MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

18th Annual International Symposium
October 27-29, 2015 • College Station, Texas

Facility Siting of an Ammonia-Urea Complex Based on Risk Analysis

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Abstract

In this study facility siting of an existing ammonia-urea complex is evaluated based on risk analysis. A number of critical process units of the plant are selected as the sources of toxic release and overpressure. Locations of control room and two operators' shelters are considered with respect to four critical units. The consequences due to toxic release and blast overpressure are modeled for various worst case scenarios developed in critical units. Both structural damage and human mortality/injury are converted into risk factors and locations with minimum risk factors within plant area are identified for the probable siting of the control room and operators' shelters. The findings are compared with the existing layout of the ammonia-urea complex considered.

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1. Introduction

The major accident in the history of chemical industry of Bangladesh occurred in June, 1991 in a urea fertilizer factory. About 50 people in and near the control room were affected and 7 of total 11 died on spot. Although the accident was caused by faulty welding of a column, the location and safety features of the control room were the key factors that lead to the fatality. Bangladesh is an agro-based country and currently, seven fertilizer factories are producing approximately 2.5 million tons of urea per year. To ensure food security and improve nutritional status the government of Bangladesh is planning to build new energy efficient factories in near future. A safe facility siting plan is critical for ensuring safe operation and growth of these plants.

The present study is aimed at exploring safe options of facility siting in an ammonia-urea fertilizer plant. The study is based on the methodology developed by Jung (2010) and adopted by Rahman et al. (2014) and utilizes their concept of QRA to determine combined risk scores due to toxic release and vapor cloud explosion for an existing ammonia-urea plant. Three main units of ammonia plant, namely, the primary reformer, secondary reformer and the ammonia converter and the urea converter of the urea plant have been considered for accidental release. The layout of the existing ammonia-urea plant is used to identify safe locations for control room and operators' shelters.

2. Methodology

Figure 1 shows the steps followed for the quantification of risk and risk mapping of the plant. At first the accident scenarios were set. In this study rupture of vessel is considered to be the leading causes of accidents. The scenarios considered are:

- Rupture of ammonia converter
- Rupture of primary reformer
- Rupture of secondary reformer
- Rupture of urea synthesis reactor

These units are chosen based on their operating conditions and reported accident frequencies (Rahman et al., 2014). In each of these units, toxic release of ammonia and blast over pressure for vapor cloud explosion (VCE) due to hydrogen are considered.

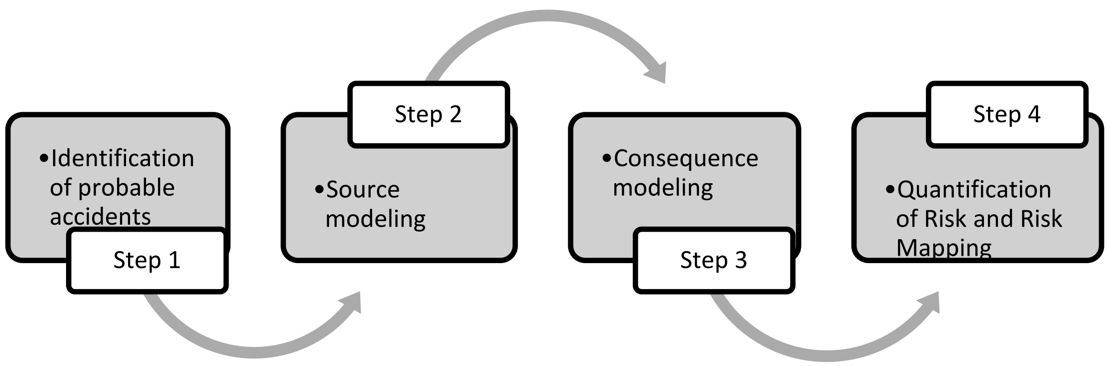


Figure 1: Steps used for risk quantification and risk mapping

After selection of accident scenario, realistic accidents are considered with worst outcomes. The ruptures are considered to be of the size of holes of the largest pipe entering or exiting a unit. In order to incorporate the worst case scenario it is assumed that entire content within the unit is released upon the rupture within 10 minutes. The wind speed was considered to be 1.5 m/s (Crowl and Louvar, 2011). From the data available for annual average temperature, the ambient temperature is considered to be 32℃. The relative humidity is considered to be 50%. The substances released are considered to be at the exit temperature of each unit.

Dispersion of gas due to leakage or rupture in process equipments generally depends on wind speed, wind direction, atmospheric stability, ground conditions, and height of the release above the ground level, momentum and buoyancy of the initial material released. As the wind speed increases, the plume becomes longer and narrower. Consequently, the substance is carried downwind faster with more dilution by large quantity of air.

In this study ALOHA is used for modeling the accidental release. One of the significant factors highlighted in this study is the wind direction. Wind directions are considered to be north-west and south-east based on annual wind directions in consequence modeling. At first, the amount of release occurring is expressed either in the form of concentration or blast overpressure. The concentration/blast overpressure at a certain distance from the origin of source is determined for the toxic release/VCE. Next, the concentrations and overpressures are converted into probit functions to determine probability of death. In case of toxic release, the probit function used for ammonia is,

$$Pr = -28.33 + 2.27 (\ln(C^{1.36} * t))$$

Here, C is concentration in ppm and t is time in minutes (Q. Consultant, 2010).

Unlike toxic release or potential fire hazards, persons who are exposed to overpressures have no time to react or take shelters. Thus, time does not enter into the hazard relationship. Work by the Health and Safety Executive, UK, has produced a probit relationship based on peak overpressure. This probit equation has the following form (HSE, 2011)

$$Pr = 1.47 + 1.37 (\ln(P))$$

Where, p = peak overpressure, psig

The above probit values were then converted into Risk Scores. Risk Score is the probability of toxic release or structural damage in the entire lifetime of the plant and is expressed as follows (Jung, 2010; Jung et al., 2010):

Risk Score = Pr × Frequency of occurrence × Lifetime of plant × weighing factor

The lifetime of the plant was considered 20 years and the weighing factor was taken 100. Table 1 presents the frequencies of occurrence of different accidents (GHD, 2009; HSE, 2012; P. Consultant, 2011) considered in this study.

Table 1: Frequency of occurrences

Process Unit	Type of Worst Case Scenario	Frequency (Leak/yr)
Ammonia Converter	Blast Overpressure due to VCE	1.14×10^{-5}
	Toxic Release of Ammonia	
Primary Reformer	Blast Overpressure due to VCE	2.05×10^{-3}
Secondary Reformer	Blast Overpressure due to VCE	2.28×10^{-5}
Urea Reactor	Blast Overpressure due to VCE	5×10^{-5}
	Toxic Release of Ammonia	

3. Case Study: Evaluation of Facility Siting of an Existing Ammonia-Urea Plant

The ammonia-urea complex under consideration resides in Chittagong, Bangladesh. Figure 2 shows the current locations of four major units and three facilities in a simplified plot plan of the complex. The major units that have been considered in this study are, namely, the ammonia converter, primary reformer, secondary reformer and the urea synthesis reactor. The objective is to evaluate whether the facilities, such as, control room or operators' shelters are safely sited with respect to the major units mentioned above. In the existing layout, the ammonia and urea plant share a common control room located at the south-east part of the complex outside of the processing area. There are three operators' shelters in the plant. The first and second shelters reside within the plant area. The third one is situated at the north-east part of the complex outside of the plant area. The location of the plant experiences annual wind mainly from north-west and south-east directions.

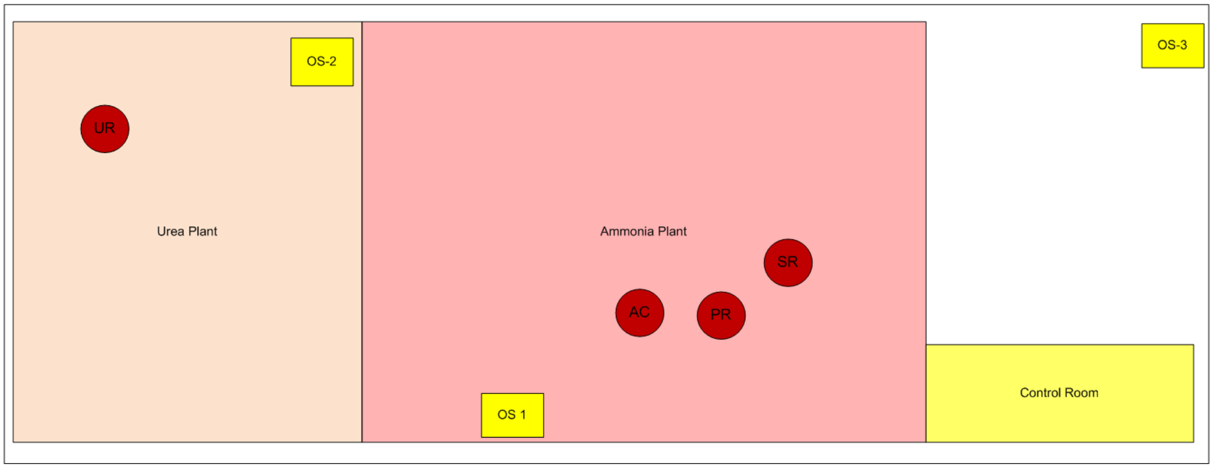
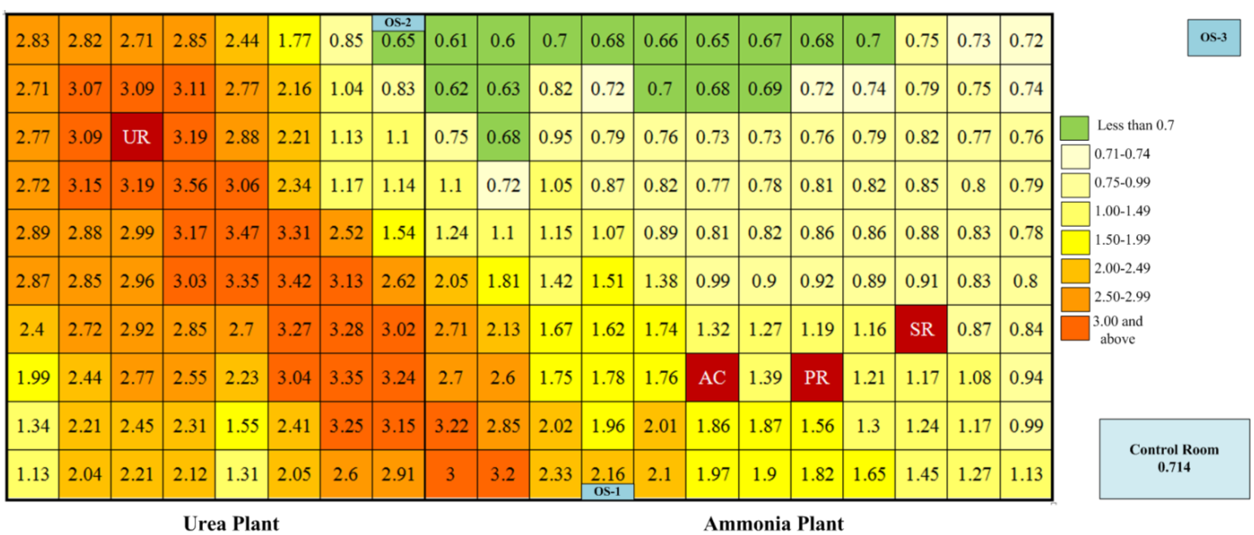


Figure 2: Simplified plot plan of the ammonia-urea complex showing major units and facilities

For the present study, the plant area is divided into 10 by 20 grids. Each grid is of a square of 10 meters on each side. Figure 3 shows the estimated risk scores for different grids. The combined risk scores vary from 0.6 to 3.5. From the trend of the risk score values, it is noted that both wind velocity and direction are key contributors to the risk scores. The relatively high risk scores along north-west and south-east directions of the four units reflect this effect of wind.



2.83	2.82	2.71	2.85	2.44	1.77	0.85	0.65	0.61	0.6	0.7	0.68	0.66	0.65	0.67	0.68	0.7	0.75	0.73	0.72
2.71	3.07	3.09	3.11	2.77	2.16	1.04	0.83	0.62	0.63	0.82	0.72	0.7	0.68	0.69	0.72	0.74	0.79	0.75	0.74
2.77	3.09	UR	3.19	2.88	2.21	1.13	1.1	0.75	0.68	0.95	0.79	0.76	0.73	0.73	0.76	0.79	0.82	0.77	0.76
2.72	3.15	3.19	3.56	3.06	2.34	1.17	1.14	1.1	0.72	1.05	0.87	0.82	0.77	0.78	0.81	0.82	0.85	0.8	0.79
2.89	2.88	2.99	3.17	3.47	3.31	2.52	1.54	1.24	1.1	1.15	1.07	0.89	0.81	0.82	0.86	0.86	0.88	0.83	0.78
2.87	2.85	2.96	3.03	3.35	3.42	3.13	2.62	2.05	1.81	1.42	1.51	1.38	0.99	0.9	0.92	0.89	0.91	0.83	0.8
2.4	2.72	2.92	2.85	2.7	3.27	3.28	3.02	2.71	2.13	1.67	1.62	1.74	1.32	1.27	1.19	1.16	SR	0.87	0.84
1.99	2.44	2.77	2.55	2.23	3.04	3.35	3.24	2.7	2.6	1.75	1.78	1.76	AC	1.39	PR	1.21	1.17	1.08	0.94
1.34	2.21	2.45	2.31	1.55	2.41	3.25	3.15	3.22	2.85	2.02	1.96	2.01	1.86	1.87	1.56	1.3	1.24	1.17	0.99
1.13	2.04	2.21	2.12	1.31	2.05	2.6	2.91	3	3.2	2.33	2.16	2.1	1.97	1.9	1.82	1.65	1.45	1.27	1.13

Figure 3: Estimated risk scores of ammonia-urea plant

In the existing layout, the control room is at the south-east corner of the complex. When wind comes from the north-west direction, the present location of the control room is susceptible to higher risk of release compared to any other locations north to it. Figure 3 also shows that the location of operators' shelter 3 is in high risk zone due to the same reason, i.e. it is at the south-east corner of the urea plant and susceptible to north-west wind flow. The risk map also shows that the lowest risk scores are obtained along the north boundary of the ammonia plant.

Figure 4 shows suggestions for safe locations for the facilities based on the estimated risk scores. While operator's shelter-2 and operator's shelter-3 have safe locations in present layout, moving the operator's shelter-1 upward towards the north boundary would place it in a relatively low risk zone compared to the current location. There are two alternative suggestions for the location of control room. Considering the high risk scores at the south-east part of the layout, a safer position for the control room would be at the top right i.e. north-east corner of the complex compared to the present south-east location. One the other hand, the existence of relatively safe zone between the urea and ammonia plant at the north boundary is of great interest from both design and operational perspectives. Since the control room is shared by both urea and ammonia plants, locating this room between the two plants along the north boundary will reduce the cost of wiring and piping significantly as well as make operators' movement to and from plant sites convenient.

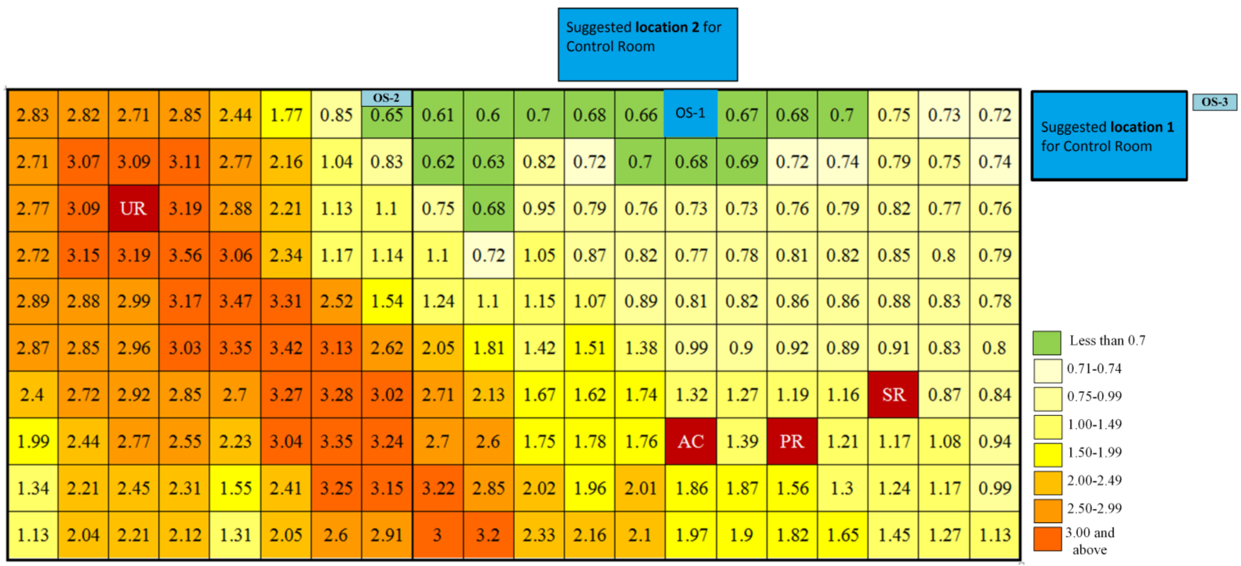


Figure 4: Suggested locations for control room and operators' shelter -1

4. Conclusion

An approach to determine safe locations for the facilities of an ammonia-urea complex is presented here. The effect of accidental release from four major units on the surrounding plant area is expressed in terms of combined risk scores. Based on the relative values of the risk scores inferences are drawn regarding the safe siting of facilities including control room and three operators' shelters. It is found that the wind direction play a critical role in determining safe locations in the plant area.

It is to be noted that the exact value of risk scores are very much sensitive to the considered accident scenarios as well as used consequence model, probit function and frequency. The present study gives an estimate of the risk scores for an ammonia-urea plant that would be useful for further study and comparison purpose.

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