territorium 31 (II), 2024, 101-110
journal homepage: https://territorium.riscos.pt/numeros-publicados/
DOI: https://doi.org/10.14195/1647-7723_31-2_7
Artigo científico / Scientific article

THE TERRITORY FACED WITH TECHNOLOGICAL RISKS IN ALGERIA: CASE OF THE BLEVE PHENOMENON'S EFFECTS RELATED TO THE TRANSPORT OF HAZARDOUS MATERIALS*

O TERRITÓRIO DIANTE DOS RISCOS TECNOLÓGICOS NA ARGÉLIA: CASO DOS EFEITOS DO FENÔMENO BLEVE RELACIONADOS AO TRANSPORTE DE MATERIAIS PERIGOSOS

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ABSTRACT

The risks associated with the Transport of Hazardous Materials (THMs) are distinguished from other technological risks through their mobile and diverse nature. This is due to the wide variety of substances transported and the territories covered. Therefore, the THMs risk management approach has prompted considerable progress in terms of infrastructure and vehicle safety. However, a residual risk persists, mainly near cities and on highways, where the areas crossed by the flow of hazardous materials present a high vulnerability that needs to be assessed and modelled according to different accident scenarios. The purpose of this study is to estimate the effects of the boiling liquid expanding vapour explosion (BLEVE) phenomenon at a GPL filling centre in El-Eulma, a city in Algeria. For this, the methodology used is based on the use of the preliminary risk analysis (PRA) to determine the hazardous phenomena that may occur. Then, the ALOHA software was used to estimate the consequences of the BLEVE. The obtained results illustrate the severity of the human and material consequences. Accordingly, preventive measures were proposed.

Keywords: Hazardous materials transportation, BLEVE, GPL filling centre, safety distance.

RESUMO

Os riscos associados ao Transporte de Materiais Perigosos (TMP) distinguem-se de outros riscos tecnológicos pela sua natureza móvel e diversa. Isso se deve à grande variedade de substâncias transportadas e aos territórios cobertos. Neste sentido, a abordagem de gestão de riscos do TMP despoletou progressos consideráveis ao nível das infraestruturas e da segurança veicular. No entanto, persiste um risco residual notadamente próximo às cidades e nas rodovias, onde as áreas atravessadas pelo fluxo de materiais perigosos apresentam alta vulnerabilidade que precisa ser avaliada e modelada de acordo com diferentes cenários de acidentes. O objetivo deste estudo é estimar os efeitos do fenômeno Explosão do Vapor Expandido pelo Líquido em Ebulição (BLEVE em um centro de enchimento GPL na cidade de Eulma, na Argélia. Para isso, a metodologia utilizada baseia-se na utilização da Análise Preliminar de Risco (APR) para determinar os fenômenos perigosos que podem ocorrer. Em seguida, o software ALOHA foi utilizado para estimar as consequências do BLEVE. Os resultados obtidos ilustram a gravidade das consequências humanas e materiais. Assim, foram propostas medidas preventivas.

Palavras-chave: Transporte de materiais perigosos, BLEVE, centro de enchimento GPL, distância de segurança.

* *O texto deste artigo foi submetido em 09-01-2023, sujeito a revisão por pares a 18-02-2023 e aceite para publicação em 27-08-2023.*
*Este artigo é parte integrante da Revista **Territorium**, n.º 31 (II), 2024,* © Riscos, ISSN: 0872-8941.

Introduction

Natural and technological hazards often pose an unpredictable threat to society as a whole. In this regard, technological risks directly related to human activity and more particularly those related to the transport of hazardous materials, seem to be, a priori, easier to predict and control. Moreover, past accidents (Saint-Armand-les-Eaux, France, 1973; Los Alfaques, Spain, 1978; Dakar, Senegal, 1992; Mont-Blanc Tunnel, France-Italy, 1994; Italy, 2009; Gironde, France, 2016; Tanzania, 2019) prove that progress remains to be made in the areas of prevention and forecasting of these risks.

Industrial activities require the production and use of hazardous materials and their transport between installations. Therefore, these materials represent risks not only on industrial sites but also during transport. In general, all types of hazardous materials transport (i.e., road, air, rail, etc.) have risks. However, it can be said that road transportation is the most common way and that presents most of the risks due to several factors such as the driver's skills and conscience to comply with safety rules, the traffic circumstances, the vehicle condition, and the road conditions.

The consequences of accidents related to the Transportation of Hazardous Materials (THMs) can be human, economic, and environmental. Human consequences are related to persons directly or indirectly exposed to the consequences of the accident. They may be in a public place, at home or at work. The risk for these people can range from minor injury to death. Economic consequences are related to businesses near the site of the accident and infrastructures, as roads and railways, for example, that can be destroyed or seriously damaged, resulting in disastrous economic consequences. Finally, an THMs accident can have significant repercussions on ecosystems if partial or total destruction of fauna and flora occur. The consequences of an accident can also have an impact on geo-resources (e.g. pollution of groundwater) and, consequently, an effect on humans.

Among the main THMs risks, one can cite toxic clouds, fire, explosion and the BLEVE phenomenon. Hazard studies in the THMs field favor an approach centered on the source of the hazard and the Impact (distances) of effect. The presented study is part of this reflection and aims to estimate the effects of the BLEVE phenomenon at the GPL filling center of El Eulma and determine safety distances. The results of this work can be used to strengthen existing prevention measures and provide professionals with THMs risk assessment tools.

Emergence of the risk on the vulnerable territory

A given territory is subject to a certain number of hazards (natural or technological hazards). It is characterized by a certain vulnerability, of more or less intensity and which varies in time and space. The risk can only appear on the vulnerable territory if the hazard is present at a given moment on this same territory. In the THMs risk, three fundamental notions must be considered: the THMs hazard, the THMs risk, the territorial vulnerability to the THMs risk (fig. 1).

The hazard

The THMs hazard corresponds to the transport of hazardous materials itself. Several modes of transport are possible such as road, rail, river, sea, air or even by pipeline. The hazard is defined from several points of view: spatial (the route taken), temporal (date and time interval), quantitative (volume transported) and qualitative (nature of the hazardous material).

THMs risk

Risk only appears on the territory if the hazard is present at a given moment on this same territory. Risk is defined as a combination of the probability of occurrence of an accidental event and the severity of the potential consequences.

In addition, risk is a relative concept that depends on the perception that the social group has of the hazard and its vulnerability. Thus, risk evolves according to time and place and will be more or less accepted. Similarly, vulnerable spaces are constantly changing with changes in the demographic growth and urban expansion. Therefore, vulnerability is responsible for modifying different risk management approaches.

The vulnerability

Vulnerability studies applied to technological risks are very rare. The territory's vulnerability to THMs risks can be defined as a combination of the assessment (quantitative and qualitative) of targets, their sensitivity and their degree of exposure to risk factors.

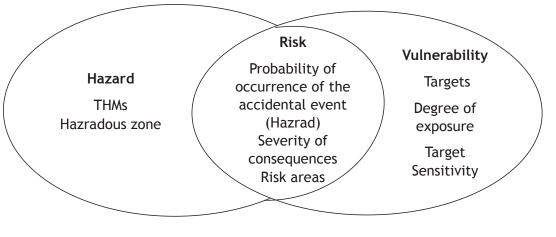


Fig. 1 - Relationships between THMs hazard, vulnerability and risk (Source: CNRS, 2001).

***Fig. 1** - Relações entre TMP perigo, vulnerabilidade e risco (Fonte: CNRS, 2001).*

The risk associated with THMs is difficult to assess due to the interplay of many factors, including

- The diversity of products transported each representing a specific risk;
- The diversity of probable accident locations (75 % of road accidents taking place in open area);
- The diversity of risk sources (failure of transport mode, containment, human error, etc.);
- The diversity of means of transport used.

Each year, the development of traffic, the opening of new transport routes, whether by road, rail, water or even pipelines, increase the risk of accidents, which raises many questions concerning THMs hazard, methods of occurrence, potential consequences and the vulnerability of the spaces located on each side of transport axes.

State of the art on TDG risk assessment

THMs related risk assessment methods are numerous and diversified. The calculation of effect distances and the evaluation of foreseeable consequences constitute the common ground of most works. Several studies have been carried out in this field using different methods and tools. An inventory of main studies is presented below.

The first study carried out by Griot was based on a method for assessing territorial vulnerability applied to risks associated with the transport of hazardous materials in close consultation with civil security. Inspired by systemic risk analysis, the vulnerability model incorporates three main dimensions: targets, their sensitivity and their degree of exposure to hazard. The use of expert judgments and decision support methods to model vulnerability is the innovative aspect of this method. Then the prototype of a Geographic Information System decision support tool relating to THMs risks intended for Civil Security was developed. The original contribution of this tool lies in the integration of vulnerability maps that makes it possible to shorten the time devoted to the analysis of the space and thus to accelerate the management of the accident. (Griot, 2003; 2007).

The second study carried out by Grivault and Barczak in 2007 presents a method for assessing the vulnerability of urban areas to risk of transporting hazardous materials. It consists of identifying issues present in the study area and assessing their vulnerability. The weight of each vulnerability factor was estimated using a hierarchical multi-criteria and spatial analysis using a geographic information system. The result is presented in the form of an easily mappable summary index of vulnerability offering the possibility of analytical questioning.

The method makes it possible to propose several other indicators according to the type of vulnerability or according to the type of phenomenon. These indicators can be mapped in grid cells for the entire study area or assigned to each section of the road. The integration of these indicators in a geographical information system makes it possible to compare the level of vulnerability along different road routes. Graph traversal algorithms can be applied to determine the optimal routes in terms of vulnerability (Grivault and Barczak, 2007).

In 2012, a work was carried out by Garbolino and Lachtar as part of the SECTRAM project that contributes to the safety of freight transport in France. The main objective of the project is the development of common logistics solutions to improve the safety of transport services and infrastructure at cross-border and interregional level. This is a collaborative work between ARMINES, the University of Genoa, the "*Groupement d'Exploitation du Fréjus*" and the Ligurian Region. For each of the two modes of road and rail transport, accident simulation was carried out for propane and chlorine. The mapped results allow the identification and rapid understanding of the most vulnerable areas (Garbolino and Lachtar, 2012).

In 2015, Luè and Colorni in Italy carried out a study as part of the perspective of reducing risks of transporting hazardous materials. The proposed a method for assessing territorial vulnerability regarding these risks in the PACA and Rhône-Alpes. The authors used a risk assessment model that considers the consequences of an accident for each road segment on the population, territorial infrastructures and environmental elements. As a result, critical areas were determined and can be located and taken care of during prevention and intervention operations (Luè and Colorni, 2015).

El Safadi's work carried out as part of his doctoral thesis in 2015 consists in evaluating the level of risk in areas subject to the transport of hazardous materials. To do this, a certain amount of information is used, such as the quantification of the intensity of the phenomena that occur using effect models. These models mainly contain input variables related to exposure database, meteorological data, etc. To correctly carry out a mapping by determining the danger zone where the level of risk is deemed too high, it is necessary to identify and take into account the uncertainties on the inputs in order to propagate them in the effects model and thus to have a reliable assessment of the level of risk (El Safadi, 2015).

The work carried out by Soto and Renard in 2016 proposes an operating mode which makes it possible to acquire precise knowledge of territorial vulnerability, which can be applied to all types of hazards and applicable to all territories. In the context of this work, the subject concerns the transport of hazardous materials, which constitutes, by nature, a diffuse and transient risk, the effects of which are still little known on the experimental territory: the urban community of Greater Lyon.

For this, a methodology is proposed based on an inventory of the issues present in the territory, and on an assessment of their vulnerability, using a multi-criteria hierarchical decision-making aid method and semi-structured interviews with local experts. . The results take the form of fine-scale cartographic representations that make it possible to point out the specific vulnerability of environmental issues to the consequences of an accident during THMs, particularly in the east of the agglomeration (Soto and Renard, 2016).

Finally, the work carried out by Mabrouki *et al.*, proposes a new approach to routing and planning the transport of hazardous materials in urban areas. The purpose of this work is to find the safest and shortest routes for transporting hazardous materials. This allows us to reduce risk, minimize damage, and ultimately keep people, property and the environment as far away as possible from the effects and consequences of hazardous materials.

The work carried out is based on the calculation of spatial Voronoi diagrams. The development of such a spatial model will make it possible to assess the proximity of areas vulnerable to risk by calculating the distance separating these spatial objects from vehicle routes. The weighting of these spatial structures by socio-economic data constitutes an important support for spatially analyzing the urban environment and geo-governing the hazardous materials transport network. (Mabrouk and Karim, 2016; Mabrouk and Boulmakoul, 2017; Mabrouk and al., 2017).

It appears that the evaluation of territorial vulnerability can be estimated using different tools and methods. Studies carried out in this area use geographic information systems to map risk areas and various software to model the effects of hazardous phenomena related to THMs. The choice of these tools and methods depends on the objectives of these studies and data availability.

Estimation of the BLEVE effects at the filling center of El Eulma

Presentation of the study field

In order to make a simulation of the BLEVE phenomenon effects, we carried out field work at the LPG filling center of EL Eulma city in Algeria. The company is located in the industrial zone of El Eulma near the national road N° 77 linking El Eulma to Batna. The Center has an area of 60,000 m^2 (fig. 2).

The distribution network of the El Eulma filling center consists of:

- 09 GD stations;
- 01 GL station;
- 72 PVS;
- 19 ACP;
- 01 ASR, 65 AR and 04 RD.

Fig. 2 - Presentation of the El Eulma filling center.

Fig. 2 - *Layout of the El-Eulma filling centre.*

The El Eulma filling center packages 37,500 tons annually and distributes 41,500 tons of LPG, with a staff of 133 permanent workers and 58 temporary. Bulk Butane is transported to the filling center of El Eulma from the GIS of Khroub - Constantine and the bulk Propane from the Filling Center of Skikda.

The center has an infrastructure consisting of:

- One (01) Butane storage sphere with a total capacity of 1000 Tons; i.e. an autonomy of 04 days;
- Two (02) Propane storage cigars with a total capacity of 150 Tons; i.e. an autonomy of 03 days;
- Two (02) B13 filling carousels (01 carousel with 24 stations with mass flowmeters and 01 carousel with 12 mechanical scales); i.e. an annual filling capacity of 37,500 tons per shift;
- One (01) Butane filling station 03 kgs;
- One (01) firewater reserve of 1500m^3;
- Three (03) electric fire pumps of 150 m^3/h each;
- One (01) motor pump of 500 m^3/h.

Work methodology

The methodology pursued is based on the use of the preliminary risk analysis (PRA) to determine the hazardous phenomena that may occur. Then, the ALOHA software was used to estimate the effects of the BLEVE that was selected as the most dangerous phenomenon according to the results of the preliminary risk analysis.

Preliminary risk analysis

The collection and analysis of information and lessons learned from TDG accidents that have occurred in Algeria and even elsewhere make it possible to better understand the course of accidents, their causes, and their consequences. This information is necessary for the TDG risk analysis.

Thus, based on the national and international TDG experience feedback and on the information available at the company level, we carried out the preliminary analysis of the TDG risks. This analysis was based on three elements:

- The human factor: driver,
- The technical factor: tank truck;
- The environment factor: road, signage.

In this work we have only presented the part which concerns the first two factors, namely the human factor and the technical. Moreover, the preliminary analysis aims to identify, for a dangerous element, one or more hazardous situations. A hazardous situation is defined as a situation that, if not controlled, can lead to the exposure of targets to one or more hazardous phenomena. The phases of a preliminary risk analysis are:

- To determine the causes and consequences of each of the identified hazard situations;
- To identify of existing safety barriers.

After the identification of dangerous elements, the construction of the PRA table was conducted. This table is made up of 8 columns:

- The system or function to be studied;
- Phase;
- Dangerous situation;
- Causes;
- Existing safety barriers;
- Possible consequences;
- Control of the consequences-

The analysis was carried out for two dangerous elements in the studied systems: the tanker and the driver. A summary of the results obtained are presented (Table I and II).

For this work, we have focused on the study of the most feared phenomenon in the field of the transport of hazardous materials, which is the BlEVE as shown by the preliminary risk analysis.

Presentation of the scenario

For the selection of the scenario, it was considered the information from the analyzes of the accidents that have occurred at company level, which show that two types of errors have been observed:

- errors made by drivers during transport and during loading and unloading operations, such as driver failure, speeding, dangerous maneuvers when parking inside the company and even outside, difficulties when avoiding an obstacle, sudden braking, etc. It should be noted that most of these errors were included in the preliminary risk analysis;
- errors related to the organization within the company due to lack of control and monitoring in relation to the execution of the various operations by the drivers.

It was also taken into consideration one of the mistakes made by the drivers and this in consultation with the persons in charge of safety in the company.

The scenario selected for this work consists of an explosion of a truck’s LPG tank according to the following sequence:

Table I - Results of the preliminary analysis for the technical factor – Tank Truck.

***Table I** - Results of the preliminary analysis for the technical factor - Fuel tanker.*

System or Function	Phase	Hazardous situation	Causes	Control of causes	Consequences	Control of consequences
Brakes	On the road	- Fire - BLEVE - UVCE if rupture	- Overheating of the brakes - Drum warm-up	- Temperature sensor - Driver training - Emergency brake	- Dense smoke - Fire - Explosion - Release of toxic fumes	- Extinguisher - Notify emergency services
	Parked	- Fire - BLEVE - UVCE	- Overheating of the brakes - Drum warm-up	- Control methods - Temperature sensor	- Dense smoke - Fire - Explosion - Release of toxic fumes	- Extinguisher - Notify emergency services
Tires	On the road	- Explosion - BLEVE - UVCE - Fire	- Tire burst - Tire pressure	- Periodic mechanical check - Driver training	- Explosion - BLEVE - UVCE	- Extinguisher - Notify emergency services
	Parked	- Fire	- Burst of a tire - Tire inflation	- Periodic mechanical check - Driver training	- Violent breath - Projection of fragments - Fire - Burns - Poisoning	- Extinguisher - Notify emergency services
Coupling	On the road	- BLEVE - Fire - Overturning of the vehicle	- Coupling breakage - Non respect of transported weight	- Emergency brake - Trailer control valve (VCR) - Emergency relay valve	- Overturning of the vehicle - burns - poisoning - corrosion	- Emergency brake - Trailer control valve - Emergency Relay valve

Table II - Results of the Preliminary analysis for the human factor – Driver.

***Tabela II** - Resultados da Análise preliminar para o fator humano - Motorista.*

System or Function	Phase	Hazardous situation	Causes	Control of the causes	Consequences	Control of the consequences
Driving	On the road	- Collision Rollover of the vehicle - BLEVE - UVCE - Toxic Cloud	- Driver failure - Obstacle avoidance - Sudden braking	- Speed bump - Emergency brake - Brake assist (ABS or ABR)	- Collision - Overturning of the vehicle - Accidental pollution	- Extinguisher - Notify emergency services
			- Obstacle avoidance - Path error	- Driver training	- Collision - Overturning of the vehicle - Accidental pollution	- Isolate the leak - Extinguisher - Notify emergency services
			- Priority refusal	- Driver training	- Collision - Blast - Fire - Burns	- Extinguisher
			- Excessive speed due to delay	- Speed limiter - Notify the recipient of the delay - Driver training - Traffic restrictions	- Collision - Pileup - Overturning of the vehicle - Burns - Poisoning - corrosion	- Extinguisher - Notify emergency services
	Parked	- Collision Rollover of the vehicle - BLEVE - UVCE	- Overheating of the brakes - Drum warm-up	- Driver training - Steering system	- Collision - Overturning of the vehicle - Accidental pollution	- Fire extinguisher - Notify emergency services - Isolate the (non) ignited leak
		- Collision Rollover of the vehicle - BLEVE - UVCE		- Driver training - Emergency brakes - Parking brake	- Collision - Overturning of the vehicle - Accidental pollution	- Fire extinguisher - Notify emergency services - Manhole cover protection - A collector tank in plastic

During the return of a tank truck to the company to load propane, there was a collision with the electric pole causing a hole in the cistern. The driver did not notice the fracture and fills the tank with propane. Then, the driver parks in the company parking lot while waiting for the route card. When the driver turns on the engine, a spark occurs triggering an explosion followed by a BLEVE.

This study is considered the first for this site in which we have considered the most dangerous phenomenon. We started our study with a single scenario having a set of characteristics related to the tanker truck and the transported material. But, the change of the parameters related to the characteristics of the tank truck, the nature and the quantity of the materials transported can effectively give several scenarios with more information on the effects of the phenomenon studied. In this sense, we have already started work which will subsequently constitute a database for the company for better management of the phenomenon

Estimation of the BLEVE effects

Many software programs are available and that can model the explosion effects of various chemicals. Some of them are particularly oriented to emergencies. In this work, the ALOHA model was used for its advantage of controlling several variables.

The ALOHA software (Areal Locations of Hazardous Atmospheres) is an integral-type model that solves the equations for a large number of chemicals. Its database contains information on chemical properties of approximately 1,000 of the products that are likely to be involved in chemical accidents. Modeling makes it possible to know the extent of the potential effects related to the BLEVE phenomenon such as Radiation and Overpressure, and to develop emergency and intervention plans. In this work, only modeled the effects of radiation were modeled at the LPG filling center of El Eulma.

Modeling results

The first stage of modeling consists in setting the parameters related to the meteorological conditions and the characteristics of the tanker truck that are:

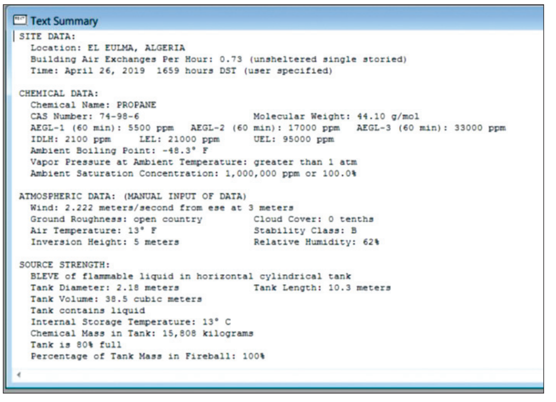
- Capacity: 38500 liters;
- Empty weight: 7500 kg;
- The tank filling: 26245.09 kg of LPG;
- The maximum pressure of this tank: 19.3 bars;
- Maximum temperature: 50° C.

These characteristics partly determine the nature and extent of the effects of BLEVE that may occur (Table III and fig. 3).

Table III - The conditions considered for the ALOHA modeling.

Tabela III - The conditions considered for the ALOHA modelling.

Environmental conditions and tank characteristics	Values
Wind speed	2.22 m/s
Wind direction	ESE
Air Humidity	62 %
Air temperature	13 C°
The product transported	Propane
Tank volume	38.5 m^3
Tank localization: Latitude	36° 07’ 45.52’’ ESE
Tank localization: Longitude	5° 41’ 58.66’’ ESE
Tank localization: Altitude	1.53 km
Tank Diameter	2.18 m
Tank Fill percentage	80 %
Mass of ~~liquid~~ transported	16900 kg


Text Summary
SITE DATA:
Location: EL EULMA, ALGERIA
Building Air Exchanges Per Hour: 0.73 (unsheltered single storied)
Time: April 26, 2019 1659 hours DST (user specified)

CHEMICAL DATA:
Chemical Name: PROPANE
CAS Number: 74-98-6 Molecular Weight: 44.10 g/mol
AEGL-1 (60 min): 5500 ppm AEGL-2 (60 min): 17000 ppm AEGL-3 (60 min): 33000 ppm
IDLH: 2100 ppm LEL: 21000 ppm UEL: 95000 ppm
Ambient Boiling Point: -48.3° F
Vapor Pressure at Ambient Temperature: greater than 1 atm
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
Wind: 2.222 meters/second from ese at 3 meters
Ground Roughness: open country Cloud Cover: 0 tenths
Air Temperature: 13° F Stability Class: B
Inversion Height: 5 meters Relative Humidity: 62%

SOURCE STRENGTH:
BLEVE of flammable liquid in horizontal cylindrical tank
Tank Diameter: 2.18 meters Tank Length: 10.3 meters
Tank Volume: 38.5 cubic meters
Tank contains liquid
Internal Storage Temperature: 13° C
Chemical Mass in Tank: 15,808 kilograms
Tank is 80% full
Percentage of Tank Mass in Fireball: 100%

Fig. 3 - Summary of the test performed.

***Fig. 3 -** Resumo do teste realizado.*

After inserting the data and testing it, the effects were modeled. The results of modeling thermal radiation effects by ALOHA are presented (Table IV).

Table IV - Modeling Effects by ALOHA - El Eulma.

Tabela IV - Modelling Effects by ALOHA - El-Eulma.

Area	Threshold	Distance
Red	10 kW/m^2	363 m
Orange	5 kW/m^2	513 m
Yellow	2 kW/m^2	802 m

The colors used in Table IV present the safety distances and determine the risk zones of the most serious in red, less serious in orange and acceptable in yellow. These colors coincide with the colors used in figure 4.

The thermal effects of the BLEVE can be human and material according to the reference values relating to the thresholds of thermal effects on humans and on structures (CERTU, 2003). These effects can be divided into three areas (Table IV and fig. 4):

- A red zone affected by thermal radiation that exceeds 10 kW/m² with the threshold of significant lethal effects corresponding to the zone of very serious danger to human life. It also corresponds to the threshold of domino effects corresponding to the threshold of serious damage to structures;
- An orange zone affected by thermal radiation that exceeds 5 kW/m² with the threshold for the first lethal effects corresponding to the zone of serious risk to human life. This zone also corresponds to the threshold for significant destruction of windows;
- A yellow zone affected by thermal radiation that exceeds 2 kW/m² with the threshold of irreversible effects corresponding to the zone of significant danger to human life. Effects on structures is absent.

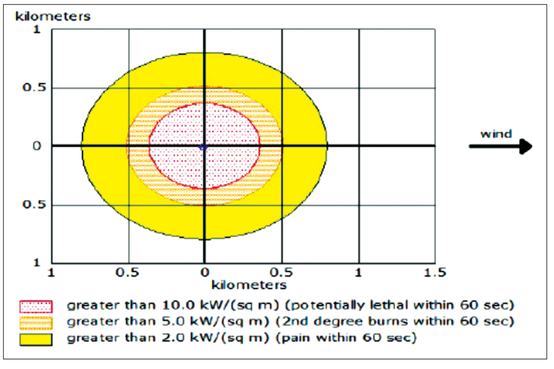


Fig. 4 - Thermal effect zones of the BLEVE.

***Fig. 4** - Zonas de efeito térmico do BLEVE.*

Modeling also makes it possible to locate the areas affected by the effects of the BLEVE at the level of the filling center (fig. 5).

The results show that the effects of radiation can be significant for people at the center and even on structures. The results also show that safety distances must exceed 802 meters. Therefore, specific prevention measures must be implemented for each area:

- For the first zone: measures prohibiting access and movement must be considered in place for all people in the center and even elsewhere;
- For the second zone: strict traffic restriction measures must be considered in place for company personnel. Exceptions are made for civil protection, for example;
- For the third zone: traffic limitation measures must be taken to minimize the number of people likely to be present.

Finally, it should be noted that the impacts of the BLEVE phenomenon recorded can cause domino effects. These effects are the most destructive accidents for industrial sites. But studies of domino effects are difficult because they require deep analyses. This kind of work requires a lot of information that is not currently available for our study but could be the subject of another research in the future.

Conclusion

BLEVE is an explosion of expanding gases from boiling liquid that can occur both inside and outside industrial sites. This phenomenon can impact the storage and transport tanks of liquefied gases (Butane, Propane, Propylene but also ammonia, carbon dioxide, etc.) and generate thermal and pressure effects. These effects can affect, depending on the nature and quantity of

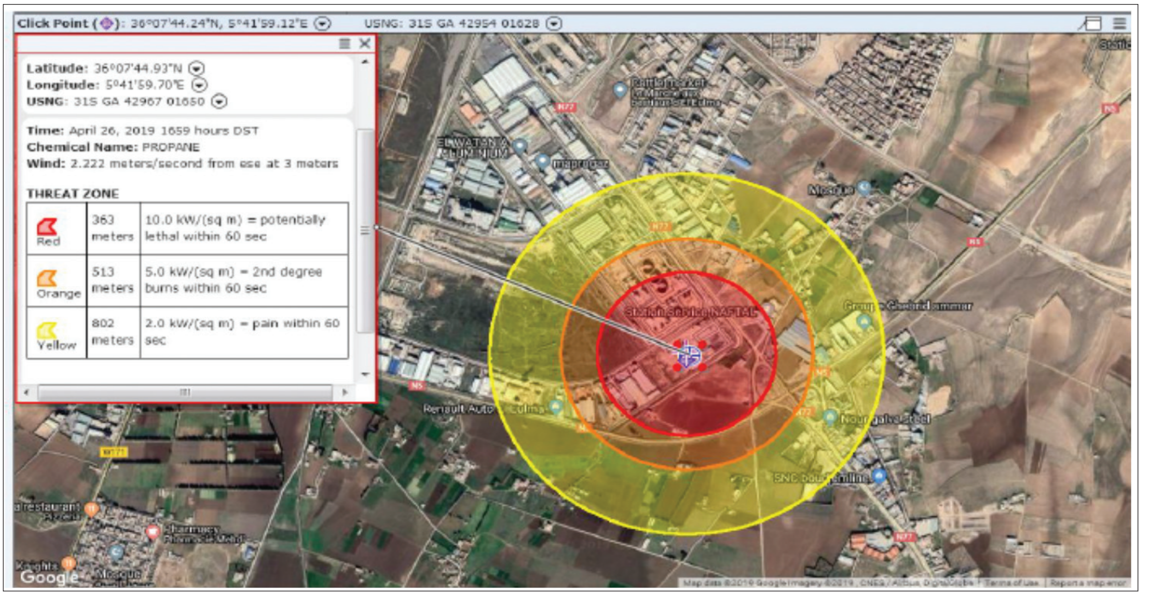


Fig. 5 - Areas affected by the BLEVE's thermal effects.

***Fig. 5** - Áreas afetadas pelos efeitos térmicos do BLEVE.*

the materials transported, people, structures and even the environment in the same territory. In addition, the modeling of the effects of BLEVE makes it possible to highlight the extent of this phenomenon in this territory and to determine the zones at risk. Taking into account the safety distances delimited by the risk areas makes it possible to strengthen prevention, protection and intervention strategies within the territory.

In this work we have tried to estimate the effects of the BLEVVE phenomenon at the LPG filling center of El Eulma in Algeria. The results show that the proposed BLEVE phenomenon can have negative thermal effects at the LPG filling center. These thermal effects can affect people and even structures:

On people:

- Significant lethal effects correspond to the zone of very serious dangers for human life with a distance of 363 meters;
- Lethal effects correspond to the area of serious danger to human life with a distance of 513 meters;
- Irreversible effects correspond to the zone of significant dangers for human life with a distance of 802 meters.

On structures:

- Serious structural damage threshold corresponds to the red zone affected by thermal radiation greater than 10 kW/m^2 with a distance of 363 meters;
- Significant window destruction threshold corresponds to the orange zone affected by thermal radiation greater than 5 kW/m^2 with a distance of 513 meters.

The detailed study of the domino effects was not carried out in this work.

These results suggest that the safety distances must be exceeded 802 meters and the preventive measures to be considered in the area. In this sense, we propose the following measures that allow both to prevent and to intervene in the event of accidents and to increase the safety of the territory in general:

- Responsiveness of emergency services;
- Traceability of authorized parking places and routes;
- Establishment of risk maps to locate high THMs risk sectors:
- Identify sectors that can be the subject of crisis management exercises;
- Organize emergency services specializing in THMs accidents in the best possible way (installation of equipment to optimize on-site intervention times).

These proposals could also be supplemented by training actions for people who are potentially exposed to risk and crisis management in the event of an accident (beyond the training already compulsory for drivers specialized in THMs). This would make it possible to train the entire supply chain on these issues.

Thus, the management of THMs requires expertise and knowledge in terms of regulations, inventory of flows and routes, identification of accident-prone areas, geolocation of issues, definition of risk scenarios and information of the public.

However, these skills and knowledge are generally not available. In order to overcome the difficulties related to the availability of data, we propose the use of new technologies that makes it possible to follow the flow of THMs even in real time and to help those responsible for intervention operations to collect sufficient information on the type of accident and effective means to use.

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