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Contribution to the Analysis of the Toxic Ammonia Cloud Dispersion Associated with Pipeline Catastrophic Rupture case study of Arzew Oran

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Abstract. As part of its activities related to accidental risk, The Fertial factory in Arzew must determine safety perimeters around industrial facilities. For example, during a loss of containment on a facility, the risks involved can be instantaneous such as the explosion of flammable products or delayed like toxic releases. This research work focused on the fate of a toxic cloud formed after an accidental release of liquid-stored ammonia (NH3) under pressure. The study of atmospheric dispersion of ammonia presents the main importance since this chemical is very toxic, corrosive, flammable, and explosive under certain conditions. To remind, the loss of containment of a 22-tonne tank of ammonia on 24 March 1992 at DAKAR resulted in numerous deaths (129 deaths and more than 1.100 injuries), including some several weeks after the accident due to the toxic nature of ammonia. This work aims to analyze the risks presented by installations using ammonia quantities of up to a few dozen tonnes and supplement the knowledge on the atmospheric dispersion of ammonia in an open and congested environment or be able to propose measures to assess the levels observed in the region and to provide elements to local actors to initiate improvement actions.

Keywords. Ammonia, Toxic cloud, Dispersion, Major risk and assessment.

INTRODUCTION

The effects, the sources, and the dangers of ammonia are little known by the general public but also by its producers. However, it actively participates in air pollution and in particular in the formation of particles. For example, ammonia can have various adverse effects on the environment, especially after its transformation (including nitrates), which contributes to the acidification of the environment. Acidifying emissions disturb the composition of air, surface water, and soil (Bouet et al., 2005; Gooch, 2006). Thus, these emissions are damaging to ecosystems and are the cause, among other things, of forest decay, acidification of freshwater lakes, and disturbances in freshwater and marine aquatic food chains. They also contribute to the formation of acid rain, which is responsible for the degradation of buildings and monuments.

In terms of the acidification phenomenon, the relative importance of NH_3 emissions increases as a result of the downward trend in SO_2 emissions. On the other hand, ammonia emissions contribute to the eutrophication of the environment. Excessive nutrient intake (nitrogen in our case but phosphorus can also play a role) disrupts ecological processes and cycles. Deposits of large amounts of nitrogen attack the vitality of forests, can negatively affect crop quality, reduce biodiversity, and contribute to surface and groundwater pollution. However, it is important to remember that air pollutant concentrations are not solely related to local emission sources. They also depend on favorable or unfavorable weather conditions for the dispersion of pollutants, physico-chemical transformations in the atmosphere, and the contributions of pollution external to the Region.
From now on, the danger of a chemical is the set of properties that can give this product an aggressiveness towards man, material, and the environment. It is an intrinsic property of the compound that depends on its structure. Thus, exposure to a chemical substance is the set of conditions under which it is handled that is likely to cause a target to be exposed to the adverse effects of that substance (Chaib, 2019), in particular, products named persistent that may be miles away from the source of contamination and may affect anyone at any time. Therefore, any company must focus on analyzing these risks and controlling them.

METHODOLOGY

The methodology is based on the following points:
- Data recovery: recover all the data needed to carry out the study;
- Identification of hazard scenarios (HAZID, HAZOP….);
- Scenarios development: define the scenarios to be analyzed;
- Analysis of the frequency of the scenarios: estimate the frequency of the scenarios analyzed;
- Analysis of the consequences of the scenarios: estimate the consequences of the analyzed scenarios;
- Risk Estimation: Combine the frequency and consequences of the scenarios analyzed to obtain the associated risk levels and determine their acceptability to the acceptability criteria defined for the study.

These steps are detailed in the following paragraphs (Fig.1**)** **(**Hellas et al., 2018):

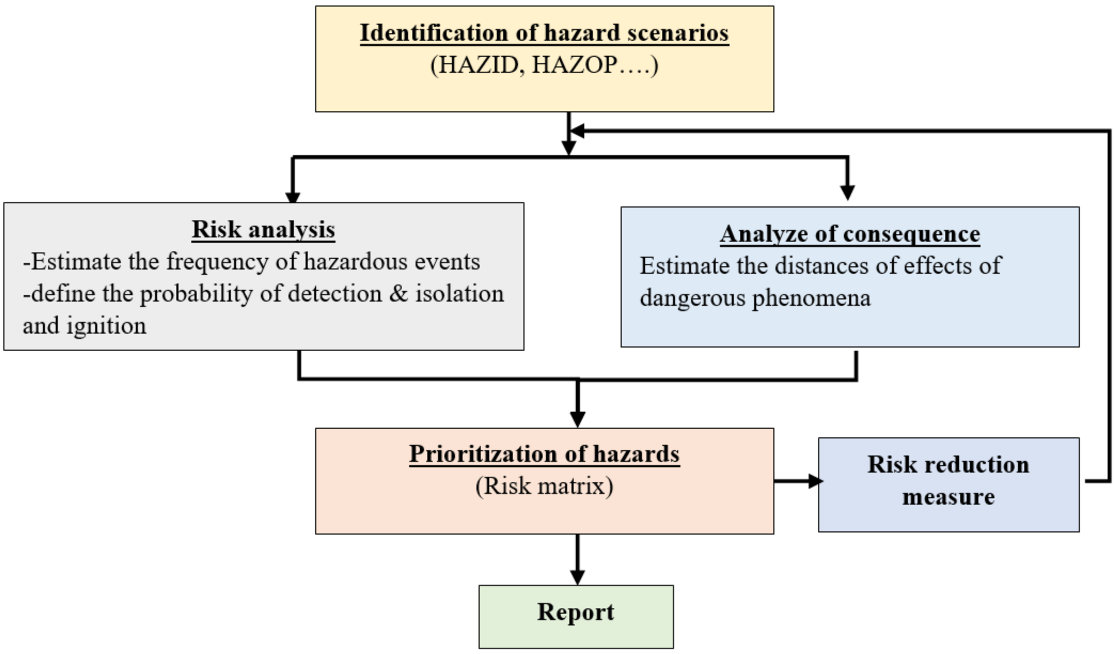

Fig.1. Methodology of the Proposed Work.

FIELDS OF STUDY

General Description of Site

The Fertial Factory in Arzew is for the purpose to construct a new facility to increase ammonia shipping. An ammonia transport structure, therefore, consists of two types of elements: A new pipe (ammonia transport line with a diameter of 16”) which allows the loading of ships from the tank with a loading rate of 1000t/h, and ancillary facilities: ammonia pumping facilities from the tank to the shipping dock, and new marine loading arms, and cooling pump.

Properties of ammonia

Ammonia is identified by the following characteristics (Table 1) (Bouet et al., 2005):

Table 1. Ammonia Characteristics

Name	Ammonia
CAS number	7664-41-7
CEE number	007-001-00-5
Code of danger RTMD	268
ONU number	1005
Chemical formula	NH3
Molar mass	17.03 g

Under atmospheric pressure and at 20°C, ammonia is a colorless gas with a characteristic pungent and irritating odor.

Thermodynamic data

- The main thermodynamic data for ammonia are as follows:
- melting point.......: - 77.7°C;
- Boiling point....: - 33.4°C to 1.013 bar abs;
- Critical temperature: 405.55 K;
- Critical pressure: 114.80 bar;
- Heat of fusion at 1.013 bars: 332.3 kJ.kg-1;
- Heat of vaporization at -15°C: 1 210 kJ.kg-1 (289.5 kcal.kg-1);
- Heat of vaporization at -33.4°C: 1 370 kJ.kg-1 (328 kcal.kg-1);
- Dynamic viscosity of the liquid at – 33.5°C: 10.225 mPa.s;
- One liter of liquid releases 947 liters of gas (expanded to 15 ℃, under 1 bar of pressure);
- Vapor pressure variable as a function of temperature (Table 2).

Table 2. Ammonia vapor pressure as a function of temperature

Temperature (°C)	Absolute pressure (bar
- 77.71	0.060
- 33.40	1.013
- 18.70	2.00
0.00	4.29
4.70	5.00
20.00	8.56
25.70	10.00
30.00	11.66
50.10	20.00
78.90	40.00

Density of ammoniac

- Gas: 0.772 kg.m-3 at 0 ° C and 0.610 kg.m-3 at 20 °C;
- Liquid: variable depending on the temperature as reported in Table 3:

Table 3. The density of ammonia as a function of temperature

Temperature (°C)	The density of liquid ammonia (kg.m^{-3})
-40	690
-33,4	679
-20	659
-10	647
0	634
10	621
15	617
20	607
30	592
50	558

Explosibility and Flammability

In literature, different values exist for Lower and Higher Explosive Limits (LEL and LSE). The reference sheet TOX 003-06-1998 [1]of the Industrial Environment Service of the Ministry of Spatial Planning and Environment provides the following values: LEL 16% and LSE 25%. These values are also indicated by Clouet (1989) and Lewis and Sax (1996). Other authors give slightly different values: LEL 15% and LSE 28% according to NFPA (1994)[2] and Medart (1979), LEL 15.5% and LSE 27% according to Weiss (1985).

Reference Values for Toxic Effects Thresholds

The reference values for classified facilities are as follows: Table 4:

Table 4. Thresholds of toxic effects for humans by inhalation

Types of effects observed	Exposure concentration	Reference
Lethal for 10 min	SELS (CL 5%) =12044ppm SEL (CL 1 %) =5400ppm CL50%=3700ppm	Acute inhalation toxicity curves - Ministry of Regional Planning and the Environment - 1998. (PRIMARIS.INERIS(2021))

- The thresholds of the first lethal effects in French (Les seuils des premiers effects létaux: SEL) correspond to a CL of 1% for the area of danger to human life;
- Significant Lethal Effects Thresholds significatifs in French (Les seuils des effects létaux: SELS) corresponding to a CL of 5% for the Very Serious Danger to Human Life Area.
- CL50 % The median lethal concentration (CL 501%) is the statistically inferred concentration of a substance that is expected to cause 50% of exposed animals over a specified period during or after exposure for a defined period (PRIMARIS.INERIS, 2021)).

IDENTIFICATION OF THE HAZARD SCENARIOS

[1] https://www.ineris.fr/sites/ineris.fr/files/contribution/Documents/ammonia.pdf
[2] https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1994

The purpose of this step is to identify the sources of hazards associated with the ammonia transport line using the HAZID method, Table 5, to determine the major accident scenarios and to list the prevention and protection measures in place.
Following the study of the HAZID review, it was decided that the most dangerous scenario is the total pipeline rupture which will emit a large quantity of gas into the atmosphere.

Table 5. HAZID

Danger	Cause	Consequence	Risk Master Measure
Loss of containment	-Design defect. -Failure or lack of leak detection. -Mechanical aggression, -Failure on neighboring pipelines, -Human error during manipulation, -Connection connection failed or unsuitable, -Obsolete equipment.	Spreading of liquid products on the ground and the formation of a toxic cloud in the atmosphere will present a danger for people (Liquid ammonia, which would spill, would contribute to the dispersion of a large amount of gas.).	-Hydraulic, strength, and sealing test -choice of materials adapted to the fluid under pressure, -visual and radiographic controls with strict criteria, -the production and inspection of connection welds by authorized agents; -Use of base materials of suitable pipe supports.

ANALYSE THE FREQUENCIES OF CONSEQUENCES

The frequencies of the initiating events are extracted from the company's data. On the contrary, probability detection, isolation, and inflammation are drawn from the literature (Exida, 2005; CCPS, 2000; Hellas et al., 2019). The accident scenarios are shown in figure 2:

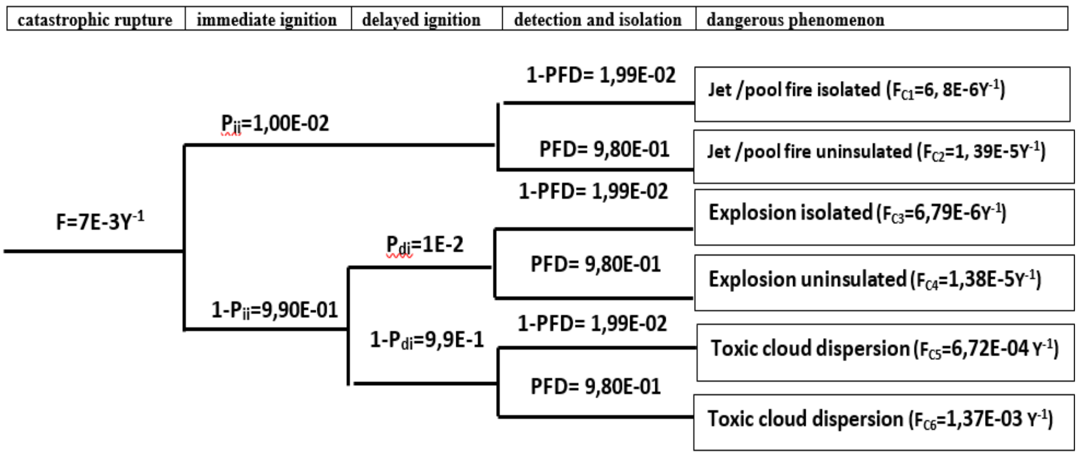

Fig.2. Event tree of the different accident scenarios.

According to the experiment router and the results of accident consequence frequencies (based on event tree), the toxic cloud dispersion phoneme is more common. Therefore, this phenomenon will be studied in detail in the consequence analysis step below.

ANALYZE OF CONSEQUENCE

The PHAST v8.2 (DNV, 2014) consequence modeling software was used to assess the consequences of releases to the area. The results of the analysis of the toxic effects of a catastrophic pipeline rupture are presented in figure 3 and Table 6:

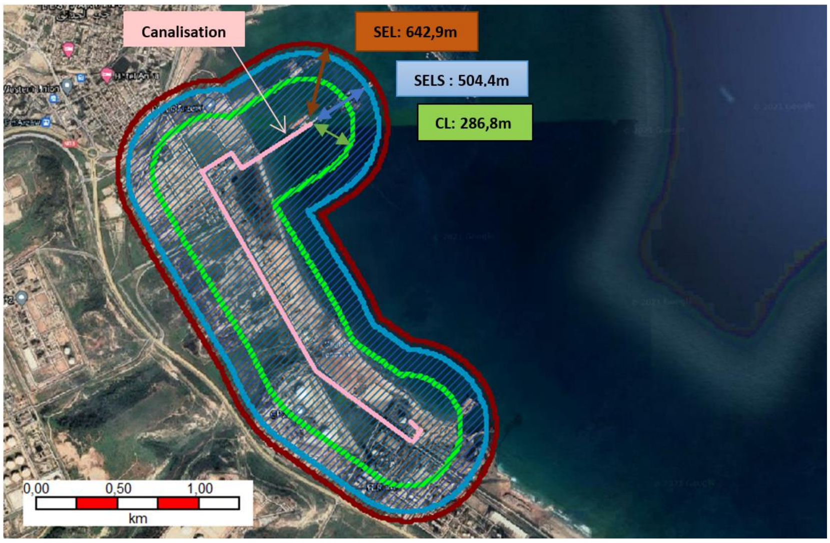

Fig.3. Dispersal zone for catastrophic failure.

Table 6. Determined distances from the dispersal zone

	value	unit
Mass flow rate	25.2616	kg/s
Temperature after atmospheric expansion	-33.4024	degC
Liquid fraction	0.998683	fraction
Velocity after atmospheric expansion (input)	4.12741	m/s
Rainout fraction time-averaged	0.961521	fraction
SALTS distance (CL 1%)	642.957	m
SALTS distance (CL 5 %)	504.474	m
Distance CL50%	286.858	m

PRIORITIZATION OF RISKS

All cases considered and analyzed are included, for illustrative purposes in the risks matrix (Mouilleau, 2012) in Table 7:

Table 7. Risks matrix

Probability of occurrence							
	5. certain	1,00E-02		FC6			
	4. likely	1,00E-03		FC5			
	3. possible	1,00E-04	FC2 FC4				
	2. unlikely	1,00E-05	FC1 FC3				
	1. Rare	1,00E-06					
			neglectable	minor	moderate	critical	Catastrophic
			impact				

Based on a risk acceptability criterion (risk matrix Table 8), the accident scenarios Fc1, Fc2, Fc 3, and Fc 4 are considered acceptable, whereas the scenarios Fc5 and Fc 6 are tolerable.

CONCLUSION

This paper has defined the risks incurred by the activity through its various phases. Following this study, necessary health and safety recommendations were established to avoid or fail to reduce the adverse effects on the health of the priority staff, the property of the Fertiel spa Unit of Arzew site, and the immediate environment., Lastly, from the results of risk analyses that the Fertiel project located in the industrial area of Arzew in the wilaya of Oran, does not present significant risks to the environment and the public as it meets the guidelines for the protection of the environment and the natural environment with the best technologies available internationally. However, we recommend the following operations:

- Regular verification of security equipment;
- Emptying and degassing of the hollow volumes (pipe);
- Installation of extinguishing and alarm means;
- Inform operators in the vicinity or who have pipelines in the same corridor.

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