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CONTRIBUTION TO THE ASSESSMENT OF EFFECT DISTANCES OF ATMOSPHERIC DISPERSION: CASE STUDY

Storage tanks are vital to the oil industry, functioning as essential components in the operation of oil fields. However, their strategic importance is accompanied by significant environmental risks, particularly due to atmospheric dispersion events. These events, characterized by the release and spread of pollutants such as aerosols, gases, and dust into the atmosphere, can stem from both human activities and accidental releases. The consequences are often severe, leading to considerable human, material, and ecological damage. Atmospheric dispersion of pollutants has emerged as a major environmental concern, especially within industries where storage tanks are integral to operations. This concern is magnified by increasingly stringent regulatory frameworks. Industries, particularly those operating within classified facilities subject to environmental protection laws, are now mandated to thoroughly identify, analyze, and assess potential accidental risks associated with their operations. These regulations are designed to mitigate the adverse impacts of such incidents, and this forms the object of this study.

In this study, we concentrated on the T-403A/B/C storage spheres at the ALRAR gas complex. Utilizing dynamic consequence modelling with ALOHA software, it was possible to conduct a comprehensive assessment of potential pollutant releases in the processing area. This approach allowed to meticulously map out the hazardous phenomena linked to these scenarios and to develop targeted preventive and protective measures. The findings from this study highlight the critical need for rigorous risk assessments and the implementation of proactive safety strategies. By doing so, the environmental and operational risks associated with storage tanks in the oil industry can be significantly reduced. This research underscores the imperative of integrating advanced modelling techniques and stringent safety protocols to safeguard both the environment and industry operations.

Keywords: *environmental risks, spread of pollutants, atmospheric dispersion of storage tanks, safety, modeling, protection and prevention.*

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1. Introduction

Atmospheric dispersion refers to the movement and behavior of particles such as aerosols, gases, and dust that are released into the atmosphere over time and space [1–3]. These emissions can be either anthropogenic-resulting from human activities or accidental, occurring due to unforeseen incidents. The dispersion of pollutants in the atmosphere is a major environmental concern, particularly for industries, as it has the potential to cause severe harm to human health, safety, and the environment [4–6]. Pollutants of anthropogenic origin, once present in the atmosphere, can lead to a wide range of health issues, including respiratory problems, cardiovascular diseases, and even cancers [7]. In addition to their health implications, these pollutants can pose serious safety risks, as they may serve as catalysts for fires and explosions [8–11]. Furthermore, their environmental impact is profound, with significant adverse effects on wildlife and vegetation [12–17].

Given the potential consequences of atmospheric dispersion, it is crucial to understand and control these emissions. This understanding is essential not only for quantifying their impact but also for reducing their environmental footprint wherever possible. Effective management of these emissions is particularly important in industrial settings, where the risk of accidental releases is higher [18–21]. Addressing these risks requires a proactive approach, particularly during the early stages of design and planning for industrial installations. One of the most effective ways to mitigate the risks associated with atmospheric dispersion is through the early estimation of potential accidental consequences. By analysing the likely outcomes of events such as explosions, fires, and toxic dispersions, industries can make informed decisions about the placement of facilities, the technologies they employ, and the safety measures they need to implement. This proactive approach enables the selection of optimal locations for new installations, minimizing the potential impact on surrounding communities and the environment. Additionally, it aids in the identification of key safety constraints that must be considered to ensure the well-being of workers and the public [22–26].

The data generated from such studies are invaluable not only for industries but also for public authorities. Accurate assessments of effect distances for explosions, fires, and toxic dispersions provide crucial information for emergency planning and response [27–31]. Public authorities can use this data to develop more effective regulations and guidelines for industrial activities, ensuring that safety and environmental considerations are adequately addressed. For industries, this information is essential for the design and operation of facilities that meet regulatory requirements while minimizing their environmental impact [32–37].

Eventually, the atmospheric dispersion of pollutants is a complex and significant challenge that requires careful consideration and management. By understanding the behavior of emissions and their potential consequences, industries can take proactive steps to reduce their environmental impact and enhance safety. The early estimation of accidental consequences plays a critical role in this process, enabling the selection of optimal facility locations, the implementation of appropriate technologies, and the identification of essential safety measures. This approach not only benefits industries by ensuring compliance with regulations but also serves the broader public interest by protecting health, safety, and the environment. Thus, *the aim of the research* is to assess of effect distances of atmospheric dispersion using case study.

2. Materials and Methods

To assess the atmospheric dispersion of gases, a numerical simulation was employed. This simulation serves as an advanced analytical tool designed to evaluate hazardous scenarios and model dangerous phenomena [38–42]. In contemporary industry practices, atmospheric dispersion modelling has become indispensable, providing critical insights into the physical processes at play and supporting the development of effective pollution control strategies. Atmospheric dispersion modelling enables a comprehensive understanding of how pollutants disperse in the environment, which is vital for devising strategies to mitigate their impact. For this purpose, let's utilize the ALOHA program to simulate the dispersion of emissions from a storage tank, specifically focusing on toxic or flammable substances. The ALOHA software facilitates the prediction of how these substances behave once released into the atmosphere, helping to estimate their potential impact on health and safety [43–45].

The use of a computer model in this context enhances project management by forecasting various variables and assessing associated risks. Typically, such simulations present risk in probabilistic terms, offering a quantifiable measure of potential hazards [46, 47].

In this study, we applied this approach to the T-403A/B/C storage spheres at the ALRAR gas complex. This case study provided a practical example of how numerical simulations can be used to evaluate and manage risks related to atmospheric dispersion. By analyzing the dispersion patterns and potential consequences, it is possible to gain valuable insights into the behavior of hazardous substances and improve safety protocols.

2.1. Overview of the ALOHA simulation software. CAMEO-ALOHA is a software tool designed for situations in emergency. It was developed collaboratively by two American agencies: the Environmental Protection Agency's Office of Emergency Prevention, Preparedness, and Response (EPA) and the National Oceanic and Atmospheric Administration's Office of Response and Restoration (NOAA) [48]. ALOHA models atmospheric dispersion of gases using two primary approaches: a Gaussian-based module for neutral gases and a dense gas module for heavier-than-air gases. The software supports the modelling of emissions from various sources, including boiling or non-boiling spills, pressurized gas or liquid storage tanks, unpressurized liquid tanks, tanks containing liquefied gases, and pressurized gas pipelines.

2.2. Scenario parameters and source description

Input Parameters: Input parameters encompass details such as the accident's location, the chemical substance involved, atmospheric conditions, site characteristics, and specifics of the release scenario. This comprehensive data is crucial for accurate modelling and effective assessment of potential impacts.

Site Location: AIN AMENAS, ILLIZI, ALGERIA.

Chemical Product: PROPANE.

Atmospheric Conditions: Detailed in Table 1.

Table 1

Input parameters

Characteristics	Values
Wind speed	8 m/s
Air temperature	45 °C
Humidity	5 %
Surface roughness	Free terrain

The source: It identifies the origin of the pollutant and the type of leak. Additionally, it requires information on the storage temperature, volume, and the container of the tank.

2.3. Accident scenario. For the atmospheric disperse on modelling of gas and emissions from pressurized tanks containing liquefied gases, a specific scenario was developed: Due to human error during maintenance on valve PSV502A/507A/508A, compounded by the aging factor of the valve, an explosion occurred. As a result, a simulation of the dispersion of the evaporated gas can be conducted, as to simulate the most common phenomenon in such cases, known as BLEVE (Boiling Liquid Expanding Vapour Explosion), as shown in Fig. 1.

2.4. Presentation of the study area

2.4.1. Geographical situation of the region. The gas complex is situated in a region characterized by a hot desert climate, specifically classified as Köppen BWh, emblematic of the vast Sahara. This environment is marked by prolonged, scorching summers and brief, mild winters. The climate is predominantly hyper-arid, with extremely low humidity and minimal annual precipitation, averaging just 23 mm. Summers are intensely hot, with maximum temperatures consistently exceeding 40 °C from mid-May to late September, often peaking around 45 °C. In contrast, winter days are pleasantly warm, though night-time temperatures can drop sharply to around 4 °C, a consequence of the desert's inability to retain heat. The skies over this region are typically clear, with cloud cover being a rare occurrence throughout the year. Overcast days are virtually non-existent, allowing for abundant sunlight year-round. The average daily temperature across the year is approximately 23.7 °C in Amenas. This extreme climate, with its intense heat and lack of moisture, presents significant challenges for both human activity and industrial operations, necessitating specialized infrastructure and rigorous safety measures to ensure continuous and safe functioning of the gas complex.

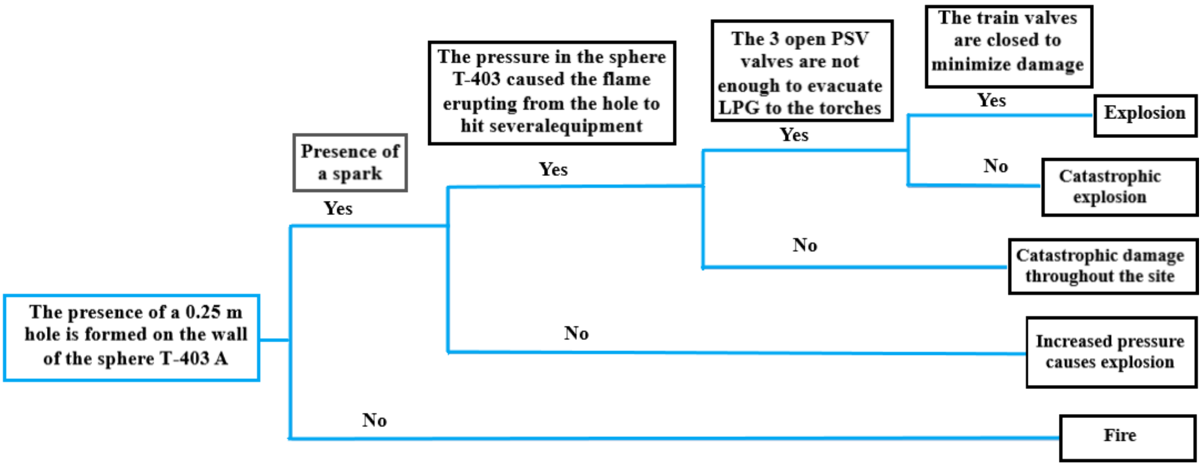


Fig. 1. Accident scenarios

2.4.2. Tank characteristics. Liquefied Petroleum Gas (LPG), a liquid primarily consisting of propane and butane, is stored and managed with precision to ensure safety and quality. The storage sphere T-403A is typically filled to two-thirds of its 3,978 m^3 capacity, with the remaining space occupied by fuel gas from the gas processing units. This LPG product, which meets stringent specifications, is produced at the top of column V-163 across four processing trains. The LPG that meets quality standards is stored in three identical spheres – T-403A, T-403B, and T-403C – each maintained at a pressure of 3 bars and a temperature of 2 °C. In contrast, off-specification LPG is stored separately in sphere T-404, which has a capacity of 949 m^3, under higher-pressure conditions of 6.5 bars and temperatures ranging from 2 °C to 60 °C.

When LPG does not meet the required specifications, it is pumped by either the P-421A or P-421B pumps to one of the E-104 reprocessing units (01, 02, 03, or 04) or to the vaporizer E-177 for reinjection into the system. Additionally, LPG can be transferred between the spheres using pumps P-411A or P-411B, as illustrated in Fig. 2.

Booster pumps P-407A, P-407B, and P-407C are used to discharge LPG to the HEH terminal via shipment pumps P-408A, P-408B, or P-408C [49]. The specific characteristics of these storage tanks, including their capacities, pressures, and temperatures, are detailed in Table 2.

The impact distances were determined using operational data collected directly from the installation sites. The subsequent analysis of these effects is shown in the next section, where presented the consequences of the identified hazardous phenomena.

3. Results and Discussion

3.1. Pollutant and flame concentration

The concentration of pollutants and flames poses significant risks, with impacted zones extending up to 200 meters for butane and 750 meters for propane, as illustrated in Fig. 3. These distances highlight the extensive reach of the threat, underscoring the need for effective mitigation measures within these critical areas.

The Threat of flames. In terms of fire hazards, the impact zones for both propane and butane are equivalent, with pollutant exposure extending beyond 750 meters, as illustrated in Fig. 4. The threat posed by flames is substantial, demonstrating the need for stringent safety measures across the entire affected area.

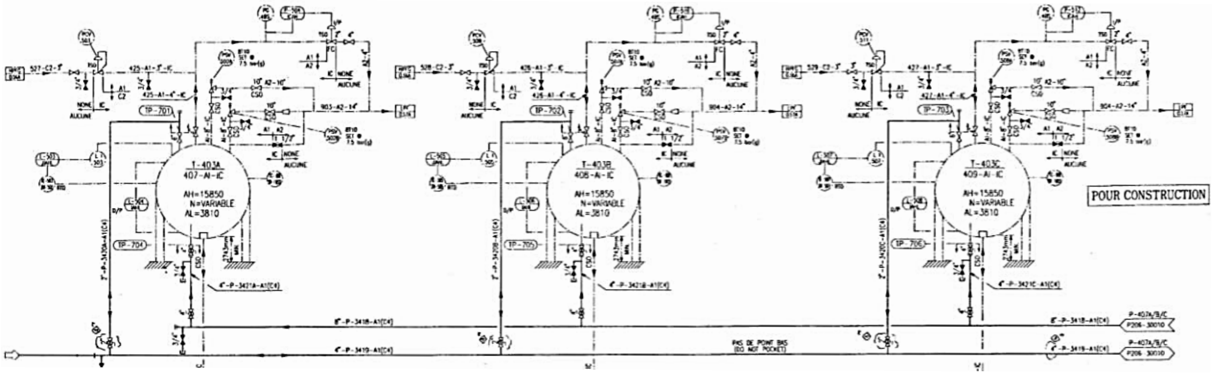
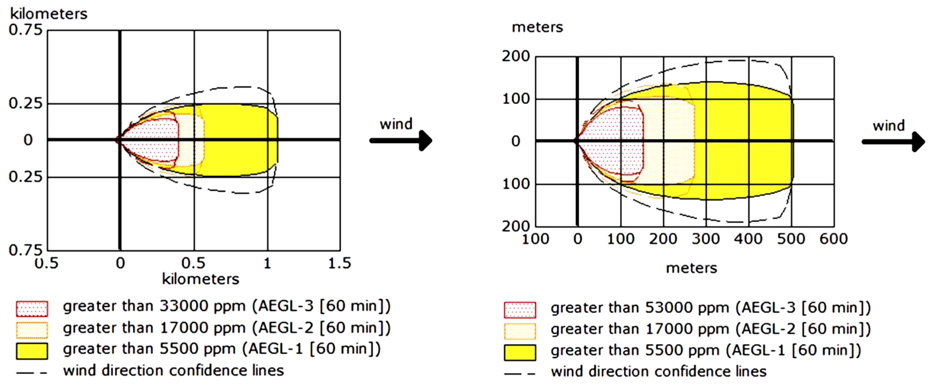


Fig. 2. The three spheres studied T-403A/B/C (identical)

Table 2

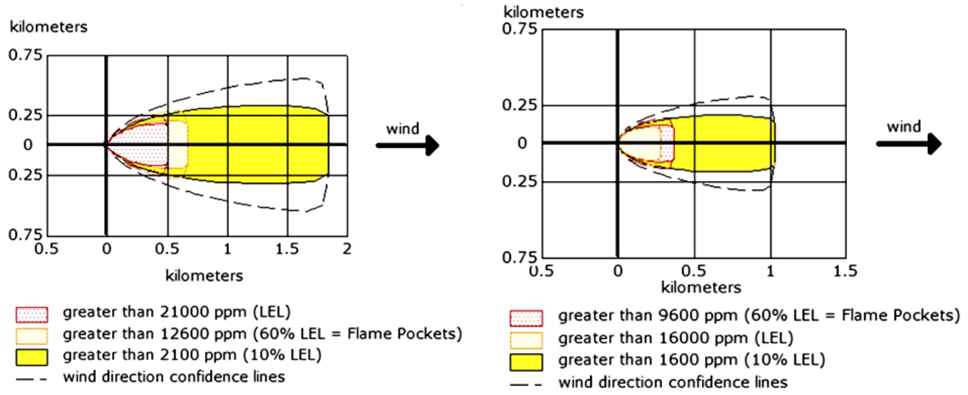
Characteristics of the tanks

Tanks	Capacity (m^3)	Volume (m^3)	Diameter (m)
T-403A/B/C	3978	2652	19.7
T-404	948	633	12.5



a *b*

Fig. 3. Concentration areas of pollutants: *a* – propane; *b* – butane

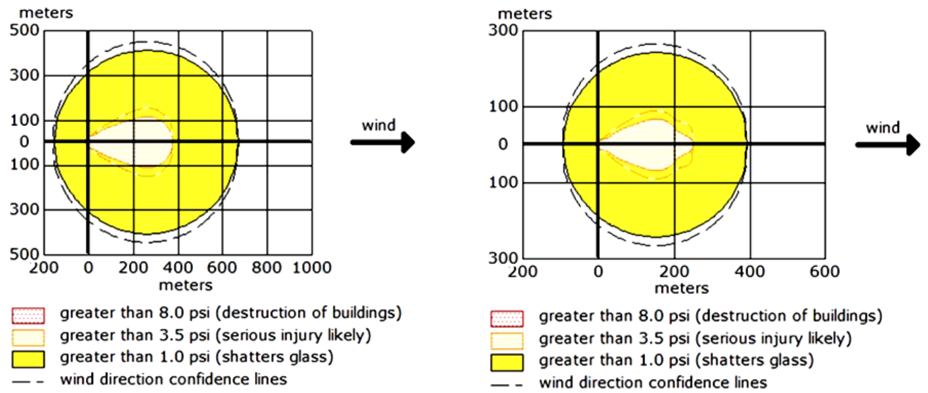


a *b*

Fig. 4. Areas threatened by pollutants from flames: *a* – propane; *b* – butane

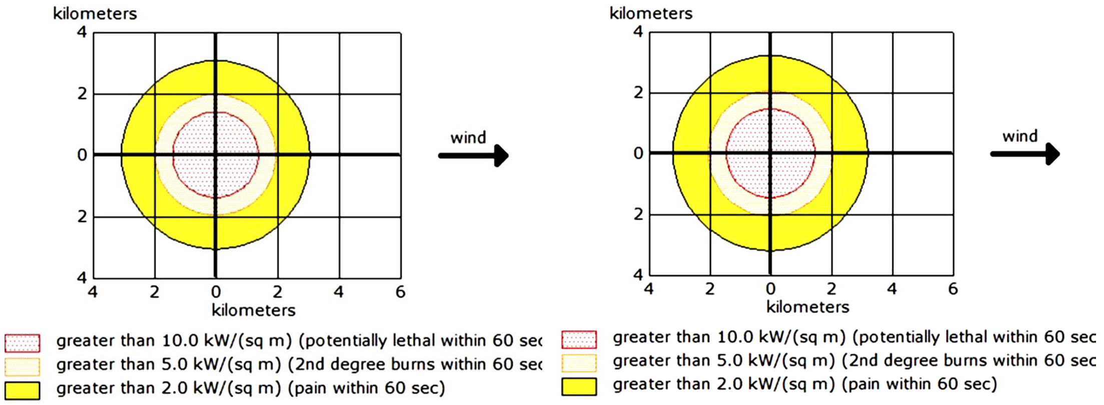
3.2. Impacts of overpressure waves. The data presented in Fig. 5 highlight the extensive effects of overpressure waves on surrounding areas. Buildings situated within a 400-meter radius from the explosion source are at significant risk of destruction when exposed to a pressure of 8.0 psi. Furthermore, individuals in the southern 400-meter zone may experience severe injuries if subjected to a pressure of 3.5 psi. Glass and other fragile materials within a 600-meter radius are likely to shatter under a pressure of 1.0 psi. These findings, as illustrated in Fig. 5, underscore the potential for substantial damage and safety risks associated with overpressure waves, emphasizing the need for stringent safety measures and strategic planning to mitigate such hazards.

3.3. Thermal radiation. Fig. 6 illustrates the effects of thermal radiation from propane or butane. Within a 1,500-meter radius, thermal radiation can reach up to 10.0 kW/m^2, which is intense enough to be potentially fatal within 60 seconds. In a 2,000-meter radius, the radiation level decreases to 5.0 kW/m^2, still high enough to cause second-degree burns within the same 60-second period. Furthermore, at a radiation intensity of 2.0 kW/m^2, exposure for just 60 seconds can result in significant pain. These data highlight the severe and escalating risks associated with thermal radiation at varying distances from the source, underscoring the critical need for effective safety measures and response strategies.



a *b*

Fig. 5. Areas at risk of overpressure: *a* – propane; *b* – butane



a *b*

Fig. 6. Areas threatened by thermal radiation: *a* – propane; *b* – butane

Proximity of the sphere. By examining the sphere's circumference, let's determine the following insights:

1. The three spheres T-403A/B/C.
2. The sphere T-404.
3. The fuel cicadas.
4. Four decommissioned tanks.
5. Pipeline to the flares.
6. Pipelines to the spheres.
7. The pumps.

Based on the satellite imagery and simulation results presented in Fig. 7, the analysis reveals significant overheating issues affecting the walls of the T-403A/B and T-404 storage spheres. Additionally, the fuel cicadas, which serve as pressure regulators to prevent depressurization or system failure, are also experiencing elevated temperatures. This overheating poses potential risks to the structural integrity of the spheres and the effectiveness of the pressure regulation system, highlighting a critical area of concern for ongoing safety and maintenance protocols.

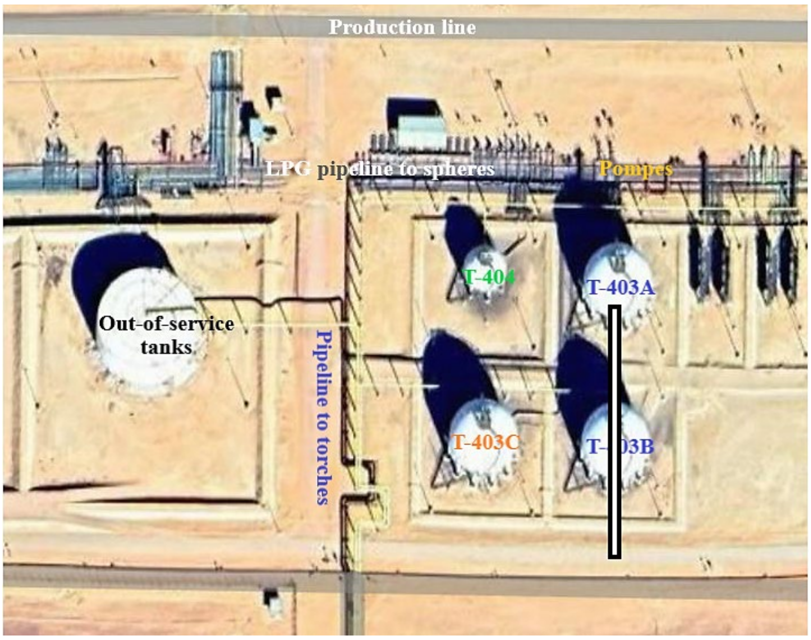


Fig. 7. Thermal radiation threat area superimposed on a satellite photo

These findings enable to estimate the necessary safety distances to avert potential future incidents, particularly concerning the impacts of pollution, flames, and thermal radiation. By understanding these effect distances, it is possible to establish effective preventive measures to safeguard against the risks associated with leaks, ensuring enhanced safety and mitigation strategies for any future occurrences.

The risks associated with storage activities are notably greater than other risks generated by other operations, underscoring the need for rigorous management and heightened vigilance. Accidents in storage can escalate into disasters with potentially devastating consequences, including significant human and material losses, along with severe and often irreversible environmental damage. This study highlights the critical importance of comprehensive hazard assessments and the implementation of robust preventive measures. By focusing on these aspects, it is significantly possible to enhance safety in storage operations, thereby ensuring stability, security, and sustainability. Ongoing vigilance and proactive risk management are essential to mitigate potential hazards and protect both people and the environment.

4. Conclusions

This study highlights the grave potential for catastrophic harm to human life, property, and the environment due to storage tank accidents. Through comprehensive simulations of various scenarios and a detailed analysis of their outcomes, there are critical insights into the required safety distances essential for effective primary prevention. Thermal radiation levels are assessed for each threat scenario. For example, at a distance of 1.500 meters, the radiation intensity reaches 10.0 kW/m^2, potentially fatal within 60 seconds. At 2,000 meters, it decreases to 5.0 kW/m^2, causing second-degree burns in the same time frame. At 2.0 kW/m^2, radiation induces pain within 60 seconds. Our findings underscore the crucial need for a well-trained and proactive maintenance team to ensure the safe operation and management of industrial facilities. In future applications, the determined impact distances will form the foundation for elaborating guidelines on the strategic placement of storage tanks and similar installations. This approach aims to shield surrounding communities from the severe consequences of accidental incidents, thereby enhancing overall protection and improving risk mitigation strategies.

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Conflict of interest

The authors confirm that they have no conflicts of interest, whether financial, personal, or otherwise, that could influence the research, its findings, or the integrity of the results presented in this paper.

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Data availability

There is no data associated with the manuscript.

Use of artificial intelligence

The authors confirm that artificial intelligence technologies were not utilized in the creation of the current work.

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