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Major Hazard Risk Assessment on Ammonia Storage at Jordan Phosphate Mines Company (JPMC) in Aqaba, Jordan

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The aim of this paper is to discuss the risks associated with the storage of liquid ammonia in an industrial facility close to the Red Sea (Jordan, Aqaba region). This region has a unique ecosystem where touristic and industrial facilities coexist. Therefore, the identification of the accidental scenarios that may harm people or the environment is very important in order to assess the effectiveness of the existent safety measures and to recommend additional ones for improvement.

Liquid ammonia is delivered to the facility in a dedicated port on the Red Sea and pumped through a 1.6 km long pipe to the two storage tanks of 30,000 and 10,000 ton. A risk analysis was conducted together with the technical staff of the facility as part of the Cleaner Production Project financed by the Swiss State Secretariat for Economic Affairs (seco).

The "worst case" scenarios identified were:

- Total rupture of the ammonia storage tank with a capacity of 30,000 ton.
- Total rupture of ammonia feeding pipeline from ship.
- Hole (crack) in ammonia storage tank.
- Ammonia vapor release through the safety valves of the storage tank with a capacity of 30,000 ton.
- Hole in ammonia feeding pipeline during the unloading

The existing safety measures proved to be sufficient. However, it was recommended to provide an automatic foam installation on the bund of the tanks and better protection of the pipeline in order to improve the safety of the storage facility.

1. Introduction

This paper presents the result of major risk analysis study concerning the ammonia storage tanks and their facilities (pipeline and refrigeration system) at Jordan Phosphate Mining Company (JPMC) in Jordan. The study was done by JPMC, FHNW and Cleaner Production Unit (CPU) of the Royal Scientific Society (RSS) staff under the supervision of Dr. Pablo Lerena a Risk Analysis (RA) Consultant of the Swiss Institute for the Promotion of Safety and Security (SWISSI). The study based on the information given by JPMC following the guidelines of the Major Hazard Accidents Bureau of the

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European Community and using the effects modelling software Areal Locations of Hazardous Atmospheres (ALOHA) created by the United States / Environmental Protection Agency (US-EPA).

JPMC was established in 1935 to exploit phosphate deposit. It owns and operates an Industrial Complex located about 20 km south of Aqaba town. The facility produces sulphuric acid, phosphoric acid, di-ammonium phosphate and aluminium fluoride. It employs about 900 persons in all departments. The plant runs 24 hours in 3 shifts. The main raw materials consumed are phosphate rock, sulphur, anhydrous ammonia, aluminium hydroxide and small amounts of sodium hydroxide.

2. Methodology

This study is limited to identifying the major accident hazard of ammonia storage tanks (including cooling system) and pipeline from the Jetty. The methodology described in the Appendix 2 of the User Guide of the EC Project Aramis [www. aramis.jrc.it/] was applied in order to identify which parts of the installations should be considered as a potential source of major accidents. This method consists of comparing the mass of the hazardous substance contained in the equipment with a reference mass which depends on the dangerous properties of the substance. This reference mass is corrected by certain coefficients that takes into account the physical state of the substance in the equipment and its volatility. According to this method, the feeding pipeline from tanker (ship) to the ammonia storage tank and the storage tank itself (30,000 ton capacity) were identified as relevant hazardous equipment.

Then the major-accident scenarios were identified by the risk analysis team. The team defined - based on its experience - the safety relevant loss of containment events (LOC) that could happen in the selected hazardous relevant equipment. Accordingly, five major accident scenarios were identified which will be presented in the next section.

ALOHA software was used to model the effects of each scenario taking into consideration the usual atmospheric conditions as well as the worst case atmospheric conditions. ALOHA is a computer program designed specially for use by people responding to chemical releases, as well as for emergency planning. ALOHA models key hazards - toxicity, flammability, thermal radiation (heat) and overpressure (explosion, blast, force) - related to chemical releases that result in toxic gas dispersions, fires and/or explosions.

Also, the failure rate per year of each scenario is calculated based on the failure rates stated in the Rijnmond database.

Finally, the mitigation measures which are implemented by JPMC are assessed and additional mitigation measures are recommended.

3. Results

The Ammonia storage tanks and feeding pipeline from tanker (ship) have been considered as the potential sources of major accidents according to the above mentioned methodology. The maximum quantity of liquid ammonia in both of them respectively is 111,120 kg and 21,000,000 kg which are much larger than the reference mass of 5,995 kg.

The study team defined the safety relevant loss of containment events (LOC) that could happen in the selected hazardous relevant equipment. Accordingly, the following five major accident scenarios were identified:

Scenario 1: Total rupture of the ammonia storage tank with a capacity of 30,000 ton.

Scenario 2: Total rupture of ammonia feeding pipeline from ship.

Scenario 3: Hole (crack) in ammonia storage tank.
Scenario 4: Ammonia vapor release through the safety valves of the storage tank with a capacity of 30,000 ton.
Scenario 5: Hole in ammonia feeding pipeline during the unloading.
ALOHA was used to model the effects of each scenario. The atmospheric data in Table 1 was used to model the scenarios using ALOHA software where in addition to the usual atmospheric conditions, extreme conditions (very low wind speed at extremely stable atmosphere) was taken into consideration as worst case scenario.

Table 1 Atmospheric data used in ALOHA

Property	Value
Wind velocity [$m \cdot s^{-1}$]	2 (extreme)
	5 (usual)
Stability Class	F: High stable weather condition (extreme)
	B: Normal (usual) weather condition
Wind direction (prevailing)	North
Humidity [%]	70
Ambient Temperature [°C]	30
Inversion Height	No inversion
Cloud Cover	Clear

Table 2 shows the results of the assessment using the above mentioned ALOHA modeling software.
The failure rates per year (critical event frequency) of each scenario is calculated based on the failure rates from Rijnmond database (in different units) and according to some facts and assumptions. The final conclusive data base failure rate per year of each scenario is shown in Table 3.

Table 2: ALOHA modeling results (different scenarios effects)

Scenario No.	Atmospheric condition	Toxic Effects (meter from source)				100 % LEL (meters)
		LC 100%	LC 1% (5 min.)	LC 1% (10 min.)	LC 1% (30 min.)	
1	Extreme 2F	111 (5 min.) 117 (30 min.)	1’754	1’904	2’124	164
	Usual 5B	No threat zone outside the pool	170	144	170	No threat zone outside the pool
2	Extreme 2F	423 (5 min.)	1’500	No threat zone	No threat zone	452
	Usual 5B	75 (5 min.)	300	No threat zone	No threat zone	80
3	Extreme 2F	85 (5 min.) 129 (30 min.)	360	440	735	89
	Usual 5B	No threat zone	58	68	90	No threat zone
4	Extreme 2F	No threat zone	No threat zone	No threat zone	No threat zone	No threat zone
	Usual 5B	No threat zone	No threat zone	No threat zone	No threat zone	No threat zone
5	Extreme 2F	No threat zone	330	No threat zone	No threat zone	No threat zone
	Usual 5B	No threat zone	59	No threat zone	No threat zone	No threat zone

Notes:
100 % LEL: Lower explosive limit at which 100% lethality occur due to flash fire.
LC 100%: Lethal concentration 100% of persons affected, which according to Effects Modeling Software Database equals 90’000 ppm for exposure time of 5 min. and 40’000 ppm for exposure time of 30 min.
LC 1%: Lethal concentration 1% of persons affected according to Effects Modeling Software:
LC 1% (5 min) = 4'150 mg/m^3 = 5'860 ppm (volume)
LC 1% (10 min) = 2'930 mg/m^3 = 4'137 ppm (volume)
LC 1% (30 min) = 1'690 mg/m^3 = 2'386 ppm (volume)
In Scenario No 1 the distance is from the edge of the pool (ALOHA considers the pool as circle and calculate the effective diameter (in this case, the pool radius = 66 m).
According to international standards, we can use the lethal concentration 1% for 30 minutes exposure time as a toxic level of concern for vulnerable (national roads, crowded traffic) or very vulnerable targets (schools, hospitals, mosques).
In Scenario No 2 the time of toxic-cloud passage is 5 minutes.
In Scenario No 3 the distance is from the tank edge.

Table 3: Failure rates per year for each scenario

Scenario name	Failure rate (per year)	Interpretation
Catastrophic rupture of atmospheric storage tanks	$6x10^{-6}$	The frequency of occurrence of this scenario is 6 times every 1 million years
> 150 mm diameter pipe catastrophic rupture	$4.6x10^{-6}$	The frequency of occurrence of this scenario is 4.6 times every 1 million years
Serious leakage of atmospheric storage tanks	1×10^{-4}	The frequency of occurrence of this scenario is 1 time every 10 thousand years
Leakage of pressure relief valve	2.16×10^{-4}	The frequency of occurrence of this scenario is 2.16 times every 10 thousand years
> 150 mm diameter pipe significant leakage	$1.38 x10^{-4}$	The frequency of occurrence of this scenario is 1.38 times every 10 thousand years

4. Discussion and evaluation of results

In regard to the severity of risk, the modeling results of Scenario No 1 show that at the extreme weather conditions (2F) there is a risk of having fatalities at short distance from the pool, even with short exposure times (5 minutes) as well as and public toxic effects, while the threat zone will be inside the company in case of usual weather conditions (5B). Regarding to the other scenarios, the threat zone is expected to be in the company border and at the extreme weather conditions the threat zone could reach the nearby industrial neighbors, taking into consideration that much lower concentrations of ammonia are expected to occur inside enclosed offices (Building Air Exchange per Hour = 0.50).

The final frequency of damage (e.g. no of deaths or severe injured per year) depends not only on the failure rates of the loss of containment event but also on other factors such as the probabilities of weather conditions (wind speed, wind direction and stability), existing safety mitigation measures and the presence of unprotected persons in the threat zone (outside the buildings).

According to available meteorological data of Dura-station in Aqaba, the average monthly wind speed is always higher than 2 m/s (or 4 knots). This means that - even if we do not consider additional safety measures - the probability of having negative effects of different scenarios at the extreme atmospheric condition (2F) will be low.

JPMC has implemented mitigation measures that could reduce the calculated effect of the scenarios such as safety equipments at ammonia control room, safety showers, ammonia sensors in the tanks area, two firefighting vehicles (water & foam), medical center, two ambulances, a warning system located in site to warn all employees in the event of an emergency in their particular work area and wind measurement system (speed & direction). In addition, it is worth to mention that JPMC has a regular inspection program of the ammonia storage tanks and pipelines.

5. Conclusions

The existing safety measures proved to be sufficient, however the evaluation of the risk assessment results in addition to site auditing lead to a number of major recommendations and as follows:

- The installation of a high expansion foam system will reduce significantly the toxic effects in case of any significant leakage in the ammonia storage area (scenarios 1 and 3). Its installation is thus highly recommended.
- Coordinate and exercise emergency plan together with neighboring companies e.g., “neighbors to stay inside the buildings in case of alarm after a major ammonia leak”.
- The road close to the pipeline bridge is equipped with physical barriers to protect the pipeline rack and structural support. However, because of works on the road, these are partially dismantled. It is recommended to reinstall them properly.
- Firefighters should be aware of the possibility of flash fires and should take adequate precautions (portable explosimeters, protective equipment, etc.).
- Check the possibility to introduce further isolation valves in the ammonia feed pipe between jetty and the tanks (would reduce the amount of ammonia released in case of a major leak).
- During the discharge the people working in the jetty should have rapid access to personal safety equipment and search for shelter in a short time (minutes).

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