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ORIGINAL RESEARCH PAPER

Risk analysis of ammonia release in food refrigeration Using FTA technique and fuzzy logic

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ABSTRACT

The purpose of this research was to analyze the risk of ammonia release in the cold storage of one of the large food companies in Mashhad. This was applied research that was done using FTA technique and fuzzy logic. Fuzzy logic was used to weight experts' opinions (Delphi panel). In this study, to model the consequences and calculate the collective risk using the DNV PHAST 7.2 software, the most critical conditions that have the greatest possible contribution to the release of ammonia were lack of proper and planned maintenance, pressure increase and failure and defects in gaskets respectively. Also, the results showed that the rate of death, toxicity and explosion was directly related to the distance. On the other hand, the maximum amount of possible losses in the event of an explosion will be in the winter season and at a distance of 14.26 meters, and finally, 95% of the losses due to the blast wave will occur at a distance of 13.54 meters and 99% of deaths of people up to a radius of 38.89 meters, also 50% of the deaths of people from the radius of 38.89 meters to the radius of 124.93 meters, and 10% of the deaths of people from the radius of 124.93 meters to the radius of 178.53 meters, also 1 percent of deaths from the radius of 178.53 meters to the radius of 234.05 meters. The FTA tree showed that several factors alone or together can be involved in the occurrence of the peak event.

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1. Background

Using cold and cold storage for food storage has been one of the basic and old methods to maintain the quality of food and prevent the process of spoilage. A cold room is a place to keep goods cold (Amini 2014). In fact, it is a set of buildings and facilities to maintain the quality of a product. One of the most important tasks of a cold store is to prevent the spoilage of the goods inside it by maintaining long-term quality (Bek Beki et al. 2016). Its application in food storage, agriculture, all kinds of medicines, military systems, fruit and vegetables and other similar cases is not summarized and is very wide (Anjana et al. 2018). The importance of this industry is such that one of the criteria for measuring technological growth in a country is the number of food freezing industrial units and refrigerated transportation systems and cold storage facilities (Mirzaei Aliabadi et al. 2015). Ammonia refrigeration system was formed in 1930 with the production of various types of Feryons and was widely used in home and commercial systems. Until 1985, the issue of preserving the ozone layer and the role of chlorine atoms in the destruction of the ozone layer was raised (Zhu et al. 2019; Mousavi Moghanjooghi et al., 2022). In 1987, with the approval of the Montreal directive entitled "Prohibition of production of ozone-depleting refrigerants" during the schedule, all CFC and HCF refrigerants were removed from the production and use schedule, which led to the invention of new HFC refrigerants. HFC refrigerants do not have the problem of destroying the ozone layer, but they have a high potential in greenhouse heat, which is prohibited by the adoption of the Kyoto Protocol in 1997 under the title "Prohibition of the use of substances with a high potential for global warming" and led to the discovery and use of synthetic and synthetic refrigerants, as well as a return to the use of natural refrigerants such as ammonia (Oruji et al. 2013; Amini 2014; Fataei et al., 2017).

Today, the condensation refrigeration cycle is widely used in the food industry, such as sub-zero and above-zero cold stores, ice factories, meat and poultry freezing tunnels, dairy and soft drink industries, and chemical industries. One of the most important issues in Ammonia cold storage is the possibility of Ammonia leakage from storage tanks of this toxic substance, which must be carefully studied and prevented (Liu et al. 2016). Ammonia with the chemical formula NH3 is the most important hydrogenated-nitrogen compound. Ammonia molecule is a polar molecule that can form hydrogen bonds with it and many other molecules (Jafari & Zarei 2012 Esmaeilzadeh et al., 2021). Ammonium is not a toxic substance, but its toxicity is related to the pH value. Ammonium ion NH4 can be converted to ammonia NH3. Therefore, ammonia exists in two forms: ammonium (NH4), which is not toxic, and ammonia (NH3), which is a highly toxic substance (Anjana et al. 2018;Fataei, 2016). Two factors, pH and water temperature, affect its toxicity. pH has the greatest effect on ammonia toxicity(Jeddi et al.,2015; Nouri Mashiran, and Fataei,2015). Ammonia irritates the respiratory system, skin and eyes, and it can cause death by damaging the lungs due to exposure to a large volume of this gas (Dave 2018; Alishiri and Fataei,2015; Coronel-Chugden, 2023).

Ammonia has the ability to explode and burn, but the risk of combustion is much lower than the risk of toxicity. Its contact limit for 8 hours of work per day and 5 days per week (TLV) is about 25 ppm. Exposure to gaseous ammonia in very high concentrations (above 2000 ppm) can cause damage to the skin and organs (Anvaripour 2018). Its 72 ppm eye contact can cause discomfort for some people, and its 134 ppm concentration can be irritating for everyone. Contact with 700 ppm concentration of ammonia quickly and severely causes discomfort and eye irritation (Bahoo Toroodi et al. 2016; Sun and Khayatnezhad, 2021, Wang et al., 2022). Considering the above, any release of ammonia from the closed-circuit cooling system in very large industrial cold stores can have irreparable consequences and a high risk. The leakage of toxic and dangerous substances in process and chemical industries has always been one of the factors that threaten the health of workers and residents around these industries, as well as damage to the environment (Jafari & Zarei 2012; Ahmadi et al., 2019; Fazeli et al., 2019; Talaei et al., 2022). Ammonia levels above 200 ppm are dangerous for humans, and due to the special conditions of its storage and maintenance in large tanks of urea and chemical fertilizer production units and cold storage systems, the leakage of this gas always causes the death of dozens of people (Dong et al. 2017). Although in the chemical industry, special measures are taken to prevent the leakage of materials and the occurrence of such incidents, but often due to human errors during unit control or process problems during repairs, leakage occurs. Therefore, one of the effective methods in carrying out preventive measures is to study the consequences of accidents using risk assessment methods (Goldshleger et al. 2018; Karimi et al., 2023). Nowadays a project confronts with many different risks that if faced with each of them the results have to be reviewed (Cheraghi et al. 2018). Risks are an inherent part of all industrial projects and their complete elimination is impossible (Jabraeil Nejad and Fataei 2015; Jafari et al., 2017; Marrani et al., 2019).

Most parts of cooling systems contain large amounts of ammonia. If ammonia is under pressure, this issue can greatly increase the possibility of contamination of the environment with this toxic substance. This pollution and leakage of ammonia gas to the surrounding environment can be due to two reasons, which are:

- An unusual increase in the pressure of ammonia gas in the cooling system, more than the normal operating mode, so that the system can no longer tolerate its maintenance.
- Technical defects in cooling equipment due to impact, decay, corrosion and other similar cases (Yazdi et al. 2017).

In the past, little research has been done on the risk of ammonia. Like: Amini (2005); Rashtchian et al. (2005); Talebzadeh et al. (2009); Amyotte et al. (2009); Narimannejad et al. (2009); Molaei & Rashtchian (2010); Bek Beki (2016); Shem et al. (2017); Anjana et al. (2018).

In this research, an attempt was made to evaluate the risk caused by the release of ammonia from an ammonia cooling system in one of the largest food cold storage complexes in the east of the country.

2. Materials and Methods

This research is of applied type. Library studies were used to collect basic data about activities, operations, processes and also to identify risks. In order to analyze the data and convert them into the desired information, the following techniques have been used:

- Fault Tree Analysis Technique
- Fuzzy Logic Technique
- ISO Graph Reliability Workbench 4 software

In order to quantify the probability of ammonia release, two approaches have been used that include the following steps:

A) Determining the probability of the final event (release and leakage of ammonia) with the approach of fault tree analysis (FTA), which includes the following steps:

- Definition of the top event in this research
- Definition and identification of possible errors / Basic & Intermediate Events
- Calculate the probability of basic events using the component failure rate or repeatability of events
- Calculate the probability of the final event using the probability of basic and intermediate events (Li et al. 2017).

b) Determining the probability of the final event with the combined approach of FTA and fuzzy logic technique for basic events without information about the failure rate or ambiguous information (Zhang et al. 2020).

Regarding the unknown risks and converting the obtained information into corresponding fuzzy numbers, the opinions of experts were measured using a questionnaire.

Linguistic terms were used to quantify the opinion of experts regarding the amount of basic occurrences. Five language terms including very low, low, medium, high and very high were used (Preyssl 1995). The fuzzy domain of linguistic terms used in the research proposed by Jangjoo (2021) and is shown in Figure 1.

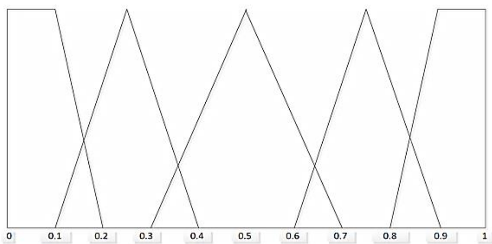

Fig 1. A language term used by experts

Expert opinions were quantified using the method provided by Hwang and Chen (1992). To obtain the weight of the experts' opinion, the relative weight of each expert is multiplied by the fuzzy corresponding number of that opinion (Rausand & Hoyland 2004). To obtain the final number of the opinion, Equation 1 is used to obtain the final number of comments (Qu et al. 2013).

$$M_{ij} = \frac{\sum W_i A_i \quad (i = 1,2,3,\ldots,m)}{J} \tag{1}$$

In this regard, Wi is the weighted score of each expert, Ai is the score of language semesters, and J is the number of experts (Bek Beki et al., 2016).

The corresponding fuzzy number will be converted into the corresponding single number by using the Difuzzy formula (2) (Spouge, 2000).

$$CFP = \frac{1}{3}\frac{(a_4 + a_3)^2 - a_4a_3 - (a_1 + a_2)^2 + a_1a_2}{(a_4 + a_3 - a_2 - a_1)} \tag{2}$$

In this study, DNV PHAST 7.2 consequence modeling software was used to model different consequences and calculate the collective risk caused by the ammonia release event. For modeling, it is necessary to specify the 10,000-liter receiver tank containing ammonia on the site map Ammonia release event in this study is defined as a sudden release scenario. In this scenario, ammonia is released all at once and with the pressure inside the tank, and the entire contents of the fluid inside the tank are thrown out of the tank. The details related to the characteristics of weather, explosion and ignition are presented in the following tables.. The location of the tank is shown in orange on the map below. This tank is located in a building that has ventilation to the outside. According to the specification of the fan used in this building, the evacuation rate from the building is considered to be 1500 m3/hr.

Ammonia release event in this study is defined as a sudden release scenario. In this scenario, ammonia is released all at once and with the pressure inside the tank, and the entire contents of the fluid inside the tank are thrown out of the tank. The details related to the characteristics of weather, explosion and ignition are presented in the following tables. In this study, all four

Fig 2. Aerial photo of the location of the food industrial cold storage building with ammonia cooling system

Table 2. Climate conditions considered for modeling the consequences of ammonia release

Grouping	Season	T $C°$	% Relative humidity	Wind speed m/s	Wind direction	The amount of sunlight kw/m^2
1.5 F	Summer	38	%36	1.5	South	0.7
5B	Winter	2	%76	5	South	0.4

Table 2. The severity of fire damage

Intensity of thermal radiation	The amount of damage	Death percentage
0.5 kw/m^2	No damage - sunlight	%0
4 kw/m^2	Pain threshold	%1
20 kw/m^2	Severe skin damage	٪ 10
37.5 kw/m^2	Damage to equipment and instant death	٪99

(Source: Li et al., 2017)

levels of damage and percentage of death due to fire are considered.

3. Results

Figure 3, drawing the fault tree for ammonia release from the cold storage cooling system under study is shown by ISO Graph Reliability Workbench 14® software.

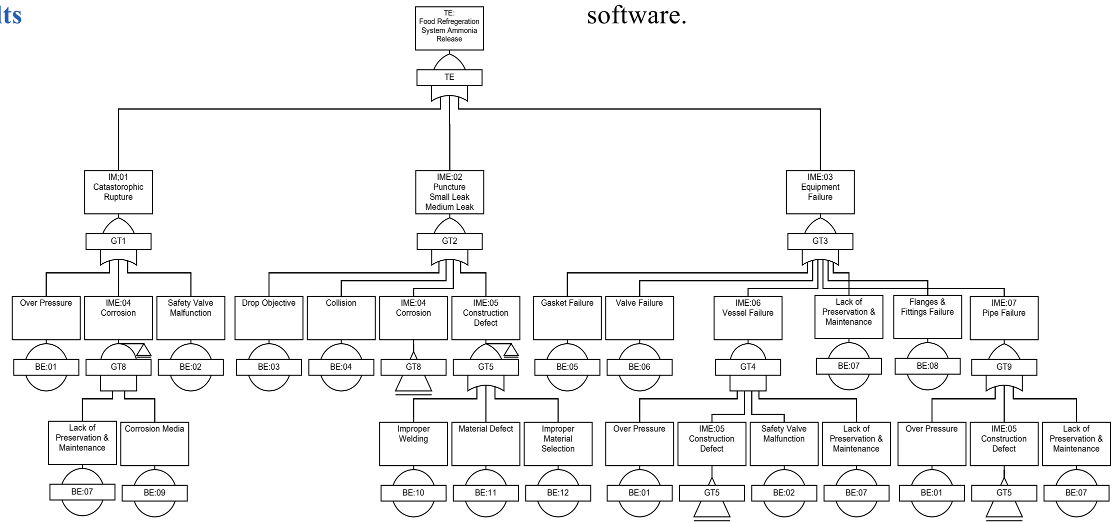

Fig 3. Drawing the fault tree for the release of ammonia from the cold storage cooling system under study (Amini, 2014)

To obtain the probability of the main (final) event, it is necessary to obtain the probability of the basic events. Based on the table (3), the weight of the language terms was replaced with their corresponding fuzzy numbers. Then, the weight of experts' opinions is multiplied by the corresponding fuzzy number of the corresponding opinion.

Next, critical short paths were drawn. An example of the shortest critical path is shown in the fig. 4.

Table 3. Calculation of fuzzy failure probability rate for basic events

Event	Description of the event	Consensus of fuzzy opinions				CFP	K	PFR
BE01	Abnormal increase in pressure	0.08	0.09	0.12	0.15	0.110	4.58	2.61E-05
BE03	Falling objects	0.03	0.05	0.07	0.10	0.064	5.59	2.56E-06
BE04	Hard object impact	0.02	0.04	0.05	0.07	0.045	6.32	4.82E-07
BE07	Defects in repair systems	0.09	0.11	0.13	0.16	0.124	4.38	4.14E-05
BE09	Corrosive environment	0.15	0.17	0.19	0.20	0.177	3.82	1.50E-04
BE10	Irregular welding	0.01	0.04	0.04	0.07	0.041	6.5	3.18E-07
BE11	Defect in material	0.02	0.05	0.05	0.09	0.054	5.91	1.24E-06
BE12	Selection of non-original material	0.01	0.03	0.03	0.06	0.036	6.82	1.51E-07

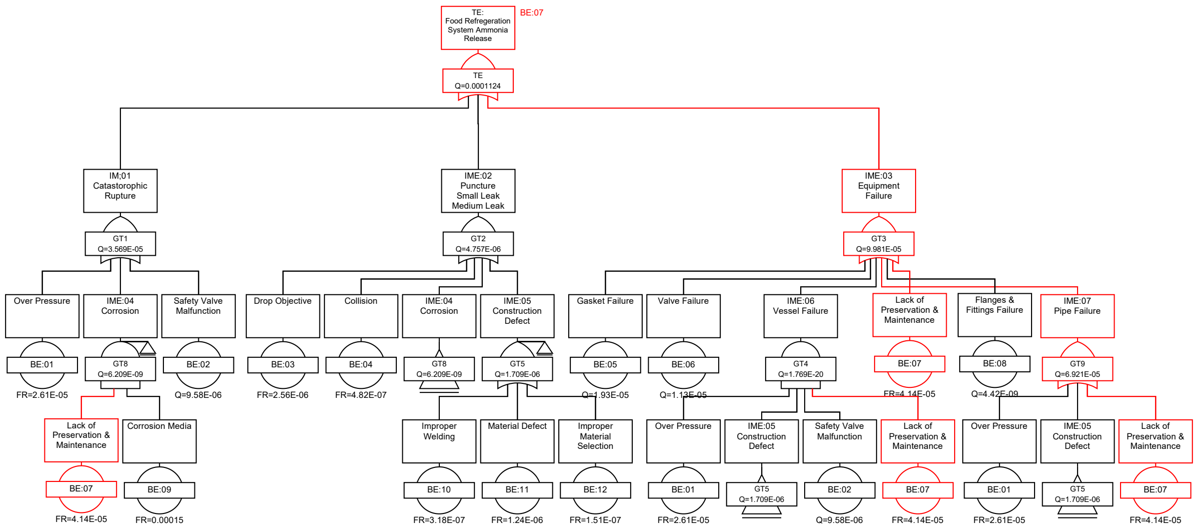

Fig 4. Determining the critical path diagram for event BE07

As these results show, the probability of the final event is equal to 7.22E-05. After calculating the interruption routes and the probability of the final event, now the most important and critical interruption routes should be determined. On the other hand, an important issue in most risk assessments is the identification of minimal cut sets that have the most importance (the most critical).

In this research, the Fussell-Vesely (F-VI) method was used to rank minimal cut sets. F-VI is actually the minimum cut-set distribution on the probability of the final event. F-VIs can be determined for each minimal cut set modeled in the fault tree. This provides the numerical importance of all elements of the fault tree and allows their ranking. F-VI is calculated by summing up all the causes (minimal cut sets) of the main event related to a particular incident. This measurement is used to determine the importance of each minimal cut set. As can be seen (Fig. 5), the three minimal cut sets BE07, BE01 and BE05 have the most importance in the fault tree. In fact, the most critical state that has the greatest contribution to the release of ammonia, are:

- BE07: Lack of proper and planned maintenance
- BE01: pressure increase
- BE05: failure and defects in washers

In figure (6): it is shown the placement of specifications in the PHAST software to solve the problem.

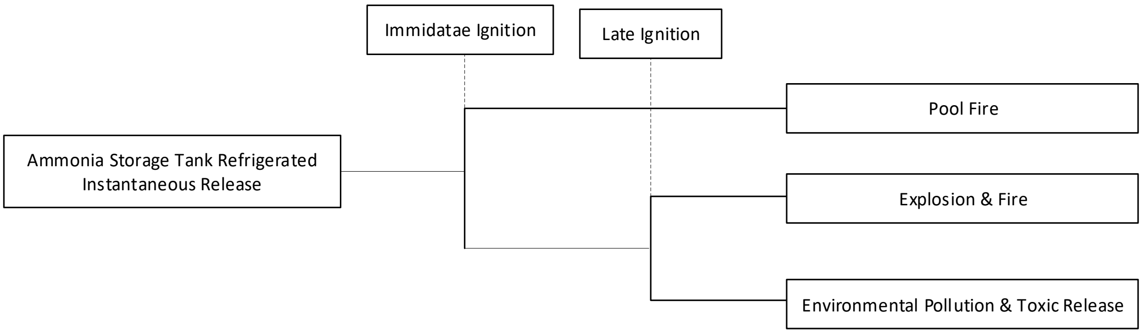

Fig 5. Drawing the fault tree for the release of ammonia from the storage tank of the second scenario

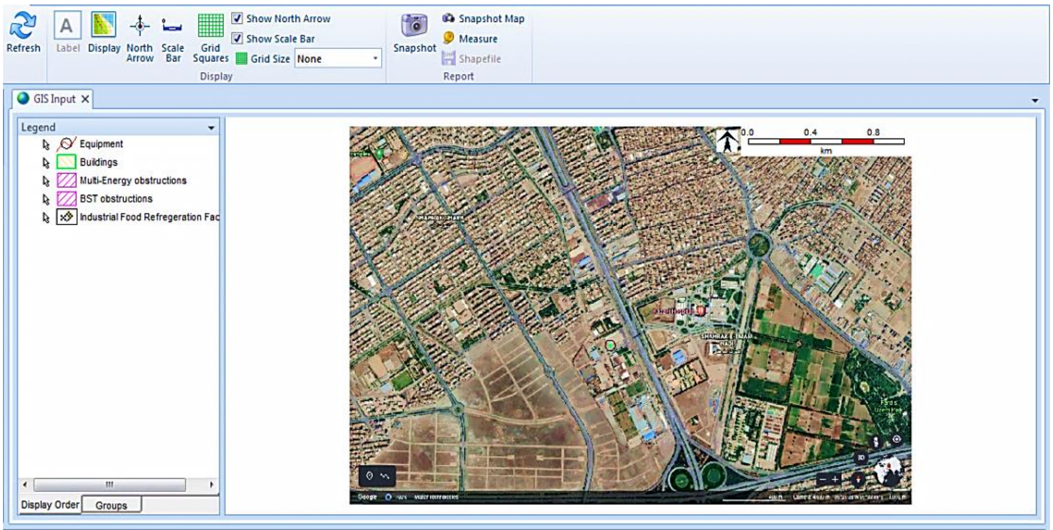

Fig 6. Placing specifications in PHAST software to solve the problem

1.3. The probability of death of people based on the release of toxic ammonia

This step is the percentage of the probability of deaths of people in two weather scenarios (summer and winter) according to the characteristics mentioned in Table (4), Weather conditions considered for modeling the consequences of ammonia release. It has been investigated based on the probability of 1%, 10%, 50% and 99%. Figure 7 shows the range of death probability on the satellite map in the summer weather scenario.

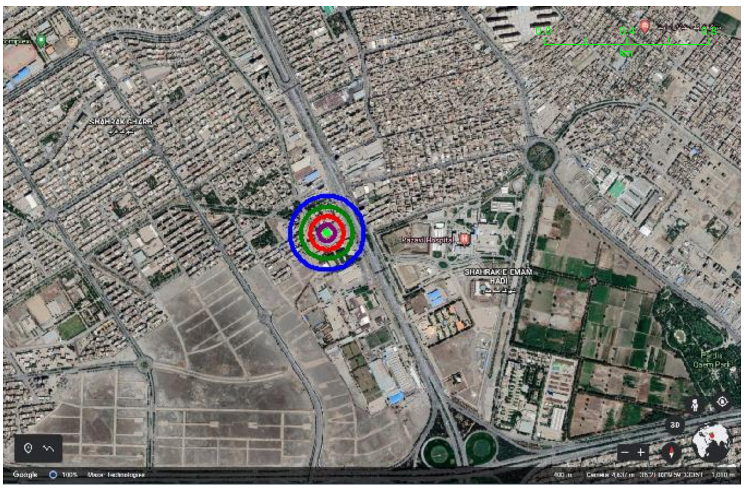

Fig 7. Determining the probability range of people's death on the satellite map in the summer weather scenario

The probability of death of people is shown based on the distance from the location of the ammonia tank in the summer weather scenario of 1.5 F.

Regarding the winter weather scenario, the results are shown in Fig 7.

In the table (5), the probability of death of people based on the distance from the location of the ammonia tank in winter 5B is shown.

It was found that there is a significant difference in the distances. Due to the fact that the weather conditions in winter and summer are completely different from each other, this has greatly affected the emission of pollutants. Therefore, the percentage of death in different weather scenarios changes according to the distance.

Table 4. Mortality percentage based on the distance from the location of the ammonia tank in the summer season

Row	Probability of death	The distance from the location of the pressurized ammonia tank
1	%99	up to a radius of 38.89 meters
2	%50	From a radius of 38.89 meters to a radius of 124.93 meters
3	%10	From a radius of 124.93 meters to a radius of 178.53 meters
4	%1	From the radius of 178.53 meters to the radius of 234.05 meters

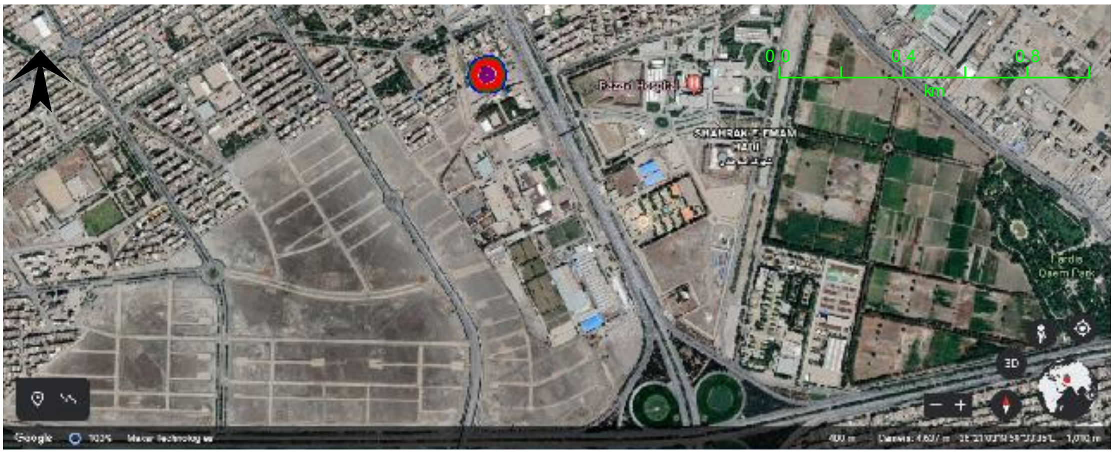

Fig 8. Drawing the fault tree for the release of ammonia from the storage tank of the second scenario

Table 5. Mortality percentage based on the distance from the location of the ammonia tank in the winter season

Row	**Probability of death**	**Radial distance from the location of the pressurized ammonia tank**
1	%99	up to a radius of 14.26 meters
2	%50	From a radius of 14.26 meters to a radius of 40.82 meters
3	%10	From a radius of 40.82 meters to a radius of 47.28 meters
4	%1	From a radius of 47.27 meters to a radius of 52.05 meters

Fig 9. The blast wave caused by the explosion of the ammonia tank of the ammonia refrigeration system

2.3. Investigating the effects of the blast wave

Considering that there is a possibility of an explosion due to the sudden release of ammonia, this consequence should also be investigated and its effects on the surrounding environment should be seen. In figure (8), the blast wave caused by the explosion of the ammonia tank of the ammonia refrigeration system is shown.

As indicated in the map and table, in the event of an explosion, the mortuary building will be completely destroyed within a radius of 30.39 meters from the accident site. Also, from the radius of 30.39 meters to 39.73 meters, all facilities will be completely destroyed. In addition, from the radius of 39.73 to 51.14 meters, the buildings will be damaged and their glass will break. Finally, from a distance of 51.14 meters to 103.92 meters, the blast wave will hit the buildings and cause them to vibrate.

Table 6. The distance of the effects of the blast wave caused by the explosion of the ammonia tank of the ammonia refrigeration system

Row	Blast wave created (bare)	The radial distance traveled by the blast wave from the location of the pressurized ammonia tank (meters)	The amount of human casualties
1	0.9032	19.29	Mortality of 50% of people and employees
2	2/9992	13.54	Mortality of 95% of people and employees

3.3. Investigating the release of toxic ammonia due to sudden release

In the table (9), the examination of toxicity levels for ammonia at different radial distances is shown.

In Figure (9), Ammonia toxic pollutant release model due to sudden release in the 1.5 F summer climate scenario and Figure (10), Ammonia toxic pollutant release model due to sudden release in the scenario 5B winter weather is shown.

Table 7. Investigation of toxicity levels for ammonia at different radial distances

The surface under investigation	The degree of toxicity (ppm)	life injuries	radial distance (m) in 1.5 F weather conditions	radial distance (m) in weather condition 5B
ERPG-1	25	A normal person can tolerate this level of toxic substance concentration for an hour and not have any special problem.	3012.07	1030.64
ERPG-2	150	A person can tolerate this concentration for an hour without the toxic substance leaving an effect on the person's body (for example, severe dizziness) that he cannot easily move away from the place or, for example, put a gas mask on his face	926.88	93.22
ERPG-3	750	This level of concentration measures the damage caused by toxic substances that can cause people to die, and its amount is higher than the previous two levels.	299.71	53.35

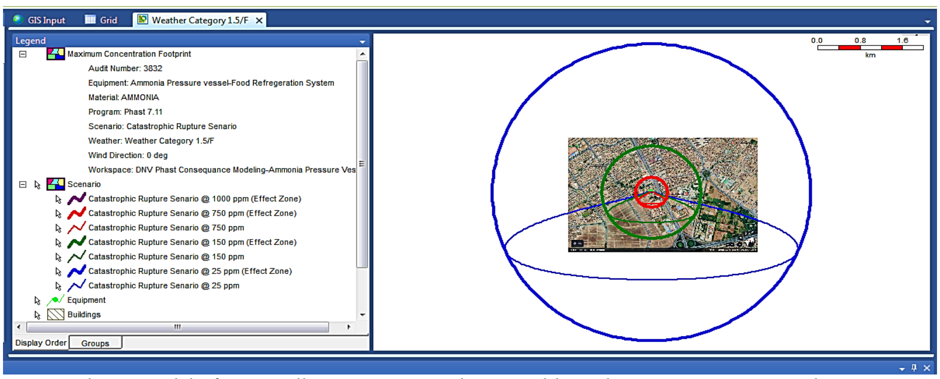

Fig 10. Release model of toxic pollutant ammonia due to sudden release in 1.5F summer climate scenario

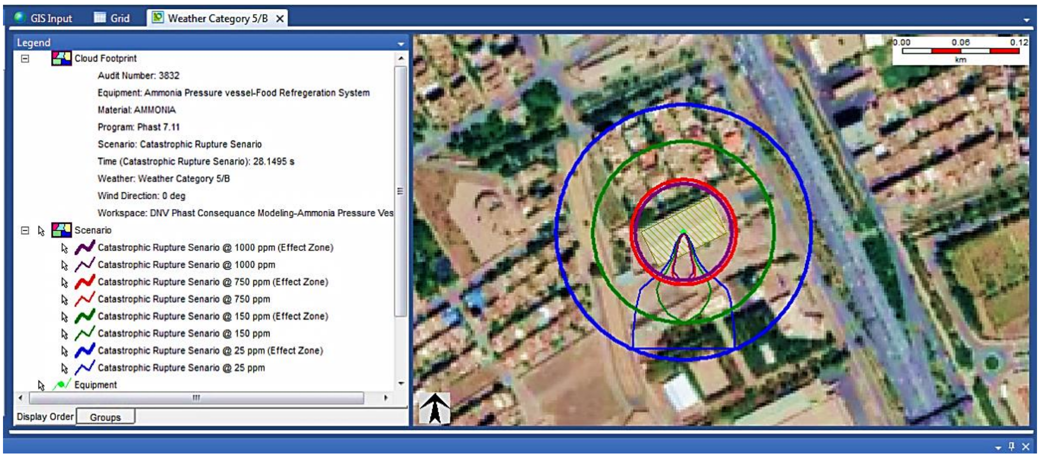

Fig 11. Ammonia toxic pollutant release model due to sudden release in winter climate scenario 5B

3.4. Investigating the amount of radiation caused by fire in sudden release

One of the desired cases is the probability of death based on the distance from the flame. In this scenario, depending on the distance from the ammonia tank, the amount of losses will also be different. In the table (10), the investigation of the amount of radiation caused by the fire and the probability of death is shown.

Table 8. Investigating the amount of radiation caused by fire and the possibility of death

Row	Distance from the tank	possibility of death
1	From a distance of 0.76 meters to 18.41 meters	%10
2	From a distance of 18.41 meters to 20.57 meters	%1

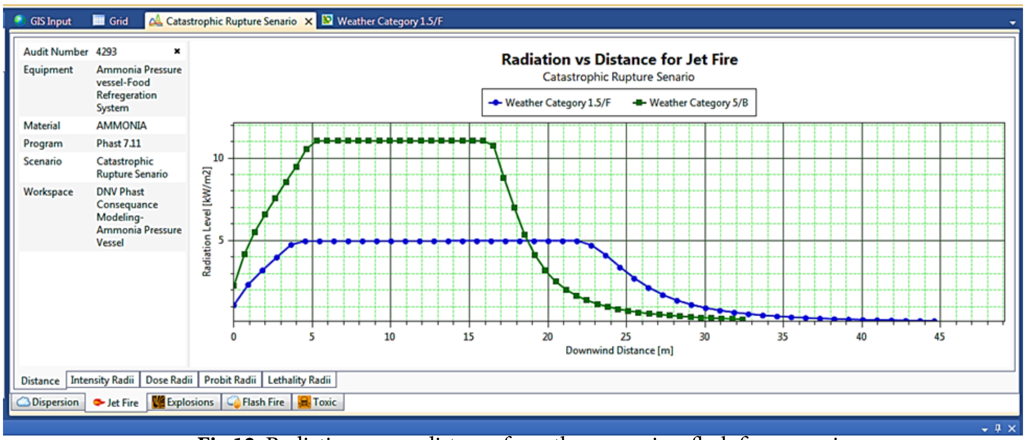

Fig 12. Radiation versus distance from the source in a flash fire scenario

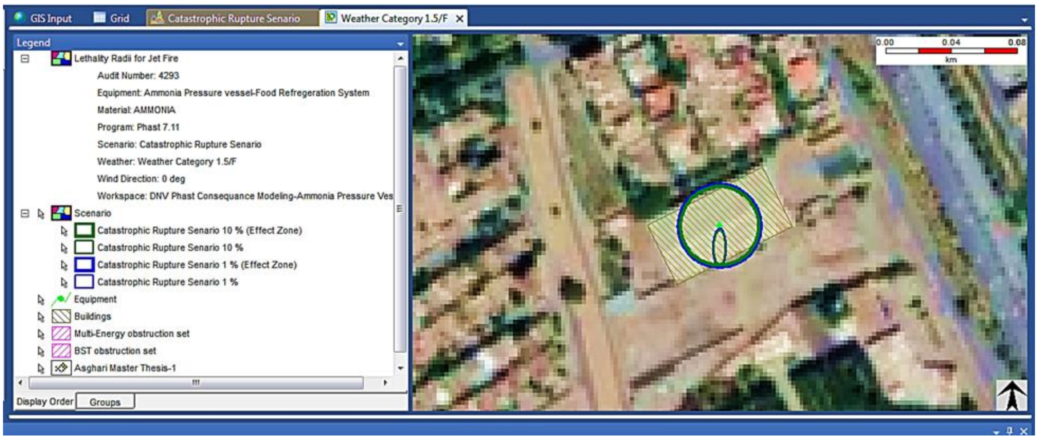

Fig 13. Percentage of radiation casualties and deaths with distance from the source in the flash fire scenario

4. Discussion

As indicated in the results, the elements of the fault tree for the event of ammonia release from the cooling system of the studied cold store are shown:

• Number of 1 final event (Top Event)

• Number of 7 intermediate events (Intermediate Events)

• Number of 12 basic events (Basic Events)

It has also been shown that:

• Number of 4 basic events with fixed failure rate

• No. 8 also without a specific fixed rate

And their failure rate was also calculated through asking experts and fuzzy logic technique. On the other hand, using the desired method of this research, which is the combination of fault tree analysis technique and fuzzy logic based on experts' opinion, the probability of each of the basic events was calculated. And then the prioritization of risks was determined. After determining the MC's, the final probability number was calculated using ISO Graph Reliability Workbench 14 software equal to 7.22E-05. Based on the calculations of three minimal cut sets, BE07, BE01 and BE05 have the most importance in the fault tree. In fact, the most critical conditions that have the greatest contribution to the release of ammonia are, respectively:

• BE07: Lack of proper and planned maintenance

• BE01: pressure increase

• BE05: failure and defects in washers

After determining the probability of occurrence the final event (Top Event), taken from the fault tree as the initial event (Initial Event) was introduced to the Event Tree Analysis (ETA) technique. In the following, the event tree for the ammonia release event from storage tanks was drawn based on two main scenarios. The most important consequences of these two scenarios are:

• Fire (pool fire, sudden fire, eruption fire, ball fire)

• Explosion (quick explosion and delayed explosion)

• Toxicity and pollution of the environment

The graphs drawn by consequence modeling software were analyzed for toxicity, explosion and fire scenarios. In the scenario of releasing ammonia toxic substance in the surrounding environment based on two climate scenarios, in the 1.5F climate scenario, intervals were drawn based on the percentage of deaths.

• 99% of deaths of people up to a radius of 38.89 meters

• 50% of the deaths of people from the radius of 38.89 meters to the radius of 124.93 meters

• 10% of the deaths of people from the radius of 124.93 meters to the radius of 178.53 meters • 1 percent of deaths from the radius of 178.53 meters to the radius of 234.05 meters

But in the 5B winter weather scenario, according to the weather conditions, this value is completely different, and the amount of effects of ammonia toxicity is reduced and we see shorter distances of the effect.

• 99% of deaths of people up to a radius of 14.26 meters

• 50% of the deaths of people from a radius of 14.26 meters to a radius of 40.82 meters

• 10% of deaths from the radius of 40.82 meters to the radius of 47.28 meters

• 1 percent of deaths from the radius of 47.28 meters to the radius of 52.05 meters

Then the effects of the blast wave caused by the sudden release of ammonia on buildings and people were investigated.

• A slight vibration in the windows of buildings from a radius of 51.14 meters to a radius of 103.92 meters

• Breaking and shattering of glass from a radius of 39.73 meters to a radius of 51.14 meters

• Complete destruction of equipment from a radius of 30.39 meters to a radius of 39.73 meters • Complete destruction of the cold storage building up to a radius of 30.39 meters

• Deaths and losses of 50% of people and employees up to a radius of 13.54 meters

• Deaths and losses of 50% of people and employees from the radius of 13.54 meters to 19.29 meters

Then the amount of casualties caused by the eruption fire was investigated.

• Mortality with a 10% probability from a distance of 0.76 meters to 18.41 meters

• Death with a probability of 1% from a distance of 18.41 meters to 20.57 meters.

Looking at the history of accidents in the studied industry (ammonia cooling system of industrial cold stores) and also the statistics of accidents in studies in Mashhad city from the point of view of repetition of the accident and the severity of the accident which are two important components in risk, it seems like this the number The result obtained regarding the possibility of ammonia release corresponds to the reality to a great extent. Because the studies show that the repetition of events leading to the release of ammonia in the studied case and industry is not high, and the calculated probability number (7.22E-05), which shows a small probability, can be very close to reality. Also, investigations and interviews with the experts and experts of the studied industry show that the causes of the event of the release of toxic, flammable and explosive ammonia are also similar to the drawn fault tree in terms of the basic event, and the most critical ones are the ones that mostly cause the event. It turns out that these are the three critical factors identified in this research. Achieving such results that are almost in line with the facts can be that the author both at the stage of drawing the fault tree and at the stage of allocating language words according to the experts of this industry who were closely familiar with the failures of this system and the possibility of any basic event. , It matches.

The use of importance level for basic events and for minimum cut events can be stated in two ways:

• Better allocation of resources for control

• Determining the scope of analysis of each of the basic events or minimum cuts

What is often concluded and inferred when calculating these importances is that only a small number of events have a more prominent role in the occurrence of the main event. In many cases, only less than 20% of the events contribute to the occurrence of more than 90% of the top event. In addition to determining the importance of events, one of the other beneficial results of this calculation is to clarify the status of resource allocation for testing, maintenance, inspection, quality control, etc., so that by optimizing the distribution of resources, costs can be minimized and the system to be led to a better situation. In addition to allocating resources, measuring importance can be used to determine repair times or take parts out of service. What is certain is that the part that has a major contribution to the occurrence of the incident should be repaired or taken out of service in a shorter time, which in this research is a washer for example. The purpose of quantitative risk assessment by FTA method is to calculate the value of the starting causes and the probability of the resulting consequences. In this process, the importance of events and minimum cuts and different scenarios were determined, which can be used in allocating resources and facilities to reduce the occurrence of accidents and their consequences. Among the other advantages of using the FTA method is its preventive and reactive nature and providing control solutions, covering all the processes related to the cooling system, being simple and applicable, low implementation cost, being understandable to everyone, diagrammatic output and installable in office spaces is.

Although the effective management of risks can reduce their impact in achieving project goals (Fataei 2020), there is a possibility of their occurrence at least in one of the dimensions of the project such as scope, time, cost or quality. Therefore, risk identification, analysis and prioritization can play a significant role in the success of industrial projects (Khezri et al. 2022).

The FTA tree showed that several factors alone or together can be involved in the occurrence of the peak event. Among the most important of these cases, defects in parts and equipment, corrosion, improper selection of materials and low quality of raw materials can be mentioned.

4. Conclusion

Considering that the greatest effect in reducing the probability of a release event and consequently reducing the probability of various consequences is the existence or proposal for the placement of preventive protective layers and mitigating protective layers before and after the incident, it is suggested that studies should be conducted on reliability of the applied protective layers and the possibility of failure and technical defects in the existing protective layers should be checked. Among the most important methods used in the analysis of protective layers are methods such as the technique of analysis of protective layers (LOPA) and bow-tie technique.

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