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Impact of Filling Stations: Assessing the Risks and Consequences of the Release of Hazardous Substances

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Abstract: In today's world, where environmental protection and sustainability are increasingly important, it is essential to pay attention to the environmental impact of different industries. One of these industries with a potentially significant impact on life, human health, the environment, and property is gas stations, which are essential links in the fuel supply chain. This article focuses on the topic of assessing the impact of gas stations on surrounding environments and will examine the potential negative impacts that these operations can have on society and the environment. The aim of the paper is to analyze how gas stations affect their surroundings in the event of an incident involving a spill of hazardous substances. The scope of the paper is to assess the impacts of a spill of hazardous substances from a gas station, with an emphasis on assessing the risks and consequences on the life and health of the people in the immediate vicinity of the gas station. The selected gas station's location in the High Tatras National Park enhances the study's significance due to the unique environmental context, heightened environmental sensitivity, and potential legislative implications. ALOHA software version 5.4.7 was chosen for simulating the release of hazardous substance due to its extensive substance database, mathematical models, support for various release sources, internet availability, and graphical result representation. This manuscript argues for risk assessment beyond current legislation, addressing unclassified sources of risk. This research contributes by utilizing predictive modeling, recognizing environmental contexts, and emphasizing legislative attention. It discusses the consequences of emergency scenarios involving gasoline and LPG, addresses potential limitations and uncertainties, and advocates for accident prevention and risk assessment, especially in environmentally sensitive areas. The conclusion suggests improvements in predictive modeling, legislative adaptation, collaboration, and an expanded scope of analysis for future research. The aim of the paper is also to discuss measures that can be taken to minimize these impacts and ensure sustainable and safe operation. Assessing the risks arising from the operation of gas stations contributes to the development of measures to protect and preserve our environment for future generations.

Keywords: assessment; consequences; environmental risks; filling station; risk

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1. Introduction

Emergencies associated with the release of hazardous substances have a significant impact on life, public health, the environment, and the sustainability of society. These events can lead to severe environmental impacts that disrupt ecosystems and degrade environmental quality [1].

The Common European framework, particularly enshrined in directives such as the Seveso III Directive (2012/18/EU), plays a key role in establishing a unified and robust approach to the prevention of major accidents involving dangerous substances across the European Union. This framework provides a structured and comprehensive set of guidelines that member states are obligated to implement, ensuring a consistent level of protection for human health, the environment, and property.

One notable contribution of this framework is its emphasis on risk management and prevention. The Seveso III Directive categorizes industrial facilities based on the quantity and types of hazardous substances they handle, thereby tailoring safety requirements to the specific risks posed by each facility [2]. The directive supports continuous improvement through regular risk assessments, emergency planning, and audits. It requires facilities to adapt to changing circumstances and technologies, ensuring that safety measures remain effective in the dynamic environment of evolving industrial landscapes. The Seveso III Directive significantly contributes to the protection of the population and the environment from major accidents involving hazardous substances in industrial installations. Its goal is to minimize risks and ensure that operators of industrial installations take responsibility for safety and preventive measures.

Moreover, the directive's emphasis on transparency and public participation underscores the commitment to accountability. Facilities are required to engage with the public, providing information about potential risks and safety measures. This not only empowers local communities but also fosters a culture of openness and shared responsibility in the management of hazardous materials.

The common European framework, as exemplified in directives like Seveso III, is a testament to the EU's dedication to harmonizing safety standards, fostering collaboration among member states, and mitigating the potential catastrophic consequences of industrial accidents involving dangerous substances. It stands as a commitment by the EU to environmental protection, public safety, and sustainable industrial practices.

Businesses that reach the thresholds defined in the legislation on the prevention of major industrial accidents [3], are subject to the obligation to carry out systematic risk assessments to minimize the negative impacts of potential accidents. Businesses with lower quantities of hazardous substances and not falling within this framework are not currently obliged to carry out similar risk analyses concerning major accidents.

In the analysis of the current situation, the published literature was searched for information related to the issue of assessing the sources of risks associated with the operation of a gas station. As a result, it was found that there are several references partially related to the issue of the gas station assessment.

In the context of the Slovak Republic, we consider the following legislative regulations and standards related to the assessment of risks at gas stations.

Selected laws:

- Act No. 128/2015 Coll. on the prevention of major industrial accidents and on amending and supplementing of certain acts as amended (hereinafter referred to as "Act on Accidents");
- Act No. 146/2023 Coll. on air protection as amended (replacing Decree No. 195/2016 Coll. of the Ministry of the Environment of the Slovak Republic, which established technical requirements and general conditions for the operation of stationary air pollution sources used for the storage, filling, and transport of gasoline, as well as the method and requirements for finding and verifying data on their compliance);
- Act No. 408/2011 Coll. on Environmental Impact Assessment;
- Decree No. 253/2023 Coll. of the Ministry of the Environment of the Slovak Republic 253/2023 Coll. on requirements for storage, filling, and transportation of gasoline;
- Decree No. 124/2000 Coll. of the Ministry of the Interior of the Slovak Republic, laying down the principles of fire safety in operations with flammable gases and combustion-supporting gas;
- Act No. 218/2013 Coll. on emergency stocks of oil and petroleum products and on dealing with state of oil emergency, and on amendment and supplement of some acts.

Selected Technical Norms:

- EN 16321 Petrol vapor recovery during refueling of motor vehicles at service stations [4],
- EN 753415 Protection of Water against Oil Substances. Facilities for Handling and Storage of Oil Substances [5];

- STN EN IEC 60079 Explosive Atmospheres. Part 10-1: Classification of Areas-Explosive Gas Atmospheres [6];
- ČSN 65 0201 Flammable Liquids-Production, processing, and stocking areas [7];
- ČSN 65 0202 Flammable Liquids. Filling and pumping. Filling stations. Combustible liquids [8];
- ISO 31000: 2018 Risk Management [9].

We also consider other laws and decrees and standards related to construction (construction, infrastructure, electrical equipment, alarm systems, etc.), the environment (assessment of environmental impacts, protective zones) or health protection at work, fire protection, and the civil protection of the population.

The main contribution and novelty of this thesis is the analysis of risks and impacts associated with the spills of hazardous substances at gas stations in the High Tatras, with particular emphasis on the consequences in the immediate vicinity of the gas station. The study not only assesses the current situation, but also identifies areas for improvement around accident prevention and response. In addition, the research sheds light on the specific threats that arise when pumping fuel from tankers to storage tanks and highlights the importance of addressing these critical moments in the operation of service stations. By providing detailed information on the risks associated with this process and suggesting strategies to mitigate them, the paper contributes to the existing literature by offering a nuanced understanding of gas station safety and environmental protection.

2. Materials and Methods

It should be stressed that the cost of risk assessment can be recouped, as it is better to prevent a major accident than to clean up an accident and restore the original state. This is not only more advantageous from a safety point of view, but also from an economic point of [10]. This can be expressed as an educated guess that the resources spent on prevention compared to those spent on eradication are approximately seven times lower [11,12].

The risk assessment of gas stations is linked to specific methods in the literature. The System Theoretic Accident Model and Processes [13] focuses on the extension of the causal principle of the safety nexus, the extended DEMATEL-STPA method and its application to hydrogen refueling stations [13], or the risk assessment of the location of a hydrogen refueling station in an urban area [14], or the use of the RISKCURVES software and the Layer of Protection Analysis method for the fire risk assessment of a hydrogen filling station in an urban area and also focusing on the applied the passive and active independent protection layers confirmed that these measures significantly reduced societal risk as well as individual risk and met international standards [15]. Another study used the Accident Risk Assessment Method for Industrial Systems (ARAMIS) [16] in conducted a risk assessment of the refueling area of a hydrogen-gasoline hybrid refueling station. Another study compared the safety situation of two other types of refueling stations, a formic acid hydrogen refueling station and a gaseous hydrogen refueling station, also using the RISKCURVES software [17]. Another interesting approach is a study that looks at finding the optimal model for the location of gas stations based mainly on demand, but as the authors also mention, it does not take risk assessment into account, and they predict further research in this area [18]. Another study involves a screening assessment of the risk of harm to human health and life associated with a hydrogen explosion and chemical release during the operation of a hydrogen filling station, with the authors identifying up to 21 different accident scenarios with Bayesian frequency estimation, and the authors also predict further research on the use of event tree analysis to estimate the frequency of accidents and to conduct hazard assessments by arranging the grid points for analysis at smaller intervals [19] or a paper, that proposes a scenario screening approach for identifying potential hazards in multi-fuel integrated energy supply stations [20]. In the study [21] the authors look at finding a risk assessment method for predicting human losses due to explosion accidents at gas stations. A detailed overview is provided by the article The health assessment of gas station attendants is the subject of a study [22], in which the authors assess the health risks, particularly the carcinogenic effects on diesel service station employees during prolonged exposure to volatile particles, e.g., spilled fuels. Melchers and Feutrill [23] describe the hazard scenarios considered, the risk analysis procedure and the selection and application of data for initiating events and for rates of the failure of mechanical components and of the pressure vessel in LPG filling stations. Other authors [24] describe applications of fuzzy faulty tree analysis and expert elicitation for evaluation of risks in LPG refueling stations or another using fuzzy logic method in risk prioritization in LPG refueling stations [25] or the authors also describe the scenario of an accidental release of LPG during the transfer operation which may lead to various consequences such as a pool fire, a fireball, and even a catastrophic rupture of the tank with a successive explosion of its contents (fire and risk analysis during LPG loading and unloading operations).

An analysis of the current situation around gas station safety shows that increased attention to filling station safety is focused on hydrogen filling stations, because of the growing interest in hydrogen as an alternative fuel. However, it is important to note that conventional filling stations offering traditional fuels such as gasoline, diesel and LPG are still an important part of the energy sector and are in operation around the world [26].

There are many companies in Europe that deal with the sale of fuels such as gasoline, diesel, LPG, and others. Some of these belong to large international energy companies, while others are local and regional chains. Here are some examples:

- BP (British Petroleum): A large international energy company based in the United Kingdom that operates many service stations throughout Europe.
- Shell: Another large international energy company based in the Netherlands, with an extensive network of service stations across Europe.
- Total: A French energy company with a global presence, including many service stations in Europe.
- Eni: An Italian energy company which operates service stations in various European countries.
- Repsol: A Spanish energy company with service stations in several markets in Europe.
- OMV: An Austrian energy company with a strong presence in Central and Eastern Europe.
- ESSO: An energy company that is part of ExxonMobil and operates service stations in several European countries.
- Q8: A Belgian energy company that is known for its service stations in Belgium and other European countries.
- Aral: A German gas station chain that is part of BP.
- CEPSA: A Spanish energy company with gas station operations in various European countries.

These are just a few of the many companies involved in fuel sales in Europe.

Each of these companies has its own brand names and networks of gas stations, which may be names such as “BP”, “Shell”, “Total”, and so on. For example, Shell has 22,539 gas stations across Europe [27] and OMV has more than 2100 gas stations in ten European countries [28].

As of 19 October 2023 there are 923 gas stations registered in the Slovak Republic in the database of the Statistical Office (Table 1).

Table 1. Total number of gas stations in the Slovak Republic [29,30].

Company	Number of Gas Stations
Slovnaft	267
OMV	91
Shell	87
Jurki	62
Orlen	60

Table 1. *Cont.*

Company	Number of Gas Stations
DaliOil	26
GAS	24
Benzinol	21
REAL-K	21
Flaga	21
1.SPS	19
Tesco	18
Tanker	15
Šajgaloil	13
TAM Autohof	12
SPP CNG	12
GULF	10
Local companies (number of gas stations < 10)	144

Assessing the safety of conventional gas stations is essential not only to protect human life and property, but also to minimize the environmental risks associated with spills and fires in the handling of these fuels [31]. These filling stations are located close to cities and residential areas, in protected landscapes, national parks, and close to drinking water sources, which increases the importance of a thorough risk assessment and the adoption of appropriate precautions [32,33]. The importance of risk assessment and the prevention of emergencies is highlighted by examples of selected accidents at pump station sites, including their consequences (Table 2).

Table 2. Overview of incidents at service stations.

Place	Event	Cause	Impact
8 October 2023 Creeslough (Ireland) [34]	an explosion at a gas station,	Gas leak	10 dead, 8 injured, demolished gas station building, damaged adjacent apartment buildings and broken windows of nearby family houses.
25 September 2023 Nagorno-Karabakh (Armenia) [35]	an explosion at a fuel depot	The cause of the explosion remains unclear, but according to the first information of the Armenian authorities, it was caused by negligence	220 people died, 300 are injured
26 August 2023 Crevedia (Romania) [36]	multiple explosions of liquefied petroleum gas (LPG) in the building of a gas station (an unlicensed gas station)	The cause of the explosions was not immediately known, the station did not have a permit to operate	6 dead, 58 injured, evacuation of people within a radius of 700 m
15 August 2023 Makhachkal (Russia) [37]	explosion at a gas station	The explosion was preceded by a fire that broke out in a car service and spread to the building of the gas station	35 dead, 100 injured, fire area 600 m^2
31 August 2022 Debrecen (Hungary) [38]	explosion at the gas station	The explosion occurred during maintenance when the gas station was closed. Pump workers were cleaning one of the fuel tanks.	4 seriously wounded, 1 slightly wounded
14 June 2021 Novosibirsk (Russia) [39]	explosion at a gas station,	Work performed in violation of safety requirements after the explosion. The reason for the explosion was allegedly the insufficient grounding of the gas carrier when it was discharged into a stationary container.	33 were injured, 7 of them seriously. The fire affected an area of approximately one thousand square meters.
5 December 2018 Rome (Italy) [40]	explosion at a gas station	The explosion occurred when fuel was being pumped from a tanker truck	2 dead, 10 seriously injured

The above examples of accidents show that accidents at service stations are often the result of a combination of negligence, improper handling of hazardous substances, and improper adherence to safety standards when working with fuels. These accidents can have profound consequences not only for human life, health, and property, but also carry serious environmental risks that persist over time and have the potential for long-term negative impacts on the surrounding environment.

3. Results

The aim of this section is to determine the explosion, thermal, and toxic manifestations of selected accident scenarios associated with dangerous substances leakage using a software simulation tool on a selected gas station facility. The ALOHA (Areal Locations of Hazardous Atmosphere) simulation software version 5.4.7 was selected as the appropriate software to model the shape and extent of hazardous substances released into the atmosphere. The choice of the software was motivated by several key factors:

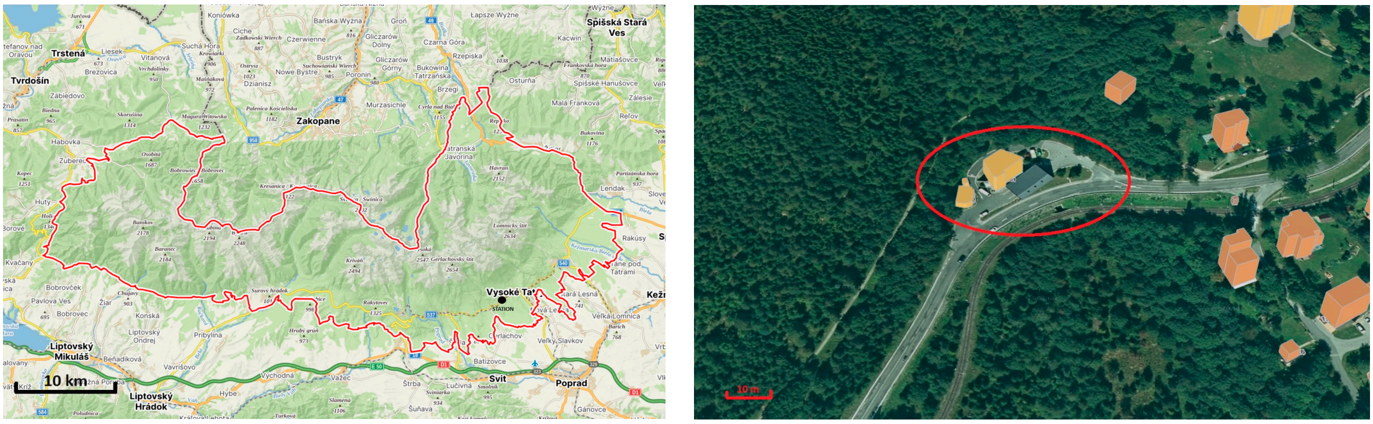
- An extensive database of chemicals contained in ALOHA that includes the physical and chemical properties of the most commonly used chemicals, including gasoline and diesel;
- The flexibility of ALOHA to model different gasoline spill scenarios and to consider diverse types of spill sources and atmospheric conditions;
- The free availability of ALOHA.

3.1. Description of the Selected Gas Station

The gas station shown in Figure 1 is situated in the city of High Tatras (before the merging of the Tatras settlements and villages into one town it was the territory of the municipality of Nový Smokovec). The construction of the gas station began in 1966 and ended in 1967. As it was constructed in a protected area, it was necessary to build a more demanding building that would correspond to the local genius loci (mountain environment, high tourist traffic). These circumstances led the investor to cancel the original plan to build a standard gas station and replace it with an individual solution. This solution was adopted at a time when the substructure of the originally intended type of gas station had already been built on the site.

Figure 1. The current state of gas station (Source: Google. (n.d.). Retrieved 22 April 2023, from https://maps.app.goo.gl/XhUBu6xjj4o2T9yY7).

The selected gas station is situated in the High Tatras National Park as shown in Figure 2a, in the cadastral area of Nový Smokovec part of the town of High Tatras on a separate plot of land on Slobody Road between the parts of the town of Nový Smokovec and Tatranské Zruby. The area of the gas station is located within the boundary of the village. At the same time, the gas station is located within the territory of the Tatras Biosphere Reserve (UNESCO), included in the international network of protected areas. The location of the gas station is above (the red circle in the Figure 2b) a stream and near an electric rail line. The nearest inhabited buildings are 90 m to the east (Figure 2b).



(**a**) (**b**)

Figure 2. (**a**) Tatra National Park-map showing the town of High Tatras (Source: State Nature Protection of the Slovak Republic, Tatra National Park, Map, from: https://www.biomonitoring.sk/InternalGeoportal/ProtectedSites/NationalSiteMap?ID=1356&CATEGORY=8) (accessed on 25 October 2023) (**b**) 3D map of the gas station location on the basis of orthophoto map (Source: Ministry of Interior of the Slovak Republic, Cadastral map, Available at: https://zbgis.skgeodesy.sk/mkzbgis/sk/zakladna-mapa-3d/detail/ease/basic/56010305?cam=49.130589,20.207485,1364.528357,359.994936,45.042687) (accessed on 25 October 2023).

3.1.1. Description of Gas Station Objects

The gas station complex consists of the following main buildings: the service building, fuel storage (storage tanks), dispenser roofing, fuel dispensing points, and LPG refueling facility, which are shown in Figure 1. The operating ensemble and the service station building provide all the required functions for the filling, storage, and dispensing of fuels using the relevant equipment. The following input data was used for modelling. The gas station facility contains hazardous substances—fuels (gasoline, diesel) (see Table 3), which are classified as hazardous class 3-flammable liquids according to the international regulations for the transport of hazardous substances (ADR) and LPG, which is classified as an extremely flammable gas.

Table 3. Hazardous substances present in the the gas station.

Hazardous Substance	Equipment	Quantity [t]
diesel	storage tank	39.1
	tank	39.1
gasoline "Natural 95"	storage tank	36.8
	tank	36.8
LPG	tank 1	2.1
	tank 2	22

3.1.2. Internal Sources of Danger

The internal sources of danger in an emergency associated with fire, vapor explosion, and leakage of fuels and their vapors into the air are the equipment of the gas station where stored and pumped fuels are found and the processes in which these substances are handled (see Table 4).

Table 4. Internal sources of danger.

Equipment	Volume [m^3]	Technological Process	Hazardous Substance
car tank	45	transfer of fuel to storage tanks	gasoline, diesel
storage tank	55	fuel storage	gasoline, diesel
connecting pipe	-	transportation of fuel from storage tanks to fuel stands	gasoline, diesel
stand dispensing gun	-	delivery of fuel to vehicles	gasoline, diesel
LPG tank 1	50	transfer of LPG to storage tanks	LPG
LPG tank 2	4.8	LPG storage	LPG

3.2. Determination of Emergency Scenarios

The determination of the worst-case situation in which the greatest number of people are at risk and the environment is at greatest risk from the effects of an explosion, toxicity or fire of the released fuel is based on the estimation and determination of emergency scenarios. The selection of possible accident scenarios was based on:

- the expected release of the maximum quantity of each hazardous substance,
- the largest area of a fire,
- the possible danger to the surroundings from an explosion and radiant heat,
- the number of persons at risk on the premises [41].

The types of hazardous substances, their fire-technical characteristics, their handling, the technological process of production, fire protection, and protection systems have a considerable influence on the determination of emergency scenarios [42]. In the gas station facility, the following possibilities of emergency leakage of oil from the storage and handling areas have been identified as significant. Realistic cases where fuel spills may occur are listed in Table 5.

Table 5. Emergency scenarios.

Emergency Scenario	Type of Leak	Cause of Leak
1. fuel leakage during filling	one-time leakage of the entire transported amount	damage of the tank shell
	continuous leakage of transported fuel	rupture of the dispensing hose, or its incorrect installation at the connections with the dispensing pipe or tank
2. leakage of fuel from storage tanks	continuous leakage	overflow of the tanks
3. fuel leakage from the connecting pipe	continuous leakage	tank leakage or leakage of the transport pipe
4. leakage of fuel from fuel stands during refueling	continuous leakage	damage to the fuel stand or fuel guns when refueling fuel into vehicles
5. leakage of LPG from the tank	one-time leakage	damage to the safety valve, damage to the integrity of the reservoir shell when a car hits the reservoir, corrosion
6. LPG leakage during filling	one-time leakage of the entire transported amount	damage of the tank shell
	continuous leakage of transported LPG	rupture of the dispensing hose, or its incorrect installation at the connections with the dispensing pipe or tank

The initiation and subsequent fire or explosion of the underground fuel storage tanks is considered as an unlikely emergency scenario under standard operating conditions and in a peaceful state. Damage to the underground fuel storage tanks is only realistic in the event of an aircraft crash on the area of the fuel storage facility and in a state of war [43].

Consequences of potential accidents modelled only for selected emergency scenarios:

- scenario 1 leakage of the entire quantity of gasoline from a tanker during filling,
- scenario 5 leakage of the entire quantity of LPG from the storage tank,
- scenario 6 leakage of the entire quantity of LPG from a tanker during filling.

The selected emergency scenarios were modeled in two basic representative weather classes:

- normal air stability, class 4 = D, wind speed medium-5 m·s^{-1} (the most common conditions during the year),
- very stable conditions, class 1 = F, wind speed low-1.7 m·s^{-1} (worst dispersion, largest area affected-worst case scenario).

3.3. Modelling the Consequences of Emergency Scenario 1-Leakage of the Entire Quantity of Fuel from the Tank during Filling

In this section, the consequences of Emergency Scenario 1, focusing on the potential leakage of the entire quantity of fuel from the tank during the filling process, were explored. The following table (Table 6) provides a detailed modeling of the leakage using the software ALOHA version 5.4.7, considering different atmospheric stability conditions (D and F). The outcomes encompass various aspects, such as the toxic effects of the vapor cloud, flammability, potential explosion, and associated risks to both structures and individuals [44].

Table 6. Leakage of the entire quantity of gasoline from the tanker during filling modeled by ALOHA software.

Leakage of the Entire Quantity of Fuel from the Tank during Filling			Atmospheric Stability D	Atmospheric Stability F
Leaked gasoline does not burn, it evaporates into the atmosphere	Toxic effects of the vapor cloud from the point of release [m]		**	**
	Creation of a flammable vapor cloud	60% DMV	41	75
		10% DMV	189	221
	A vapor cloud explosion	Severe damage to buildings [m]	*	50
		Serious personal injury [m]	*	52
		Danger to people with glass [m]	*	57
POOLFIRE	Potentially fatal threat to persons by thermal radiation [m]		45	45
BLEVE	Max. diameter of the fireball [m]		193	193
	Burning time [s]		12	12
	Potentially fatal threat to persons from thermal radiation		**	**
	2nd degree burns		**	**
	Danger of severe injury to persons outside buildings		**	**

* The vapor cloud explosion will not occur ** The threshold value at which there may be a threat to life, health of people, property and the environment due to toxic, thermal, or pressure effects will not be exceeded in the given case.

The effects of the BLEVE effect, i.e., the rolling of the heated tank and the immediate leak of the tank contents into the air with the subsequent fireball fire, are calculated only for information, because this effect is conditioned by a high pressure rise in the closed heated tank, which is not likely in tank chambers with pressure relief valves and "tank breathing" openings.

3.3.1. Consequences of Emergency Scenario-Leakage of the Entire Quantity of Gasoline from a Tanker during Filling

Explosive Effects of Gasoline

If a sufficiently large plume of explosive substances is formed within the explosive limits when mixed with air, then the initiation of the plume results in a rapid transition of combustion to explosion by the formation of an airborne shock wave. In the case of escaped gasoline, the vapor cloud on surface evaporation from the plume will attain 60% at atmospheric stability type D at a distance of 75 m from the point of escape. In the event of an explosion initiated by an automotive gasoline vapor cloud, persons at a distance of 221 m from the point of leakage will be endangered by the impact of the airborne shock wave. Serious injuries will be sustained by persons within 52 m, and the exposure of persons to glass splinters has been determined to be 57 m. Buildings within 50 m of the blast site will be damaged by blast effects. (Table 6).

Thermal Effects of Gasoline

Fatal exposure of persons to thermal radiation in the model fire scenario is possible within 45 m of the flame. In the case of a fireball, its diameter would reach a maximum of 193 m and the burning time was set at 12 s. (Table 6).

Toxic Effects of Gasoline

If gasoline leaks from a tanker during bottling, a puddle forms in the area around the dispensers, from which the gasoline evaporates. The substance evaluated does not have serious toxic effects on the human body, the inhalation of gasoline may cause headaches, dizziness, upset stomach, and contact is irritating to the skin.

3.4. Modelling the Consequences of Emergency Scenario 5-Leakage of the Entire Quantity of LPG from the Storage Tank

In this section, we examine the potential consequences of Emergency Scenario 5, specifically focusing on the leakage of the entire quantity of LPG from the storage tank. The following table (Table 7) outlines the detailed modeling of the LPG leakage utilizing the ALOHA software. Two different atmospheric stability conditions, D and F, were considered, shedding light on various aspects such as the toxic effects of the vapor cloud, flammability, potential explosion, and associated risks to structures and individuals.

Table 7. Leakage of the entire quantity of LPG from the storage tank modeled by ALOHA software.

Leakage of the Entire Quantity of LPG from the Storage Tank			**LPG Tank**	
			Atmospheric Stability D	**Atmospheric Stability F**
LPG is leaking from the tank into the atmosphere and evaporates	Toxic effects of the vapor cloud from the point of release [m]		322	355
	Creation of a flammable vapor cloud	60% DMV	107	181
		10% DMV	333	361
	A vapor cloud explosion	Severe damage to buildings [m]	94	171
		Serious personal injury [m]	135	224
		Danger to people with glass [m]	289	456

Table 7. *Cont.*

Leakage of the Entire Quantity of LPG from the Storage Tank		LPG Tank	
		Atmospheric Stability D	**Atmospheric Stability F**
LPG is leaking from the tank and burns like a JET FIRE	Potentially fatal threat to persons by thermal radiation [m]	74	67
	2nd degree burns	105	98
	Danger of severe injury to persons outside buildings	161	154
BLEVE	Max. diameter of the fireball [m]	74	74
	Burning time [s]	6	6
	Potentially fatal threat to persons from thermal radiation	176	181
	2nd degree burns	249	256
	Danger of severe injury to persons outside buildings	388	399

3.4.1. Consequences of Emergency Scenario-Leakage of the Entire Quantity of LPG from the Storage Tank

Explosive Effects of LPG

When a vapor cloud of LPG is initiated in the case of atmospheric stability D, buildings at a distance of 107 m will be damaged by the pressure effects of the explosion, persons within a radius of 135 m will be at risk of serious injury, and glass shards will be at risk of serious injury up to a distance of 289 m from the point of leakage. At atmospheric stability type F, the consequences of the explosion will be even worse (Table 7).

Thermal Effects of LPG

There will be a risk to persons from thermal radiation from a leak in an LPG container, if the LPG escapes and burns as jet fire and if the LPG container is at risk of fire and the BLEVE effect occurs (Figure 3).

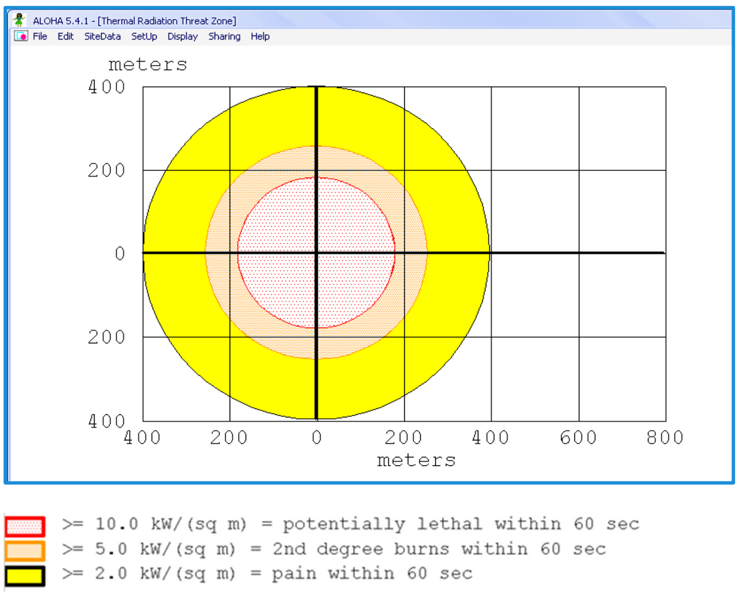


Figure 3. BLEVE effect of LPG.

In the event of a jet fire effect, a potentially fatal thermal radiation hazard to persons at a distance of 74 m, 2nd degree burns at a distance of 105 m, and serious injury at a distance of 170 m from the container will occur. For Type F atmospheric stability, the thermal hazard zones are smaller in this case (Table 7).

In the case of a BLEVE effect, the fireball diameter will reach a maximum of 74 m and the burn time will be 6 s. Potentially fatal thermal radiation exposure to persons will occur at 176 m, 2nd degree burns at 249 m and severe injury at 388 m from the container when persons are exposed for 1 min. For Type F atmospheric stability, the zones of risk of thermal effects are larger.

Toxic Effects of LPG

LPG is slightly toxic. Narcotic effects are possible, in higher concentrations it causes asphyxiation. Inhalation of low concentrations of the gas with air has mild narcotic effects on the central nervous system leading to depression. Inhalation of high concentrations of gas with air may cause coma, which is preceded by a state similar to drunkenness and loss of muscular co-ordination. The toxic effects of the escaped vapor cloud will become apparent at atmospheric stability D at a distance of 322 m (355 m at atmospheric stability F) from the point of leakage.

3.5. Modelling the Consequences of Accident Scenario 6-Leakage of the Entire Quantity of LPG from a Tanker during Filling

In this section, we analyze the potential consequences of Accident Scenario 6, specifically focusing on the leakage of the entire quantity of LPG from a tanker during the filling process. The comprehensive modeling of this scenario, utilizing the ALOHA software, is presented in Table 8. Two different atmospheric stability conditions, D and F, are considered, providing insights into various aspects, including the toxic effects of the vapor cloud, flammability, potential explosion, and associated risks to structures and individuals.

Table 8. Leakage of the entire quantity of LPG from the storage tank during filling modeled by ALOHA software.

Leakage of the Entire Quantity of LPG from the Storage Tank during Filling			Atmospheric Stability D	Atmospheric Stability F
LPG is leaking from the tank into the atmosphere and evaporates	Toxic effects of the vapor cloud from the point of release [m]		322	537
	Creation of a flammable vapor cloud	60% DMV	129	239
		10% DMV	392	551
	A vapor cloud explosion	Severe damage to buildings [m]	118	228
		Serious personal injury [m]	169	311
		Danger to people with glass [m]	360	620
JET FIRE	Potentially fatal threat to persons by thermal radiation [m]		65	51
	2nd degree burns		93	77
	Danger of severe injury to persons outside buildings		144	124
BLEVE	Max. diameter of the fireball [m]		163	163
	Burning time [s]		11	11
	Potentially fatal threat to persons from thermal radiation		403	410
	2nd degree burns		569	578
	Danger of severe injury to persons outside buildings		889	904

3.5.1. Consequences of Emergency Scenario-Leakage of the Entire Quantity of LPG from a Tanker during Filling

Explosive Effects of LPG

Upon initiation of the LPG vapor cloud in the case of atmospheric stability D, buildings at a distance of 118 m will be damaged by the pressure effects of the explosion, persons within a radius of 169 m will be at risk of serious injury, and glass splinters will be at risk of serious injury up to a distance of 360 m from the point of leakage (Table 8).

Thermal Effects of LPG

In the event of a jet fire effect, there will be a potentially fatal thermal radiation hazard to persons at 65 m, 2nd degree burns at 93 m and serious injury at 144 m from the tanker. For atmospheric stability type F, the thermal hazard zones are smaller in this case (Figure 4).

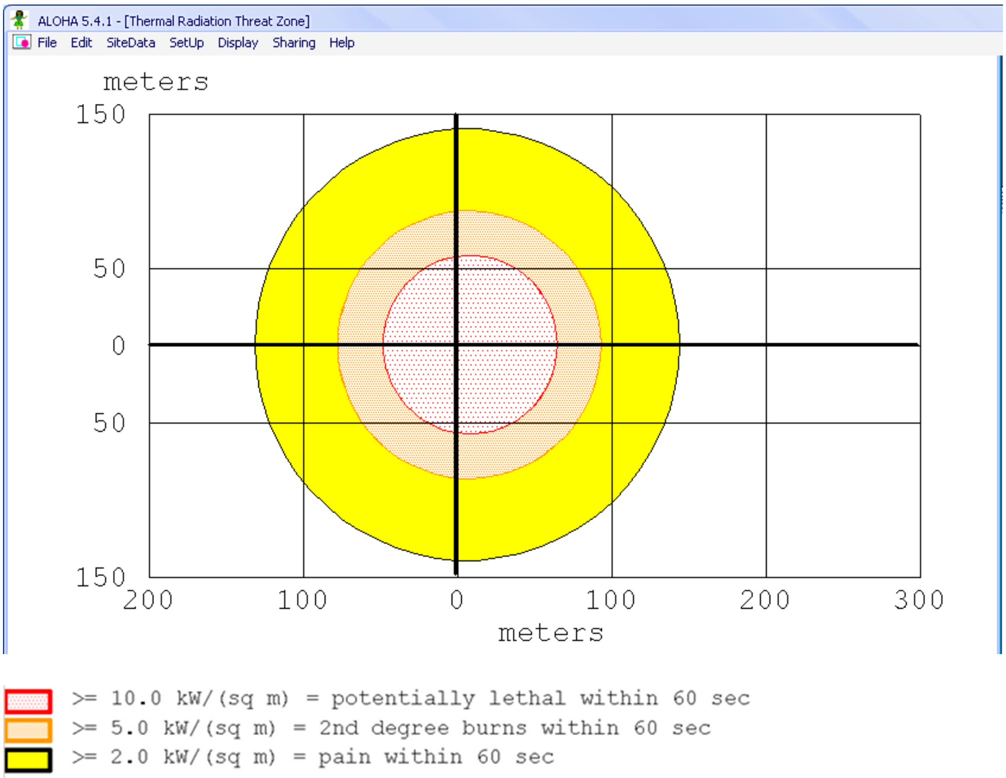


Figure 4. Jet fire effect of LPG.

In the case of a BLEVE effect, the fireball diameter will reach a maximum of 163 m and the burn time will be 11 s. Potentially fatal thermal radiation exposure to persons will occur at a distance of 403 m, 2nd degree burns at a distance of 569 m, and severe injury to persons outside the building at a distance of 889 m from the tanker when persons are exposed for 1 min. For type F atmospheric stability, the zones of thermal consequence hazard are larger.

Toxic Effects of LPG

Toxic effects of the escaped vapor cloud are manifested at atmospheric stability D at a distance of 322 m (537 m at atmospheric stability F) from the point of leak.

4. Discussion

The objective of the predictive modelling was to gain detailed and comprehensive insights into the risks and impacts associated with spills at gas stations. The results of this analysis will be used not only to assess the current situation, but also to identify areas that could be improved for accident prevention and response. In this way, the safety of gas station operations should be improved and potential negative consequences for the population and the environment minimized.

The analysis of the consequences of accident scenarios that was carried out is inevitably associated with certain uncertainties resulting from the input data used, the exposure factors chosen, the presence of the population and their behavior during the occurrence of an incident. It is therefore important to consider the uncertainty and extrapolation of uncertainties that are associated with the calculations that were performed and the estimates that were made. Uncertainties in the assessment of the consequences of emergency scenarios that may limit the application of the data obtained arise from [45]:

- The software used;
- The input data;
- The limited application of the data obtained;
- The presence of the population in the gas station facility or in the vicinity of the road;
- The behavior of people during the occurrence of an emergency.

Based on the prognostic modelling and the analysis of the consequences of the selected accident scenarios and the associated hazards, it can be concluded that the activity carried out in the gas station creates the preconditions for a threat to persons located in the vicinity of the gas station. The risk of endangering the population in the event of an emergency is greatest at the time of fuel transfer from a tanker to the storage tanks. In this case, the worst impacts of the effects of the emergency were determined. The occurrence of an incident may be caused by a vehicle striking a parked tanker, as the tanker partially obstructs the access roads during the filling process and the effects of the accident may be felt outside the gas station site.

The threat to the population and the environment from the separate technology of the storage and dispensing of fuels (gasoline, diesel) is minimal, and it is not expected that an accident of such a magnitude will occur that would cause any impact (toxicity, fire, explosion) that would endanger the population in the vicinity of the gas station.

Based on the modelling of the consequences of accidental LPG leaks, the LPG tank, especially the process of its refilling from a tanker, represents a significant source of danger in the gas station facility, because in the event of an emergency, not only the persons located in the gas station facility but also in its wider surroundings will be at risk. The various methods and approaches mentioned in the introduction of the paper may be applicable to the assessment of the risk associated with conventional filling stations. These methods can help to identify potentially hazardous situations, risk scenarios and factors that contribute to risk [46]. In the future, it would be appropriate to carry out a more detailed assessment of the negative impacts resulting from the operation of the gas station on the individual components of the environment.

Based on the analysis and the obtained results, it is recommended to implement risk management for facilities that have been identified as significant in terms of the potential for a serious accident. The risk management system includes [42]:

- Assessment of the risk of a serious accident: to be conducted every 5 years or in the case of significant changes in the safety of facility operations;
- Organization and employees: conducting regular training, define responsibilities, and empower individual employees in accident prevention;
- Management of facility operations: developing and adhering to safety procedures for individual technological facilities;
- Management of changes in the facility: evaluating risks before making changes in technologies (changes in hazardous substances, changes in equipment);
- Emergency planning: developing an emergency plan and conducting exercises (response training);
- Control: monitoring the effectiveness of the risk management system for continuous improvement.

When defining preventive measures implemented by the management of the facility and service personnel, it is advisable to rely on a set of rules ("Golden Rules") for preventing serious accidents outlined in the OECD Guiding Principles for Chemical Accident Prevention, Preparedness, and Response, Guidance for Industry. These rules are defined generally but are universally applicable.

Role of management:

- Understand the dangers and risks of facilities where hazardous substances are present;
- Promote a "safety culture" known and accepted throughout the company;
- Establish a safety management system and monitor its implementation;
- Apply the principles of "inherently safer technologies" in the design and operation of facilities containing hazardous substances;
- Exercise caution when managing changes;
- Prepare for any accident that may occur;
- Assist others in carrying out their respective functions and responsibilities;
- Strive for continuous improvement.

Role of employees:

- Act in accordance with the company's safety culture, safe procedures, and training;
- Strive to be informed and provide information and feedback to management;
- Be active in helping raise awareness and educate the community.

Given that hazardous substances are stored and handled at the facility, posing potential risks to life, health, or property, it is necessary to carry out preventive activities to reduce the likelihood of a serious accident. Preventive activities encompass a set of organizational, managerial, personnel-related, educational, technical, technological, and material measures to prevent the occurrence of a serious industrial accident.

In the context of gas station operations, effective environmental control and risk management are paramount to mitigate potential adverse impacts on the surroundings. Robust environmental control measures involve the implementation of advanced technologies and protocols to prevent and respond to hazardous substance spills. This includes state-of-the-art containment systems, real-time monitoring, and emergency response plans tailored to minimize the environmental fallout. Moreover, proactive environmental risk management necessitates a comprehensive understanding of the potential consequences on air quality, vegetation, and fauna. Regular environmental assessments and audits can play a crucial role in identifying vulnerabilities and refining preventive strategies. Collaborative efforts with environmental agencies and stakeholders further contribute to the development of sustainable practices that not only uphold the safety of gas station operations but also safeguard the ecosystems in their vicinity. By integrating effective environmental control and risk management strategies, gas stations can strive for a balance between their operational needs and the preservation of the environment, ensuring a safer coexistence with surrounding ecosystems and communities.

5. Conclusions

The intention of this work was not only to give a brief introduction to the issue of gas station safety, but also to point out that the issue of accident prevention in buildings is not systematically addressed at present. These enterprises, which due to their location, e.g., near residential areas, water sources, and in densely populated areas may represent a significant source of risk for the life and health of persons and the environment, in the event of an emergency occurrence, almost no legislative pressure in the field of prevention of major accidents is created.

The recent increase in incidents related to the spills of hazardous substances in gas station facilities should be a warning signal for all stakeholders to optimize the provision of measures to protect life, health, property, and the environment. For these reasons, there is a need for risk assessment and prevention of major accidents at gas stations.

It is important that further research and increased attention is focused on preventing emergencies and minimizing negative consequences to ensure that conventional gasoline, diesel, and LPG stations remain safe for the public and the environment.

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