



# Modeling the Consequences of Benzene Leakage from Tanks Using PHAST Software in a Process Industry

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## Abstract

**Background:** Benzene is a highly toxic and flammable chemical widely used in industrial processes, with a substantial risk of accidental release, fire, and explosion. This study aimed to model the potential consequences of benzene leakage from storage tanks in one process industry using PHAST software.

**Methods:** In this study, two scenarios were modeled with PHAST software: (1) a 100-mm leakage from a benzene tank and (2) a tank explosion. Modeling parameters included the type and quantity of material, tank temperature and pressure, and worst-case atmospheric conditions (unstable atmosphere). The consequences of fire, explosion, and toxicity were assessed.

**Results:** The modeling results showed that from the point of view of toxicity, the benzene cloud, with a concentration of 6000 ppm, advances to a distance of approximately 163 meters from the tank. In the benzene tank scenarios in prevailing weather conditions, the minimum dangerous distance was 18.3 meters, and the maximum dangerous distance was 132.8 meters. Also, the results showed that in the event of a benzene tank explosion, it can cause destruction of walls and indirect human casualties up to a distance of 171.9 meters.

**Conclusion:** The findings of the study indicate that the area around the benzene tanks should be declared free of personnel up to a radius of at least 18.3 meters, and a safe assembly point should be designated at a distance greater than 132.8 meters so that the personnel are protected from possible injuries.

**Keywords:** Leakage, PHAST, Benzene, Risk management, Explosion

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## Introduction

Process industries, such as petrochemical plants, often deal with hazardous chemicals. Their units operate under extreme conditions, involving large volumes of hazardous material storage, high pressure, and elevated temperatures. Therefore, there is a possibility of accidents such as leakage of toxic substances, explosions, and fire in them. (1,2)

Accidents in these industries always start with events including the bursting or breaking of pipelines, the formation of holes in tanks, or uncontrollable reactions. In addition to the loss of resources, the events cause the spread of materials in the surrounding environment. (3,4) Accidents causing human and environmental disasters have led experts to turn to predictive methods to estimate the effects of these accidents. By using these methods, it is possible to plan before an accident occurs in order to control it. (5) As an important raw material and chemical solvent, benzene has important applications

in dying, pesticides, perfumery, pharmaceuticals, and many other industries. The dangers of benzene mainly include strong toxicity and high flammability. A benzene explosion can be accompanied by toxic emissions that cause further damage. (6) The International Agency for Research on Cancer (IARC) has classified benzene as a human carcinogen. (7,8) Benzene can lead to impaired lung function, asthma, lung infection, genetic effects, chromosomal abnormalities, DNA damage, central nervous system suppression, and cancer, especially leukemia. (9,10)

Modeling the consequences of possible incidents in a process unit is one of the most important stages of risk assessment. This stage includes modeling the release of substances in the environment and then modeling the consequences of the toxicity, ignition, or explosion of these substances. Due to the complexity of modeling the relationships and the time-consuming nature of modeling, nowadays, it is done by computer software. Today,



multiple software models such as Hazard Prediction and Assessment Capability (HPAC), Process Hazard Analysis Software Tool (PHAAT), and Areal Location of Hazardous Atmosphere (ALOHA) have been developed to predict the spread of dangerous toxic materials, each with its particular characteristics and application. (11,12)

PHAAT software is one of the most powerful and widely used software programs available. (13) PHAAT software acts as one of the decision-making tools of companies and governments regarding industrial risks and public safety. PHAAT software has been extensively reviewed and evaluated. In addition, the results of a separate study of the Unified Dispersion Model (UDM) comprehensive outcome model provided by DNV indicate that both the theory and the ability of this model are very effective in predicting incidents. Accident simulation in this software includes modeling from the first moment of release (leakage model) to the modeling of fire and explosion incidents caused by the spread. (14)

In a study conducted by Biglerzadeh et al in 2011 on the reservoir of Krusen farm using PHAAT software, they concluded that in case of an accident, information about wind speed and direction should always be available to deal with emergencies. The accident should be reported as soon as possible so that necessary measures can be taken to prevent further incidents. (15) In the study of Cheraghi et al which was conducted in 2016 using PHAAT software, the field data obtained indicated that, in addition to the very high risk of explosion of ethylene oxide storage tanks, the modeled scenarios show different consequences in different weather conditions. (16) In a study conducted by Shojaei et al using the MPACT model and response surface analysis (RSM) for benzene leak, the maximum distances of intolerable individual risks for worst-case scenarios resulting from exposure to a concentration of 1000 ppm benzene were estimated to be up to 2500 meters from the emission point. (17)

Therefore, considering the flammability of benzene, this study aims to analyze and model the consequences and determine the amount of damage caused by eruption fire, pool fire, explosion, and toxicity due to the leakage of benzene from storage tanks in a process industry. This study has been designed and conducted on people and equipment, providing control solutions and reducing possible damage and losses in maintenance conditions. The findings of this study are expected to help provide a plan for a quick response to this type of incident.

## Methods

This study was carried out in a series of systematic steps to evaluate the potential consequences of benzene leakage from storage tanks in a process industry. The methodology consisted of seven stages:

### *First step: Determining the goals of quantitative risk assessment*

The aim was to evaluate the consequences of process accidents, such as fires, explosions, and benzene toxicity, that occur due to benzene leakage from tanks, by means of modeling in PHAAT software, and as a result, determine the safe space around these tanks.

### *PHAAT software*

PHAAT (Process Hazard Analysis Software Tool) is a comprehensive consequence analysis tool. This software investigates a possible incident from the initial spill to dispersion in the environment by modeling evaporation, flammability, and toxicity. PHAAT is capable of simulating various release scenarios such as leaks, line ruptures, long release pipelines, and roof collapses in pressurized and non-pressurized tanks or pipes. (5)

### *Second step: Description of the process unit under investigation*

At this stage, all information needed for quantitative risk assessment related to benzene storage tanks is collected. This information generally includes items such as geographic location (taken from Google Earth software), weather conditions such as wind direction, wind speed, air humidity, ambient temperature (collected from information registered in Zarand Meteorological Department), information on the environment where the tanks are located, different types of process maps, location plans, technical documents, and the physical properties of the materials in the tanks, such as temperature, pressure, phase, and composition (collected from the engineering unit).

### *Third step: Data on the source of material release*

In order to model the result with the help of PHAAT software, the characteristics of the emission source should first be specified.

### *Brief description of benzene storage tanks*

Benzene is a colorless, aromatic liquid with a high evaporation rate and extremely high flammability. This material is used in plastic materials, resin, nylon, lubricating oils, dyes, cleaners, pesticides, etc... After separation in the benzene removal unit, it is transferred to the benzene storage tanks in the storage unit through pipes.

These tanks are operated 365 days a year in three shifts by eight people. These tanks are kept at ambient temperature. The diameter of the benzene inlet pipe to the tank is 80 mm, entering at a height of 200 mm from the bottom of the tank on the west side, and the diameter of the outlet pipe is 150 mm, exiting at a height of 500 mm from the bottom of the tank on the west side. These reservoirs are located on the southern side of the coking plant, which is located 10 kilometers from Zarand city

and three kilometers from Behesht Vahdat village.

The specifications of these tanks and the physical and chemical properties of benzene are shown in Table 1. The location of the tanks relative to the city and on the site is also shown in Figure 1.

#### *Weather conditions*

Since one of the most important factors in the release of substances is the weather conditions of the region, in all the scenarios of the study models, the information obtained from the regional snow charts during one year has been modeled. The atmospheric parameters of the study area were acquired from the nearest weather station in 2018, and for the stability of the atmosphere, the worst-case scenario, i.e., unstable atmosphere, was considered, as shown in Table 1.

#### *Fourth step: Identification of risks*

At this stage, with the help of the technical documents available in the engineering department, reliable authorities, and the checklists and PMs available in the archives of the engineering unit, the potential risks related to benzene tanks, such as leaks related to flanges and valves (the most obvious risks), were identified.

#### *Fifth step: Determination and analysis of scenarios*

At this stage, the various consequences that can cause physical and financial loss or damage in case of an accident are evaluated. Any scenario (leaking or tearing in a flange or pipe or a tank containing flammable or toxic substances) can have several consequences (spread of toxic substances, fire, and explosion). In this project, the studied scenario is a tank leak, the consequences of which include pool fire, eruptive fire, and steam cloud explosion, which are determined through the models presented for fire in the environment. The effects of fire are determined in the form of radiation intensity in different places.

#### *Scenarios studied*

- A) A leak with a diameter of 100 mm occurs in the benzene storage tank, which is operating at a pressure of 5 bar and a temperature of 25 °C, at a height of one meter.
- B) An explosion occurs in a benzene storage tank operating at a pressure of 5 bar and a temperature of 25 °C.

#### *The sixth step: Modeling the outcome*

At this stage, the scenarios determined are modeled based on the process data and meteorological information of the region with the help of PHAST software, using fluid buoyancy models and solving momentum equations and mass transfer at the same time.

#### *Seventh step: Determining a safe gathering point and providing solutions*

At this stage, the appropriate assembly point with the least risk for people is determined according to the results of

**Table 1.** Characteristics of the tanks, the physical and chemical properties of benzene, and weather information

	Title	Value
Properties of benzene	CAST NUMBER	2-43-72
	Density	0.8765 g/cm <sup>3</sup>
	Melting temperature	5.5 degrees Celsius
	Boiling temperature	80.1 degrees Celsius
	Ignition temperature	-11 degrees Celsius
	Physical condition	Liquid
	Self-ignition temperature	498 degrees Celsius
	LEL (lower explosive limit)	1.4% by volume
	UEL (upper explosive limit)	8% by volume
	TWA (time-weighted average)	0.5 PPM
Properties of benzene storage tanks	STEL (Short-term exposure limit)	2.5 PPM
	Tank height	10000 mm
	Tank diameter	11000 mm
	Tank volume	950 cubic meters
	Tank type	Vertical
	The height of the tank from the ground	500 mm
	Pressure inside the tank	5 Bar
Atmospheric parameters	Average temperature	17.6 degrees Celsius
	Average wind speed	3 meters per second
	Prevailing wind direction	Southeast
	Average humidity	33%
	Atmospheric stability	F

modeling for possible accidents and the arrangement of equipment and available spaces, and possible solutions to reduce the effects of model accidents are proposed.

## **Results**

### *Modeling results*

First, the leakage from the tank was modeled based on the scenarios using the PHAST software.

### *Jet fire*

This section includes the output results of the PHAST software for modeling the eruption fire for the leak scenario, including the radius of radiation and the percentage of human casualties.

This fire can be caused by a small leak in the pipelines and pressure tanks if the fluid quickly leaves the tank and reaches the spark source. (18)

According to Figure 2-A and Table 2, during a possible fire eruption, we see the maximum radius of radiation (37.5 kw/m<sup>2</sup>) at a distance of 102.6 meters from the benzene tank.

According to Figure 2-B and Table 2, up to a distance of 104.3 meters from the benzene tank, the intensity of damage is 100% probable, and also the lowest intensity of damage is seen from a distance of 130.4 meters from the tank.



Figure 1. The location of the tanks relative to the city and site

### Pool fire

After entering the data into the software to model the scenario, the following results, including the radiation radius and the percentage of losses, were obtained for the pool fire. The results are shown on the maps and charts in the figures.

According to Figure 3-A and Table 2, in the case of a pool fire with a source of spark caused by a leak up to a radius of 52.8 meters, the fire radiation is 4 kW/m<sup>2</sup>, and the radiation is 12.5 kW/m<sup>2</sup> up to a distance of 20 meters from the benzene tank.

According to Figure 3-B and Table 2, we can see the damage intensity of 43.56% up to a distance of 19.7 meters from the tank.

### BLEVE

The momentum and pressure resulting from the explosion of the tank are shown in the diagrams and maps below.

According to Figure 4 and Table 3, the blue circle is 0.02068 bar pressure resulting from the explosion, which shows that up to a distance of 663 meters from the tank, the explosion pressure reaches this number. According to the DOD6055 standard, this amount of damage does not break the windows. The green circle is 0.1379 bar

pressure, which advances up to a distance of 171.9 meters and, according to the mentioned standard, can cause the collapse of light structures and break 100% of the windows. The yellow circle is 0.2068 bar pressure, which advances up to a distance of 132.8 meters from the tank. According to the standard, there is a 100% chance of breaking windows and damaging heavy structures. (19)

### Toxicity

Considering the nature of benzene and its toxicity, the concentration of the toxic substance in terms of radius has been determined on the graphs and charts.

Figure 5 shows that in the case of a possible 100 mm leak, the highest concentration of benzene vapor is expected up to 18.3 meters from the tank, reaching 80,000 ppm, and up to 163 meters from the tank at a concentration of 6,001 ppm (Table 4).

### Discussion

Benzene storage tanks need more care due to their toxic and flammable nature. As the data obtained from the modeling shows, the tank explosion scenario (BLEVE) is the most dangerous in completely stable weather conditions. Because in this case, the pressure reaching

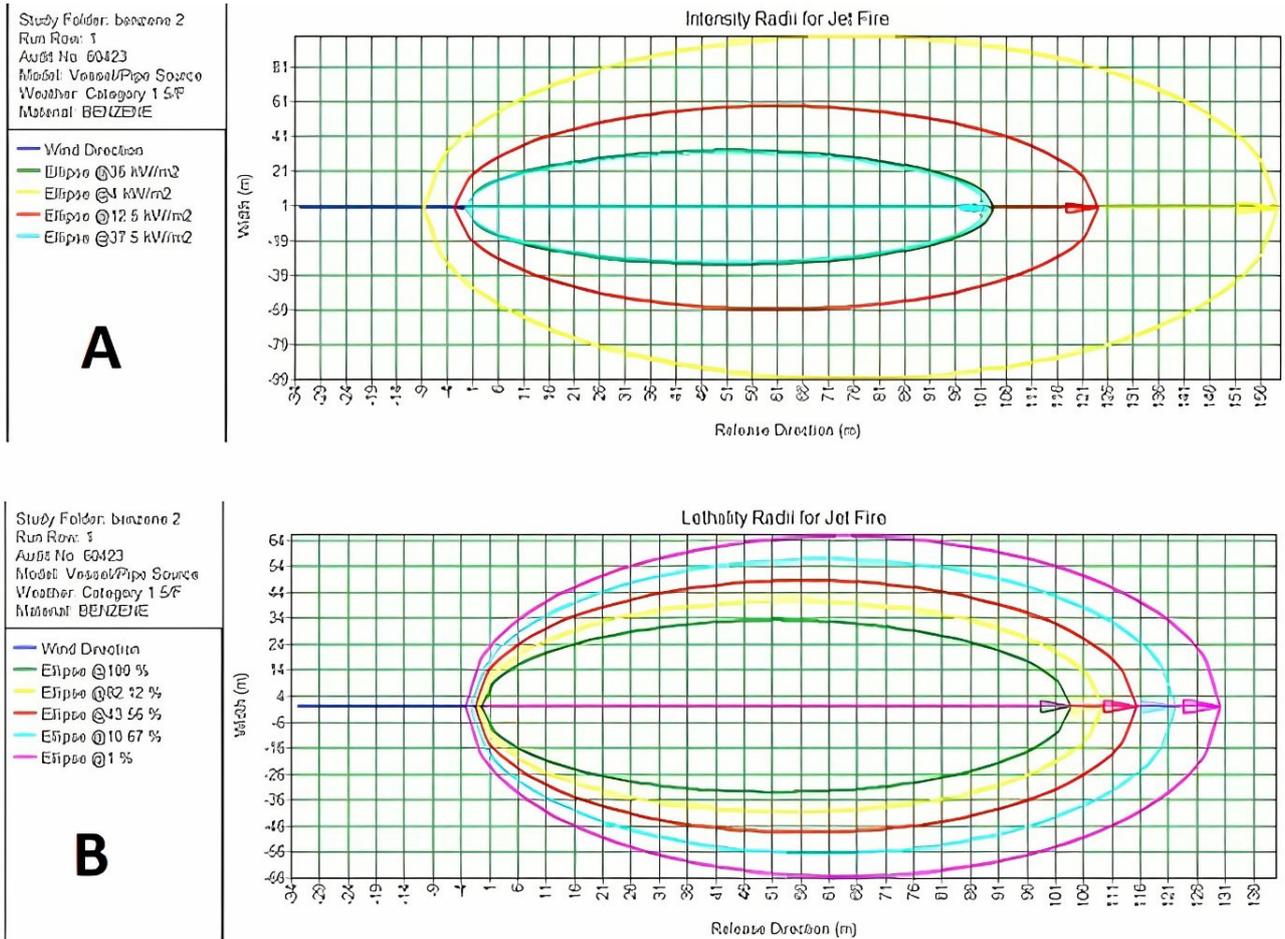


Figure 2. The radiation radius and radius of lethality percentage of jet fire for a 100 mm leak

Table 2. Review of the situation of the jet fire scenario and the pool fire scenario

Jet fire scenario			Pool fire scenario		
Distance in meters	Radiation	Severity of injury	Distance in meters	Radiation	Severity of injury
102.6	37.5 kW/m <sup>2</sup>	-	N/A	37.5 kW/m <sup>2</sup>	-
103.7	35 kW/m <sup>2</sup>	-	N/A	35 kW/m <sup>2</sup>	-
124.1	12.5 kW/m <sup>2</sup>	-	20	12.5 kW/m <sup>2</sup>	-
159.6	4 kW/m <sup>2</sup>	-	52.8	4 kW/m <sup>2</sup>	-
104.3	-	100%	N/A	-	100%
109.5	-	82.12%	N/A	-	82.12%
115.2	-	43.56%	19.7	-	43.56%
123.1	-	10.67%	21	-	10.67%
130.4	-	1%	24.9	-	1%

0.02068 bar caused by the explosion affects up to a distance of 663 meters. The resulting damage is superficial. The pressure reaching 0.1379 bar caused by the explosion affects a distance of 171.9 meters, causing the destruction of walls and the possibility of indirect human casualties. The pressure reaching 0.2068 bar caused by the explosion affects up to a distance of 132.8 meters, leading to severe damage to structures and equipment and causing human casualties.

The following scenario is a leak of 100 mm from the

tank. This scenario results in a burst fire with a radiation radius of 37.5 kW/m<sup>2</sup>, causing damage to equipment at a distance of 102.6 meters from the tank, and a 100% death rate was calculated at a distance of 104.3 meters.

For a pool fire, the distance value for the radius of 37.5 kW/square meter and the death rate of 100% is not defined in the software. Therefore, we find that the consequences of a possible fire eruption are far more dangerous than a possible pool fire.

In addition to the mentioned consequences, there

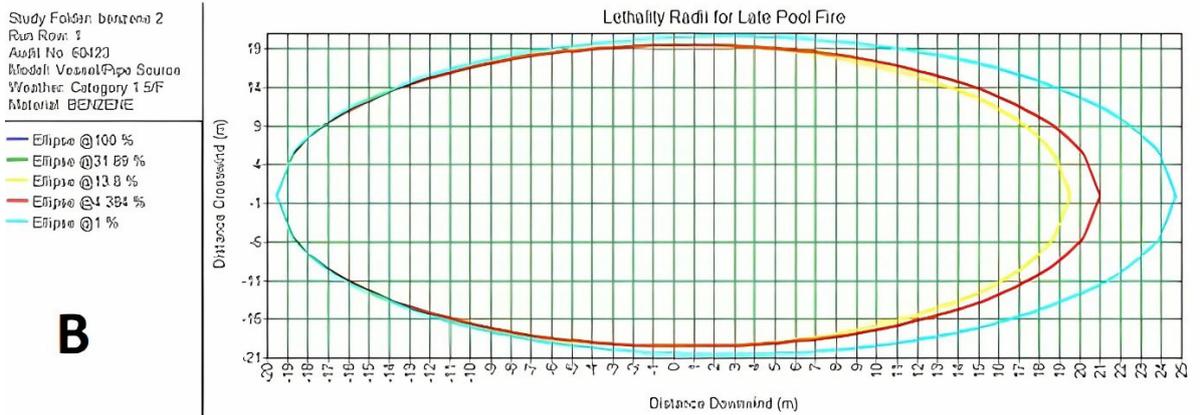
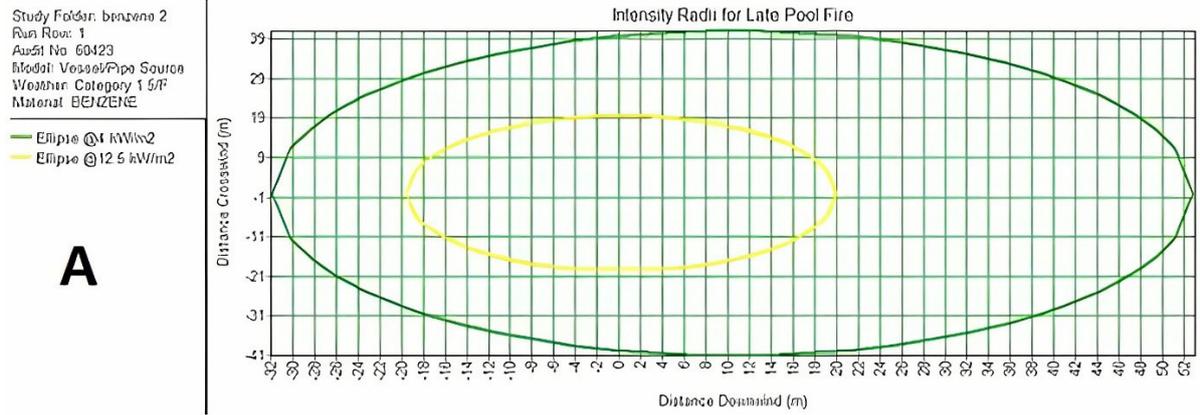


Figure 3. The radiation radius and the radius of fatality percentage of the pool fire for a 100 mm leak

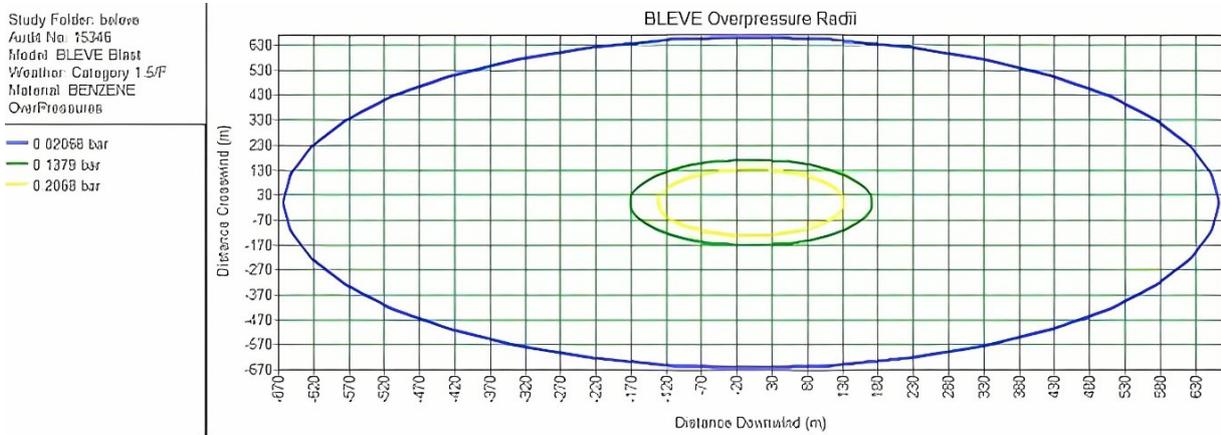


Figure 4. Pressure radius caused by the explosion from the release source

is also the risk of creating a chain of accidents and involving nearby tanks, which can significantly increase the dimensions and severity of the incident. These results have been observed in the research of Abdolhamidzadeh et al who examined 224 cases of the major domino event, as well as Lopez-Molina et al who looked for ways to prevent the occurrence of domino events. (20,21)

The toxicity caused by a 100 mm leakage of benzene tanks is at its highest concentration at a distance of 18.3

meters from the location of the leak, but in general, we will have high concentrations of benzene vapor up to a distance of 163 meters from the location of the possible leak. Natural factors such as wind and air flow are also involved in the formation of concentration clouds. Therefore, this leakage can have wider consequences in the autumn and winter seasons due to the decrease in wind speed. Studies by Mr. Shojaee Barjoe et al conducted using ALOHA software on benzene tanks in one of the

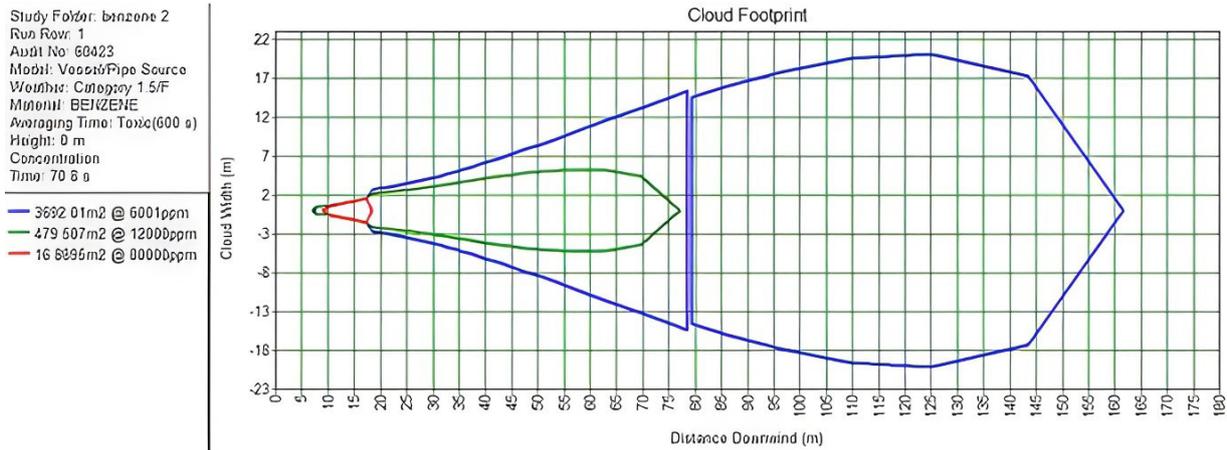


Figure 5. Radius of effect of substance concentration according to the distance from the release source for a leak of 100 millimeters

Table 3. Examining the status of the explosion scenario

Scenario	Consequence	Pressure due to explosion (in terms of load)	Distance (in meters)
Benzene tank explosion	BLEVE	0.02	663
		0.14	171.9
		0.21	132.8

industries also showed that the maximum radius of danger is predicted in the fall season, and studies by Mr. Shojaee Barjoe et al conducted on toluene tanks in one of the industries using ALOHA and PHAST software also showed that the highest probability of death is likely in the cold seasons. (22,23)

The obtained results can be used for the construction of high-traffic environments, the deployment of important equipment, the determination of safe assembly points for personnel, the placement of emergency exit routes, and the training of personnel on how to react by conducting drills, so that we will witness the least damage to the workforce and equipment.

**Limitations**

This study was conducted only in one specific industry, and the results may not be generalizable to other industries or different geographic regions.

**Conclusion**

The results obtained using PHAST software in this study indicated that the area around the tank up to a distance of 18.3 meters, in all conditions, is high-risk, and accordingly, the employees of this department are not safe from risk at this distance. Therefore, the surrounding area of these tanks should be declared free of personnel up to a radius of 18.3 meters, and the personnel who are working within a radius of 132.8 meters of this unit should be given the necessary training for emergency response when benzene is released. Also, the necessary facilities and equipment, such as masks, breathing equipment, and

Table 4. Examining the status of the toxicity scenario

Distance in meters	Value concentration in PPM
18.3	80000 PPM
77	12000 PPM
163	6001 PPM

special clothes, should be provided to them so that in case of such incidents, the employees will suffer the least harm.

**Authors' Contribution**

**Conceptualization:** Abbas Nazemi.  
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**Methodology:** Sajad Zare and Abbas Nazemi.  
**Project administration:** Sajad Zare and Abbas Nazemi.  
**Software:** Abbas Nazemi and Mohammadreza Baniasadi Zare.  
**Supervision:** Sajad Zare.  
**Writing—original draft:** Mohammadreza Baniasadi Zare.  
**Writing—review & editing:** Sajad Zare and Mohammadreza Baniasadi Zare.

**Competing Interests**

The authors declare no conflicts of interest.

**Ethical Approval**

No human or animal subjects were involved

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