and upper gallery, and validate projection-based models. The financial loss amounted to €7 million, half of which written off as operating losses.

ARIA 44541 - 2nd November 2013 - BASSENS
Naf code 10.41 : production of oils and fats
Around 10 pm in a plant processing sunflower for use in foods, the food industry and energy applications, a technician detected a characteristic burning smell and witnessed a fire within a bag filter at the base of an elevator feeding grain shells into a concrete cell of a (50-m high) silo. He notified the shift foreman and turned off the material handling device. While battling this blaze, employees noticed smoke escaping from the cell, containing 800 tonnes of shells, and called emergency services (at 11:05 pm). The internal emergency plan was activated. Site personnel were evacuated and energy supply lines shut off. The operator inerted the cell with nitrogen and fire-fighters installed a foam blanket at the surface where product was being stored. Regular measurements of carbon monoxide (CO), oxygen (O_2), temperature and explosion potential were recorded. A silo drainage operation, which had begun that night, was suspended on 3rd Nov at 5:45 am, as the pumping effort using a tanker lorry specifically moved to the site had proven ineffective. Shell removal (at a rate of 20 tonnes/hour) resumed with a hired conveyor belt during the afternoon of 4th Nov, to be replaced the next morning by a Redler conveyor (running at 30 to 40 tonnes/hour). Once the silo extraction screw had been plugged (5th Nov), a 0.6 m x 0.6 m orifice was drilled into the 0.20-m thick reinforced concrete wall at the bottom of the cell. The use of a special "*GERICO*" nozzle, designed to penetrate to the core of a burning mass, made it possible to loosen the screw and create a (1-m diameter) hole in the stored product, making the top of the silo visible. The fire-fighters' mission ended on 8th Nov around 4 pm. The 40 tonnes of residue covering a 4-m height were extracted by the plant operator.
The foam blanket, kept in the cell until the evening of 4th Nov, required 9.5 m³ of emulsifier. Inerting the silo with nitrogen first by the bottom then the top, in order to inert the expansion space, relied on the site's process gas reserves followed by the provision of external supplies.
Fire-fighters faced various difficulties, namely: conveying emulsifier to the top of the silo, along with

emulsifier quality concerns, owing to its exceptional source; a technical problem on the dry standpipe requiring replacement by a hose; pipe diameters throughout the installation not standardised with respect to emergency equipment; failure to accompany the nitrogen tanker lorry's on-site delivery with a heater; external nitrogen supply issues; and clogging of the product to be extracted when placed in contact with the foam water.
According to the operator, self-heating inside a shell processing hopper upstream of the storage zone could have triggered this accident, given that a combustion outbreak had been brought under control in this hopper on 3rd Nov around 10 am following the appearance of smoke. The operator carried out an in-depth analysis of the causes surrounding this accident and proceeded to both modify its response procedure in conjunction with Fire Department officials and initiate improvements to shell hotspot detection prior to silo storage.

Foreign accidents

ARIA 11618 - 15th July 1997 - UNITED STATES - KALAMA
NAF code 10.61: Grain processing
Fire broke out in a metal silo containing grain. It was extinguished by injecting carbon dioxide.