



Determining the safe distance of city gas station (CGS) and town boarder station (TBS) pressure reduction stations using PHAST software

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Abstract

Background and Objective: The safety of distribution networks at gas pressure reduction stations has become increasingly important as a critical aspect in gas industry. This study aimed to determine the safe distances around City Gas Stations (CGS) and Town Border Stations (TBS) in Tabriz.

Methods: Station data were collected over the course of one year. Additional information was obtained through interviews and correspondence with officials from the local Gas Company. To model the consequences and determine the safety zones (fire zone, restricted area, and impacted area), the Total GS EP SAF 253 standard and PHAST software (version 8.22) were utilized.

Findings: Based on the findings, the safe distances are 81 m for the fire zone, 529 m for the restricted zone, and 649 m for the impacted zone. At TBS stations, these distances were determined to be 24, 282, and 338 m, respectively. The results indicate that adhering to these distances, particularly during the design phase and implementation of the defined zones in accordance with the Total GS 253 standard, plays a significant role in mitigating the consequences of potential accidents. However, the results also show that the safety zones were not properly observed at most stations.

Conclusion: The TBS station was identified as requiring special safety attention owing to its high-traffic location. Overlapping hazard effects were observed in the CGS stations due to the close proximity of the pressure reduction units. Furthermore, the boundaries of the restricted zone were not adequately considered during the design of most stations.

Keywords: Safety zone, Pressure reduction station, CGS, TBS, PHAST



Introduction

Industrial development and technological advances, while improving living standards, have simultaneously exposed humans to hazardous risks resulting from accidents related to the daily use of thousands of chemical compounds (1-3). This has led to an increase in the release of toxic substances and explosions of chemicals, adversely affecting the health of workers and surrounding communities. Therefore, it is critically important to understand the behavior of hazardous chemicals and estimate the consequences of potential fires and explosions (4, 5). Consequence modeling methods have been employed to determine hazard zones associated with fires and explosions. Software tools have been developed for modeling explosions and fires and evaluating their consequences. However, some software packages lack flexibility due to their computational intensity, long execution times, and inability to perform multifunctional tasks (5-8).

The PHAST software has been utilized in many studies to model chemical process accidents and assess their consequences (5-8). The software enables evaluation of fire and explosion ranges, extent of damage caused by accidents, pressure generated by blast waves, number of individuals at risk, and safety zones surrounding the sites (9-11). Bahmani et al., for example, reported fire and explosion as the most significant and common consequences of chemical release. They maintained that any potential leakage of vinyl chloride from storage tanks could lead to catastrophic outcomes, indicating an extremely high and unacceptable risk level. Consequently, based on the damage caused by blast waves, it was recommended that preventive measures be planned and implemented in such industries (12). In another study aimed at determining the safety zone of a pipeline using PHAST, it was found that a mere three-millimeter increase or decrease in pipe thickness could alter the safety zone by approximately 60 m or more (13). Jahedshahraki et al. simulated the consequences of fire incidents in gas pipelines using PHAST. They concluded that, in the event of a fire, various safety zones would exist due to differences in the leak diameter and dispersion mode. To determine the fire hazard safety zone, they recommended applying the GS EP 253 standard (14). Özay et al. investigated the consequences of methane gas explosions at a biogas station in Turkey for estimating the threat zones caused by both explosion and toxicity. They modeled various gas leakage and explosion scenarios using ALOHA and PHAST (15). Torfi et al. assessed the risks and modeled potential accidents at a natural gas pressure reduction station in the Boroumi area of Ahvaz, southwest of Iran. They concluded that identifying safe boundaries and high-risk zones is essential for ensuring the safety of personnel and the public. They emphasized that consequence analysis should be

integrated into the initial design and operational phases of such stations (16).

Based on the literature review, it can be concluded that despite the importance of consequence assessment and safety zone determination for City Gas Stations (CGS) and Town Border Stations (TBS), very few studies have been conducted in Iran or internationally. Therefore, the objective of this study was to determine the safety zones of CGS and TBS stations in Tabriz using the PHAST software and the Total GS EP SAF 253 standard. By identifying the impact thresholds and influence ranges of potential incidents, this study aims to play a key role in reducing the consequences of such events. Furthermore, by identifying accident-inducing scenarios and their mechanisms, this study aims to support risk identification and hazard control in the process industries.

Methods

The Total GS EP SAF 253 standard and PHAST software (version 8.22) were utilized to model consequences and determine safety zones, respectively. The Total GS EP SAF 253 standard is based on industry design and operational parameters, outlining required safety measures in line with established practices in the oil and gas industry. Table 1 summarizes standard scenarios outlined in Total GS EP SAF 253, including criteria for defining safety zone distances.

All relevant data from CGS stations (No. 1 station and Bagh-e-Marouf station) and TBS stations (Golgasht station and Bagh-e-Marouf Cabinet-type station) were collected for consequence assessment and safety distance determination. The data consisted of locations, process diagrams (Plot Plan, P&IDs, and PFDs), layout and siting maps, operational procedures, and chemical properties of materials. The layouts of CGS and TBS stations were imported into the PHAST software, with detailed properties of natural gas (Table 2) based on data from the local Gas Company used as the basis for modeling mixture behavior.

To incorporate climate parameters, both cold and warm seasonal conditions were defined in the model. Two weather scenarios, labeled 3F and 5D, were established to represent seasonal conditions and their potential effects on modeling outputs. The 3F condition represents the cold season with a wind speed of 3 m/s, Pasquill stability class F, ambient temperature of -3°C, relative humidity of 80%, and solar radiation of 0.1 kW/m². The 5D condition represents the warm season with a wind speed of 5 m/s, Pasquill stability class D, ambient temperature of 32°C, relative humidity of 30%, and solar radiation of 0.9 kW/m².

The CGS and TBS stations were operated at two pressure levels: 1000 and 250 psi for CGS, and 250 and 60 psi for TBS. As a result, two separate pressure vessel units were defined for the CGS and TBS sections. The

equipment was then placed on a map, and data were set following the Total GS EP SAF 253 standard. To determine the safety zones (fire zone, restricted area, and impacted area), the criteria outlined in the Total GS253 standard were applied. The fire zone defines the adjacent radius with the expected highest levels of destruction and thermal damages. A thermal radiation threshold of 9.5 kW/m² was used to establish the jet fire safety distance, with an overpressure effects threshold value of 200 millibars within the fire zone. In the restricted area, the leak diameter was determined based on the pipeline diameter. The jet fire criteria for this zone were set at 4.7 kW/m² for early and late pool fires, as well as jet fires. The Lower Flammable Limit (LFL) was used as a flash fire index, with a threshold of 140 millibars applied for overpressure effects. Similar scenarios with more conservative criteria were used to define the impacted area. The thermal radiation threshold was set at 3.2 kW/m² for jet fires, early and late pool fires, while a 50-

millibar threshold was applied for overpressure effects, in accordance with the relevant standard. This safety zone extends beyond the site's perimeter fencing to include areas where members of the general public may be present or pass through.

Specifications and Satellite Maps

Natural gas enters the facilities at CGS stations with a pressure exceeding 1000 psi. After undergoing various processes, the gas stream leaves the CGS stations with a pressure of 250 psi and is directed toward the TBS stations. Mercaptan is stored in tanks with volumes of 2400 and 1600 liters at CGS stations No. 1 and Bagh-e-Marouf, respectively. The pressure of the mercaptan tanks is 30 psi. Gas enters the TBS stations with a pressure of 250 psi and leaves with a pressure of 60 psi to be introduced into the local distribution network. Fig. 1 shows the locations of the CGS and TBS stations.

Table 1. Standard scenarios of Total GS253.

Scenario	Criteria fire zone	Criteria restricted area	Criteria impacted area
Un-ignited flammable gas/spray cloud dispersion from gas/2-phase or liquid release	LFL	LFL	NR
Un-ignited toxic gas/spray cloud dispersion from gas/2-phase or liquid release	NR	Toxic gas LC1%	Toxic gas IDLH
Jet fire from gas, 2-phase or liquid release	9.5 kW/m ²	4.7 kW/m ²	3.2 kW/m ²
Pool fire in retention basin	9.5 kW/m ²	4.7 kW/m ²	3.2 kW/m ²
Liquid pool vaporization (LPG only)	LFL	NR	NR
Vapor cloud explosion (VCE) in unit	200 mbar	140 mbar	50 mbar
BLEVE	NR	1000 (kW/m ²) 4/3.s	600 (kW/m ²) 4/3.s
Roof tank explosion	NR	140 mbar	50 mbar
Boil over	NR	1000 (kW/m ²) 4/3.s	600 (kW/m ²) 4/3.s
Flare flame out	NR	LFL Toxic gas LC1%	Toxic gas IDLH

Table 2. Detailed properties of natural gas.

No.	Gas Composition	Amount of gas mixture
1	Mole percent of gas composition	Methane 91.00174
2		Ethane 2.83366
3		Propane 0.69481

4		Butane	0.24202
5		Pentane and higher	0.09264
6		Nitrogen	4.29536
7		Carbon dioxide	0.83161
8		Oxygen	0.00815
9) mg/scm(Sulfur	Hydrogen sulfide	0.347
10		Sulfur mercaptan	5.324
11		Total sulfur	8.573
12) kcal/scm(Gross calorific value		8907.32
13) kcal/scm(Net calorific value		8026.14
14	Relative density		0.6069



Fig. 1. Locations of CGS and TBS stations.

Results

Safety distances for City Gas Stations (CGS)

The safety distance calculations were conducted separately for CGS TBS stations due to the dissimilar inlet and outlet pressures. For each safety zone, the maximum value obtained from the defined scenarios was

selected as the required safety distance. The safety distances of the fire zone, the restricted area, and the impacted areas at CGS station No. 1 are listed in Table 3. According to Table 3, the maximum distance of 81 m was associated with the explosion scenario under weather condition 5D designated as the safety distance

for the fire zone. For the restricted area, a distance of 529 m was found in relation to an explosion under weather condition 3F. Similarly, for the impacted area, a distance of 649 m was selected in relation to an explosion under 3F conditions. In accordance with the Total GS 253 standard, the effects of flash fires were disregarded in the impacted area. Because all calculations were performed using the PHAST software with input parameters derived from the Total GS 253 standard, the output charts and safety distances obtained for the other CGS station (Bagh-e-Marouf) were consistent with those of CGS station No. 1.

Safety distances for Town Border Stations (TBS)

Safety distance calculations were conducted for two separate sections of the TBS stations, corresponding to inlet and outlet pressures of 250 psi and 60 psi. The safety distances for the fire zone, the restricted area, and the impacted areas of the TBS stations are listed in Table 4.

According to Table 4, a distance of 24 m, associated with an explosion under 3F weather conditions, was found to be the safety distance for the fire zone at 250 psi. In addition, a distance of 5.7 m under D5 weather conditions was found to be the safety distance for the fire zone at 60 psi. For the restricted area, a distance of 282 m, related to an explosion under 3F weather conditions, was determined as the safety distance at 250 psi. Additionally, a distance of 338 m, corresponding to an explosion under 3F conditions in the horizontal leak

with obstacle impact scenario, was defined as the safety distance for the impacted area at 250 psi. Since the calculations of the PHAST software were based on the Total GS EP SAF 253 standard, the output diagrams and safety distances for both the TBS stations were identical.

Safety zones for mercaptan compounds at CGS

The results of the fire zone, the restricted area, and the impacted area for mercaptan compounds at CGS stations are presented in Tables 5 - 7. According to Table 5, the maximum fire-zone distance obtained for CGS Station No. 1 corresponded to the late pool fire scenario (thermal radiation criterion of 9.5 kW/m²) and was 46 m under 3F weather conditions. Similarly, at the CGS Bagh-e-Marouf station, the highest value was observed in the late pool fire scenario, with the same thermal radiation criterion (9.5 kW/m²) and a distance of 41 m under 3F weather conditions. These values defined the extent of the fire zone in each case.

According to Table 6 and Fig. 2, the maximum value obtained from the defined scenarios for the restricted area at CGS station No. 1 corresponded to the toxicity scenario with LC of 1% criterion and occurred at a distance of 345 m under 3F weather conditions. At the CGS Bagh-e-Marouf station, the highest value was observed in the jet fire scenario, characterized by a thermal radiation criterion of 4.7 kW/m² and a distance of 217 m under 5D weather conditions. These values defined the extent of the restricted area in each case.

Table 3. The safety distances of fire zone, restricted area, and impacted area at CGS station No. 1.

Distances Obtained for the Fire Zone (meter)									
Horizontal Leak with Obstacle Impact					Horizontal Leak				
	1000 psi (Release rate: 3.788 kg/s)		250 psi (Release rate: 0.9188 kg/s)		1000 psi (Release rate: 3.788 kg/s)		250 psi (Release rate: 0.9188 kg/s)		
Weather	5D	3F	5D	3F	5D	3F	5D	3F	

Flash fire (LFL)	75	75	11	21	28	28	-	-
Jet fire (9.5 kw/m ²)	10	10	4.3	4	28	26	12.5	12.5
Explosion (200 mbar)	81	79	23	24	35	35	12.5	12.5
Distances Obtained for the Restricted Area (meter)								
Horizontal Leak with Obstacle Impact					Horizontal Leak			
	1000 psi (Release rate: 96.5827 kg/s)		250 psi (Release rate: 23.4676 kg/s)		1000 psi (Release rate: 96.5827 kg/s)		250 psi (Release rate: 23.4676 kg/s)	
Weather	5D	3F	5D	3F	5D	3F	5D	3F
Flash fire (LFL)	438	448	233	241	281	250	114	103
Jet fire (4.7 kw/m ²)	91	90	43	41	160	155	81	78
Explosion (140 mbar)	511	529	269	282	320	294	128	119
Distances Obtained for the Impacted Area (meter)								
Horizontal Leak with Obstacle Impact					Horizontal Leak			
	1000 psi (Release rate: 96.5827 kg/s)		250 psi (Release rate: 23.4676 kg/s)		1000 psi (Release rate: 96.5827 kg/s)		250 psi (Release rate: 23.4676 kg/s)	
Weather	5D	3F	5D	3F	5D	3F	5D	3F
Jet fire (3.2 kw/m ²)	115	108	54	50	184	173	92	86
Explosion (50 mbar)	624	649	318	338	375	352	152	145

Table 4. The safety distances of fire zone, restricted area, and impacted area for the TBS stations.

Distances Obtained for the Fire Zone (meter)								
Horizontal Leak with Obstacle Impact					Horizontal Leak			
	250 psi (Release rate: 0.9188 kg/s)		60 psi (Release rate: 0.2487 kg/s)		250 psi (Release rate: 0.9188 kg/s)		60 psi (Release rate: 0.2487 kg/s)	
Weather	5D	3F	5D	3F	5D	3F	5D	3F

Flash fire (LFL)	11	21	-	-	-	-	-	-	-
Jet fire (9.5 kw/m ²)	4.5	4.3	1.5	1.3	12.5	12.5	5.7	5.5	
Explosion (200 mbar)	23	24	-	-	12.5	12.5	-	-	
Distances Obtained for the Restricted Area (meter)									
Horizontal Leak with Obstacle Impact					Horizontal Leak				
	250 psi (Release rate: 23.4676 kg/s)	60 psi (Release rate: 6.414 kg/s)	250 psi (Release rate: 23.4676 kg/s)	60 psi (Release rate: 6.414 kg/s)					
Weather	5D	3F	5D	3F	5D	3F	5D	3F	
Flash fire (LFL)	233	241	133	54	114	103	47	43	
Jet fire (4.7 kw/m ²)	43	41	21	20	81	78 m	48	44	
Explosion (140 mbar)	269	282	148	80	128	119 m	70	61	
Distances Obtained for the Impacted Area (meter)									
Horizontal Leak with Obstacle Impact					Horizontal Leak				
	250 psi (Release rate: 23.4676 kg/s)	60 psi (Release rate: 6.414 kg/s)	250 psi (Release rate: 23.4676 kg/s)	60 psi (Release rate: 6.414 kg/s)					
Weather	5D	3F	5D	3F	5D	3F	5D	3F	
Jet fire (3.2 kw/m ²)	54	50	26	23	92	86	48	44	
Explosion (50 mbar)	318	338	172	106	153	145	97	90	

Table 5. Results of fire zone at CGS station No. 1 and Bagh-e-Marouf station.

Jet Fire Results	Study/ME Path RC	Scenario	Weather	Flame length [m]	Distance downwind to intensity level 1 (9.5kW/m ²) [m]	Distance downwind to intensity level 2 (11kW/m ²) [m]	Distance downwind to intensity level 3 (12.5kW/m ²) [m]	Distance downwind to intensity level 4 (37.5kW/m ²) [m]
		Time varying leak	5d	25.1093	35.4599	34.1257	33.0173	26.7273

Path	Scenario	Weather	Poll diameter [m]	Distance downwind to intensity level 1 (9.5kW/m ²) [m]	Distance downwind to intensity level 2 (11kW/m ²) [m]	Distance downwind to intensity level 3 (12.5kW/m ²) [m]	Distance downwind to intensity level 4 (37.5kW/m ²) [m]
Study/MERC Fire Zone Bagh-e-Marouf	CGS1	3f	27.9109	36.5357	35.278	34.2171	29.5638
		5d	25.0403	35.3394	34.0101	32.9056	26.653
		3f	27.8236	36.4076	35.154	34.0965	29.4747
		5d	7.59096	28.2733	27.2676	26.3878	14.3734
		3f	8.08617	27.2622	26.1929	25.2623	14.5063
		5d	14.6092	43.2322	41.4593	39.9524	21.3353
Study/MERC Fire Zone Bagh-e-Marouf	Time varying leak	3f	17.7306	46.641	44.5265	42.7255	24.2933
		5d	7.56153	28.1786	27.1752	26.2968	14.3235
		3f	8.05853	27.1783	26.1121	25.184	14.4513

		Scenario	Weather	Distance downwind to LFL [m]	Distance downwind to LFL Fraction [m]							
Late poll fire results	FirePath	5d		12.7051 39.2404 37.6716	36.332 19.3349							
		3f		14.9309 41.1249 39.3069	37.7551 21.3612							
Flash fire results	Study/MERC Zone Bagh-e-Zone CGS1	Time varying leak	5d	7.74311	31.8983							
			3f	-	29.4484							
			5d	-	30.5641							
			3f	-	27.0034							
	Fire Zone	Scenario	Weather	Over Pressure level [bar]	Maximum distance [m]	Diameter [m]						
							5d	0.2	36.3056	12.6112		
								0.14	38.1305	16.2611		
								0.05	49.0499	38.0998		
Explosion results	Study/MERC Bagh-e-Marouf	Time varying leak	Fire Zone	Scenario	Weather	Over Pressure level [bar]	Maximum distance [m]	Diameter [m]				
									5d	0.2	36.1057	12.2113
										0.14	37.8727	15.7455
										0.05	48.4459	36.8918
	ZoneStudy/MERC CGS1	Time varying leak	Fire Zone	Scenario	Weather	Over Pressure level [bar]	Maximum distance [m]	Diameter [m]				
									3f	0.2	25.684	11.3679
										0.14	27.329	14.658
										0.05	37.1719	34.3438
Study/MERC Bagh-e-Marouf	Time varying leak	Fire Zone	Scenario	Weather	Over Pressure level [bar]	Maximum distance [m]	Diameter [m]					
								5d	0.2	36.1057	12.2113	
									0.14	37.8727	15.7455	
									0.05	48.4459	36.8918	
ZoneStudy/MERC CGS1	Time varying leak	Fire Zone	Scenario	Weather	Over Pressure level [bar]	Maximum distance [m]	Diameter [m]					
								3f	0.2	25.4411	10.8822	
									0.14	27.0158	14.0317	
									0.05	36.4382	32.8764	

Table 6. Results of restricted area at CGS station No. 1 and Bagh-e-Marouf station.

Jet Fire Results		Path	Scenario	Weather	Flame length [m]	Distance downwind to intensity level 1 (4.7kW/m ²) [m]	Distance downwind to intensity level 1 (9.5kW/m ²) [m]	Distance downwind to intensity level 3 (12.5kW/m ²) [m]	Distance downwind to intensity level 4 (37.5kW/m ²) [m]
Jet Fire Results	Study/MERC Fire Zone Study/MERC Fire Zone CGS1	Bagh-e-Marouf	Time varying leak	5d	110.109	211.738	171.843	159.935	122.361
				3f	118.414	204.813	171.714	160.848	124.262
				5d	112.746	217.343	212.955	164.128	125.539
				3f	121.196	210.136	206.76	165.031	127.78
Early poll fire results		Path	Scenario	Weather	Poll diameter [m]	Distance downwind to intensity level 1 (4.7kW/m ²) [m]	Distance downwind to intensity level 1 (9.5kW/m ²) [m]	Distance downwind to intensity level 3 (12.5kW/m ²) [m]	Distance downwind to intensity level 4 (37.5kW/m ²) [m]
Early poll fire results	Study/MERC Fire Zone CGS1	Time varying leak	5d	20.7436	82.0381	64.9323	60.3717	37.3135	
			3f	21.2481	76.9092	62.1389	57.544	36.7289	
			5d	20.7436	82.0381	64.9323	60.3717	37.3135	
Late poll fire results	Study/MERC Fire Zone CGS1	Time varying leak	3f	21.2481	76.9092	62.1389	57.544	36.7289	

Results Category	Study/Zone	Scenario	Weather		Distance downwind to LFL [m]				
			5d	3f	5d	3f			
Early poll fire results	Study/MERC Fire Zone Bagh-e-Marouf	Time varying leak	5d	16.9604	72.0277	70.5456	54.0225	33.6123	
			3f	17.3186	67.2375	65.9762	51.1852	33.0587	
			5d	16.9604	72.0277	70.5456	54.0225	33.6123	
			3f	17.3186	67.2375	65.9762	51.1852	33.0587	
			5d	16.9604	72.0277	70.5456	54.0225	33.6123	
			3f	17.3186	67.2375	65.9762	51.1852	33.0587	
Late poll fire results	Study/MERC Fire Zone Bagh-e-Marouf	Time varying leak	5d	16.9604	72.0277	70.5456	54.0225	33.6123	
			3f	17.3186	67.2375	65.9762	51.1852	33.0587	
			5d	16.9604	72.0277	70.5456	54.0225	33.6123	
			3f	17.3186	67.2375	65.9762	51.1852	33.0587	
			5d	16.9604	72.0277	70.5456	54.0225	33.6123	
			3f	17.3186	67.2375	65.9762	51.1852	33.0587	
Flash fire results	Study/MERC Fire Zone CGS1	Time varying leak	5d	101.212			147.236		
			3f	59.5454			85.3441		
			5d	93.8716			132.99		
			3f	54.1175			75.5144		
			5d	93.8716			132.99		
			3f	54.1175			75.5144		
Explosion results	Study/MERC Fire Zone Bagh-e-Marouf	Time varying leak	5d	0.14	0.05	0.2	Over Pressure	Maximum distance [m]	Diameter [m]
							0.14	150.828	41.6559
							187.033	154.066	
							146.153	32.3059	
							114.257	68.514	
							160.265	160.529	
			3f	0.14	0.05	0.2	106.568	53.1356	
							138.64	37.2801	
							135.541	31.0813	
							134.134	28.268	
							102.689	65.3782	
							97.2537	54.5074	

	0.2068	94.7868	49.5736
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CGS 1



CGS Bagh Marof

Fig. 2. Results of toxic probability of death vs. distance at CGS stations.

According to Table 7, the largest impacted area at CGS station No. 1 corresponded to the toxicity scenario with the IDLH criterion, with a distance of 873 m under 5D weather conditions. Similarly, at the CGS Bagh-Marouf station, the same toxicity scenario with the

IDLH criterion resulted in an impacted area extending 751 m under 5D weather conditions. These distances define the extent of the Impacted Area for each case.

Table 7. Results of impacted area at CGS station No. 1 and Bagh-e-Marouf station.

Jet Fire Results	Path	Scenario	Weather	Flame length [m]	Distance downwind to intensity level 1 (3.2kW/m ²) [m]	Distance downwind to intensity level 1 (4.7kW/m ²) [m]	Distance downwind to intensity level 3 (12.5kW/m ²) [m]	Distance downwind to intensity level 4 (37.5kW/m ²) [m]		
					1	1	3	4		
Jet Fire Results	Study/MERC Fire Zone Study/CGS1 Bagh-e-Marouf	Time varying leak	5d	110.109	243.605	211.738	159.935	122.361		
			3f	118.414	227.327	204.813	160.848	124.262		
			5d	112.876	250.201	217.461	164.245	125.675		
			3f	121.196	233.249	210.136	165.031	127.78		
Early poll fire results	Path	Scenario	Weather	Poll diameter [m]	Distance downwind to intensity level 1 (3.2kW/m ²) [m]	Distance downwind to intensity level 1 (4.7kW/m ²) [m]	Distance downwind to intensity level 3 (12.5kW/m ²) [m]	Distance downwind to intensity level 4 (37.5kW/m ²) [m]		
					1	1	3	4		
					5d	20.7436	95.3216	82.0381	60.3717	37.3135
					3f	21.2481	87.3037	76.9092	57.544	36.7289
Late poll fire results	Study/MERC Fire Zone CGS1	Time varying leak	5d	20.7436	95.3216	82.0381	60.3717	37.3135		
			3f	21.2481	87.3037	76.9092	57.544	36.7289		

Path	Scenario	Weather	Material		Concentration of interest [ppm]	Averaging time selected	Distance downwind to concentration of interest [m]						
			Material	Material to track									
Explosion results	Study/MERC Bagh-e-Marouf	5d	0.05	187.033	154.066	153.182	50.7036						
								0.14	150.828	41.6559			
											0.2	146.153	32.3059
		3f	0.05	160.265	160.529								
			0.14	114.257	68.514								
			0.2	106.568	53.1356								
	ZoneStudy/MERC CGS1	5d	0.05	169.647	119.294	153.182	50.7036						
								0.14	138.936	37.872			
											0.2	134.686	29.3713
		3f	0.05	146.591	153.182								
			0.14	102.689	65.3782								
			0.2	95.3518	50.7036								
Late poll fire results	Study/MERC Fire Zone Bagh-e-Marouf	5d	16.9527	82.9639	71.9796	53.9956	33.4945						
								3f	17.3186	75.8357	67.2375	51.1852	33.0587
		3f	17.3186	75.8357	67.2375	51.1852	33.0587						
								5d	16.9527	82.9639	71.9796	53.9956	33.4945
	Early poll fire results	ZonePath	5d	0.05	187.033	154.066	153.182	50.7036					
									0.14	150.828	41.6559		
												0.2	146.153
			3f	0.05	160.265	160.529							
				0.14	114.257	68.514							
				0.2	106.568	53.1356							
Scenario		5d	0.05	169.647	119.294	153.182	50.7036						
								0.14	138.936	37.872			
											0.2	134.686	29.3713
		3f	0.05	146.591	153.182								
			0.14	102.689	65.3782								
			0.2	95.3518	50.7036								

Toxic Results	Study/MERC Impacted Zone CGS1	5d	Methyl mercaptan	Methyl mercaptan	150	IDLH	873.01
	Study/MERC Impacted Zone CGS1	3f			150		820.226
	Study/MERC Impacted Zone CGS1	5d	Methyl mercaptan	Methyl mercaptan	150	IDLH	751.654
Study/MERC Impacted Zone CGS1	3f			150		484.78	

Discussion

This study employed Total GS EP SAF 253 document and PHAST software for the consequence analysis and calculations. According to this standard, three safety zones including fire zone, restricted area, and impacted area, along with their corresponding distances, were defined for the stations. Based on the findings, the safety zones and their distances were established in accordance with the Total GS EP SAF 253 standard. The characteristics and functions of each zone were examined with respect to the equipment layout and mitigation of potential consequence severity. According to Jahedshahraki et al., in the event of process accidents, three types of safety zones can be defined: fire, restricted, and impacted areas. They utilized the Total GS EP SAF 253 standard for determining the safety zones and reported that accurate definition of the zones can help in better planning and designing emergency response scenarios and support the optimal placement of units or new facilities to enhance operational safety (14). Results of Chen et al. showed that the leakage mode (horizontal or vertical), the leak to hole diameter ratio, and environmental conditions such as wind speed can significantly affect the dispersion distance and the severity impacts of ammonia leakage. Based on their findings, the data can serve as an effective basis for safety and environmental agencies to predict, manage, and control accidents involving liquid ammonia leakage, highlighting the practical importance from both industrial safety and environmental protection perspectives (17). In a

study by Rashidi et al., the consequences of accidents involving an atmospheric storage tank in a petrochemical complex were simulated and analyzed using PHAST (version 8.22). The study revealed that weather conditions play a crucial role in the extent of the consequences of pool fires. Such fires can impact adjacent tanks and increase the likelihood of domino effects. Consequently, the design of a comprehensive emergency response plan, which includes the evaluation of mutual and sequential consequences of damage to neighboring tanks, was recommended (18).

According to the results, due to the higher risk of equipment and building within the fire zone, emergency control equipment such as emergency shutdown valves (ESDVs), control rooms, and guardrooms should be installed within the fire zone and restricted area. Key principle recommendations for the fire zone may include minimizing the size of fire zones; installing fire and gas (F&G) detection systems, fire suppression systems, and emergency shutdown valves; maintaining a maximum allowable distance of 45 m with a flow rate of 120 m³/h for firefighting monitors; ensuring access for firefighting operations under any scenario and weather condition; and positioning control equipment (such as ESDVs) at least 15 m outside the fire zone.

The restricted area is the most critical zone during the design phase, as adherence to its boundaries can sig-

nificantly reduce the severity of potential consequences. Observing the prescribed distances within this zone allows the implementation of special safety measures to protect human life, which is the most valuable asset of any country. Key safety actions in this zone include the proper placement of critical equipment, buildings, safety systems, and relief valves, ensuring they are located outside the fire zone.

The impacted area is generally outside the direct control of the company or site; however, agreements should be made with local authorities to minimize the presence of residents within this zone. Such measures may include restricting the construction of buildings especially permanent residential areas or limiting public transportation traffic through this area.

The reliability of the PHAST simulation results was further supported by a comparison with published consequence modeling studies. Mirzakhani et al., for example, investigated fire and explosion risk consequences in a CGS station using PHAST and reported that the hazard radius associated with jet fire and explosion scenarios extended up to approximately 751 m from the station boundary, depending on seasonal meteorological conditions. This reported impact distance is comparable to the impacted area distances obtained in the present study (e.g., 649 and 873 m), indicating a similar order of magnitude. Furthermore, Panahi et al. conducted a consequence modeling of methane gas release in a gas refinery and demonstrated that hazard distances associated with fire and explosion scenarios varied significantly between summer and winter conditions, with larger affected distances occurring during warmer seasons. These findings are consistent with those of the present study, in which atmospheric stability and meteorological conditions played a critical role in defining the extent of the fire zone, the restricted area, and the impacted area. Overall, the comparison confirms that the safety distances predicted in this study are in line with previously published PHAST-based analyses and can be considered realistic within the accepted industrial safety assessment practices (19, 20) .

Conclusions

Based on the findings of this study, the Golgasht TBS station was identified as the most critical gas pressure reduction station in terms of compliance with the defined safety zones. It is located within a densely populated and high-traffic urban area, significantly increasing the po-

tential consequences of accidental events. The results indicate that the fire zone may affect adjacent buildings, whereas the restricted area extends beyond the station boundaries into pedestrian and built-up areas, contrary to the standard design requirements. Moreover, the impacted area was found to include extensive construction and heavy vehicular and pedestrian traffic, which conflicted with its intended safety function. These findings highlight the urgent need to implement corrective measures to reduce the likelihood of accidents and mitigate the potential consequences at this station.

One of the main limitations of this study was the absence of a specific standard for defining safety zones in confined environments that are fully compatible with consequence modeling using the PHAST software. In addition, inherent limitations of the PHAST software, particularly its inability to model simultaneous explosions involving multiple equipment units, should be acknowledged.

Footnotes

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Reference

1. Esfandian H, Goodarzian Urimi M, Shokoohi Rad A. Risk assessment of gasoline storage unit of National Iranian Oil Product Distribution Company using PHAST software. *Int J*

- Eng. 2021;34(4):763–8.<https://doi.org/10.5829/ije.2021.34.04a.02>
2. Fatemi F, Ardalan A, Mansouri N, Aguirre B, Mohammadfam I. Industrial chemical accidents: a growing health hazard in the Islamic Republic of Iran. *East Mediterr Health J*. 2019;25(1):5–11.
<https://doi.org/10.26719/2019.25.1.5>[PMID]
 3. Hadi Ahmadi V. Gas pipelines importance, accidents and hazards: a literature review study. *Int J Occup Hyg*. 2023;14(2).
 4. Askaripoor T, Kazemi E, Aghaei H, Marzban M. Evaluating and comparison of fuzzy logic and analytical hierarchy process in ranking and quantitative safety risk analysis (case study: a combined cycle power plant). *Saf Promot Inj Prev* (Tehran). 2015;3(3):169–74.
 5. Naemnezhad A, Isari AA, Khayer E, Esfandiari Birak Olya M. Consequence assessment of separator explosion for an oil production platform in South of Iran with PHAST Software. *Model Earth Syst Environ*. 2017;3(1):1–12.<https://doi.org/10.1007/s40808-017-0297-9>
 6. Dadashzadeh M, Khan F, Hawboldt K, Amyotte P. An integrated approach for fire and explosion consequence modelling. *Fire Saf J*. 2013;61:324–37.<http://doi.org/10.1016/j.firesaf.2013.09.015>
 7. Malviya RK, Rushaid M. Consequence analysis of LPG storage tank. *Mater Today Proc*. 2018;5(2):4359–67.<https://doi.org/10.1016/j.matpr.2017.12.003>
 8. Mousavi J, Parvini M. Analyzing effective factors on leakage-induced hydrogen fires. *J Loss Prev Process Ind*. 2016;40:29–42.<https://doi.org/10.1016/j.jlp.2015.12.002>
 9. Jafari MJ, Mohammadfam I, Zarei E. Analysis and simulation of severe accidents in a steam methane reforming plant. *Int J Occup Hyg*. 2014;6(3):120–30.
 10. Min LQ, Hong L, Lian S, editors. Study on safe distance and strength check of natural gas flaring. *IOP Conf Ser Earth Environ Sci*. 2019; IOP Publishing.<https://doi.org/10.1088/1755-1315/267/6/062049>
 11. Yang R, Gai K, Yang F, Zhang G, Sun N, editors. Simulation of pressure tank leakage based on PHAST. *IOP Conf Ser Mater Sci Eng*. 2019; IOP Publishing.<https://doi.org/10.1088/1757-899X/592/1/012090>
 12. Bahmani R, Pouyakyan M, Khodakarim S, Bidel H, Salehi A. Risk assessment and consequence analysis of fire and explosion in a vinyl chloride monomer tank by PHAST. *J Saf Promot Inj Prev*. 2021;8(4):208–18.
 13. Bagheri M, Badri N, Rashtchian D, Eghbalian H. Determination of safe distance for sour gas pipelines based on quantitative risk assessment. *Iran J Chem Chem Eng*. 2013;32(2):57–71.
 14. Jahedshahraki H, Esfandiari N. Simulation the fire consequence for a gas pipeline using PHAST software. *Iran Chem Eng J*. 2022;20(119):22–30.<https://doi.org/10.22034/ijche.2021.276516.1095>
 15. Özey ME, Güzel P, Can E. Consequence modelling and analysis of methane explosions: a preliminary study on biogas stations. *J Adv Res Nat Appl Sci*. 2021;7(1):132–44.<https://doi.org/10.28979/jarnas.890649>
 16. Torfi Alivi A, Shahraki F, Sardashti Birjandi MR, Khalilipour MM. Consequences modeling and determining of safe distance in the natural gas pressure reduction station using PHAST software (Case study: Borumi station in Ahvaz). *Occup Med Q J*. 2023;15(1):37–57.<https://doi.org/10.18502/tkj.v15i1.12978>
 17. Chen Y, editor. Consequence simulation and risk assessment model of liquid ammonia leakage accident based on PHAST software. In: *Proc 2020 Int Conf Adv Ambient Comput Intell* (ICAACI). 2020. IEEE.
 18. Rashidi S, Varshosaz K. Modeling and evaluation of the environmental consequences of fire in atmospheric storage tanks using PHAST software. *Adv Environ Technol*. 2023;9(2):153–64.<https://doi.org/10.22104/aet.2023.6024.1669>
 19. Mirzakhani H, Zarvanshani V, Ahmadi S. The influence of climate change on the modeling of fire and explosion risk consequences in a city gas station (CGS). *J Health Field*. 2020.
 20. Panahi S, Karimi A, Pourbabaki R. Consequence modeling and analysis of explosion and fire hazards caused by methane emissions in a refinery in cold and hot seasons. 2020.<https://doi.org/10.22037/jhf.v7i4.25456>