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Thème

Artificial Intelligence for The Recognition and Classification of Catastrophic Scenarios

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DEDICATION

We dedicate this modest work:

To our dear parents inexhaustible sources of love, affection and sacrifice. May this work be a testimony to them of the affection we have for them and of our gratitude for their ineluctable patience and dedication.

And we would like to dedicate this work to all our friends who have helped us from near or far to carry out this work.

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Artificial Intelligence for the Recognition and Classification of Catastrophic Scenarios

Abstract

The development of the energy industry in recent years has led to the complexity of the processes, hence the need to master the potential catastrophic scenarios that may occur in these processes in order to emphasize the appropriate security measures for this purpose.

This master thesis was the subject of a risk analysis by the HAZOP method on one of the spheres which stores LPG within the GL3 / Z complex (SONATRACH / Arzew industrial zone), as well as the modeling of the consequences of several scenarios using the Phast 8.0 simulation software, in order to select scenarios that can occur in the case of LPG, in order to create a program that recognize and classify these scenarios using artificial intelligence.

Keywords: Safety, fire, Artificial intelligence, Machine learning, Modelization, Phast.

الذكاء الاصطناعي للتعرف وتصنيف السيناريوهات الكارثية

الملخص:

أدى تطور الصناعات الطاقوية في السنوات الأخيرة إلى تعقيد العمليات والطرائق، مما يفرض الحاجة إلى التحكم في السيناريوهات الكارثية المحتملة التي يمكن أن تنشأ عن هذا النوع من العمليات المعقدة عن طريق إبراز وتسليط الضوء على التدابير الأمنية المناسبة الواجب اتخاذها لهذا الغرض.

تقدم هذه المذكرة تحليلا للمخاطر باستخدام طريقة HAZOP على إحدى الخزانات التي تخزن غاز البترول المسال GPLداخل مجمع (سونطارك/ المنطقة الصناعية أرزيو) لتحديد السيناريوهات الكارثية المحتملة، ثم قمنا بتطوير نموذج للعواقب الوخيمة الناجمة عن العديد من السيناريوهات باستخدام برنامج المحاكاة PHAST 8.0 بغية تحديد السيناريوهات والذي تكلل في النهاية بإنشاء برنامج يعمل بالذكاء الاصطناعي يسمح بتحديد وتصنيف هذه السيناريوهات.

الكلمات المفتاحية: السلامة، النار، الذكاء الاصطناعي، التعلم الآلي، النمذجة.

Intelligence Artificiel pour la reconnaissance et la classification des scénarios catastrophiques

Résumé

Le développement de l’industrie énergétique ces dernières années a muni vers la complexité des procédés d’où la nécessité de maitriser les potentiels scénarios catastrophiques qui peuvent survenir au niveau de ces procédés afin de mettre en évidence les mesures de sécurités adéquates a cet effet.

Cette mémoire de fin d’étude présente une analyse des risques par la méthode HAZOP sur l'une des sphères qui stockage de GPL au sein du complexe GL3/Z (SONATRACH/ zone industrielle d’Arzew) pour identifie les scénarios catastrophiques par la suite nous avons élaborer une modélisation des conséquences de plusieurs scénarios en utilisant le logiciel de simulation Phast 8.0, afin de sélectionner les scenarios pour réaliser vers la fin un programme qui détecte et le classifier ces scenarios a travers l'intelligence artificiel.

Mots clés : Sécurité, incendie, Intelligence artificielle, Machine learning, Modélisation, Phast.

Table des matières

List of Figures

List of Tables

Abbreviation List

HAZOP: Hazard and operability analysis.

PHA: Process Hazard Analysis

PHAST: Process Hazard Analysis Software.

LPG: Liquefied Petroleum Gas

LEI: Lower Explosive Limit.

UEL: Upper Explosive Limit.

LFL: Lower Flammable Limit

UFL: Upper Flammable Limit

UVCE: Unconfined Vapour Cloud Explosion.

BLEVE: Boiling liquid expanding vapor explosion.

AI: Artificial Intelligence

ML: Machine Learning

DL: Deep Learning

NLP: Natural Language Processing

ANNs: Artificial Neural Networks

PPE: Personal Protective Equipment

EHS: Environment, Health and Safety

API: Application Programming Interface

FICS: Fire Identification and Classification Software

Introduction

Introduction

With technological development, some industrial establishments can be sources of major risks that can lead to disasters, among these major risks we can cite the dispersion of gas clouds, fires, explosions ... the occurrence of these risks leads to disasters that are difficult to control for example the accident which recently occurred in Iran at the storage tanks and it took approximately 20 hours to control the fire. This has resulted in loss of life and enormous property damage.

The oil industry is one where the occurrence of major risks is omnipresent with important consequences, in order to in order to limit the impact of these risks, several methods risk analysis and hazard studies are often used for the purpose of helping to identify and assess the risks and come out with recommendations in order to reduce the likelihood or severity of those risks.

The available methods are making these studies offer the possibility of having prior results in the form of causes, consequences and recommendations to better prepare, structure and organize a rapid and effective rethinking against the feared event, but this is not enough in some cases.

In order to control catastrophic scenarios, very often, intervention teams need to identify these scenarios and what can be expected as a result in order to choose the most effective method of intervention, but in many cases, this can take time which is valuable at these critical moments.

The artificial intelligence offers the possibility to identify and classify the catastrophic scenario in the first seconds by the Object Detection method which is a computer vision technic that allows us to identify and locate an object in an image or a video[1]. A flame for example can be recognize and then classified to identify the scenario.

For this purpose, this end-of-study project proposes a model of a program which can recognize and classify catastrophic scenarios outside the accident and since hydrocarbons alone represent 60% of budget revenues and 98% of export earnings for our country, we have chosen the GL3 / Z complex and we are focusing on letting our program to detect the catastrophic scenarios in the case of LPG sphere explosion.

For this purpose, our work consists of four chapters the theoretical part is composed of two chapters:

- The first chapter is the subject of a brief presentation of the legislative framework to better highlight the work with respect to the regulations, as well as generalities on the method of risk analysis that we used and finally the catastrophic scenarios which can happen in an LPG sphere.
- The second chapter is dedicated to the presentation of generalities on artificial intelligence and its lifecycle.

And the practical part is composed of two chapters:

- The third chapter is devoted to the risk analysis for one of the LPG storage spheres by the HAZOP method, as well as the presentation of the results of the modeling of catastrophic scenarios by the PHAST 8.0 software.

- The fourth chapter is dedicated to the clarification of the functioning of our program and the presentation of the program's performance.

Chapter 01: Generalities About Catastrophic scenarios

1.1.Introduction

The petroleum industries represent major technological risks resulting in the occurrence of several catastrophic scenarios that can have serious consequences for people, installations and the environment. Frequent accidents in these industries can be divided into several categories:

- Explosion: BLEVE, UVCE, VCE;
- Fire: boil-over, pool fire, torch fire, flash fire, fireball, jet fire;
- Toxic dispersion;

In order to keep these risks in acceptable level, the government requires by decrees and laws the implementation of preventive measures and the application of safety regulations.

In this chapter, the regulatory framework and HAZOP analysis are discussed, as well as the possible catastrophic scenarios and some of accidents that happened before in the LPG industry.

1.2.Regulatory framework

The legal and institutional framework remains a key element in promoting a security and environment policy. In Algeria, there are now more than 300 diverse texts, from several sectors, dealing with security and the environment[2], but the problem is that these legislations are not applicated most of the time.

Risk analysis is a part of a hazard study which is treated by the Ministry of Environment. This ministry manages both security and environmental impacts. It continues to produce legislative texts at a high level in order to unify the country’s legislations with international standards.

This regulation defines in terms of limits, measures, plans, programs. The non-conformity has economic consequences (production shutdown, penalties, withdrawal of the operating license, etc.) and strategic consequences (loss of confidence of the company's financial, economic, and institutional partners, degradation of the brand image with the public, etc.).

The risk analysis that has been discussed is included in the framework of the development of hazard studies, which is referred to in the following texts:

- ❖ Executive Decree No. 07-144 of May 19, 2007 fixing the nomenclature of classified installations for the environment protection.
- ❖ Executive Decree No. 06-198 of May 31, 2006 defining the applicable regulations to classified establishments for environmental protection.
- ❖ Executive Decree 15-09 Of 23 Rabie El Aouel 1436 corresponding to January 14, 2015 Setting the terms and conditions for the approval of hazard studies specific to the hydrocarbon sector and their content.
- ❖ Law n ° 05-07 of April 28, 2005, promulgated on July 19, 2005, relating to hydrocarbons.
- ❖ Law n ° 04-20 of December 25 relative to the prevention of major risks and disaster management in the context of sustainable development.

- Executive Decree No. 03-451 of December 1, 2003, defining the applicable safety rules to activities relating to dangerous materials and chemicals as well as pressurized gas containers.
- Ministerial Instruction R1 of September 22, 2003 relating to the control and management of industrial risks involving dangerous substances.
- Decree n ° 90-245 of August 18, 1990, regulating gas pressure devices.
- Order of January 15, 1986, fixing the perimeter limits of protection around the installations and infrastructures of the hydrocarbon sector.
- Decree n ° 85-231 of August 25, 1985, fixing the conditions and modalities of organization and implementation of interventions and rescue in disaster.
- Decree n ° 85-232 of 25 August 1985, relating to the prevention of disaster risks.
- Decree n ° 84-105 of 12 May 1984 establishing a perimeter for the protection of installations and infrastructures.
- Decree n ° 84-385 of December 22, 1984 fixing the measures intended to protect the installations, works and means.

Note: for the regulations relating to classified establishments, it consists in applying procedures and conditions for requesting an operating license, obliging the manufacturer to comply with the requirements of the required safety and environmental standards.

Standard Norme

- ISO 45001: -Management systems of occupational health and safety
- ISO 31000:2018 - Risk management – Guideline
- IEC 31010:2019 - Risk management - Risk assessment techniques
- ISO 14001:2015 Environmental management systems

1.3. Hazard & Operability Analysis (HAZOP)

Hazard and Operability Analysis (HAZOP) is a structured and systematic technique for system examination and risk management. It is dedicated to the risk analysis of thermo-hydraulic systems for which it is essential to control parameters such as pressure, temperature, flow ...etc. The HAZOP analysis no longer considers failure modes but the potential drifts (or deviations) of the main parameters related to the operation of the installation. The identification of such deviations is facilitated by using sets of “guide words” as a systematic list of deviation perspectives. This approach is a unique feature of the HAZOP methodology that helps stimulate the imagination of team members when exploring potential deviations.

1.3.1. The history of Hazard & Operability Analysis

A group of engineers in the ICI’s division of Heavy Organic Chemicals was in charge to develop a preliminary version of the HAZOP (HAZard and OPerability) methodology in the mid-1960s. However, it was not until 1974 when the Flixborough disaster in North Lincolnshire, England caused by an explosion at a chemical plant close to the village, in which 28 people died, and at least 36 were injured, ushered the use of risk prevention techniques. Then, a safety course offered by the Institution of Chemical Engineers (IChemE) at the Teesside Polytechnic (now Teesside University), included simple HAZOP procedure to support and possibly determine failures that led to the Flixborough incident. As a result, the very first publication considering the HAZOP study appeared in the same year, and finally the Chemical Industries Association published a first HAZOP guide in 1977. Until then, the term HAZOP was not used in formal publications.

The major supporter of the HAZOP methodology was Trevor Kletz. To perform his work Kletz took advantage of the IChemE course notes (revised and updated) and structured a standard HAZOP methodology, which has been used up to recent days.

Thus, the concept which states that the HAZOP methodology is a basic technique to identify risks that may occur to the personnel, equipment, the environment and/or the objectives of the organization began to gain strength. Thereby, the technical background that characterized the hazard and operability studies had become an expected part of chemical engineering degree courses in countries like the United Kingdom and the United States of America. Moreover, although this method was initially developed to analyze chemical process systems, later spread to practically any knowledge area[3]. Through the general exchange of ideas and personnel, the methodology was then adopted by the petroleum industry, which has a similar potential for major disasters. This was then followed by the food and water industries, where the hazard potential is as great, but of a different nature, the concerns being more to do with contamination rather than explosions or chemical releases[4].

1.3.2. Objectives

The objective of the Hazard and Operability Analysis method is, to identify technical malfunctions whose sequence can lead to unwanted operative events. It is therefore a matter of determining, for each sub-assembly or element of a defined system, the consequences of operating outside the field of use for which this system was designed.

The IEC 61882 standard defines the objectives of the HAZOP method, namely:

1. "Identifying risks associated with the operation and maintenance of the system. The hazards or other risk sources involved can include both those essentially relevant only to the immediate area of the system and those with a much wider sphere of influence, for example some environmental hazards."[5]
2. "identifying potential operability problems with the system and in particular identifying causes of operational disturbances and production deviations likely to lead to nonconforming products."[5]

1.3.3. Activity sector

It applies, or can be applied, to many industrial systems called "thermohydraulics" where products (liquids, gases) are set in motion in installations. These systems are particularly suitable because their operation can be easily characterized by measurable physical quantities (Temperature, Pressure, flow ...), as well as by sequences of operations (automatic or manual). HAZOP analysis is required by the Administration when processes present major risks.

1.3.4. Hazard & Operability Analysis Process

The execution of an accurate HAZOP study requires several technical documents[3] and a multidisciplinary team. Each member of this working team is chosen for their technical expertise or their experience in operating the installation. After the data collection, the multidisciplinary team has the responsibility to analyze and design operation documents, such as Piping and Instrumentation Diagrams (P&ID)[3].

Each installation is divided into subsystems called sections or nodes. These systems must be homogeneous in terms of service and product conditions. Each subsystem will be numbered and the equipment constituting it and the process conditions will be noted. Using the keyword, the objective is to review all possible deviations from the operating parameters and their consequences for each element of the system defined previously.

The team then focuses on deviations leading to potential risks to the safety of people, goods, and the environment. It then examines and defines the recommended actions to eliminate, as a priority, the cause and/or eliminate or mitigate the consequences.

The analysis of deviations, and the recommendations are presented in the form of a table. The HAZOP process is presented in the figure below.

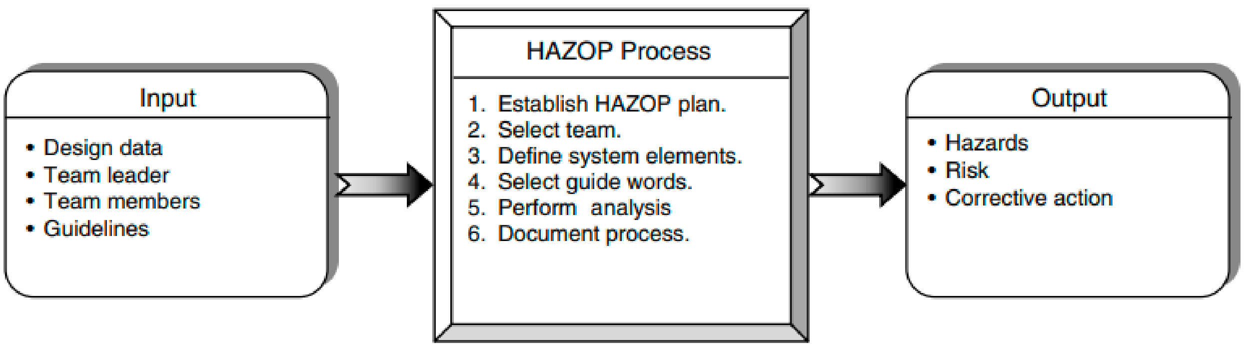


Figure 1- 1 Hazard & Operability Analysis Process

1.3.5. HAZOP Methodology

As mentioned, the correct application of the HAZOP methodology requires a dedicated multidisciplinary team and the discussion meetings usually are a time-consuming process. According to this, a structured procedure must be followed to maintain focus and objectivity along the study which are as follows:

1. Enunciate the purpose of the plant
2. Divide the plant into sections each of which has a clear sub purpose contributing to the overall purpose of the plant[6].
3. Divide each section into nodes, the function of which can be directly described by physical or chemical phenomena[6].
4. Take the first node and describe the process variables.
5. For each process variable define the relevant deviations.

6. Analyze the identified causes of hazardous conditions by using experience to judge their likelihood and record them[6]. Only the causes whose origin is inside the node are taken into account.
7. For each cause with a reasonable probability of occurrence without protective barrier, analyze the possible consequences and their severity. The consequences can be inside or outside the node.
8. Assess the consequence and frequencies, first without a protective barrier.
9. List all existing barriers.
10. Re-evaluate the consequence and frequencies, this time with all protective barriers in place.
11. If the existing barriers are judged insufficient, the team members should agree on recommendations to be taken to reduce the risk to an acceptable level.
12. Continue with the next variable. After applying all the guide words on the first parameter, continue with the next one. Once all the guide words have been used, continue on the next node until you cover the entire system in the studied system.

1.3.6. Advantages and the limitations of the HAZOP study

1.3.6.1. HAZOP study advantages

- The method relies on a simple principle.
- Members of the team do not require special training in the HAZOP study. On the other hand, the HAZOP leader must have received appropriate training.
- The use of the keywords applied to the parameters allows a systematic analysis of process deviations. In fact, by varying parameters and keywords, a list is established, as complete as possible, of the operating deviations of an equipment, and thus potential dangers.
- This risk analysis realized by the multidisciplinary working group makes it possible to practice the technique of brainstorming, which is a source of creativity and to take into account the points of view of each member.
- The method is appropriate for almost all operations in the process industry. It is suitable for the study of complex installations by making it possible to characterize the detailed sequence of events likely to lead to a major accident

1.3.6.2. HAZOP study limitations

Whilst HAZOP studies have proved to be extremely useful in a variety of different industries, the technique has limitations that should be taken into account when considering a potential application. Some of the limitations are mentioned below.[5]

- A HAZOP study is a risk identification technique which considers system parts individually and methodically examines the effects of deviations on each part. Sometimes a very high risk will involve the interaction between several of parts of the system[5].
- The identification of all the risks is not guaranteed in the HAZOP study. therefore, the study of a complex system should not depend just upon a HAZOP study.
- In the interlinked systems, a deviation in one part can have causes and consequences in other parts of the system. It is too difficult then to analyze events resulting from the

simultaneous combination of several failures. As well as, it is difficult sometimes to assign a keyword to a well-defined portion of the studied system. However, where the system is highly interlinked there is a danger that the follow through is not comprehensive of every eventuality.

- The ability and experience of the study leader and the experience, knowledge and the interaction between team members effects the success of a HAZOP study.
- Dividing the system into sectors (nodes or operations) does not always provide that all the parts appear on the design representation. The operations and Activities that don't appear on the representation might not always be considered. This can be partially overcome by applying a set of additional, non-specific guide words to a part that are not strictly properties [2].

1.4. Catastrophic Scenarios

1.4.1. Explosion

1.4.1.1. Definition

The technical literature provides numerous definitions for the term explosion[7]. NFPA 921 (2013) defines an explosion as “the sudden conversion of potential energy (chemical or mechanical) into kinetic energy with the production and release of gases under pressure, or the release of gas under pressure. These high-pressure gases then do mechanical work such as moving, changing, or shattering nearby materials”[8].

The origin of explosions usually faced in process industries are physical and chemical explosions. Subcategories of physical and chemical explosions are presented in Figure 1.1. Air-combustible mixtures are more or less prone to ignition. The following characteristics are used: the lower explosive limit (LEL) and the upper explosive limit (UEL).

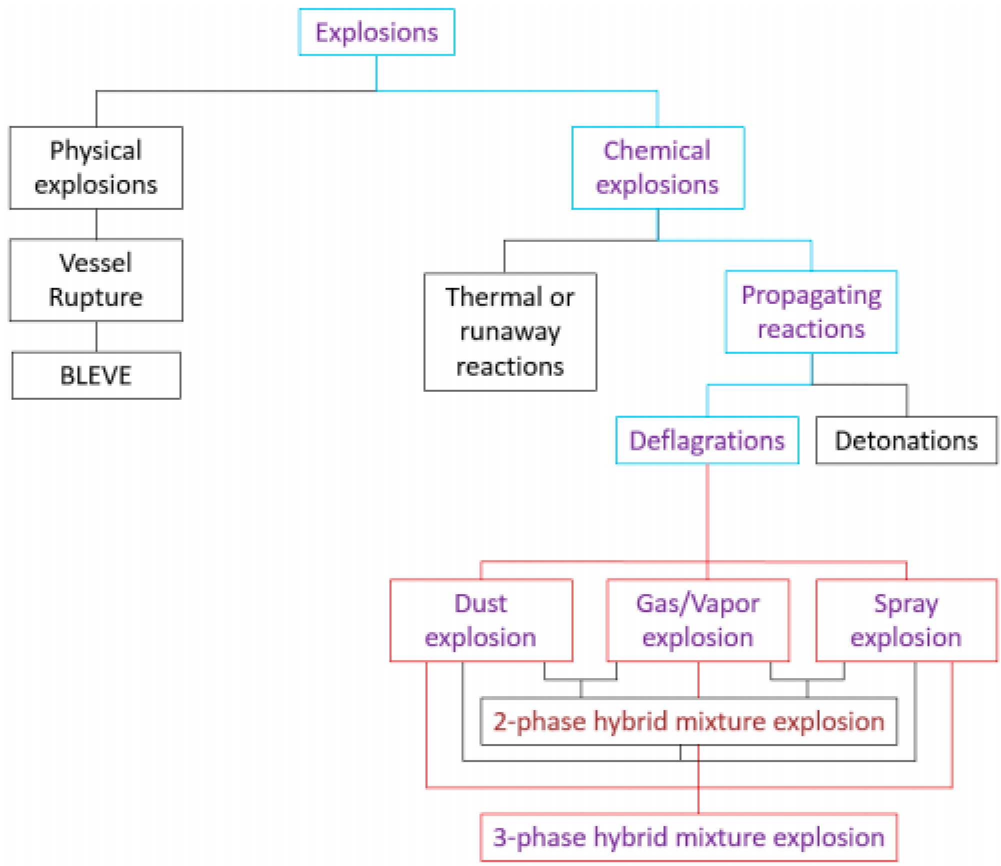


Figure 1- 2the different types of explosions.

Note: Explosive limits specify the concentration range of a material in air which will burn or explode in the presence of an ignition source. They are usually given as the percent by volume of the material in the air[9].

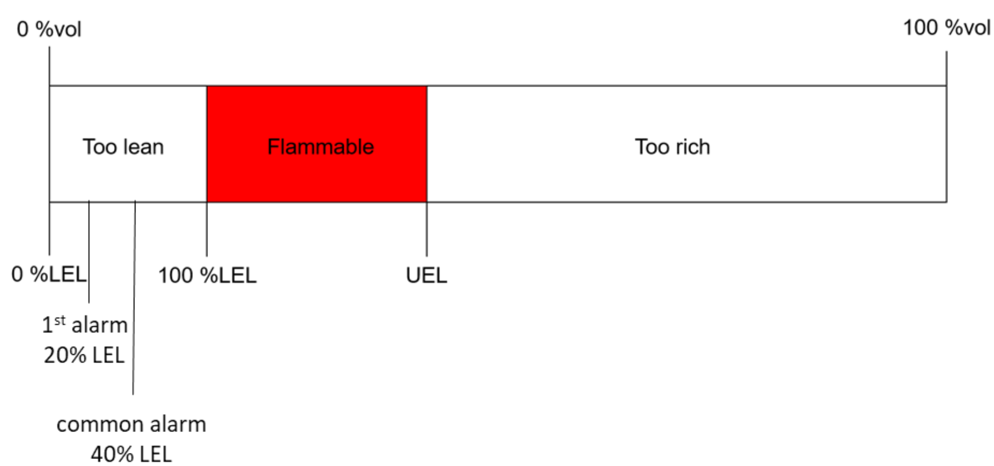
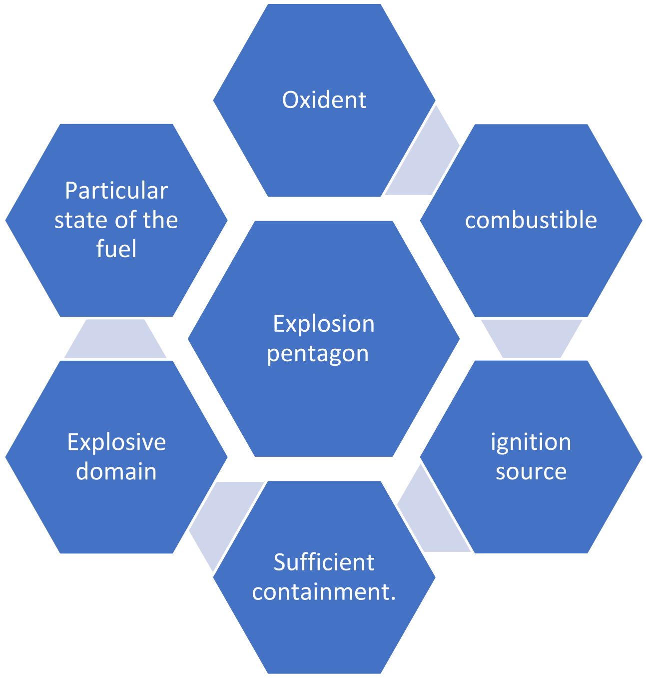


Figure 1- 3Explosive limits

1.4.1.2. Explosion pentagon



An explosion results from the meeting of six conditions which are as follows:

1- Presence of an oxidant.
2- Presence of a combustible substance.
3- Presence of an ignition source
4- Sufficient containment.
5- Particular state of the fuel, which must be in gaseous, aerosol or suspended dust form.
6- Explosive domain.[10]

1.4.1.3. Effect of Explosion

The effects of accidental fires or explosions can be devastating in terms of lives lost, injuries, damage to property and the environment, and to business continuity. they generally include those of overpressure, thermal effects, energized projectiles fragments, debris, and missiles, ground shock, and cratering[7], [11].

1.4.1.4. Explosion Prevention and protection

Numerous explosions occur in industry every year are literally everyday events worldwide[12]. The selection of suitable prevention and protection techniques, and ensure their application, defines the basis of safety for the plant. The search for preventive and protective measures focuses on:

- Replace the flammable material with non-flammable one. For example, substitute the use of a (non-flammable) degreasing cleanser in place of solvent.
- Minimize the handling of dusty materials and design transport systems to reduce the amount of dust generated to a minimum.

- Avoid the accumulation of dust which can be disturbed to form a dust cloud by careful design of the plant and process. Dust extraction at tip points, for example, can be used to contain dust within the plant equipment.
- Avoid explosible dust or gas concentrations by operating outside of the explosive region.
- Carry out the process under an inert gas (such as Carbon Dioxide or Nitrogen).
- Remove all possible sources of ignition as reasonably practicable.[12]

To protect against the explosion effects, one of these three methods must be used:

- Explosion venting: through a hole in the vessel wall the explosion pressure go out.
- Constructing the plant vessel: in such a manner that it is physically strong enough to withstand the full explosion pressure (typically 8-10 bar g)[12].
- Explosion suppression: Fitting vendor supplied detectors and suppressors to the protected vessel. Should an explosion occur, the system detects the excess pressure created and suppresses the combustion before any damage is done[12].

Note: as it has discussed before, there are different types of explosions, to suspend an explosion, a detection system must be implemented, but if the suspension failed, a system that detect and classify in the real time is suitable to be present in the plant to take the right decisions and know the best techniques to intervene.

1.4.2. Ignition

1.4.2.1. Definition

For a combustion reaction to occur, it is necessary to combine the presence of a fuel, an oxidizer, and to provide enough energy. Mixing an oxidizer and a fuel in suitable proportions can form an ATEX (explosive atmosphere). If an ignition source is present, this ATEX is likely to ignite.

Different Types of Ignition Probability

Following a release of flammable product, several dangerous phenomena are likely to occur:

- Jet fire
- pool fire
- BLEVE
- VCE or UVCE
- Flash fire
- Fireball

Ignition can be separated into the immediate ignition and delayed ignition[13].

- Immediate ignition can be considered as the situation where the flammable materials are ignited immediately after leakage accidents by auto-ignition or accident ignition source[14], it should only depend on the characteristics of the product (flash point, boiling point, discharge flow or mass, etc.).
- Delayed ignition is the result that the release and diffusing flammable gas cloud is ignited by other ignition sources apart from the release point[14].

Note: immediate ignition can lead to fire phenomena for flammable liquids and to jet fire for flammable gases. The delayed ignition leads to explosion phenomena with significant pressure effects depending on the congestion of the environment in which the flammable mixture is dispersed (UVCE or VCE). The figure bellow present the different phenomena can occur on the immediate or delayed ignition.

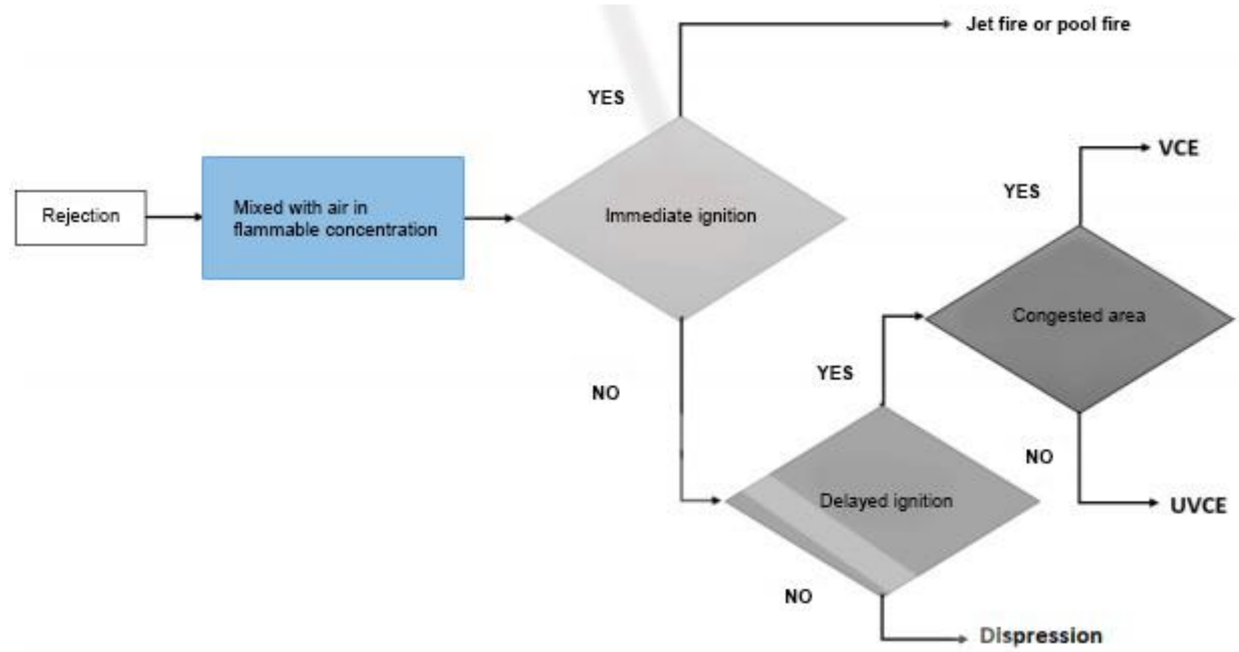


Figure 1- 4 the different phenomena can occur on the immediate or delayed ignition

1.4.3. Unconfined Vapour Cloud Explosion (UCVE)

1.4.3.1. Definition

Unconfined Vapour Cloud Explosions are explosions of flammable gas cloud in an unconfined environment (fresh air), these explosions produce thermal effects as well as air-overpressure waves called shock waves.

1.4.3.2. Description

UVCEs generally include the following steps: the release into the atmosphere of LPG, the product being in the gas phase or in the liquid phase, mixing with the oxygen in the air to form a flammable volume, concomitantly, transport of the cloud gas, part of the volume of which remains flammable, ignition of this cloud, propagation of a flame front of the flammable parts of the cloud; this flame front, associated with the expansion of the burnt gases, acts like a piston on the surrounding fresh gases and can be at the origin of the formation of an air pressure wave, called deflagration, if its propagation speed is sufficient.

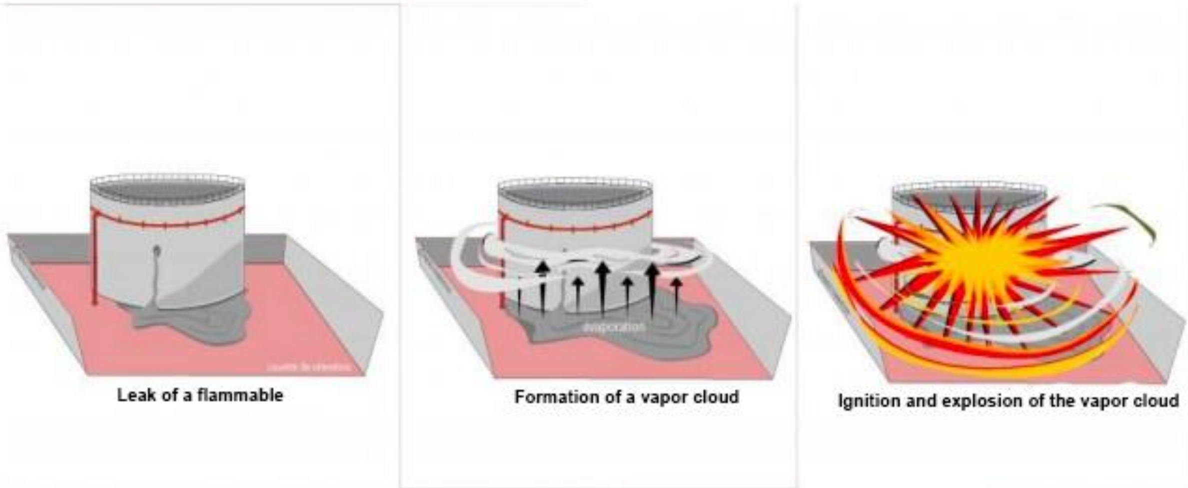


Figure 1- 5 Stages of UVCE occurrence

Note: the vocabulary distinguishes, depending on the effects produced, UVCE from Flash fire, or Cloud fire. In general, the term UVCE applies when pressure effects are observed, while the term Flash fire is reserved for situations where the combustion of the cloud does not produce pressure effects. However, in both cases it is the same physical phenomenon, namely the combustion of a flammable gas mixture.

1.4.3.3. Cause

In order obtain a UVCE two conditions are required simultaneously:

- Leakage of a liquefied combustible gas;
- Evaporation of a puddle of flammable liquid

Low energy is enough to initiate the explosion. Furthermore, ignition may be delayed in time and therefore occur at a certain distance from the site of the leak.

Effect of Unconfined Vapour Cloud Explosion

When the vapour cloud is ignited, following may result:

1. Blast waves
2. Shock waves
3. Fire Ball
4. Multiple fires

Above may causes huge loss of life and property and may also damage the onsite disaster mitigation resources making it an offsite emergency[15].

1.4.4. Boiling Liquid Expanding Vapour Explosion (BLEVE)

1.4.4.1. Definition

The term "BLEVE" is an acronym for boiling liquid expanding vapour explosion and may be defined as any sudden loss of containment of a liquid above its normal boiling point at the moment of vessel failure. Failure may result from the development of cracks which are mainly caused by impact on the vessel, corrosion, internal overheating and construction defects. A common cause of failure leading to BLEVE is due to fire engulfment of a vessel containing liquid under pressure[16].

1.4.4.2. Description

As the liquid heats up, the vapour pressure rises which may actuate the safety valve causing the liquid level in the vessel to fall as vapour is released. Because the heat capacity of vapour is lower than liquid, the portion of the vessel walls in contact with the vapour increases in temperature as heat is transferred from the fire while that in contact with the liquid remains relatively cool. This may result in non-uniform expansion and sufficient loss of strength of the vessel walls to rupture[16]. Following are the steps which can lead to BLEVE

1. Failure of the tank/hold: Tank failure may be due to different reasons which may lead to an increase in the internal pressure and failure of the weakest part of the tank
2. Phase transition: As the tank structure fails, a sudden depressurization of the liquefied gas will occur. The liquid vapour mixture, which was in a thermodynamic saturated state with a higher temperature than its boiling point, will become superheated as the original tank/hold pressure decreases to atmospheric pressure in few milliseconds.
3. Splashing of liquid vapour mixture: As the temperature is above superheated limit temperature (SLT), fast bubble nucleation will initiate inside the tank leading to a violent splashing of liquid/vapour mixture out of the vessel into the atmosphere.
4. Explosion: As the depressurization occurs, along with an intense phase transition in the superheated state, the boiling of the liquid followed by bubble nucleation will together lead to an explosion[17].

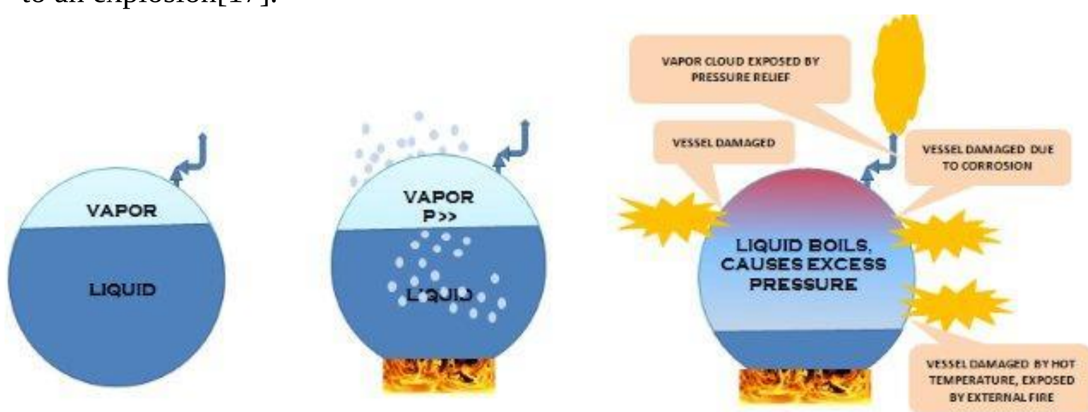


Figure 1- 6 BLEVE mechanism

1.4.4.3. BLEVE Types

There are several ways in which a BLEVE can happens. If the BLEVE occur below the superheating limit, it called cold BLEVE. however, when it occurs above the superheating temperature it is a hot BLEVE.

1.4.4.4. Cause

The most common reason which leads to BLEVE is a fire near a tank containing gas under pressure. Due to the high temperature of the surrounding, the tank temperature starts to increase and the inside of the tank gets over pressurized. The high pressure inside the tank will be usually released by the relief valve.

However, if the pressure builds up rapidly because of high temperature and high rate of heating in the surrounding, the tank will collapse at the weaker point, exposing pressurized and flammable vapour to the naked flame and leading to Boiling Liquid Expanding Vapour Explosion.

1.4.4.5. Consequences

All pressurized liquefied gas storages are likely to be the site of a BLEVE. In fact, the BLEVE is associated with an explosive change of state, and not with a combustion reaction. Also, it is not necessary for the product concerned to be flammable.

The effects of a BLEVE generally manifest in three ways;

- Pressure effects: propagation of an overpressure wave,
- Missile effects: projection of major fragments and rocketing vessel parts.
- Thermal effects: Fireball with thermal radiation with some rainout forming pool fires[18].

1.4.5. Pool Fire

1.4.5.1. Definition

A pool fire can occur when a flammable liquid is accidentally released on ground or water, and ignites. A buoyancy-driven, turbulent non-premixed flame is formed above the pool[19].

Description

When a slick of flammable liquid, produced from the loss of containment of a tank, caught a fire. This can generate significant thermal effects called pool fire.

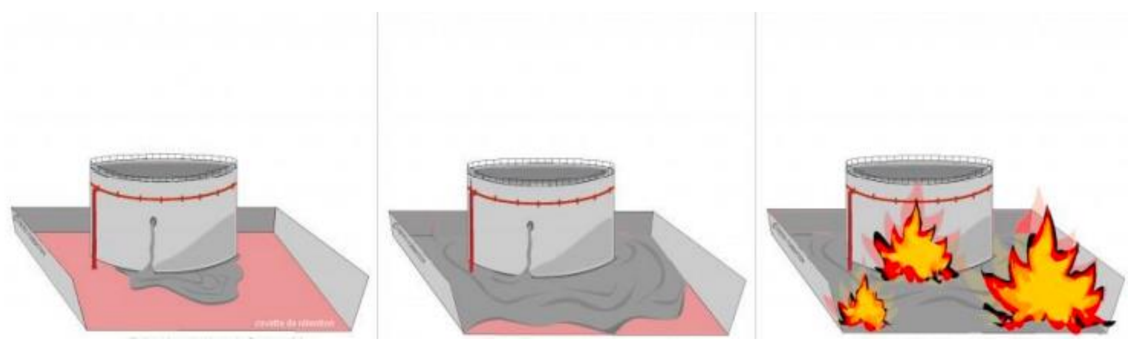


Figure 1- 7 stages of pool fire

1.4.5.2. Cause

The slick of a flammable liquid is frequently the result of a leak. It should be noted that the hot point, if it is maintained long enough, can initiate the fire of the liquid whose temperature is below the flash point: the hot point itself can locally bring the liquid to a temperature greater than its flash point, starts the fire which then spreads to the entire slick.

1.4.5.3. Consequences of Pool Fire

The impact of a pool fire depends on the size of the area on fire, the product that burns, and the duration of the fire.

In general, the main consequences observed recurrently are water pollution, surface and soil contamination, groundwater or, more rarely, injuries or dead. The thermal effects observed will depend on the size of the groundwater as well as the fuel.

1.4.6. Boil-Over

1.4.6.1. Definition

A boilover is a violent ejection of certain liquid hydrocarbons and occurs after a prolonged duration during a storage tank fire. It happens due to vaporization of the water sub-layer that commonly resides at the base of a storage tank, resulting in the ejection of hot fuel from the tank, enormous fire enlargement, formation of a fireball and an extensive ground fire. The water sub-layer exists at the base of a tank as a consequence of water being present in the fuel, the tank being open to atmosphere and hence subject to rain ingress and the introduction of water during firefighting[20].

The phenomenon of boilover, as described in many relevant publications, may occur as:

- Hot zone boilover: when the fuel layer is very large at the time boilover occurs.
- Thin layer boilover: when the fuel layer is very thin at the time boilover occurs.

1.4.6.2. Conditions of Boilover

There are three conditions in order to verify this phenomenon, which are the following:

- ➢ Fire Bac roof.
- ➢ Presence of water in the tank bottom.
- ➢ Liquid has a high viscosity.

1.4.6.3. The kinetic of Boil-Over

The kinetic of phenomenon Boil-Over as follows: when a fire is happening in an open bac containing a liquid hydrocarbon having a wide boiling range. Ten percent of the tank volume is involved in this disaster occurs. Small cuts down this hydrocarbon boiling rise to the surface and feeds the fire, while the heaviest cuts to high boiling flow to the tank bottom and form a warm layer called “heat wave”, once this wave reaches the water, located at the bottom of the tank directly evaporates. The water steam acts as a piston on the remaining quantity of hydrocarbon, and expels out the tank (like a ball of fire) before falling as rain flames)[21].

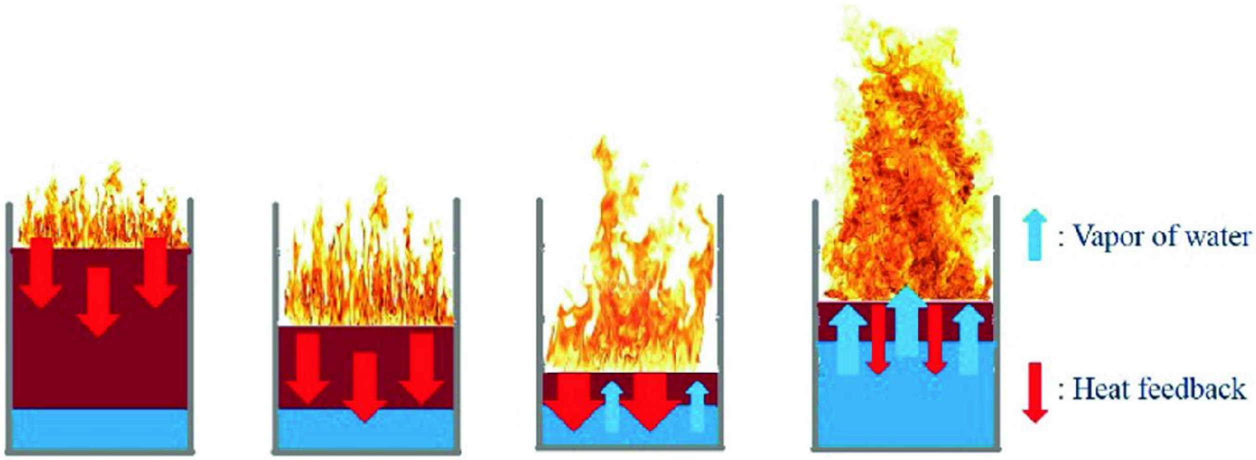


Figure 1- 8 Boilover stages

Note: In the case of a tank fire in the presence of a bottom of water, 3 scenarios can be observed at the end of combustion:

- The liquid is not viscous enough and no projection is observed. This is the case with gasoline, for example.
- A thin layer boilover with the appearance of a thermal gradient over only a few centimeters of hydrocarbon which is likely to be suspended. This is what has been observed with diesel fuel, FOD and JET-A1.
- The classic boil-over is observed when the product is sufficiently viscous and that it is likely to form a heat wave following its distillation into light cuts and heavy cuts (it can be observed with light crude e.g.).

1.4.6.4. The effects of boilover

Boilover is the cause of:

- Violent projection of fuel.
- Boiling the contents of the tank.
- The extension of the flame and the formation of a fireball[21].

1.4.7. Dangerous Phenomena Characteristics

The characteristics of the dangerous phenomena previously discussed are summarized in the table below.

Table 1- 1Summary of the characteristics of dangerous phenomena

Dangerous Phenomena	Time of occurrence	Duration of rising to steady state	Researched parameters
UVCE	Several seconds to 2 - 3 minutes (cloud formation at LEL)	A few milliseconds (inflammation of the cloud)	pressure decrease
BLEVE	Immediate as soon as the tank rupture	Several seconds (expansion and combustion of the fireball)	increased pressure and temperature
Pool Fire	immediate as soon as the ignition of the product	Several minutes to hours Several minutes to hours	Increased temperature
Boilover	immediate as soon as the water evaporates	Several seconds (expansion and combustion of the fireball)	Increased temperature

1.5. Accidentology

The study of experience feedback is often very informative and helps to support the risk analysis. In particular, it provides a lot of information on:

- The nature of the events that may lead to the release of potential hazards.
- The potential consequences of the feared event.
- The relevance of safety barriers which can prevent, detect or control the appearance of a dangerous phenomenon or reduce its consequences.

In this context, we elucidate some accidents that have occurred:

1.5.1. FEYZIN (FRANCE)

The Feyzin refinery, commissioned in 1964, processes 1.7 Mt / year of oil. Its LPG storage area includes 12,850 m3 (theoretical capacity 13,100 m3) of pressurized hydrocarbons in 10 spheres of propane or butane. The spheres are at the closest 22.50 m from the A7 highway.

An operator assistant takes a sample during a purge on a 1,200 m3 propane sphere filled to 60%. After several incidents, a strict operating procedure had been established to purge the spheres (opening of the upper valve, then gradually of the lower valve without ever fully opening it). At 6:40 a.m., the operator assistance operates in the wrong order the series valves which iced up and were blocked in the open position.

A propane leak generates a flammable cloud that slowly drifts to the highway. Cars cross it without consequences. But at 7.15 am, a car stopped 100 m from the source of the leak on the CD4 along the highway lights up the cloud. The driver, seriously burned, die later.

A violent blowtorch appears under the sphere 1 min later. The emergency services from the refinery, from Vienne and Lyon, arrived between 7 a.m. and 8:30 a.m., try to cool the neighboring spheres and extinguish the giant flare which takes on a new dimension after the opening of the safety valves on the top of the sphere.

This suddenly explodes around 8.45 a.m. (1st BLEVE), causing 13 victims. The fireball rises to 400 m in height and reaches 250 m in diameter. A nearby propane sphere explodes in turn at 9.40 a.m. (2nd BLEVE) without causing any victims. The result in terms of human lives was heavy: 18 dead including 11 firefighters and 84 injured out of 158 present people. Significant material damage was observed: ignition of neighboring tanks and opening of several storage spheres, missiles due to BLEVEs found at more than 700 m. The blast of the explosion is felt as far as Vienna[22].

1.5.2. SAN IXUATEPEC, MEXICO, (MEXIQUE), 19/11/1984

At approximately 5:35 am on November 19, 1984, a major fire and a series of catastrophic explosions occurred at the PEMEX LPG terminal in San Juan Ixhuatepec, Mexico City.

Three refineries supply the site with LPG every day. It was then supplied by a refinery 400 km away. Two large spheres and 48 cylinders were then 90% full and four small spheres were 50% full.

The control room as well as a pumping station noticed a drop in pressure. An 8 "pipe between a sphere and a series of cylinders ruptured. The LPG leak then lasts for 5 to 10 minutes when the gas cloud, estimated at an area of 200 m x 150 m at 2 m high, heads towards a flare. The cloud ignites generating a strong overpressure. Several fires occur. The operators on site try to manage the situation. An employee ends up activating the emergency stop button.

About 15 minutes after the start of the leak, a first BLEVE takes place. During the next 1h30, a series of BLEVE occurs.

The result in terms of human lives was heavy, officially 600 dead and 7,000 injured, 39,000 evacuees and 4,000 rescuers involved.

1.5.3. TEXAS CITY (ETATS-UNIS), 30/05/1978

At around 2 a.m., in a LCG storage area of the alkylation unit of a refinery, a sphere of 800 m^3 of isobutene was overfilled from a pipeline and cracks along a weld line. Very quickly the leak ignites and a torch fire is lit at the source. Less than a second later, the sphere becomes pale and a huge (but unknown dimension) ball of fire is formed: the sphere breaks into 3 main pieces projected in 3 directions. The valve is thrown 120 m into a gas unit, where it damages a tube heat exchanger, causing a general fire in the unit.

Vertical and horizontal cylinders have a BLEVE in turn; 20 seconds after the first, a second sphere of 800 m^3 of a butane-butylene (butane) mixture has a BLEVE and generates a fireball of approximately 335 x 200 m. Fragments are projected at 190 m and a valve at 500m. The explosions continue until 6 a.m.

Many other missile effects are noted, and significant thermal effects are reported. The fire required more than 12 hours of intervention. In the end, only 1 cylindrical vertical tank did not explode. 7 employees are killed and 10 others injured. The overall cost is estimated at $ 100 M$ (1986).

1.6. Conclusion

LPG sites represent considerable risks which can be the results of the most catastrophic scenarios, where it is important to install robust prevention and intervention systems that ensure these risks are under control.

The use of artificial intelligence in the prediction, detection and classification of catastrophic scenarios can ensure a hight safety level in the plant not only in terms of prevention but also in terms of response, helping to take appropriate actions.

Chapter 02: Generalities About Artificial Intelligence

2.1. Introduction

With technological development and the complexity of processes, has known the occurrence of several catastrophic scenarios, hence their control requires a significant time to set up the best security barriers. to this effect we find the importance of AI in the decision-making in a short time for effective control using object recognition and classification methods by neural networks.

2.2. Generalities About Artificial Intelligence

The word AI composed from two words, the first Artificial which means "man-made" and the second Intelligence which defines" thinking-power", hence AI means "a man-made thinking power".

Generally, AI is science of training machine to perform human tasks and automate activities that require human intelligence in different domains including safety.

The Artificial Intelligence is now it is widely used, and it is currently working with a variety of subfields, ranging from general to specific, such as suggestions for my faults while writhing this thesis, predict different catastrophic scenarios, made accurate predictions of accidents ... etc.

For creating our AI model, we should know how intelligence is composed, the intelligence is an intangible part of our brain which is combination of Reasoning**, learning, problem-solving perception, language understanding, etc**.

Like all technologies, AI have a lot of advantages like the high accuration, less errors, high speed and high reliability, and some disadvantages such as high cost which is the big obstacle for developing any systems to AI systems.

There are three types of AI, the first we have achieved it in this thesis, the second exists only in theory and the third some researchers said that's impossible to achieve this type of AI, these types are:

1) Weak or narrow AI (our model): able to perform some tasks and decisions with intelligence, it cannot thing out of box (dedicated for one task)

2) General AI: can perform any intellectual tasks efficiency like human, there is no system exists with this type, the world focus on this type of AI, they search for developing machines with general AI (perform like human)

3) Super AI: systems which could surpass human intelligence and perform tasks better than human with cognitive properties (awareness) (intelligent than human).

2.2.1. Artificial intelligence Subsets:

Artificial Intelligence consists of many sets whose common goal is to make a decision based on data and provide output. We will discuss some principal Subsets of artificial intelligence like Machine learning, Deep learning and Natural language programming[23].

2.2.1.1. Machine Learning

ML is a part of AI which provides intelligence to machines with the ability to automatically learn with experiences without being explicitly programmed[24]. Our project with this type of subset, we will discuss it in details in next part.

2.2.1.2. Deep Learning

As we know, Machine learning is a subset of Artificial Intelligence. Deep learning is a subset of machine learning. The only difference in deep learning model is that with experience model becomes better without any specific guidance[23].

2.2.1.3. Natural Language Processing

Natural language processing is a subfield of computer science and artificial intelligence. NLP enables a computer system to understand and process human language such as English. NLP plays an important role in AI as without NLP, AI agent cannot work on human instructions, but with the help of NLP, we can instruct an AI system on our language. Today we are all around AI, and as well as NLP, we can easily ask Siri, Google or Cortana to help us in our language. Natural language processing application enables a user to communicate with the system in their own words directly. The Input and output of NLP applications can be in two forms: **Speech** and **Text**[24]**.**

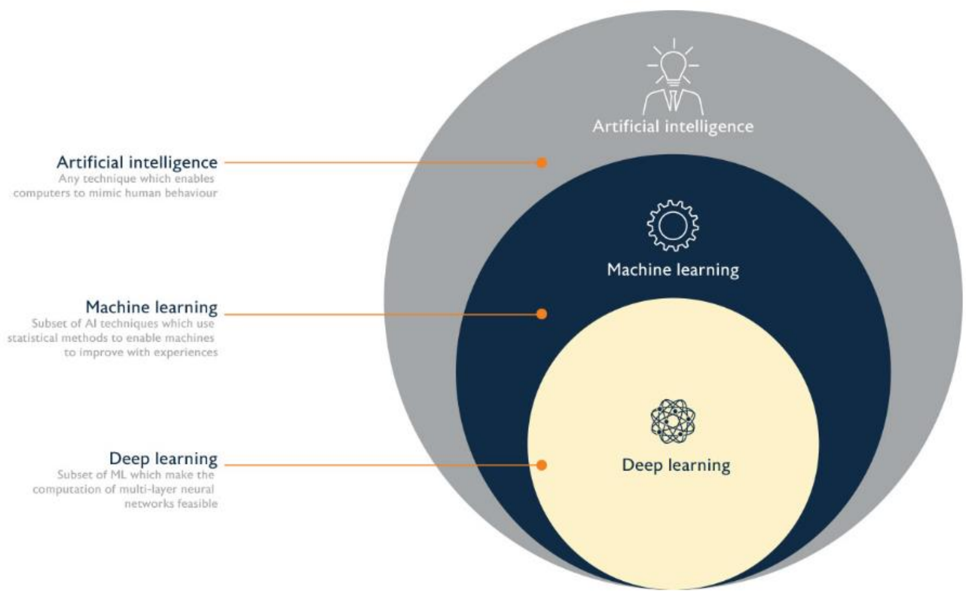


Figure 2- 1 Subsets of AI

2.2.2. The Use of Artificial Intelligence in The Safety Field

One major benefit of AI is its inability to get stressed, tired or unwell. In other words, the AI safety can scale down human factors in the workplace. Human factors play a huge role in workplace safety, with fatigue and stress readily contributing to accidents[25].

Artificial Intelligence (AI) is a powerful technology. And so far, we have only scratched the surface of what may be possible as we continue to develop AI solutions. It has an important role to play in helping manufacturers to prevent accidents, run smarter and significantly enhance the safety of operations.

Using AI technologies for safety is vital for organizations in industries, like the manufacturing industry, energy, oil & gas, chemicals, mining and minerals that can run into hazardous situations. Industrial accidents & incidents associated with disabilities & fatalities are major concerns in manufacturing sectors. The major causes of accidents come about during the operation of machineries, industrial boiler explosions, fire & harmful gas leakages, etc. By using data to help identify patterns and determine the root cause of an accident, incident or near miss, AI systems in manufacturing are aiming to prevent accidents by giving workers the tools to predict and thus, prevent accidents, and most importantly, fatalities[26].

2.2.2.1. Personal protective equipment detection

In 2018, AI-SAFE (Automated Intelligent System for Assuring Safe Working Environments) launched which cleverly detects if employees are wearing the correct PPE for each working area. Normally, PPE checks are conducted by a staff member, with potential for human error.

2.2.2.2. Drones for difficult tasks

Another application of AI is to undertake dangerous tasks, so humans don't have to. Although strictly speaking drones themselves are not AI, they are quickly incorporating it. This allows them to make decisions and operate autonomously.

For example, drone use is rising in the construction industry. In fact, between 2017 and 2018, the number of drones deployed to construction sites grew by 239%. Furthermore, one survey found over 50% of construction sites using drones reported an improvement in safety.

Construction site drones can gather and analyze data otherwise overlooked by humans. For example, one Dallas construction site has used drones to inspect roofs since 2014.

2.3. Machine Learning

2.3.1. Generalities About Machine Learning

Recent years have seen much discussion of machine intelligence, and what this means for our health, productivity, and wellbeing. In such discussion, machine learning apparently promises to save lives[27].

The world today is evolving and so are the needs and requirements of people[27]. Furthermore, we are witnessing a fourth industrial revolution of data. In order to derive meaningful insights from this data and learn from the way in which people and the system interface with the data, we need computational algorithms that can churn the data and provide us with results that would benefit us in various ways[28]. Machine Learning has revolutionized industries like medicine, healthcare, manufacturing, banking, safety, and several other industries. Therefore, Machine Learning has become an essential part of modern industry. Furthermore, machine learning has facilitated the automation of redundant tasks that have taken away the need for manual work[29].

So, what's ML, What's ML types and What is the ML Lifecycle?

ML is subset of AI that allows systems to learn directly from examples, data, and experience[27]. ***It*** allows the systems to make decisions autonomously without any external support. These decisions are made when the machine is able to learn from the data and understand the underlying patterns that are contained within it. Then, through pattern matching and further analysis, they return the outcome which can be a classification or a prediction[30].

- It is primarily concerned with the design and development of algorithms that allow the system to learn from historical data.
- Machine Learning is based on the idea that machines can learn from past data, identify patterns, and make decisions using algorithms.
- Machine learning algorithms are designed in such a way that they can learn and improve their performance automatically[24].

2.3.2. Types of Machine learning

There some variations of how to define the types of ML Algorithms but commonly they can be divided into categories according to their purpose and the main categories are the following[31]:

2.3.2.1. Supervised Learning

Supervised Learning is the most common subbranch of machine learning today, supervised machine learning algorithms are designed to learn by example. The name "supervised" learning originates from the idea that training this type of algorithm is like having a teacher supervise 1the whole process[31]. briefly is type of ML, where a computer algorithm is trained on input data that has been labeled for a particular output[32].

It is the simplest subcategory of machine learning and serves as an introduction to machine learning to many machine learning practitioners. Supervised learning is the most commonly used form of machine learning, and has proven to be an excellent tool in many fields[31].

We used this type of ML and we will discuss the process of building our model in details in the next part.

2.3.2.2. Unsupervised Learning

Unsupervised Learning is a machine learning technique in which the users do not need to supervise the model. Instead, it allows the model to work on its own to discover patterns and information that was previously undetected. It mainly deals with the unlabeled data[33].

2.3.2.3. Reinforcement Learning

Reinforcement learning is about taking suitable action to maximize reward in a particular situation. It is employed by various software and machines to find the best possible behavior or path it should take in a specific situation[34].

2.3.3. The Life Cycle of Machine Learning

The main purpose of the life cycle is to find a solution to the problem, so we should detect the fire which is the common thing in all catastrophic scenarios. This part describes the process we follow to build our model, the steps are the following:

1. **Gathering data:** is the first step of the machine learning life cycle. The goal of this step is to identify and obtain all data-related problem which are pictures and videos of fire. It is one of the most important steps of the life cycle[35],because the more data we have and the better the quality and balancing is, the better the model will learn and predict accurately[36].
2. **Data preparation:** is used to understand the nature of data that we are going to work with, we need to understand the characteristics, format, and quality of data for the best accuration.
3. **Data wrangling:** it is one of the most important steps of the whole process. this step used for cleaning our data from duplicate and invalid data and which contain noises such as blurred pictures. We must be careful in this step, the missing of any invalid data could affect our model's quality
4. **Data annotation:** in this step we should label and make a box around the fire on all pictures we have, as we said in the supervised learning, we train computer from input data which is pictures containing fire for particular output which also fire.
5. **Train the model:** the goal of this step is from our annotated pictures(80 % of data), and an algorithm chosen by the Microsoft CustomVision (in the last chapter we will discuss how the training works), make some computations and produce a model that can predict if a picture, video or real-time video contain a fire, we can say the computer can see the fire.
6. **Test the model:** In this step, we check for the accuracy of our model by providing a test with 20 % of the data we have, testing the model determines the percentage accuracy of the model[35].
7. **Deployment:** The last step of machine learning life cycle is deployment, where we deploy the model in the real-world system[35],like surveillance cameras.

2.4. Deep Learning

2.4.1. Generalities About Deep Learning

As previously described, DL is a subset of ML techniques. it is way of classifying, clustering, and predicting things by using a neural network that has been trained on vast amounts of data. The elementary bricks of deep learning are the neural networks which are combined to form the deep neural networks[37], DNN are mathematical models of intelligence designed to mimic human brains. DL creates many layers of neurons, attempting to learn structured representation of big data, layer by layer.

- Deep learning is implemented through neural networks architecture hence also called a **deep neural network**.
- Deep learning is the primary technology behind Fire detection, EPP detection and anomalies detection.
- The main challenge for deep learning is that it requires lots of data with lots of computational power[24].

So as we said , since deep learning has been evolved by the machine learning, which itself is a subset of artificial intelligence and as the idea behind the artificial intelligence is to mimic the human behavior, so same is "the idea of deep learning to build such algorithm that can mimic the brain"[38].

2.4.2. Artificial Neural Network

Artificial neural networks (ANNs) or connectionist systems are computing systems inspired by the biological neural networks that constitute animal brains. Such systems learn (progressively improve their ability) to do tasks by considering examples, generally without task-specific programming. For example, in image recognition, they might learn to identify images that contain fire by analyzing example images that have been manually labeled as "fire " or "no fire " and using the analytic results to identify cats in other images. They have found most use in applications difficult to express with a traditional computer algorithm using rule-based programming.

2.4.2.1. Biological Neurons

Neurons are the basic functional units of the nervous system, and they generate electrical signals called action potentials, which allows them to quickly transmit information over long distances.

Almost all the neurons have three basic functions essential for the normal functioning of all the cells in the body. These are to:

- Receive signals (or information) from outside.
- Process the incoming signals and determine whether or not the information should be passed along.
- Communicate signals to target cells which might be other neurons or muscles or glands.

A biological neuron is mainly composed of 3 main parts and an external part called synapse:

1. **Dendrites:** are responsible for getting incoming signals from outside
2. **Soma:** is the cell body responsible for the processing of input signals and deciding whether a neuron should fire an output signal
3. **Axon:** Axon is responsible for getting processed signals from neuron to relevant cells

4. **Synapse:** is the connection between an axon and other neuron dendrites

The task of receiving the incoming information is done by dendrites, and processing generally takes place in the cell body. Incoming signals can be either excitatory — which means they tend to make the neuron fire (generate an electrical impulse) — or inhibitory — which means that they tend to keep the neuron from firing.

Most neurons receive many input signals throughout their dendritic trees. A single neuron may have more than one set of dendrites and may receive many thousands of input signals. Whether or not a neuron is excited into firing an impulse depends on the sum of all of the excitatory and inhibitory signals it receives. The processing of this information happens in soma which is neuron cell body. If the neuron does end up firing, the nerve impulse, or action potential, is conducted down the axon.

Towards its end, the axon splits up into many branches and develops bulbous swellings known as axon terminals (or nerve terminals). These axon terminals make connections on target cells[39].

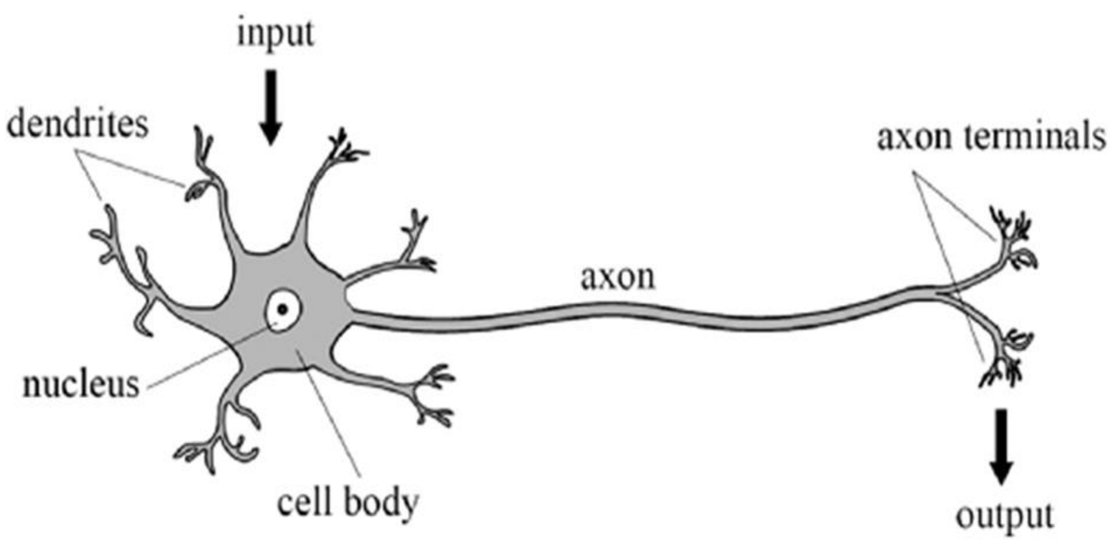


Figure 2- 2Biological neuron

2.4.2.2. Artificial Neurons

Artificial neuron also known as perceptron is the basic unit of the neural network. In simple terms, it is a mathematical function based on a model of biological neurons. It can also be seen as a simple logic gate with binary outputs. They are sometimes also called perceptrons. Each artificial neuron has the following main functions:

- Takes inputs from the input layer
- Weighs them separately and sums them up

- Pass this sum through a nonlinear function to produce output.

The perceptron(neuron) consists of 4 parts:

1. **Input values or One input layer:** We pass input values to a neuron using this layer. It might be something as simple as a collection of array values in our case the arrays are the pixels of picture. It is similar to a dendrite in biological neurons.
2. **Weights and Bias:** Weights are a collection of array values which are multiplied to the respective input values. We then take a sum of all these multiplied values which is called a weighted sum. Next, we add a bias value to the weighted sum to get final value for prediction by our neuron.
3. **Activation Function:** decides whether or not a neuron is fired. It decides which of the two output values should be generated by the neuron.

Output Layer: gives the final output of a neuron which can then be passed to other neurons in the network or taken as the final output value[39].

Table 2- 1 Biological and Artificial Neurons

Biological neuron	**Artificial neuron**
Dendrites	Input
Synapses	Weight
Axon	Output
Soma	Interconnections

The aim of Artificial Neural Networks is to realize a very simplified model of the human brain. In this way, Artificial Neural Networks try to learn tasks (to solve problems) mimicking the behavior of brain. The brain is composed by a large set of elements, specialized cells called neurons[40].

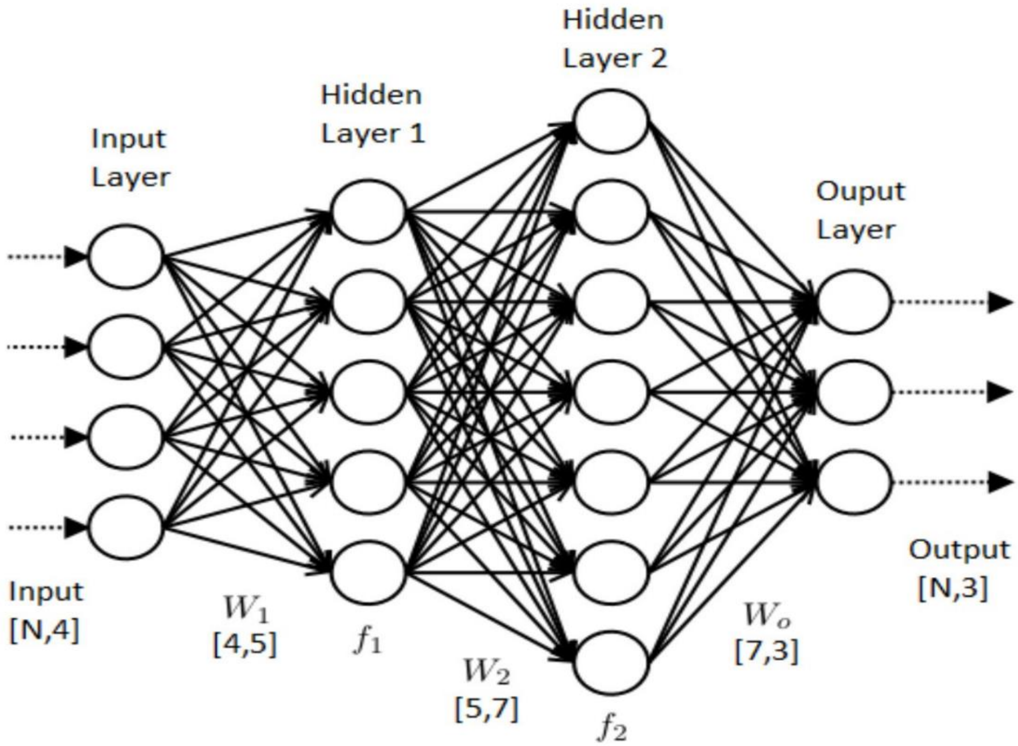


Figure 2- 3 Artificial neural network

2.5. Conclusion

Since AI is on the path to becoming an invaluable resource to maintain workplace safety and as (AI) systems begin to control safety-critical infrastructure across a growing number of industries, the need to ensure safe use of AI in systems has become a top priority.

This chapter has given an overview of artificial intelligence and its subsets as well as the life cycle to create a machine learning model. It can be applied in the field of security by several methods that we have seen some examples in this chapter.

Our choice is focused on one of the LPG storage spheres which represents one of the relevant equipment because of nature of the materials present and the high pressure in the latter.

Chapter 03: Assessment and Modeling of Catastrophic Scenarios in an LPG Sphere

3.1. Introduction

Identifying risks and analyzing consequences are essential steps in the risk management process. This chapter will be devoted to all the results obtained by the risk assessment that we carried out on the LPG storage tank, and the analysis of the potential impacts in the event of accidents as well as the modeling of the potential effects using PHAST 8.0 software.

3.2. Presentation of the GL3Z COMPLEX

3.2.1. Geographical Location of The GL3Z COMPLEX

The GL3Z Complex is located in ORAN in the north of ALGERIA and about 40 km east of Oran in the Arzew industrial zone. The complex occupies an area of 72 hectares and it was put into production on July 2014[41].

Figure 3- 1 Geographical location of the GL3Z COMPLEX

3.2.2. Description Of the Complex

GL3 / Z plant facilities include the process train, all utilities, finished product storage, related off-site facilities, an LNG jetty with an extendable LNG loading platform, a breakwater, protection of the existing seaside, all the necessary buildings and infrastructure.

The factory entrance installations are located on the southwest side of the implantation area. This is where the feed gas enters the GL3 / Z plant, the west side includes the power generation area and gas turbines, the southern part of the plant is the utilities units and their storage devices.

the northern section alongside the sea and contains the installations for the storage of products and refrigerants, the torch area and the jetty, the process train is located in the middle of the installation area. It is subdivided into two parts: the eastern part includes the pre-treatment and liquefaction units, while the western part includes the LNG fractionation and recovery equipment[42].

Figure 3- 2 Plant Overview 3D Model

3.2.3. Presentation Of Refrigerant Storage System (Unit 73)

The Refrigerant Storage System (Unit 73) consists of storage inventories, transfer and unloading facilities for Ethane and Propane refrigerants. It is designed to store and supply Ethane and Propane refrigerants to both LNG Train 1 and future LNG Train 2.

The purity of stored Ethane refrigerant is at least 96% mol/mol, whilst the one of stored Propane refrigerant is at least 98.35% mol/mol.

Unit 73 facilities provide storage and transfer capacity for:

- Ethane used in the Mixed Refrigerant Circuits (Units 16 and future 26).

Propane used in the Main Propane and Mixed Refrigerant Circuits (Units 16 and future 26) and Auxiliary Propane Circuits (Units 17/27)[43].

Ethane and propane storage facilities are located in the Storage Area, outside the process trains. They are situated at the North side of GNL-3Z plot area, respectively at the right and left side of the LNG storage tanks[43].

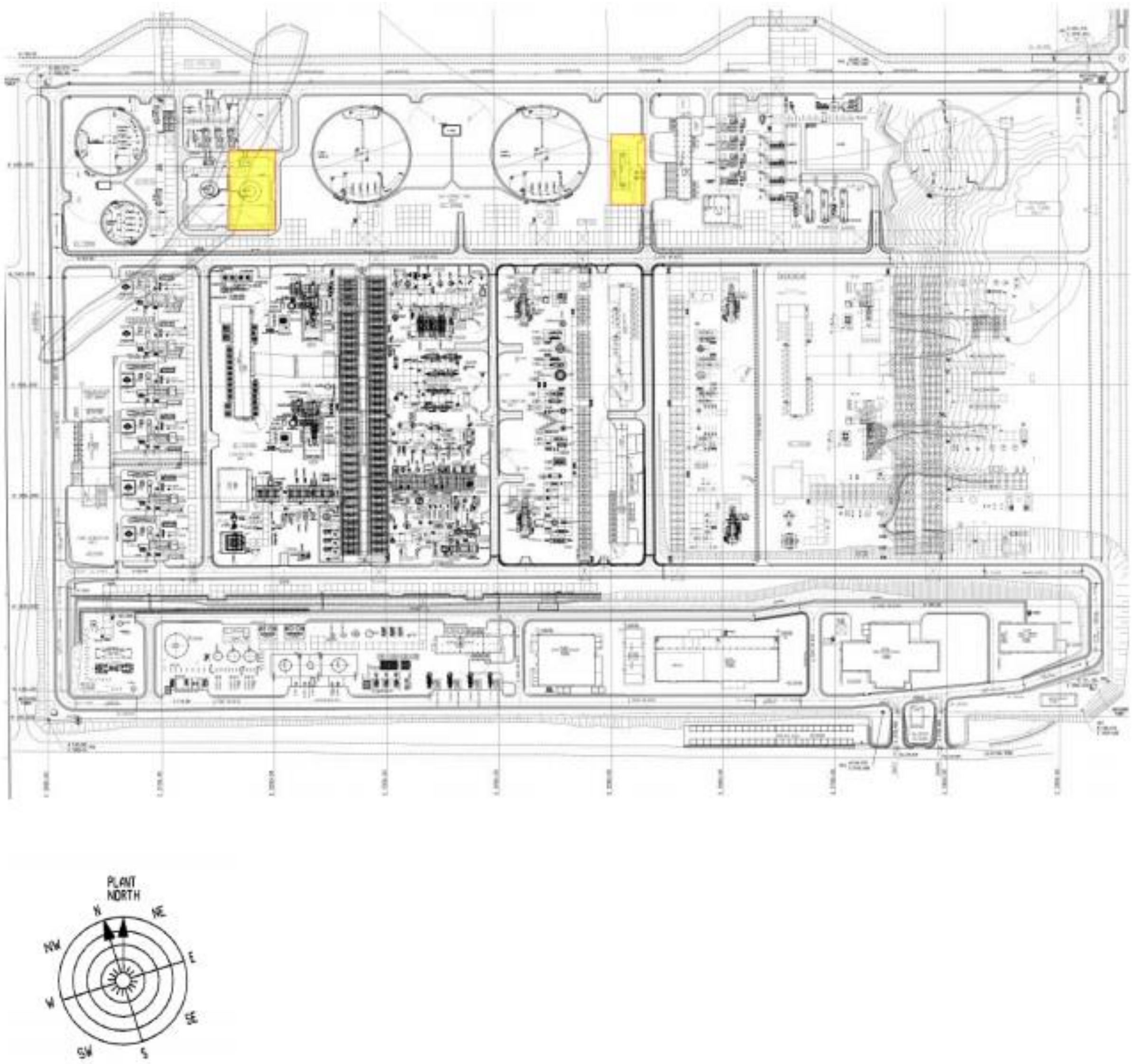


Figure 3- 3 Overall Plot Plan

Note: The location of unit 73 items is highlighted in yellow here above.

3.2.4. Process Description

3.2.4.1. Ethane Refrigeration Storage and Transfer System Operation

The Ethane Storage Drum (73-MD01) is a pressurized bullet, operated at 18 barg and -11.7°C. In order to reduce the boil-off vaporisation effect due to solar radiation, the vessel is insulated. The boil-off vapours are sent to the LP Common Fuel Gas Header under pressure control, however also an overpressure control with dedicated line to Cold Flare has been provided as secondary alternative for equipment protection. The vessel overhead line is routed to the LP MR Suction Drum (16-MD01) as ethane vapour make-up. The vessel bottom line is connected to the Ethane Transfer Pump (73-MJ01) which can alternately route the liquid Ethane under flow control[43].

3.2.4.2. Propane Refrigeration Storage and Transfer System Operation

The Propane Storage Sphere (73-MD02) is a non-refrigerated Propane storage type, where the Propane is stored at ambient temperature; the operating pressure in the sphere can vary from 3.5 barg to 14.6 barg, based on the ambient temperature, which can vary from -2.3°C to 45°C.

Propane vapour losses are not expected since the fluid is stored at the equilibrium pressure with the outside ambient temperature, nevertheless an overpressure control with dedicated line to Cold Flare has been provided for equipment protection.

The sphere overhead line is routed to the LP Main and Auxiliary Propane Suction Drums (16-MD02 / 17- MD08).

The vessel bottom line is connected to the Propane Transfer Pump (73-MJ02) which can alternately route the liquid Propane under flow control[43].

3.2.5. Main Characteristics of The Spheres

The following table shows the main characteristics of the sphere present in the storage area (Operating pressure, Operating temperature, Design pressure).

Table 3- 1 The main characteristics of the sphere

Equipment		73-MD02
Service		Propane storage sphere
Operating pressure	Barg	7.8
Operating temperature	°C	21.7
Working Capacity	m3	2934
Design Temperature Max/Min (°C)	°C	85 / -45
Design pressure	Barg	16
ID	Mm	18760

3.3. Identifications Of Potential Accident Scenarios by HAZOP

In this study, the identification of accident scenarios related to LPG spheres is made by the HAZOP method « Hazard and operability studies », This method allowed to identify possible feared events, their causes (initiating events) and their consequences (dangerous phenomena and effects generated) also evaluate the classes of probability of occurrence and severity.

The application of the HAZOP study to the finished product storage area of pressurized spheres is carried out by considering the operating parameters (Level, Pressure, Temperature, Flow and leakage).

The results obtained by the HAZOP analysis are presented in tabular form see **Annex B**.

3.3.1. Risk Assessment

After estimating the risk, it should be compared to the acceptability criteria pre-established by a risk matrix. This assessment allows a decision to be made on the acceptability or unacceptability of each risk.

The acceptability of a risk is made from its two parameters: its probability of occurrence and its severity.

The results of the risk assessment are presented in the graph below.

Table 3- 2 Criticality grid adopted by SONATRACH (translated)

Probability **Gravity**	**1- Extremely rare** (Likely scenario but not encountered globally) **< 10-5 /year**	**2- Rare** (Scenario having already occurred but still very unlikely) **10-4 – 10-5/year**	**3- Uncommon** (Scenario that could occur) **10-3 – 10-4/year**	**4- Occasional** (Scenario that could occur in two different sectors) **10-2 – 10-3/year**	**5- Frequent** (Scenario that may occur several times during the lifetime of the installation) > **10-2/year**
5- Disastrous -many deaths -Major impact external to the site with consequences durable	**Intermediate risk**	**Intolerable risk**	**Intolerable risk**	**Intolerable risk**	**Intolerable risk**
4- Catastrophic - lethal effect on a person and several permanent disabilities -Significant impact external to the site with consequences reversible	**Acceptable risk**	**Intermediate risk**	**Intolerable risk**	**Intolerable risk**	**Intolerable risk**
3- Major -possible lethal effect on a person and permanent disabilities -Significant impact	**Acceptable risk**	**Intermediate risk**	**Intermediate risk**	**Intolerable risk**	**Intolerable risk**
2- Moderate - irreversible effects -Moderate impact	**Acceptable risk**	**Acceptable risk**	**Intermediate risk**	**Intermediate risk**	**Intolerable risk**
1-Minor -no irreversible effect -Minor impact	**Acceptable risk**	**Acceptable risk**	**Acceptable risk**	**Acceptable risk**	**Intermediate risk**

3.3.2. Results Interpretation

From the results of the HAZOP report, we obtained:

- Twenty-one unacceptable events
- Nine events in the ALARP zone
- eighteen acceptable events

The unacceptable events as mentioned above represent considerable problems for our system and they are in priority to reduce to a lower scale. Some solutions proposed to reduce the risk are presented in the table in the recommendations box.

These events will be studied with simulation of catastrophic scenarios.

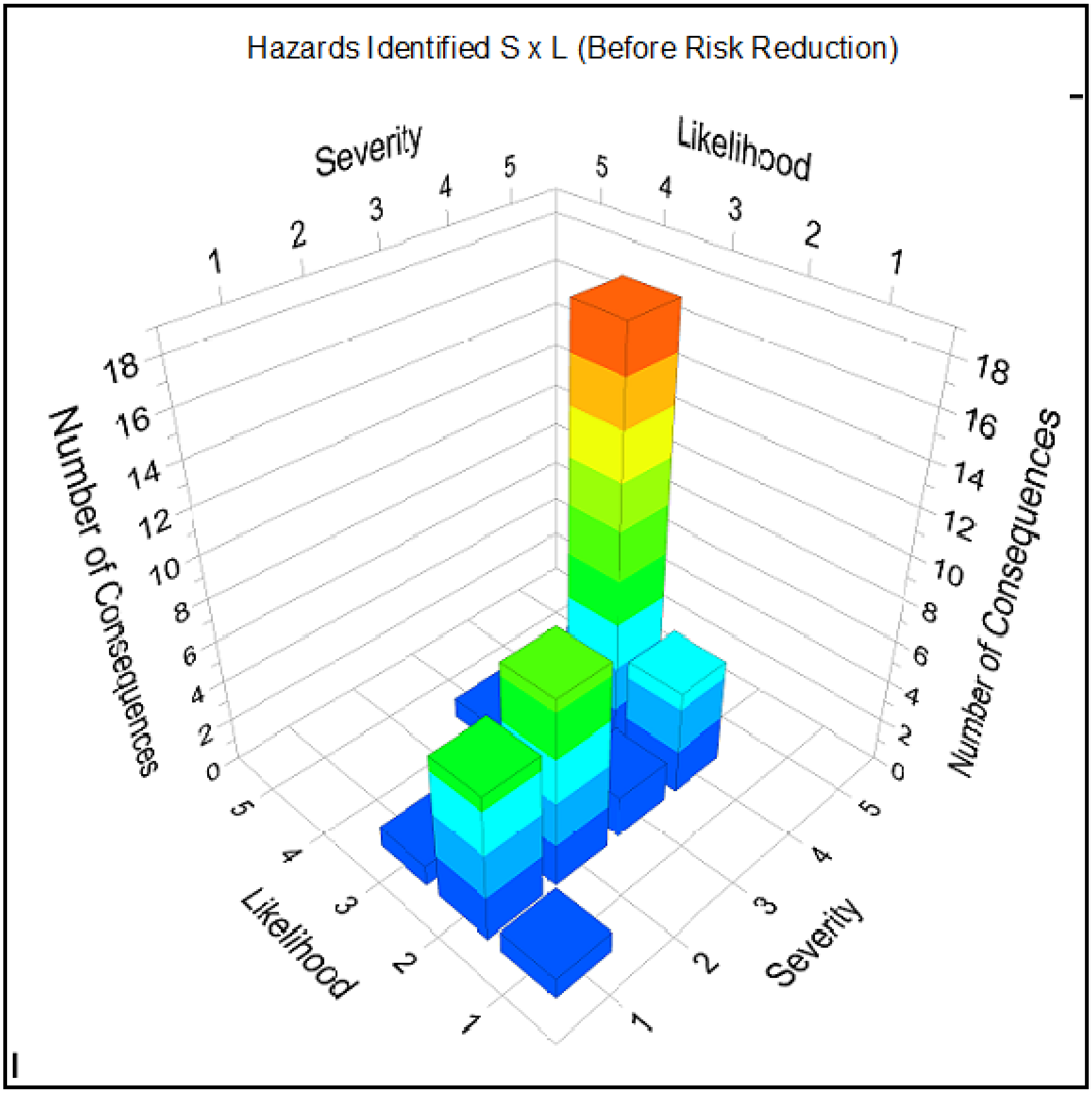


Figure 3- 4 graph shows the number of consequences depending on Severity and probability

3.4. Modeling Consequences Using PHAST Software

The PHAST software simulates the loss of containment of the dangerous substance (source terms: flow at the breach, physical state of the release, service conditions, etc.), then its evolution (formation of a cloud, etc.) and finally associated dangerous phenomena (jet fire, explosion, etc.).

3.4.1. Climatic Data

The dispersion of a cloud of LPG vapors is governed by the force and direction of the wind, atmospheric stability and, to a lesser extent, by relative humidity and temperature.

The meteorological data used in this study is based on climatological data from the Arzew area. The averages obtained for the month of August:

- Average temperature (° C): 26.2
- Average relative humidity (%): 71
- Average wind speed (Km / h): 8
- Dominant wind direction (August); NNE (NorthNorthEast)
- Atmospheric stability class: Class C[44].

3.4.2. Reference Values Relating to The Overpressure and Thermal Effects Thresholds

3.4.2.1. Reference Values Relating to The Overpressure Effect Thresholds

The reference values for classified installations are as follows:

1. For effects on humans:

Overpressure level	Effects
25 mbar	Serious damage
50 mbar	Irreversible or lethal damage

2. For domino effects:

Overpressure level	Effects
160mbar	Damage to structures (domino effect)
300mbar	Serious damage to structures

3.4.2.2. Reference Values Relating to Thermal Effect Thresholds

1. For effects on humans:

Thermal thresholds	Effects
2.5 kW/m²	The accident can affect sensitive or uninformed people
6.4 kW/m²	Serious consequences, direct or indirect, immediate or long term
10 kW/m²	1% fatality after 20s for unprotected people

2. For domino effects:

Thermal thresholds	Effects
8 kW/m²	Damage to unprotected installations
32 kW/m²	Damage to protected installations operating at atmospheric pressure

Note: the reference values was taken from a hazard study report[45] prepared by DNV.

3.4.3. Analysis Of Consequences

Note: The simulation steps are defined in **Annexes D**.

Note: the diameters of the leaks were chosen according to the following equations:

- Small leak: dl = 0.1 D
- Medium leakage: dl = 0.15 D
- **Large** leak: dl = 0.36 D

With: D = internal diameter. *(The failure frequency calculations are based on generic data taken from Handboek Kanscijfers 2009).*

3.4.3.1. First scenario

Description: Leak in the propane sphere with a diameter of 10mm. The simulations were performed using the input data presented in the table below.

Table 3- 3Input data for PHAST for 10mm leak

Parameters	substance	Operating temperature	Operating pressure	Volume	scenario	Elevation of leaking point
Values	Propane	37 ºC	21 barg	2934m3	Leak of 10mm	1m

The simulation by PHAST has gave the following results:

Dispersion

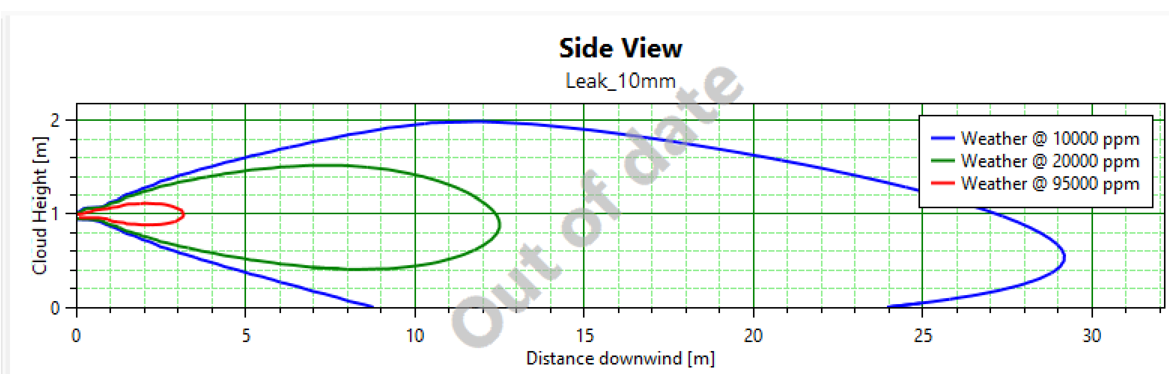


Figure 3- 5 Sectional view of the gas cloud of the 10mm-leak

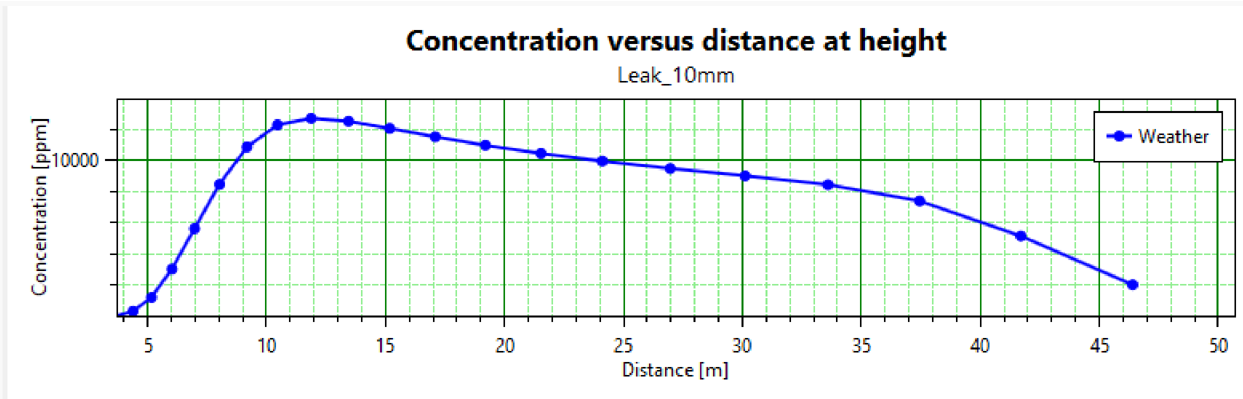


Figure 3- 6 The height of the cloud of gas depending on the concentration of the 10mm-leak

From the graph bellow and the results from simulation with PHAST, the gas cloud can reach a concentration of 12689.46ppm and the gas distance can go up to 24m distance and a height of almost 46m.

Jet Fire

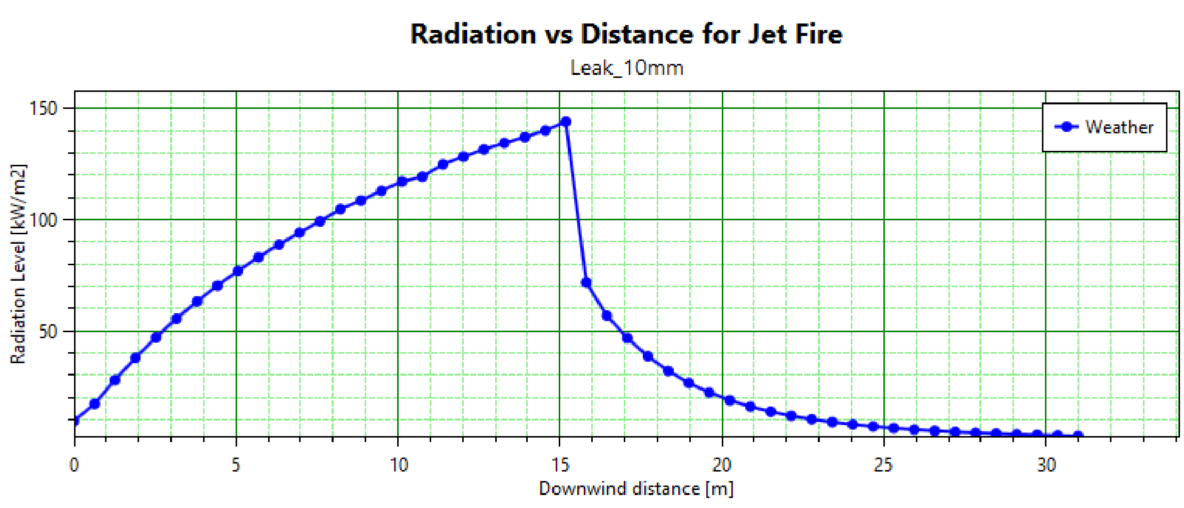


Figure 3- 7 The extent of radiation depending on the distance of the 10mm-leak

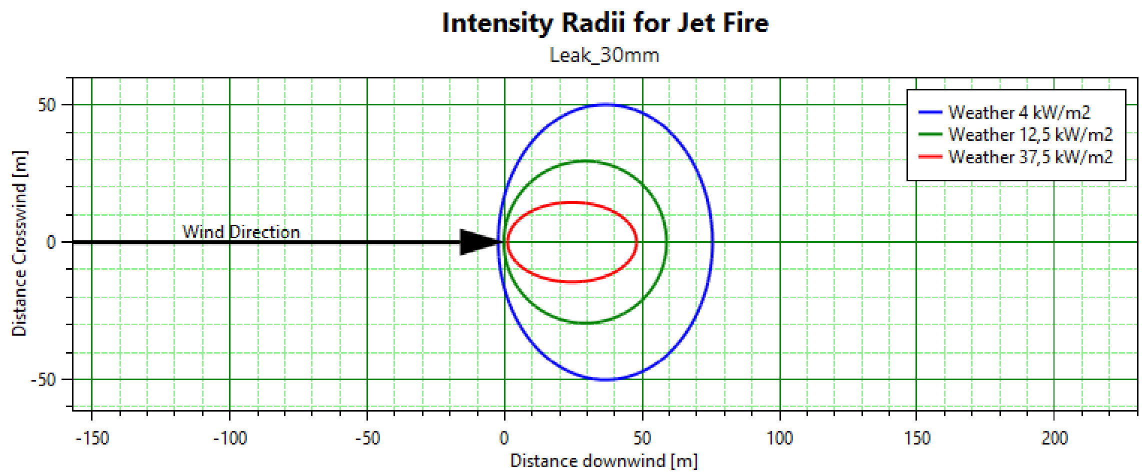


Figure 3- 8 Area affected by thermal radiation from jet fire of the 10mm-leak

The figures above show the evaluation of the level of thermal radiation generated by the jet fire as a function of the distance, we notice that the thermal radiation reaches 144kW / m² at a distance of 15.18m.

The Experience shows that the effect of heat radiation is quite limited, but anyone in the blue circle is susceptible to have Serious consequences, direct or indirect, immediate or long term.

Flash Fire

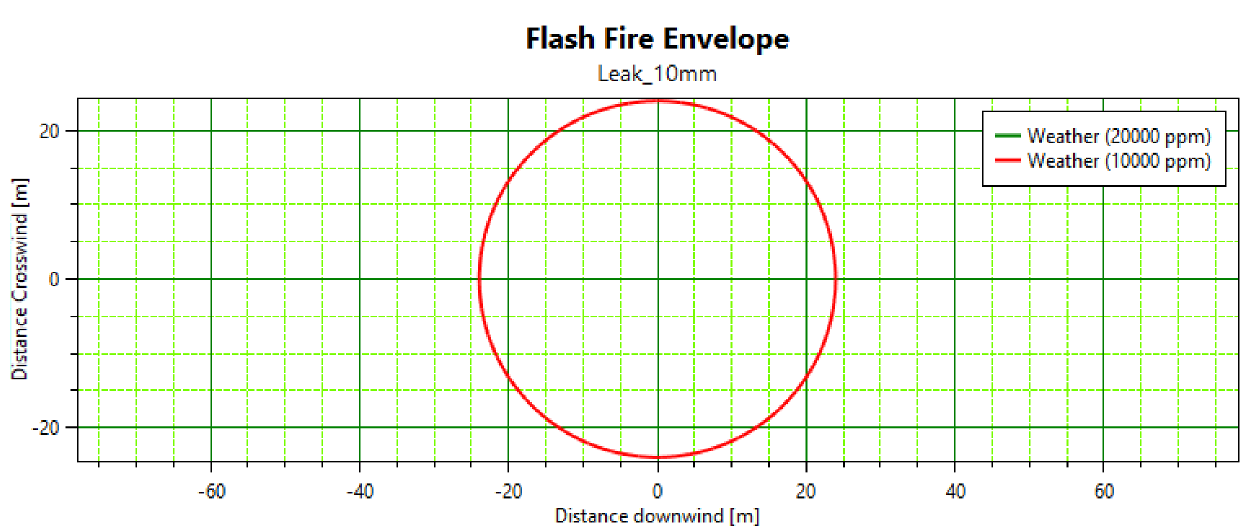


Figure 3- 9 The upper and lower explosive limits for the 10mm-leak

Experience shows that the effect of thermal radiation is quite limited, and that the lethal effect is dimensioned by the distance from LII (Lower Flammability Limit).

Explosion

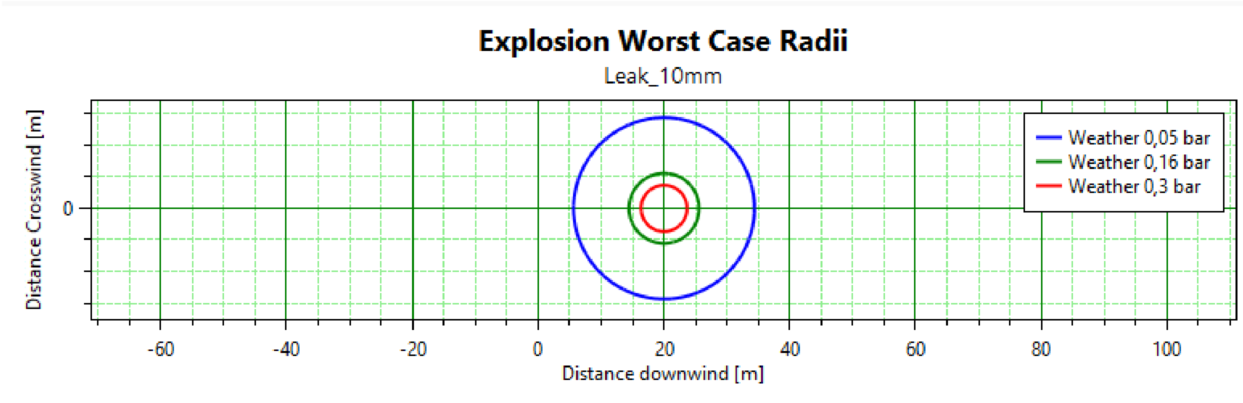


Figure 3- 10 Areas affected by thermal explosion effects in the 10mm-leak

The graph bellow shows the areas affected by thermal explosion effects. Any person in the blue circle that have a radius of 68m is susceptible to have irreversible consequences, and the buildings in the green circle are susceptible to get damaged by the domino effect.

3.4.3.2. Second scenario

Description: Leak in the propane sphere with a diameter of 30mm. The simulations were performed using the input data presented in the table below.

Table 3- 4Input data for PHAST for 30mm leak

Parameters	Substance	Operating temperature	Operating pressure	Volume	scenario	Elevation of leaking point
Values	Propane	37 ºC	21 barg	2934m3	Leak of 30mm	1m

The simulation by FAST has gave the following results:

Dispersion

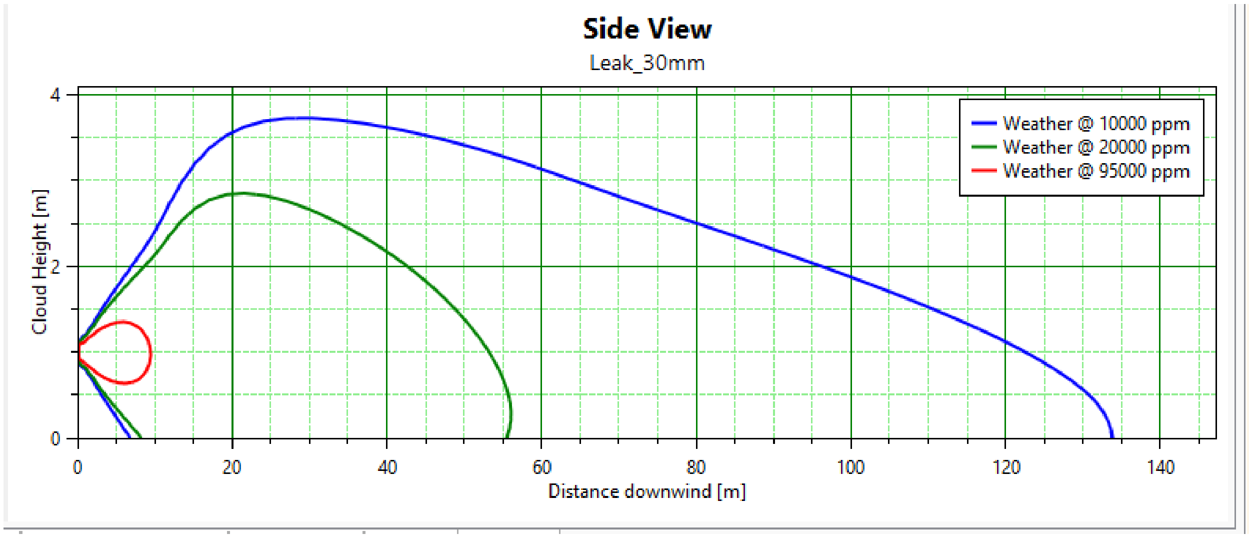


Figure 3- 11 Sectional view of the gas cloud of the 30mm-leak

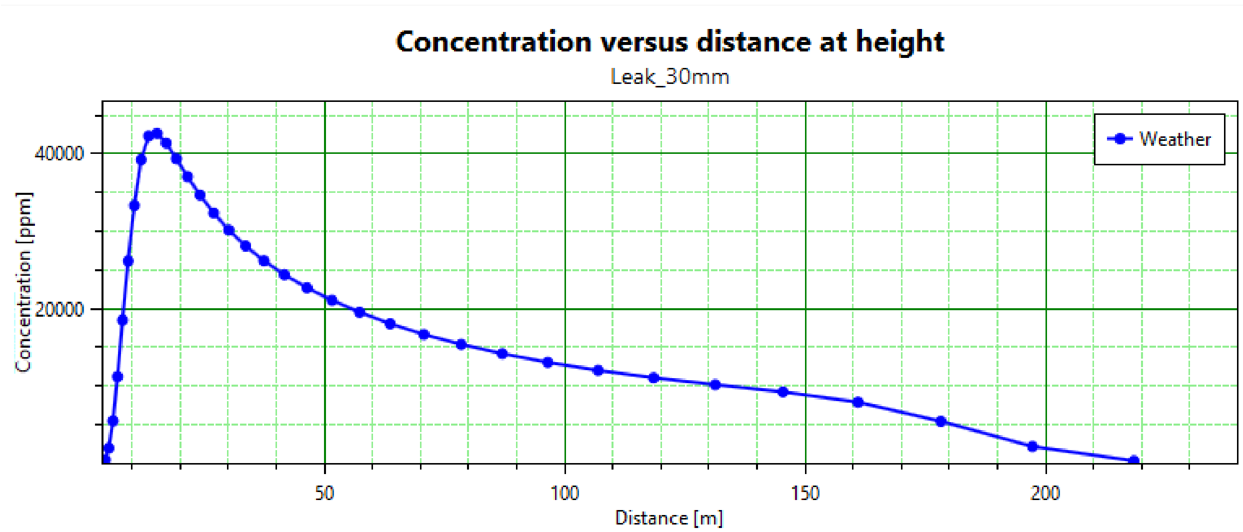


Figure 3- 12 The extent of radiation depending on the distance of the 30mm-leak

From the graph bellow and the results from simulation with PHAST, the gas cloud can reach a concentration of 42690ppm at 13.87m and the gas distance can go up to 133m distance and a height of almost 218m.

Figure 3- 13 Affected area by the gas cloud for the 30mm-leak

The figure bellow shows the affected area by the gas cloud, the big bleu cercle represent the effect zone for 10000ppm. This zone can be affected depending on the wind direction.

Jet Fire

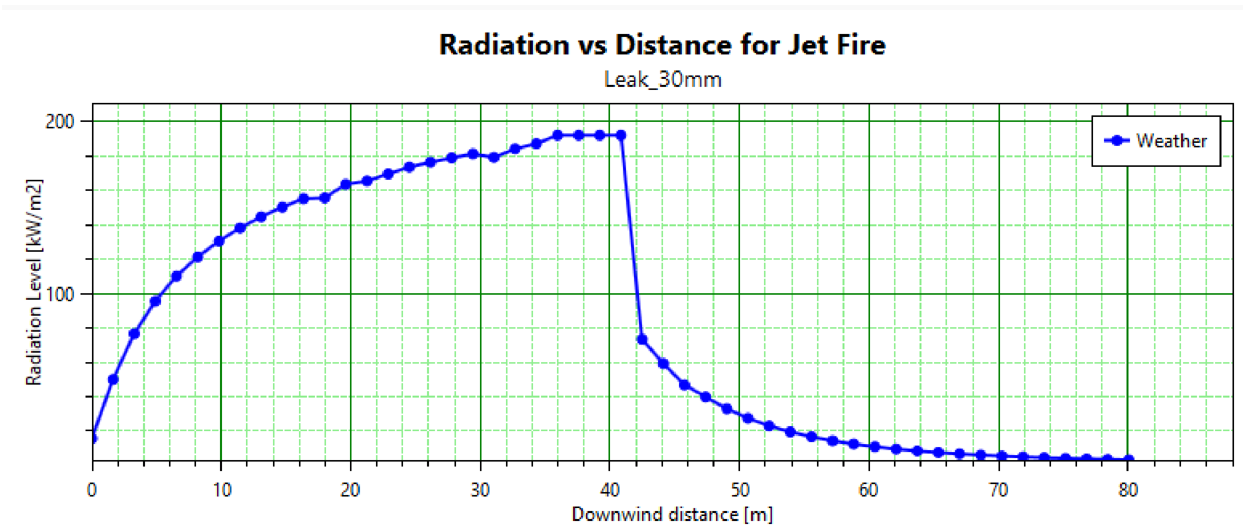


Figure 3- 14 The extent of radiation depending on the distance of the 30mm-leak

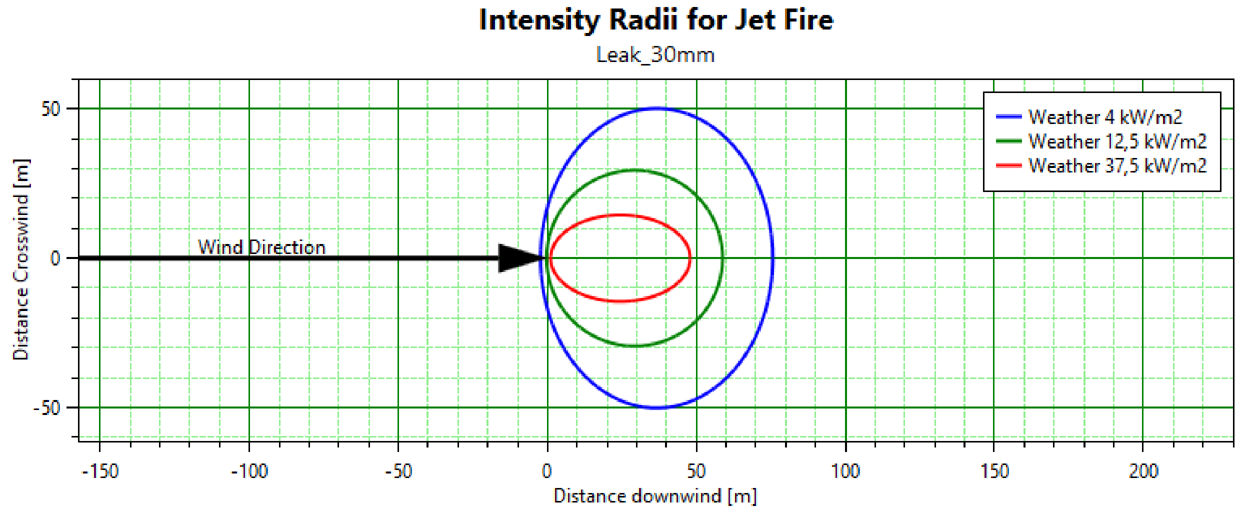


Figure 3- 15 Area affected by thermal radiation from jet fire of the 30mm-leak

The figures above show the evaluation of the level of thermal radiation generated by the jet fire depending on the distance, we notice that the thermal radiation reaches 172.27kW / m² at a distance of 40.84m.

The located installations in the red cercle in the case of jet fire, are going to get a serious damage even if they are protected, and the unprotected installation in the green cercle going to be damaged. For humans in the bleu cercle, they are susceptible to get serious consequences, direct or indirect, immediate or long term.

Flash Fire

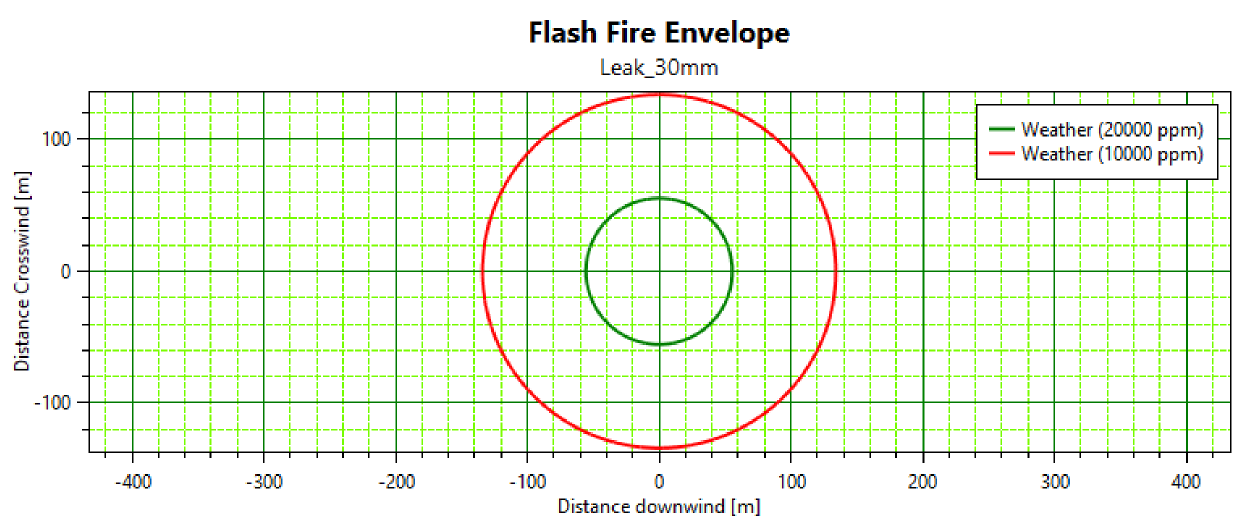


Figure 3- 16 The upper and lower explosive limits for the 30mm-leak

Figure 3- 17 The explosive area hit by flash fire for the 30mm-leak

The blue circle in the figure above represents the Lower Explosive Limit (LEL) and the green circle the Upper Explosive Limit (UEL). The distance to the LEL is estimated at a diameter of around 55.50m.

The area between the bleu and the green circle represents the explosive atmosphere, while the green cercle is the limit of this atmosphere which is estimated at a diameter of 134m, whereas where it is necessary to put the signage for an explosive atmosphere to prevent any source of ignition.

Explosion

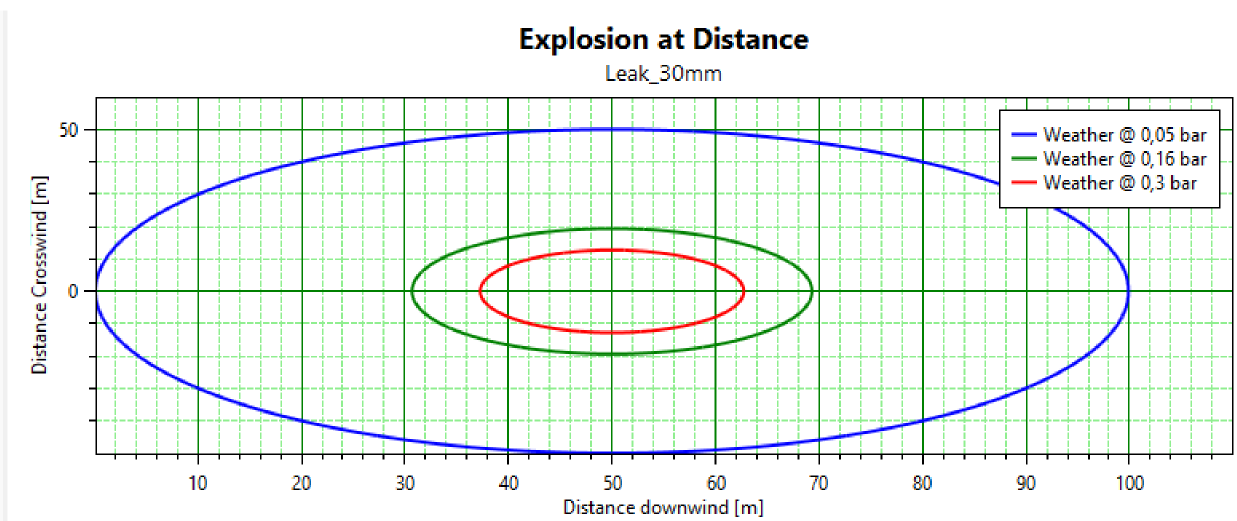


Figure 3- 18 The thermal explosion effects depending on the distance for the 30mm-leak

The graph bellow shows the areas affected by thermal explosion effects. Any person in the blue circle that have a radius of 100m is susceptible to have irreversible consequences, and the buildings in the green circle are susceptible to get damaged by the domino effect, while the structures in the red cercle are likely to get a serious damage.

Figure 3- 19 Areas affected by thermal explosion effects in the 30mm-leak

The figure bellow shows the areas affected by thermal explosion effects and the effect zone which are represented by the big blue circle.

The affected areas are represented by the small circles and was discussed in the paragraph bellow.

The effect zone is the area where it can be touched by explosion effects (Irreversible or lethal damage for humans) depending on wind direction.

3.4.3.3. Third scenario

Description: Leak in the propane sphere with a diameter of 60mm. The simulations were performed using the input data presented in the table below.

Table 3- 5Input data for PHAST for 60mm leak

Parameters	Substance	Operating temperature	Operating pressure	Volume	scenario	Elevation of leaking point
Values	Propane	37 ºC	21 barg	2934m3	Leak of 60mm	1m

The simulation by FAST has gave the following results:

Dispersion

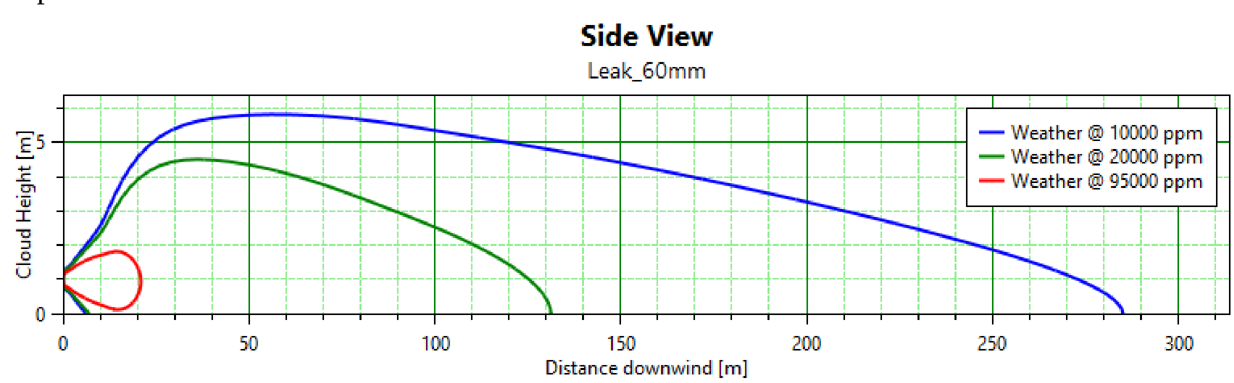


Figure 3- 20 Sectional view of the gas cloud of the 60mm-leak

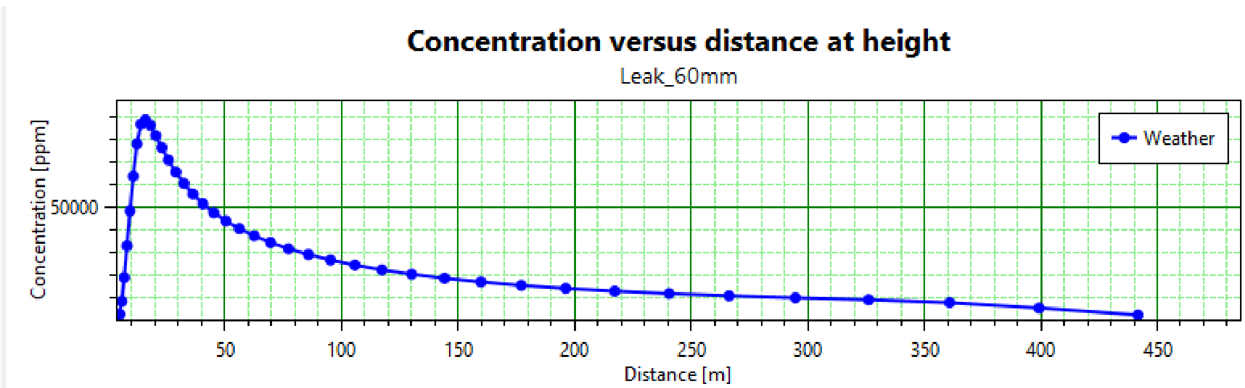


Figure 3- 21 The extent of radiation depending on the distance of the 60mm-leak

From the graph bellow and the results from simulation with PHAST, the gas cloud can reach a concentration of 88600ppm at 15.44m and the gas distance can go up to 285m distance and a height of almost 441m.

Figure 3- 22 Affected area by the gas cloud for the 6Omm-leak

The figure bellow shows the affected area by the gas cloud, the big bleu cercle represent the effect zone for 10000ppm. This zone can be affected depending on the wind direction.

Jet Fire

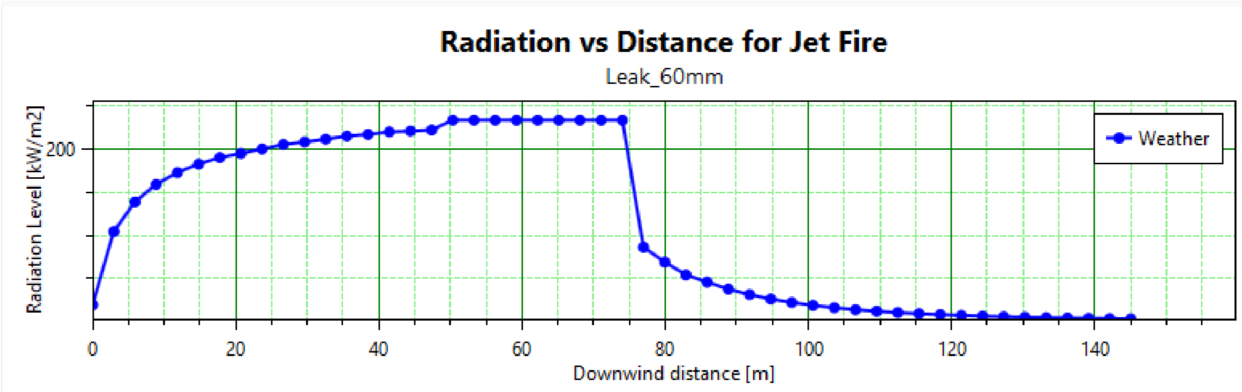


Figure 3- 23 The extent of radiation depending on the distance of the 60mm-leak

The figures above show the evaluation of the level of thermal radiation generated by the jet fire depending on the distance, we notice that the thermal radiation reaches 172.27kW / m² at a distance of 40.84m.

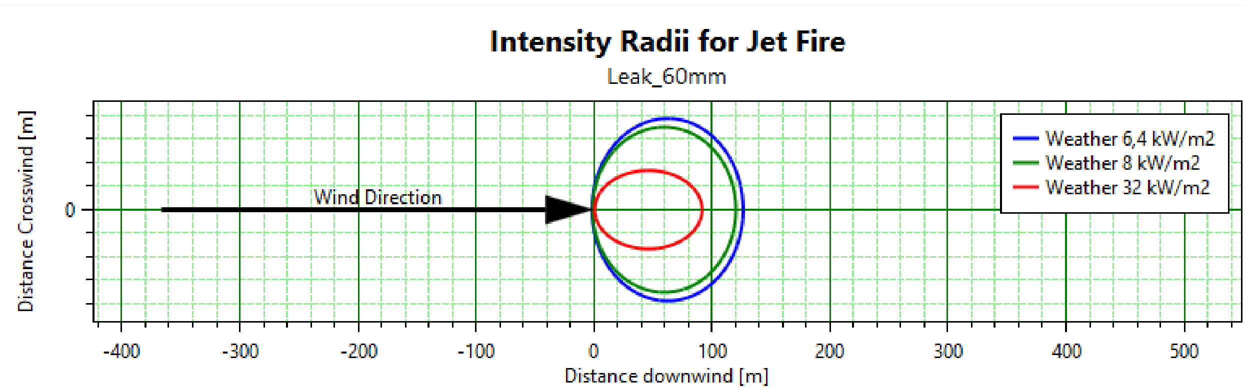


Figure 3- 24 Area affected by thermal radiation from jet fire of the 60mm-leak

Figure 3- 25 Presentation of area affected by thermal radiation on map for the 60mm-leak

The located installations in the small red cercle in the case of jet fire, are susceptible to get a serious damage even if they are protected, and the unprotected installation in the green cercle going to be damaged. For humans in the bleu cercle, they are susceptible to get serious consequences, direct or indirect, immediate or long term.

The big red circle represents the effect zone in which the protected installations can get a serious damage depending on the wind direction.

Flash Fire

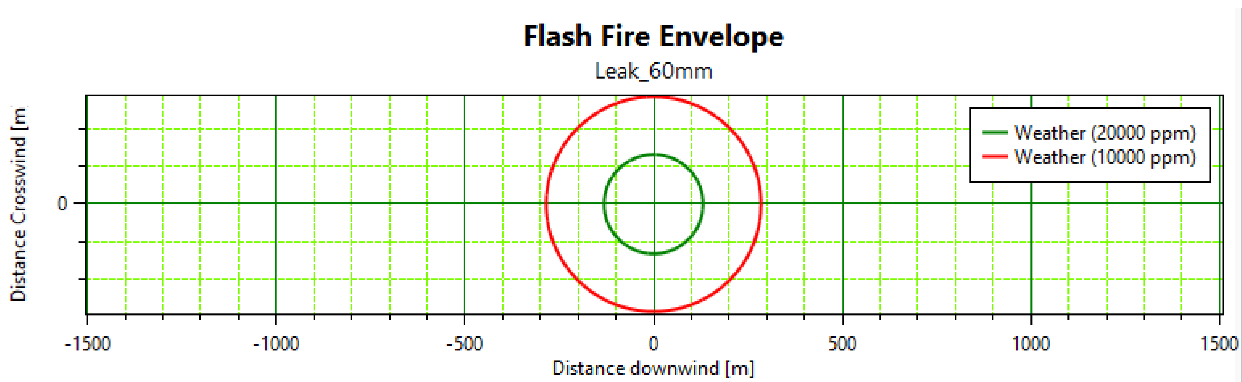


Figure 3- 26 The upper and lower explosive limits for the 60mm-leak

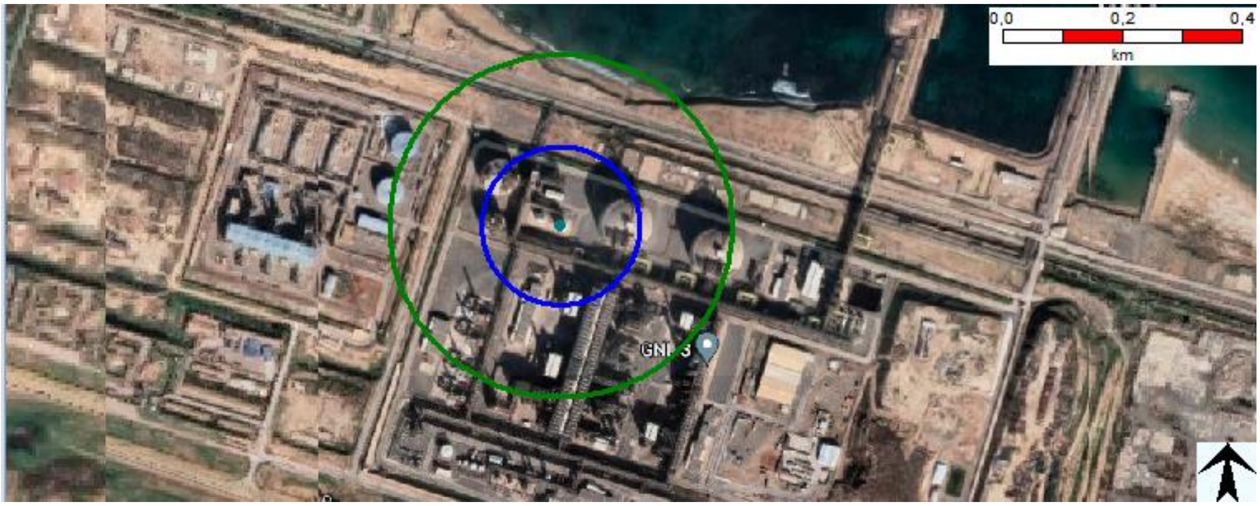


Figure 3- 27 The explosive area hit by flash fire for the 60mm-leak

The blue circle in the figure above represents the Lower Explosive Limit (LEL) and the green circle the Upper Explosive Limit (UEL). The distance to the LEL is estimated at a diameter of around 131m.

The area between the bleu and the green circle represents the explosive atmosphere, while the green cercle is the limit of this atmosphere which is estimated at a diameter of 284m, whereas where it is necessary to put the signage for an explosive atmosphere to prevent any source of ignition, but it can be seen that this zone exceeds industrial unity to the road.

Explosion

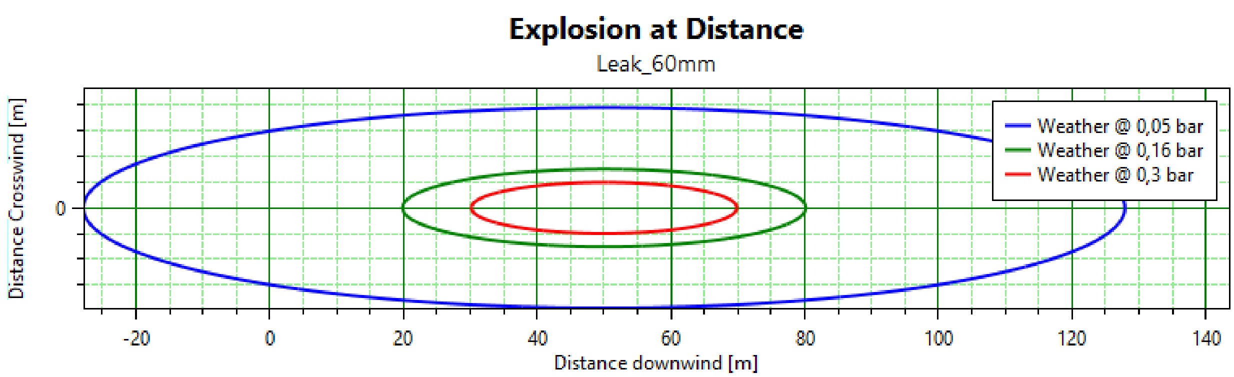


Figure 3- 28 The thermal explosion effects depending on the distance for the 60mm-leak

The graph bellow shows the areas affected by thermal explosion effects. Any person in the blue circle that have a radius of 127.89m is susceptible to have irreversible consequences, and the buildings in the green circle are susceptible to get damaged by the domino effect, while the structures in the red cercle are likely to get a serious damage.

Figure 3- 29 Areas affected by thermal explosion effects in the 60mm-leak

The figure bellow shows the areas affected by thermal explosion effects and the effect zone which are represented by the big blue circle.

The affected areas are represented by the small circles and was discussed in the previous paragraph.

The effect zone is the area where humans can get Irreversible or lethal damage. It depends on wind direction.

3.4.3.4. Fourth scenario

Failure to detect such a leak can lead to catastrophic scenarios in the industrial zone as well as nearby facilities.

A simulation of a rupture of the sphere can illustrate the impacts that can be caused.

Dispersion

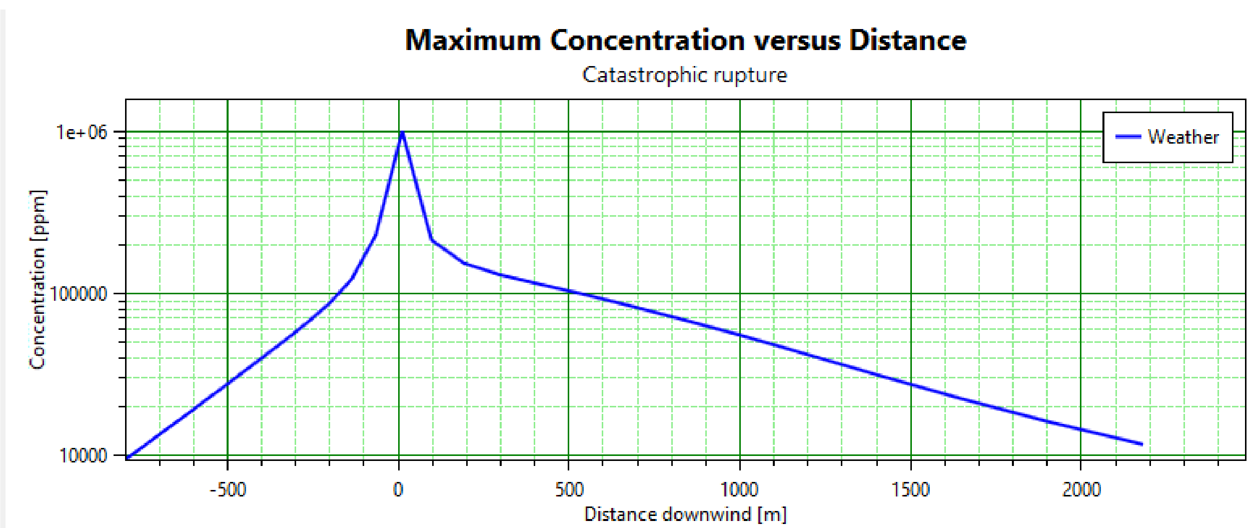


Figure 3- 30 The gas cloud concentration for the catastrophic rupture

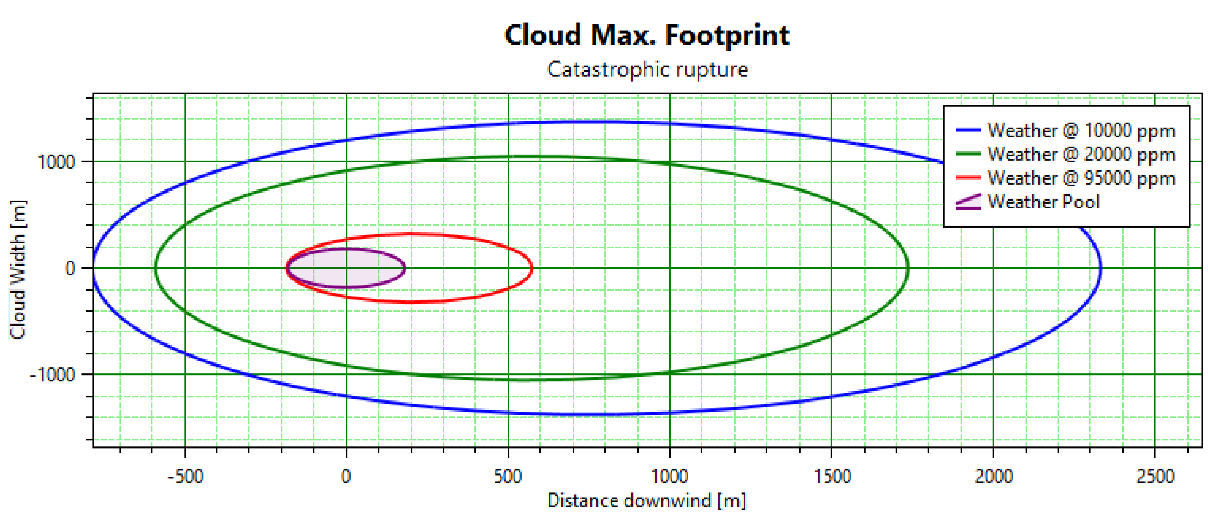


Figure 3- 31 The extent of radiation depending on the distance for the catastrophic rupture

From the graph bellow and the results from simulation with PHAST, the gas cloud can reach a concentration of 997294ppm at 11.76m and the gas distance can go up to 2331m.

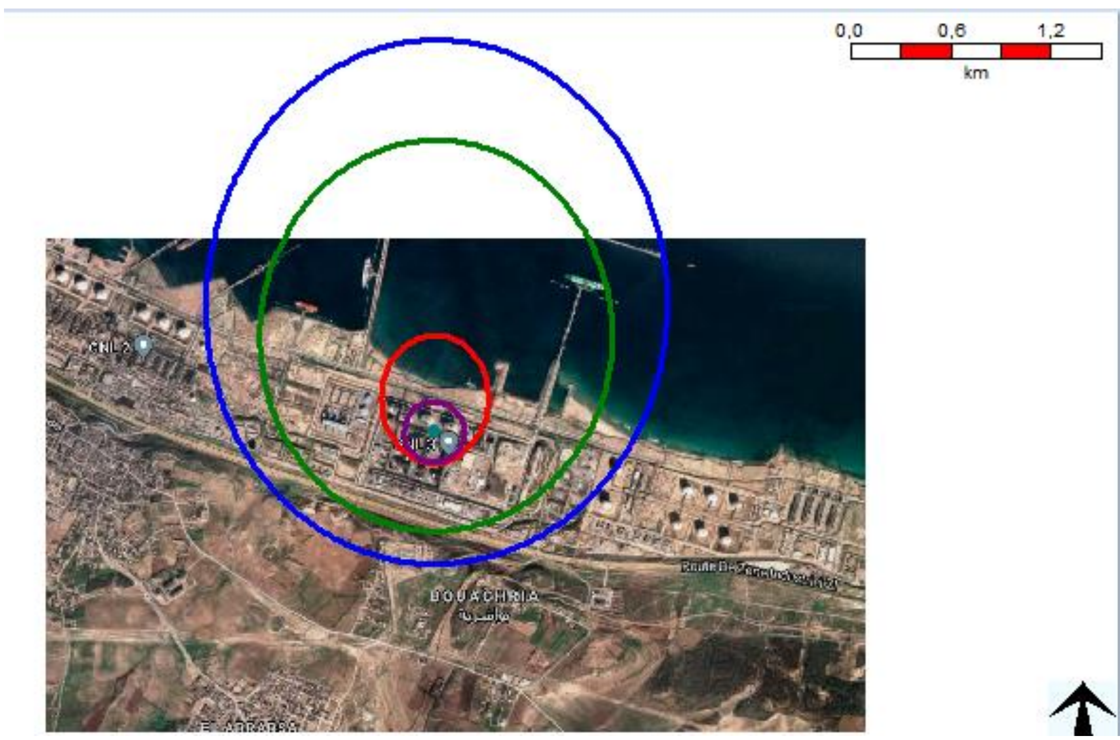


Figure 3- 32 Areas affected by thermal explosion effects in the catastrophic rupture

Fireball

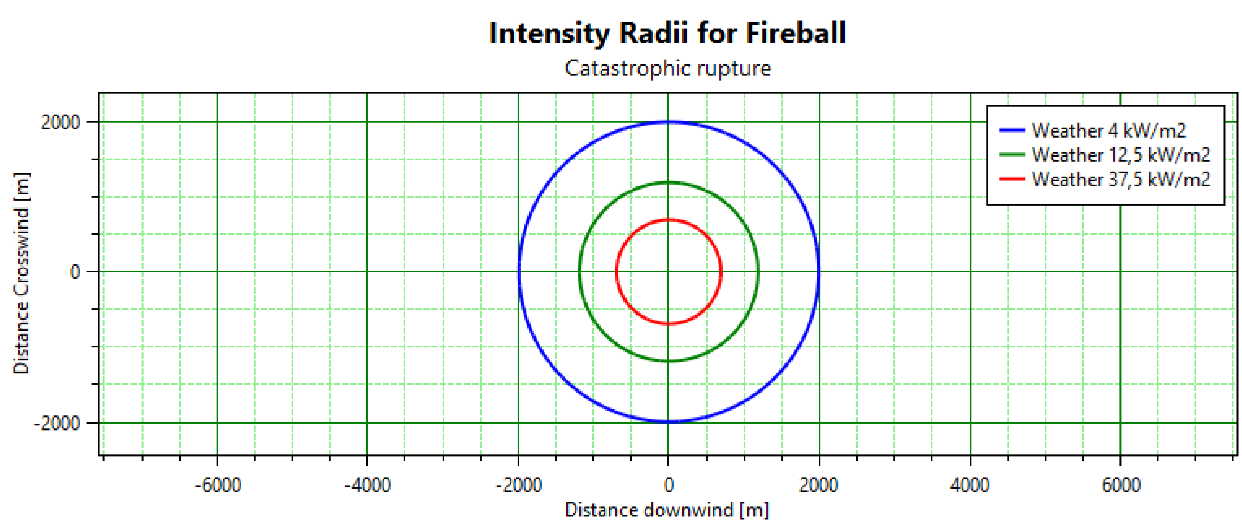


Figure 3- 33 intensity of radiations for fireball in the case of catastrophic rupture

The figure above shows the different radiation effects depending on the distance. Any person in the blue circle that have a radius of 1991m is susceptible to have irreversible consequences, and the buildings in the green circle are susceptible to get damaged by the domino effect, while the structures in the red cercle are likely to get a serious damage.

Figure 3- 34 the affected area by fireball in the case of catastrophic rupture

From the figure above, it can be seen that there is a minority segment of the population will be affected by fireball thermal effects.

The neighbor installations in the green circle are susceptible to get damaged by the domino effect, while the structures in the red cercle are likely to get a serious damage.

Flash Fire

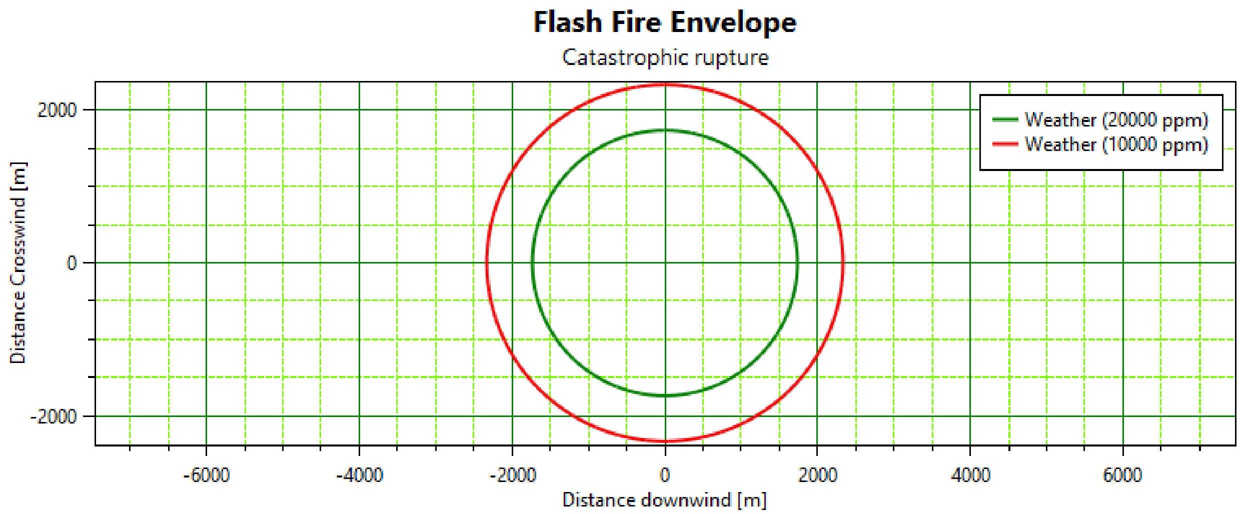


Figure 3- 35 The upper and lower explosive limits for catastrophic rupture

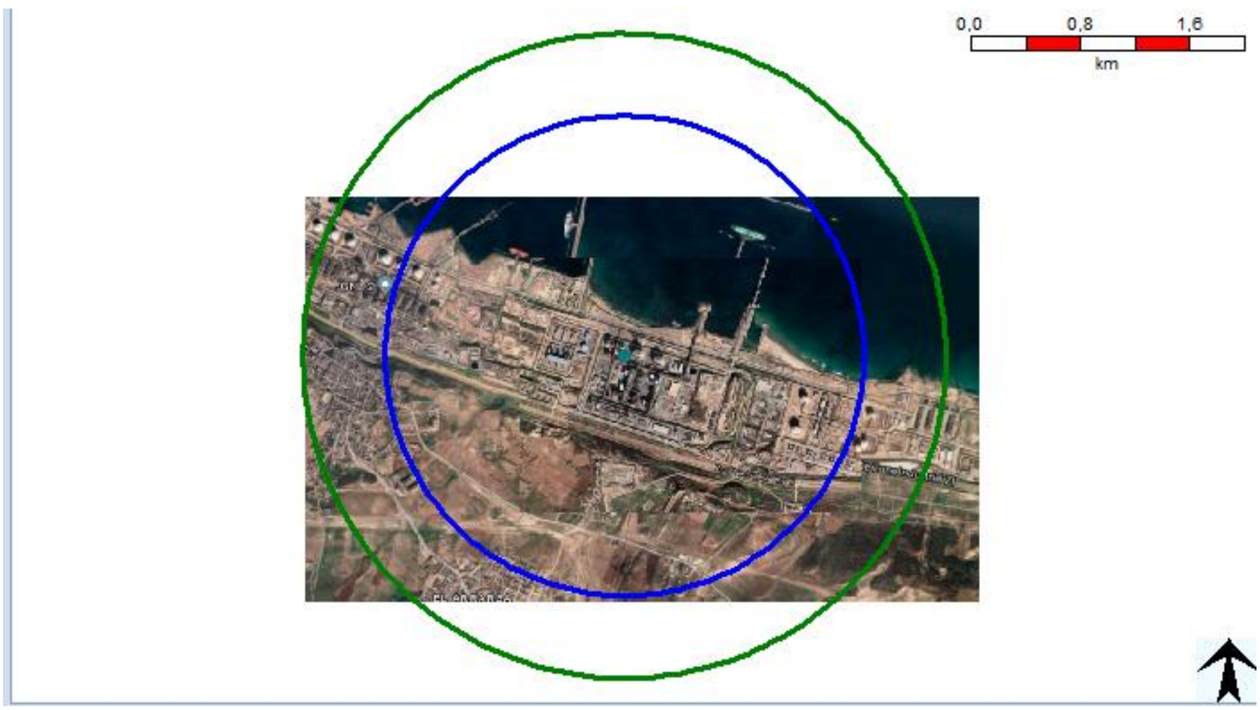


Figure 3- 36 The explosive area hit by flash fire for the catastrophic rupture

The blue circle in the figure above represents the Lower Explosive Limit (LEL) and the green circle the Upper Explosive Limit (UEL). The distance to the LEL is estimated at a diameter of around 1734.97m.

The area between the bleu and the green circle represents the explosive atmosphere, while the green cercle is the limit of this atmosphere which is estimated at a diameter of 2330.43m.

The effects inside the LEL have a high severity (anyone in this area may be considered dead), while beyond the distance from the LEL the effects will be considered null.

It can be seen that the zone inside the LEL exceeds the industrial unity to human being installation, and present a serious risk to the surrounding population.

Explosion

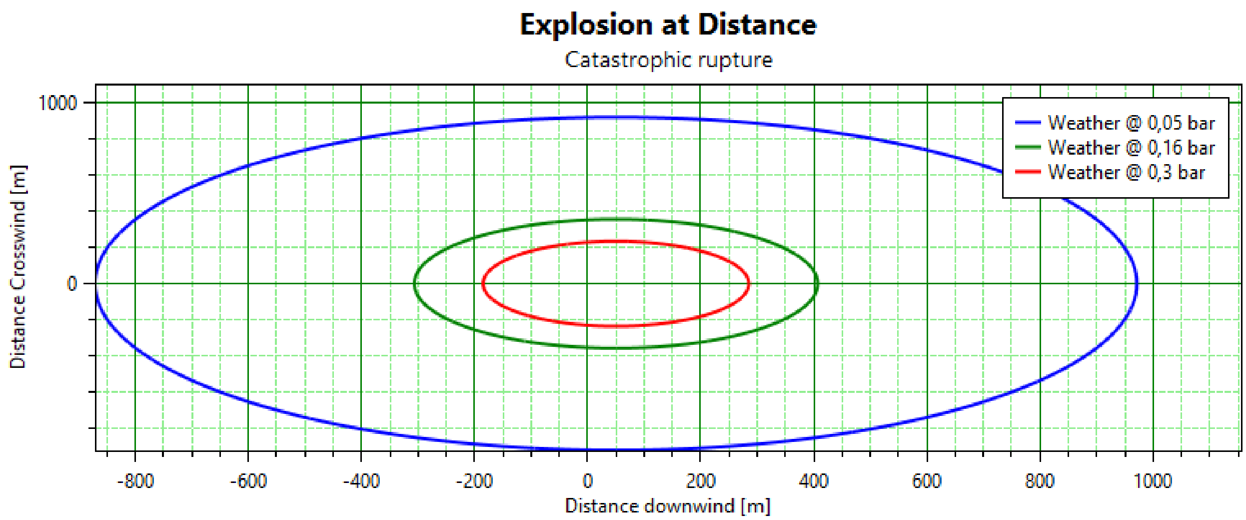


Figure 3- 37 The thermal explosion effects depending on the distance for the catastrophic rupture

The graph bellow shows the areas affected by thermal explosion effects. Any person in the blue circle that have a radius of 971.20m is susceptible to have irreversible consequences, and the buildings in the green circle are susceptible to get damaged by the domino effect, while the structures in the red cercle are likely to get a serious damage.

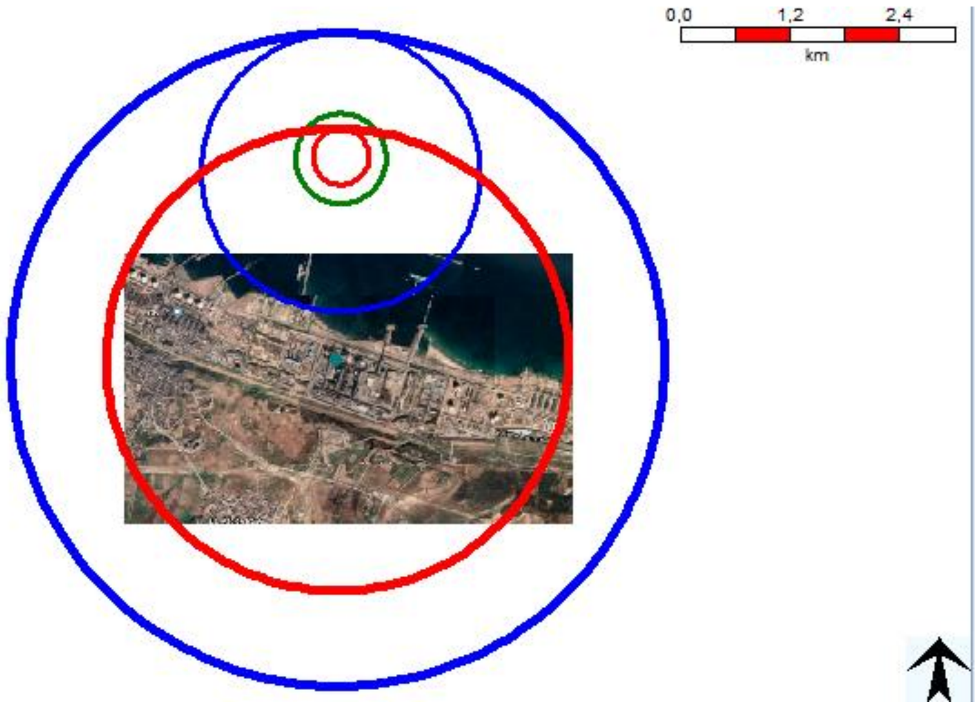


Figure 3- 38 Areas affected by thermal explosion effects for the catastrophic rupture

The figure bellow shows the areas affected by thermal explosion effects and the effect zone which are represented by the big blue circle.

The affected areas are represented by the small circles and was discussed in the previous paragraph.

The big blue circle presents the effect zone where humans can get Irreversible or lethal damage, it means that any person in that area is in danger.

The big red circle presents the effect zone where all the structures are likely to get a serious damage.

3.5. Conclusion

The HAZOP study of the sphere allowed the identification of probable catastrophic scenarios following a loss of containment. Subsequently, the catastrophic scenarios were modeled by PHAST software. The modeling of the expected consequences of the three leaks in the sphere's pipes as well as the catastrophic rupture of the latter, allowed us to broaden our vision of the damage incurred.

This led us to note that the consequences would be catastrophic and this could lead to the damage of several neighboring equipment (domino effects), themselves presenting potential dangers that could lead to major risks.

Moreover, the effects of overpressure as well as those of thermal radiation can reach several hundred meters, and affect other neighboring complexes (GP1Z, GL2Z, KAHRAMA). The results obtained also showed us that the effects of the explosion and thermal radiation could impact all the buildings on the site (control rooms, departments, administrations, etc.) and thus lead to severe injuries or even to the loss of several human lives, such as the operators present on the plant at the time of the accident.

To this end, the implementation of an intelligent system for predicting and recognizing catastrophic scenarios is essential to ensure safety not only at the LPG storage area but of all regions, hence the objective of the next chapter.

Chapter 04: Presentation of The Proposed Decision Support FICS

4.1. Introduction

In this chapter we will present our model that we named **it FICS (Fire Identification and Classification Software)** that allowed detecting fire using Object Detection by ImageAI library for image prediction form images and videos. This program recognizes and classify fire from video in order to determine it it's jet fire or a fireball.

4.2. Object detection

4.2.1. ImageAI

It is a python library built to empower developers, researchers and students to build applications and systems with self-contained Deep Learning and Computer Vision capabilities using simple and few lines of code.

Built with simplicity in mind, ImageAI supports a list of state-of-the-art Machine Learning algorithms for image prediction, custom image prediction, object detection, video detection, video object tracking and image predictions trainings. ImageAI currently supports image prediction and training. ImageAI also supports object detection, video detection and object tracking.

The simplicity of this library made us to build, train and build our models without complexity and with simple lines of code

4.2.2. Fire detection

As we said in the Machine learning lifecycle, we need images to build our fire detection model, ImageAI required at least 200 images containing fire to build our model.

4.2.3. Data collection

We found a dataset which contains about 512 images, with this dataset we can build our fire detection based on computer vision.

We split our data in two folders, the first folder called train, this one contains about 80% of our dataset and the second one called validation, contain the rest of our data (20%).

4.2.4. Data annotation

We use a tool named LabelIMG to annotate our images, the annotation in our case is to make a box around the fire in the image. This tool will generate a file in XML format, the file contains the coordinates of fire in the picture. we will annotate all images in the train folder and placed them in folder called annotations, the same think for the images in validation folder.

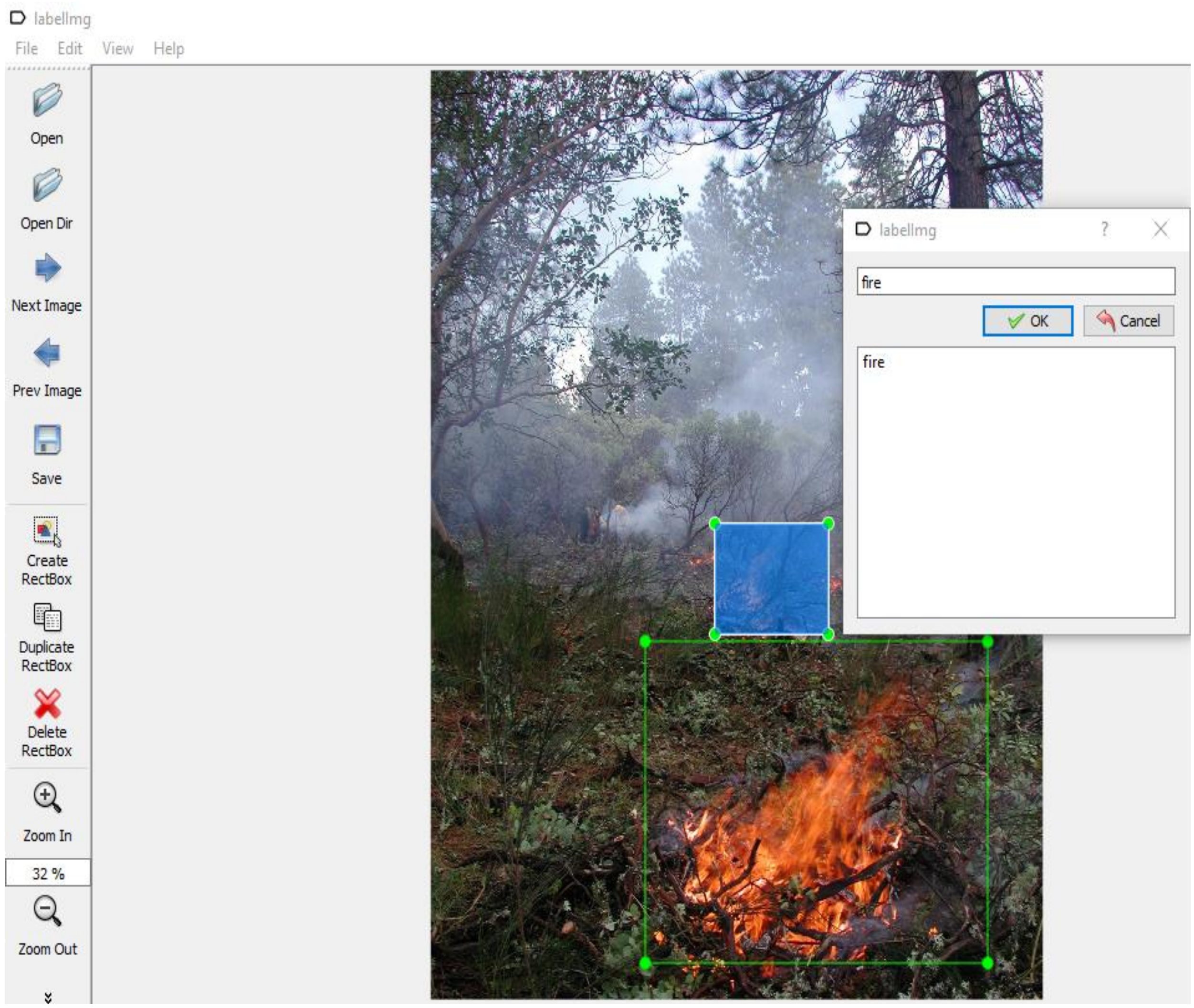
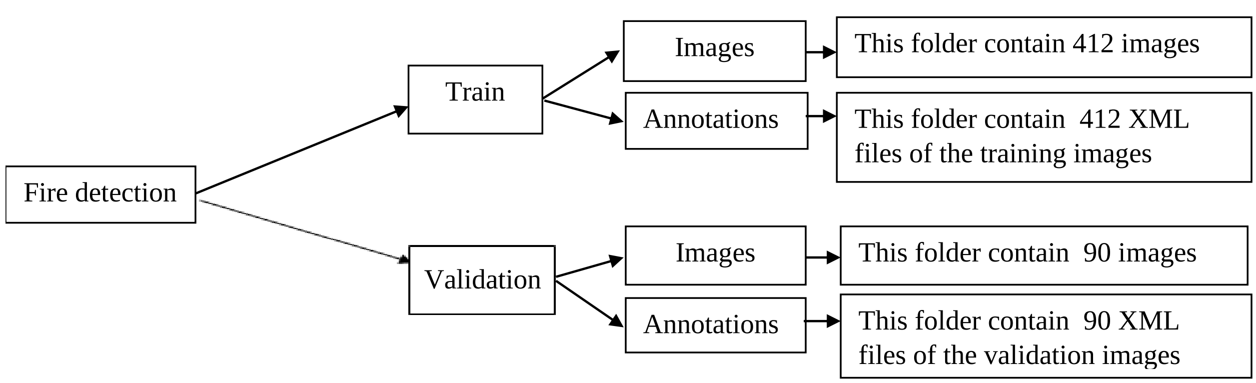


Figure 4- 1 LabelIMG tool

Our project folder will be like this chart:



4.2.5. Train the model

The code of the training contains these following lines:

```
1 from imageai.Detection.Custom import DetectionModelTrainer
2 trainer = DetectionModelTrainer()
3 trainer.setModelTypeAsYOLOv3()
4 trainer.setDataDirectory(data_directory=r"E:\Imsi Project\Fire detection")
5 trainer.setTrainConfig(object_names_array=["Fire"], num_experiments=200)
6 trainer.trainModel()
```

Explanation of the code:

- In the first 2 lines, we imported the DetectionModelTrainer class from imageai library.
- In the third line, we called the function (`.setModelTypeAsYOLOv3()`) . This function sets the model type of the object detection training instance to the YOLOv3 model.
- The fourth line we called the function (`.setDataDirectory()`) . This function is sets the path to our dataset folder (train and validation folders).
- In the fifth line we called the function (`.setTrainConfig()`) . This function sets the properties for the training instances:
  - **object_names_array :** name of the object we want to detect (Fire)
  - **num_experiments (Epoch) : the number of times the network will train on all the training.**
- The sixth line we called the function (`.trainModel()`) . This function starts the training of our model.

When the training started, the output will show us the number of experiment and the accuration value of our model which is (100- loss):

```
Epoch 1/200
480/480 [==============================] - 395s 823ms/step - loss: 36.9000
```

4.2.6. Test model

We used a built model with accuracy of 95 %, we can test our model with images, videos or live video and detect the fire with ImageAI library, we will make a test for an image which contains fire and see the results:

Figure 4- 2 Before detection

Figure 4- 3 After detection

Note:

- **The box** represents the predicted zone of fire, and **56.497 is** the Probability of fire

4.3. Classification

4.3.1. Azure Custom Vision by Microsoft

Azure Custom Vision is an image recognition service by Microsoft that lets us build, deploy, and improve our own image identifiers. An image identifier applies labels (which represent classes or objects) to images, according to their visual characteristics. Unlike the Computer Vision service, Custom Vision allows as to specify the labels and train custom models to detect them.

4.3.2. Classification of catastrophic scenarios

4.3.2.1. Data collection

In this step, we collected some images for each scenario because this service requires 5 images as minimum, the more images we collect the more accuracy we will have.

We uploaded the data to our **Azure Custom Vision** account for building our classifier for catastrophic scenarios.

4.3.2.2. Data annotation

In the classification, we gave a tag for each scenario, when we uploaded our data, the service asked us to tag each group of images with the corresponded catastrophic scenario name.

17 images of Jet Fire → JET FIRE

17 images of Fire Ball → FIRE BALL

3003 negative images → No image of one of all scenarios

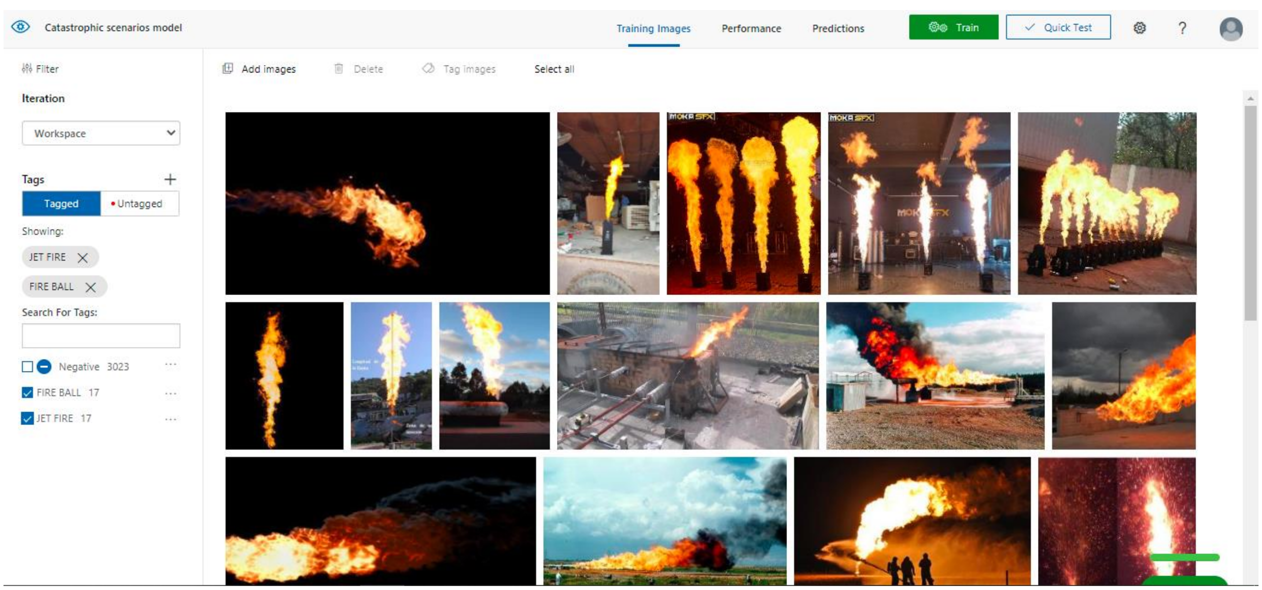


Figure 4- 4 training images

4.3.2.3. Train and test the model

The simplicity of this applications is that we didn't write any code for the training or testing, we just upload images, write tags, click train and the model will be built by the service, when the training finished, we will receive an email which tell us that the training completed and we can export our model.

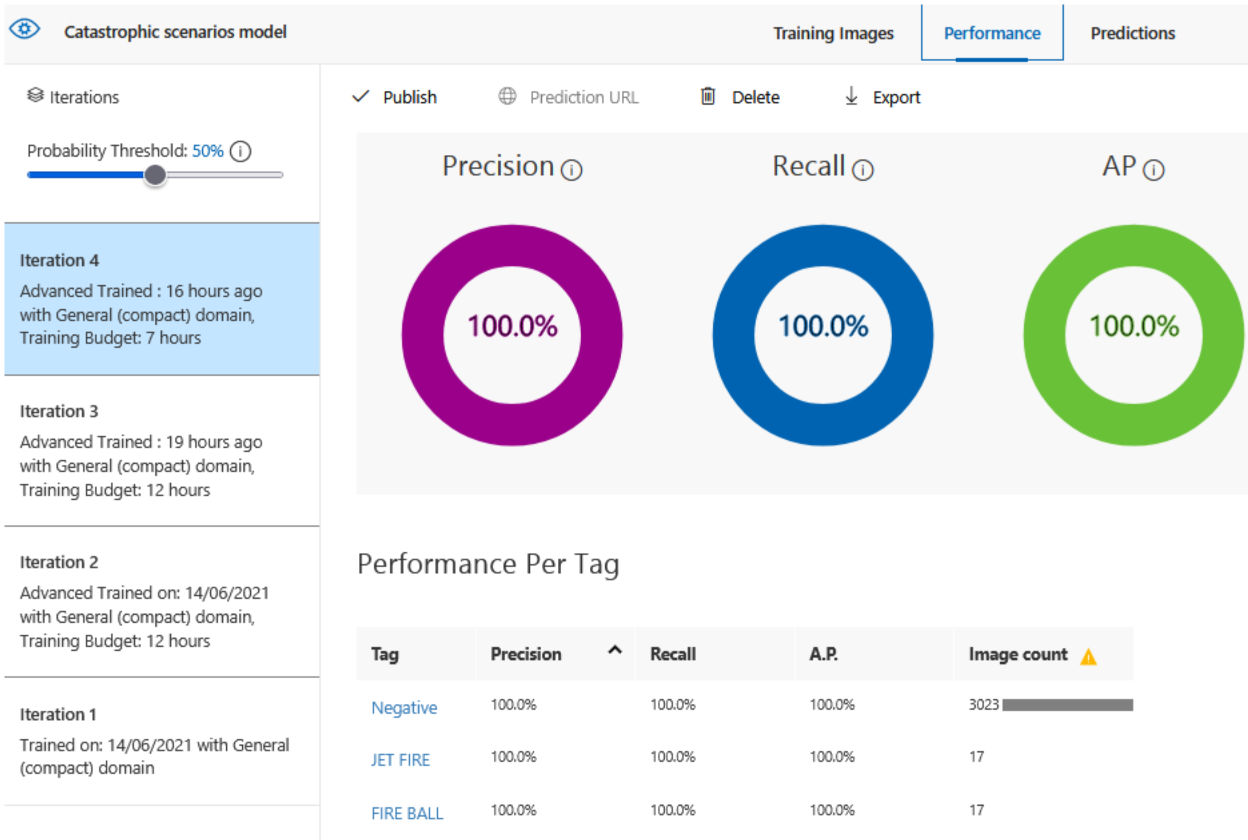


Figure 4- 5 Training results

We tested our model accuracy with various images for each scenario and the results is the following:

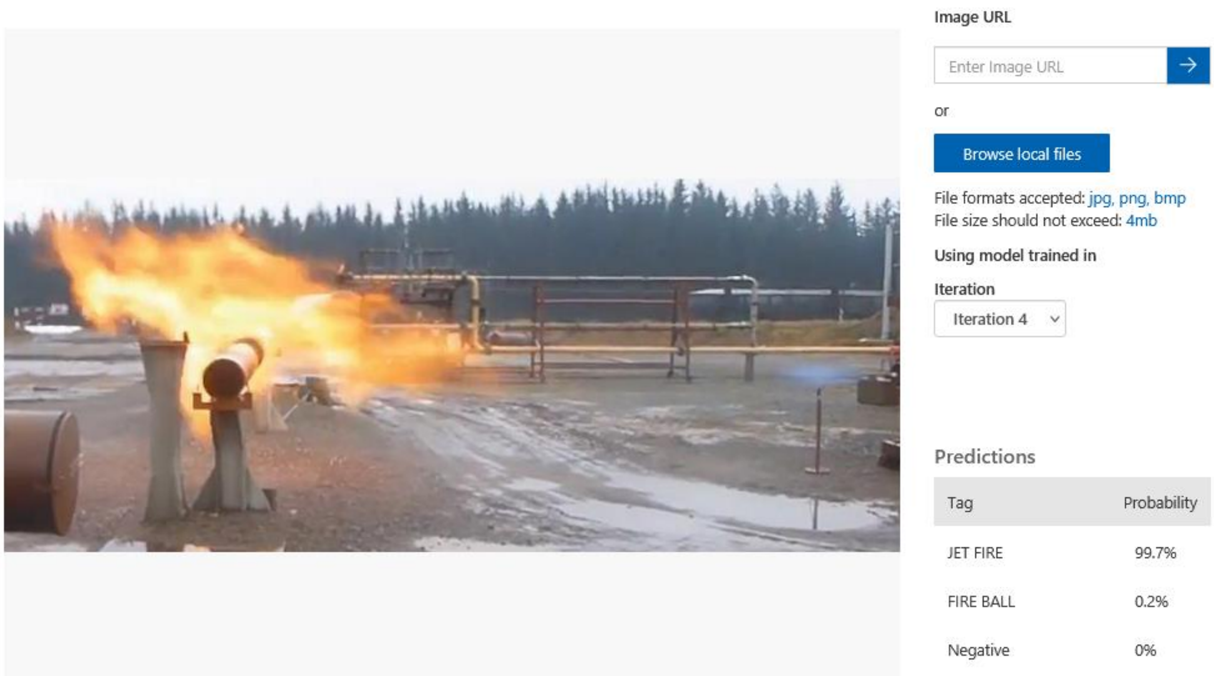


Figure 4- 6 The results of test 1

Figure 4- 7 The results of test 2

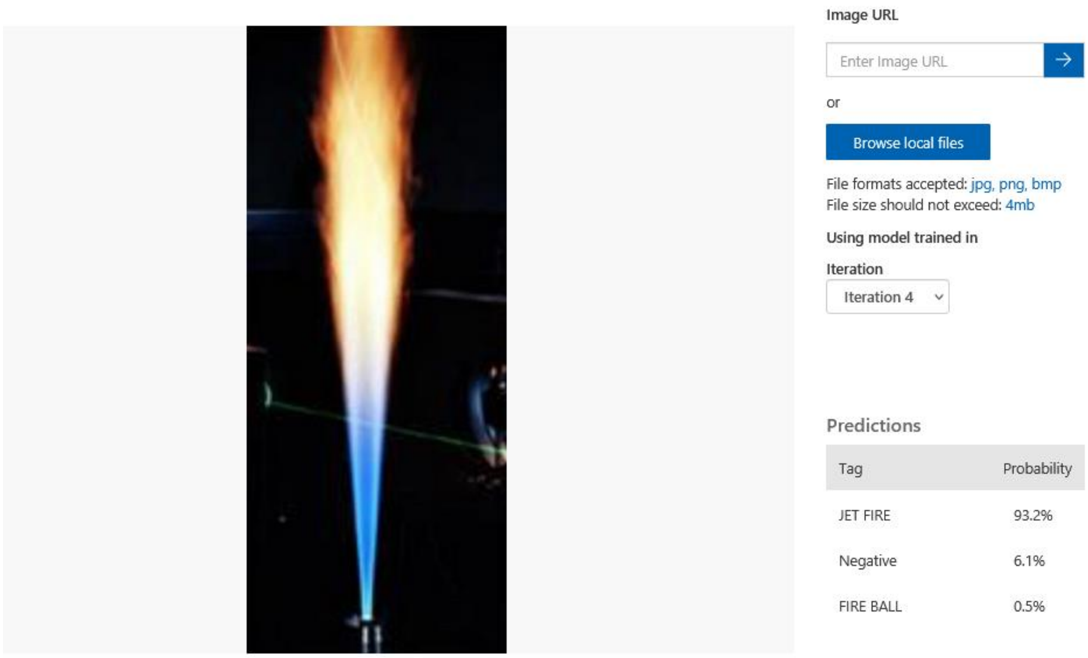


Figure 4- 8 The results of test 3

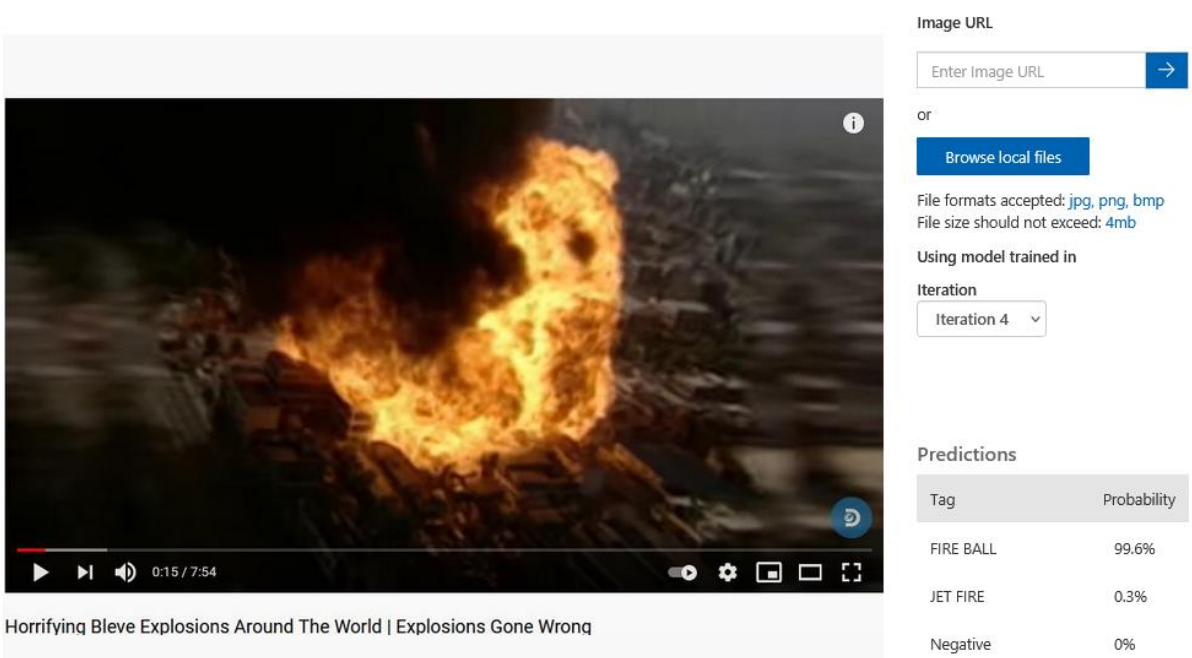


Figure 4- 9 The results of test 4

4.4. Alert

4.4.1. Telegram API

Any systems should have an alert part for diffusing and transmitting the message to the concerned persons, we create a bot with Telegram API in Python for transmitting the alert to specific persons who subscribed in this bot called @IMSI_PROJECT_BOT.

Telegram is an instant messaging service just like WhatsApp, Facebook Messenger and WeChat. It has gained popularity in recent years for various reasons: its non-profit nature, cross-platform support, promises of security[1], and its open APIs.

The more well-known of Telegram's APIs is its Bot API for developers to interact with the bot platform in different programming language including Python. The Bot API allows developers to control Telegram bots, for example receiving messages and replying to other users, send images, voice call and also video call.

Through the Telegram API you can do anything you can do in a Telegram app programmatically[46], from the previous points we chose telegram for the alert. The steps for creating a bot are the following:

- Search for this bot (@BotFather) in the search bar
- Send a random message to (@BotFather) r
- We will get a reply containing a menu from (@BotFather)
- Choose (/newbot) from the menu
- Name the Bot (IMSI PROJECT)
- Choose username for our bot (IMSI_PROJECT_BOT)
- Get the token of our bot

Each created bot has a specific token number. the token used to login to the bot programmatically with Telegram API (backend), anyone has this token can manage and control your bot for that the token should not be shared.

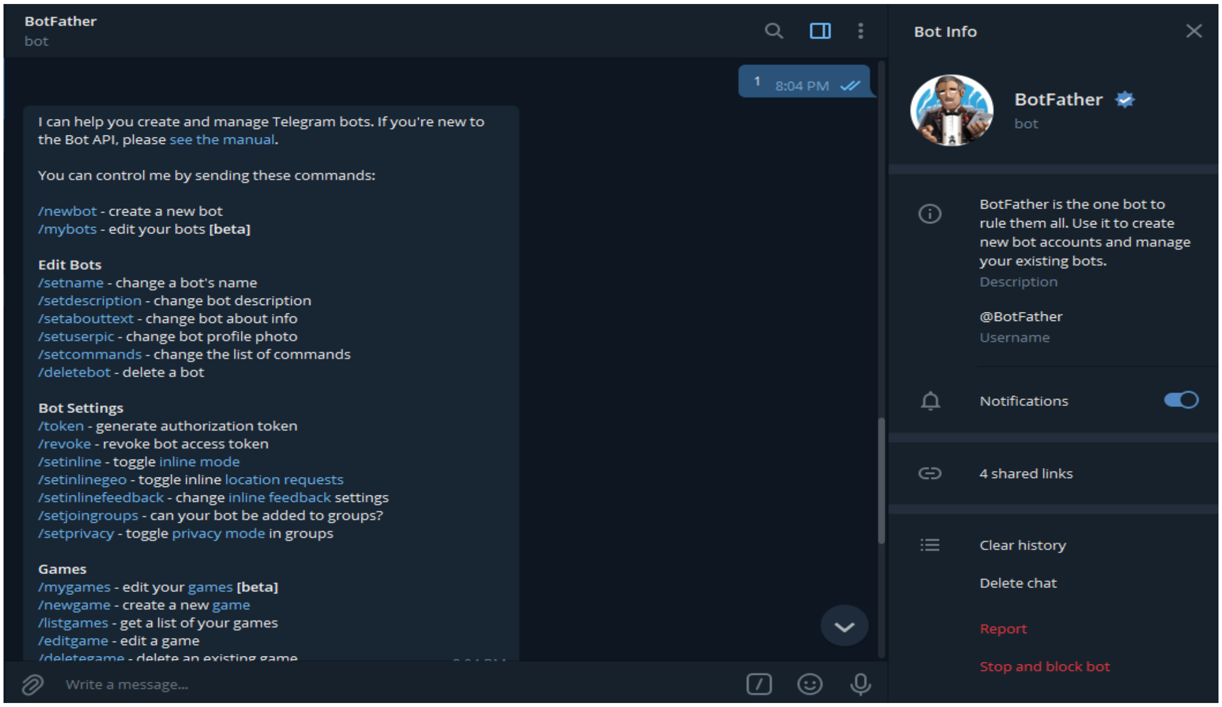


Figure 4- 10 Step 1 of creating a telegram bot

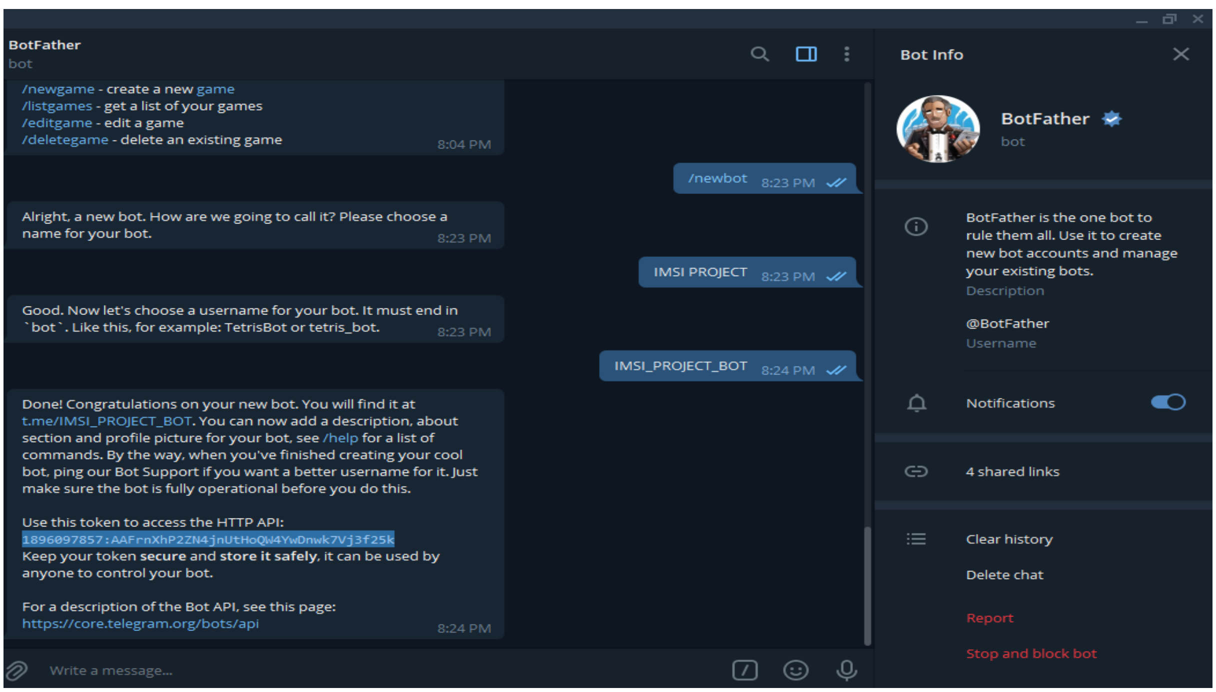


Figure 4- 11 Step 2 of creating a telegram bot

4.4.2. Code and test

The code of the alert is the following:

```
1 import telebot
2 bot = telebot.TeleBot(token)
3 bot.send_message(chat_id,text)
4 bot.send_image(chat_id,image or frame path)
```

Explanation of the code:

- The first 2 line for importing the telegram API library and create an instance of Telebot .
- The third line we call function `.send_message()` to send message containing the name and the probability of the scenario in text variable.
- The fourth line we call function `send_image()` to send image or the frame containing the fire .
- Chat_id is the number of our telegram account.

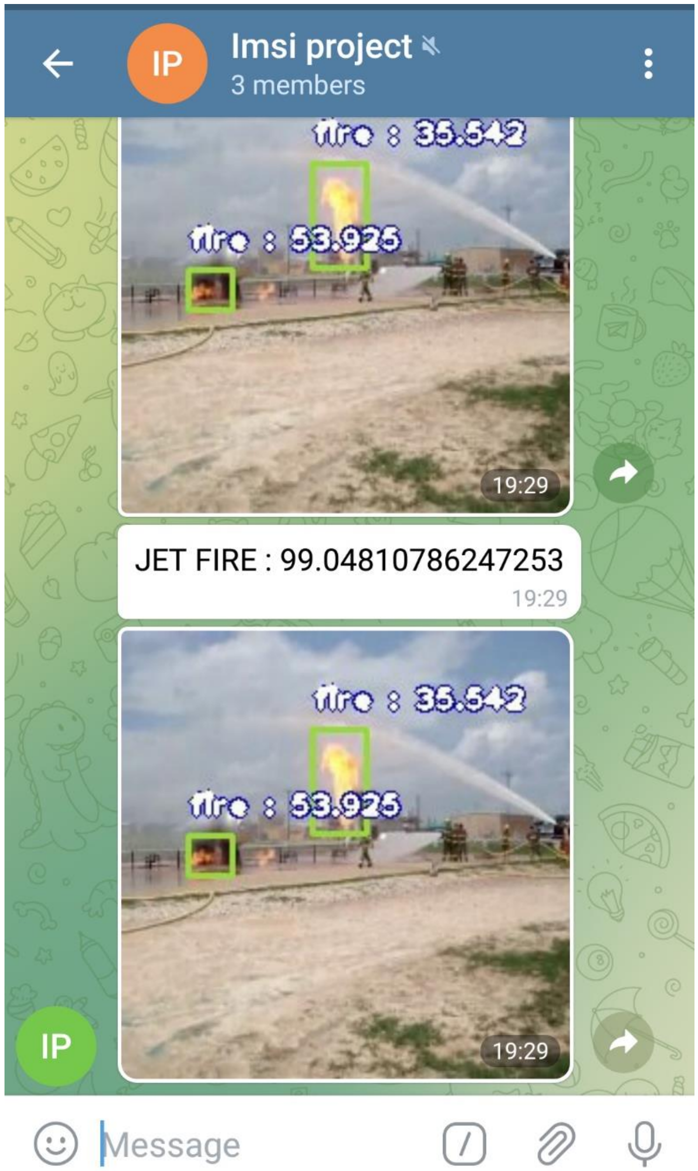


Figure 4- 12 Alert message template

The process of alert will be executed automatically when the probability of the existing of fire is higher than 30 % in the live video.

4.5. An overview of how the program works

In synthesis of our work, we built two models, the first based on object detection with ImageAI library in Python, we used it for detecting fire and the outputs are as we show in the fire detection part: the probability of fire and box of fire with his coordinates.

The second model based on classification, this model trained with various images of each scenario and the outputs will be: one of the scenarios FIRE BALL OR JET FIRE and the probability of each scenario.

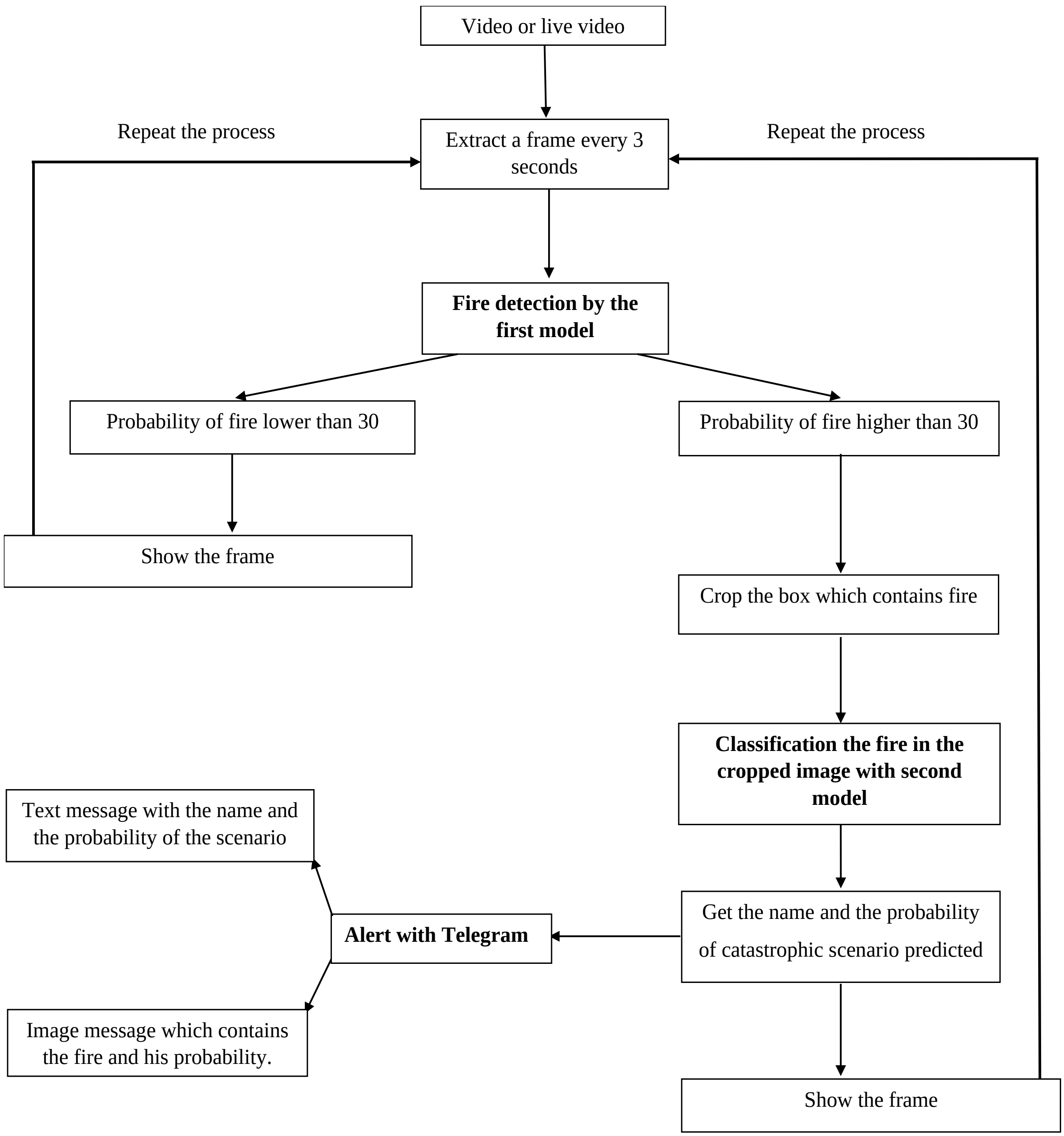
The Alert will be as we mention in the alert part, the program will send a text message containing the name and the probability of catastrophic scenario predicted and the frame which contains fire and his probability.

In this part we described the process of our program in detecting and classifying from videos, the process will be as the following:

- Every one second gets a frame. (Time is a parameter which we can change anytime)
- Detecting if the frame contains fire with first model.
- If the probability is higher than 30 %
    - Classify the fire in which catastrophic scenario corresponded with second model.
    - Show the frame with probability and catastrophic scenario name.
    - Alert with sending text message the frame (image) in Telegram
    - Get the next frame and repeat the same process.
- If the probability is lower than 30 %
    - Show the frame with no detection or probability.
    - Get the next frame and repeat the same process.

The code and its explanation are presented in ANNEXES E.

Although we have obtained satisfies results, but the program still makes fatal errors. We did some tests with negative images that you can find in ANNEXES F.



4.6. Conclusion

Traditional fire sensors based on photometry, thermal, or chemical detection can react within several minutes, requiring a large amount of fire to trigger an alarm. Moreover, they cannot provide information about fire location and fire size and the catastrophic scenario based on the detected fire, and they cannot work for outdoor scenes. The development of new camera-based solutions improves the robustness and reliability fire detection by filling the gap of previous systems.

The use of smart cameras allowed us to identify various suspicious incidents such as fire which is the most dangerous abnormal occurrence, because failure to control it at an early stage can lead to huge disasters, leading to human, ecological and economic losses. Inspired by the great potential of Machine Learning, we can detect fire from images or videos at an early stage. This chapter shows two custom models for fire detection and classification. Considering the fair fire detection accuracy, it can be of assistance to disaster management teams in managing fire disasters on time, thus preventing huge losses.

Conclusion

Conclusion

For an efficient intervention it is essential to intervene in the first moment, where in these moments of a disaster, the intervention team needs to know the nature of the scenario in order to adopt the best technique and this will take time which is precious, hence the importance of developing a system of decision-making using artificial intelligence.

Recall that the objective of this work is to create a program using artificial intelligence that recognizes and classifies catastrophic scenarios, and alert stakeholders with a message after the validation.

In this work, we carried out an analysis by the HAZOP method which allowed us to have a detailed view of the various scenarios which are most likely at the LPG storage sphere, and which are judged unacceptable following a rating using the risk matrix.

Likewise, modeling gave us the possibility to study some disaster scenarios leading to serious consequences where the target of the risk will be the operating personnel, the economic future, as well as the environment in turn, as long as, near the storage tank, there are installations which also present potential dangers. Despite the technology of control and safety devices in place, the occurrence of disasters is still probable and therefore possible.

On the other hand, we were able to make a program that recognizes and classifies scenarios as well as alerts with a message that contains the image and the probability that the type of scenario identified is correct. This program can use the site surveillance cameras in order to capture the images and then analyze them.

This program can become more efficient if we find a dataset that contains more descriptive images of the scenarios. A part of prediction can be added in the case where we find the values of development of the temperature and the pressure in function of time use linear regression.

The probability of detection can be raised by training over and over the model by different images as well as a lot of scenarios can be added in the future.

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Annexes A

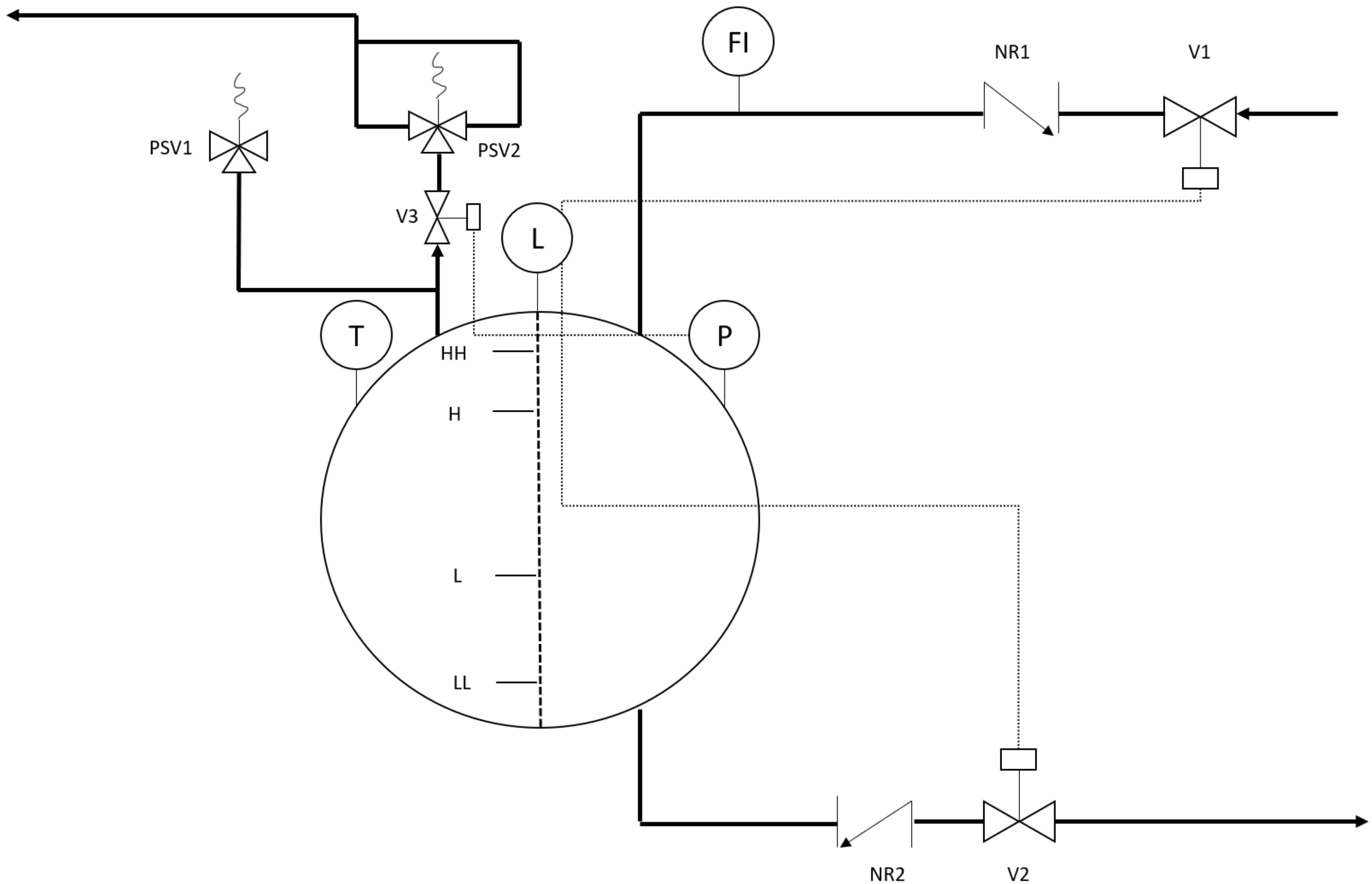


Figure 1 1 Simplified PID

Annexes B

Study Report

Deviation	Cause	Consequence	Effective Safeguards	Before Risk Reduction			Recommendations
				S	L	SL	
1. High Pressure	1. - Pressure / flow rises from previous node - Increase in ambient temperature without cooling the sphere - Overfilling of the sphere	1. Increase in fluid level inside the sphere.	1. Pressure sensor with Hight alarm.	4	3	12	1. Deluge system automation.
		2. The pressure in the sphere exceeds the maximum value (Overpressure).	2. Fire detection.	4	3	12	2. Retention tank must be placed.
		3. Rupture of the sphere's wall and loss of confinement.	3. Gas detection.	4	3	12	3. Check if the PRV1 and PRV2 are designed for this case.
		4. Rupture or bursting of the conduits of the sphere.	4. Level sensor.	4	3	12	
		5. Explosion, Jet Fire, [pool fire and BLEVE (in case of rupture)], dispersion of flammable gas.	5. Pressure relief valve (PRV).	4	3	12	
	2. Fail inn closing the valve PSV1 in the entering line and fail in opening the pressure relief valve (PRV).	1. Pressure increasing of in the tank.	1. Pressure relief valve (PRV).	4	3	12	4. Regular maintenance of pressure sensors and valves Calibration and balancing of pressure relief valves.
		2. Potential overpressure in the tank leading to potential damage and external leak.	2. Pressure sensor.	4	3	12	5. Check if the PRV1 and PRV2 are designed for this case.
		3. Explosion, Jet Fire, pool fire, BLEVE.		4	3	12	6. install ESD or redundance PSV
	3. Failure of pressure safety valves. (PSV1 and PSV2)	1. Propane escapes to atmosphere if the pressure relief valve opens, and if it does not open, an overpressure in the sphere will take place.	1. Pressure relief valve (PRV).	4	3	12	7. Regular inspection and maintenance of pressure sensors and valves Calibration and balancing of pressure relief valves.
		2. Explosion, Jet Fire, pool fire, BLEVE.	2. Pressure sensor.	4	3	12	
	4. - Presence of an external heat source (fire). - High temperature of the fluid in the pipe or in the tank. - Increase in temperature from previous node.	1. - Increase in steam volume. - excessive overpressure in the sphere. - BLEVE can takes place. - If the pressure relief valve opens the propane escapes to atmosphere.	1. Temperature sensor.	4	3	12	8. Fire proof wall for the sphere.
			2. Fire detector system.				9. Check if the PRV1 and PRV2 are designed for this case.
			3. Pressure relief valve (PRV).				

Deviation	Cause	Consequence	Effective Safeguards	Before Risk Reduction			Recommendations
				S	L	SL	
2. Vacuum Pressure	1. - Low pressure / flow from previous node. - Large leak in the pipe or the wall of the sphere. - Decrease in temperature	1. Sudden drop in pressure (Depression), production losses.	1. Pressure sensor.	2	2	4	
		2. Reduction of export flow, the manometric head of the pump is insufficient for the export of propane.	2. Temperature sensor.	2	2	4	
		3. In the event of delayed ignition of: UVCE, flash fire (Jet Fire).		4	2	8	
		4. Occupation of BLEVE (cold).		4	2	8	
		5. Risk of rise in level in the sphere.		3	2	6	
		6. Implosion of the sphere.		3	2	6	
3. High Temperature	1. - Hotter propane from previous node. - Temperature increase in the environment without cooling the sphere. - Increased pressure in the tank - Presence of an external heat source (fire). - Failure of the cooling system.	1. Increase in storage temperature.	1. Temperature sensor with Hight alarm.	4	3	12	10. Deluge system automation.
		2. The rupture of the sphere with a large amount of dangerous release.	2. Gas detection.	4	3	12	11. add a water curtain system (LMBA)
		3. Occurrence of: UVCE, Jet Fire.	3. Pressure sensor.	4	3	12	
		4. Increased pressure and high evaporation of the fluid.	4. Pressure relief valve (PRV).	4	3	12	
		5. The creation of a hot spot on the wall of the sphere and the possibility of a BLEVE occurring.		4	3	12	
		6. Excessive overpressure in the sphere.		4	3	12	
		7. dispersion of flammable vapors (when pressure relief valve opens).		4	3	12	
4. Less/Low Temperature	1. - Cooler propane from previous node. - Ambient temperature very low than normal.	1. Pressure drops in the sphere.	1. Temperature sensor with low alarm.	1	2	2	
		2. Possible damage to the tank bottom due to frosting.		2	2	4	
5. High Level	1. - High flow from the previous node.	1. Risk of overpressure and rupture of the **wall**.	1. Level sensor with Hight alarm.	2	2	4	12. Regular maintenance of level sensors and valves.

Deviation	Cause	Consequence	Effective Safeguards	Before Risk Reduction			Recommendations
				S	L	SL	
	- Excessive propane tank filling. - The valve V1 blocked fully opened on the entering propane line. - Failure on opening the valve V2 on the propane extraction line. - Tank level indication failure. - Failure of the export pump.	2. Pumps cavitation and damages.	2. Pressure sensor. 3. Non-return valve.	2	2	4	13. Place a manual valve on the entering line.
	2. Overpressure.	1. idem 1.1		4	3	12	
6. Less/Reduced Level	1. - Leak in the pipe or the sphere. - Failure of the level sensors indicating a high level in the sphere where the valve V1 is closed. - The valve V2 blocked fully opened on the discharge propane line.	1. Total emptying of the sphere and risk of cavitation and damage to the export pumps.	1. Level sensor with low alarm.	1	2	2	14. Place a manual valve on the discharge line.
		2. Pump runs in shut off condition, and possible damage on pump.		1	2	2	15. Regular maintenance of level sensors and valves.
		3. Decrease in production and plant efficiency.		1	1	1	
		4. Dispersion of the fluid then a depression.		1	2	2	
		5. **Pool fire or VCE.**		3	3	9	
		6. Environmental damage.		3	3	9	
7. More Flow	1. - **More flow** and production from the previous node. - The valve V2 fails fully opened on discharge line. - Start of second transfer pump while the first one is working	1. Risk of faster rise in the level in the sphere.	1. Flow indicators with Hight alarm.	2	2	4	
		2. Increased pressure in the tank.	2. Overload alarm for motor transfer pumps.	4	2	8	
		3. Increased transfer speed causes vibrations on the pumps.		1	2	2	
		4. Transfer flow increasing and high velocity in the line leading to vibrations.		1	2	2	
		5. Possible motor pump overload.		2	2	4	
8. Less Flow	1. - Propane transfer pump fails.	1. Loss of propane export (production).	1. Flow indicators with low alarm.	1	2	2	16. Regular inspection of the pipes and the sphere.

Deviation	Cause	Consequence	Effective Safeguards	Before Risk Reduction			Recommendations
				S	L	SL	
	- Failure on the export pumps. - Low / no flow from previous node. - The valve V1 on the entering line stuck closed. - Leak in the pipe or the sphere. - Failure of the level sensors indicating a high level in the sphere where the level is low.	2. Decrease in level in the tank.		1	3	3	17. Protection against corrosion.
		3. Evaporation then overpressure.		4	2	8	
		4. Increased pressure in the tank.		4	2	8	
		5. Cavitation and potential damage to pumps.		2	2	4	
9. Reverse Flow	1. Opening of the propane inlet valve V1 in the discharge mode.	1. Cavitation and potential damage to pumps.		2	2	4	18. Testing the correct operation of the recirculating non-return valve.
10. Small Leak	1. - Leaking pump packing. - Flange leak. - Leaking valve.	1. Dispersion of flammable gaz.	1. Fire detector system.	3	4	12	19. Protection against corrosion.
		2. Jet fire, UVCE, BLEVE.	2. Gas detection.	5	4	20	

Annexes C

PHA software:

Sphera's PHA-Pro offers a framework, configurable methodologies and risk assessment workflows to help organizations standardize and record risk assessment data and ensure that the appropriate controls are in place.

PHA-Pro software is the most recognized and respected hazard identification and risk assessment tool to strengthen the risk assessment process. It identifies, assesses and controls the impact of process-related risks.

It is mainly used in processing industries such as oil and gas, chemicals and pharmaceuticals.

PHA Advantage:

- ✓ HAZOP and LOPA linked.
- ✓ Professional reports exportable in HTML, MSWord, MS Excel avoiding you having to repeat the data entry in several worksheets.
- ✓ International support such as multi-language and right-to-left data entry
- ✓ Help create matrix sheets that expand your abilities to include new types of risk assessment techniques.
- ✓ Pre-formatted templates - saves time when creating assessments.
- ✓ Comprehensive libraries - allows you to shorten study time and take advantage of best practices.
- ✓ Multilingual support - enables more efficient collaboration - English, French, German, Spanish, Portuguese, Japanese, Chinese (Simplified), Korean Flexible and user-friendly
- ✓ The software also allows you to customize spreadsheets and forms for your existing templates, as well as create new templates.

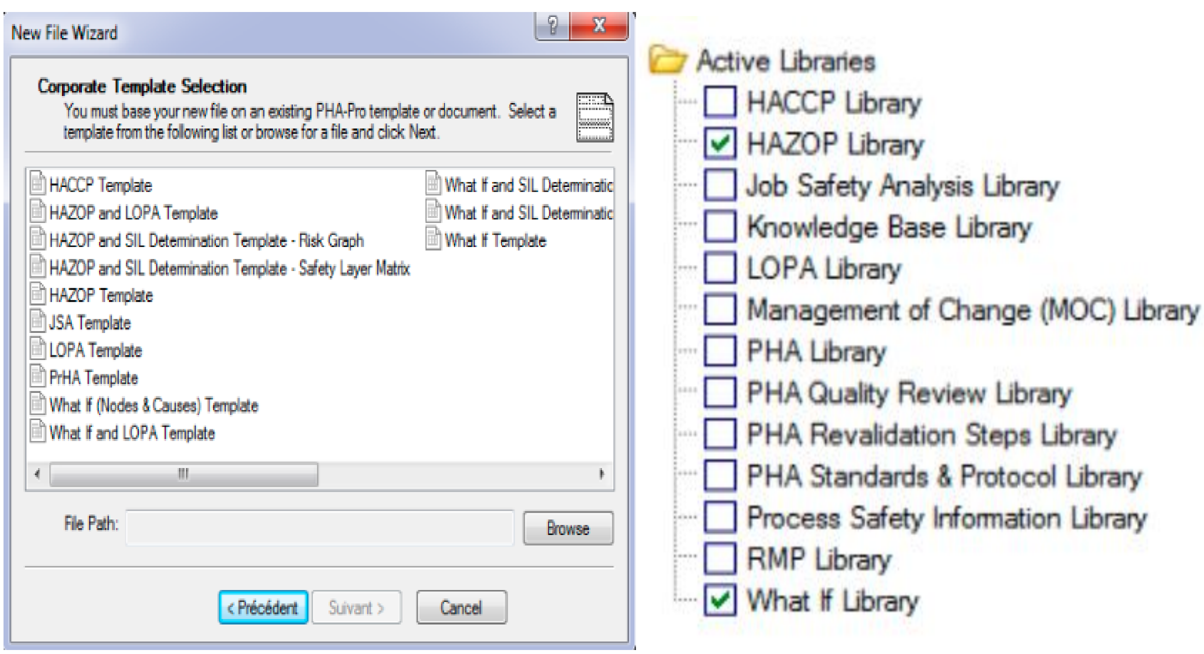
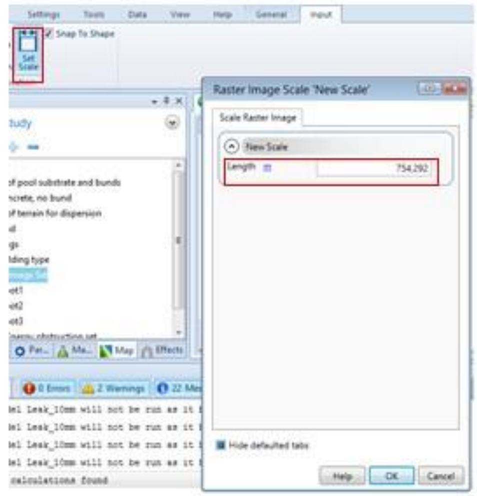


Figure 2 Templates and libraries of PHA PRO

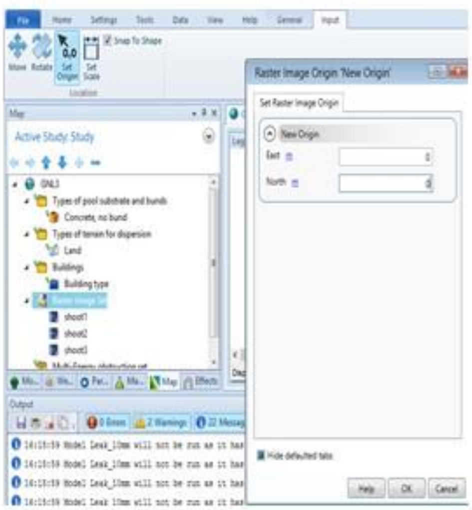
Annexes D

01 Insert the image

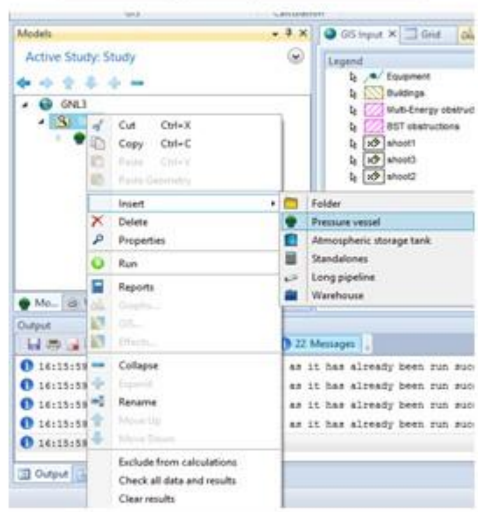
02 Define the real dimension in the map



03 Add an origine

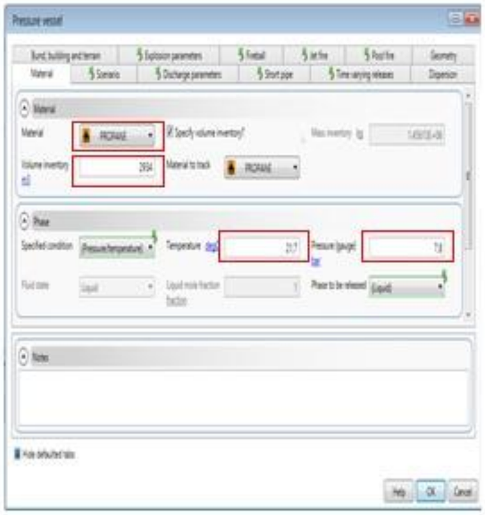


05 Choose the equipment (sphere)

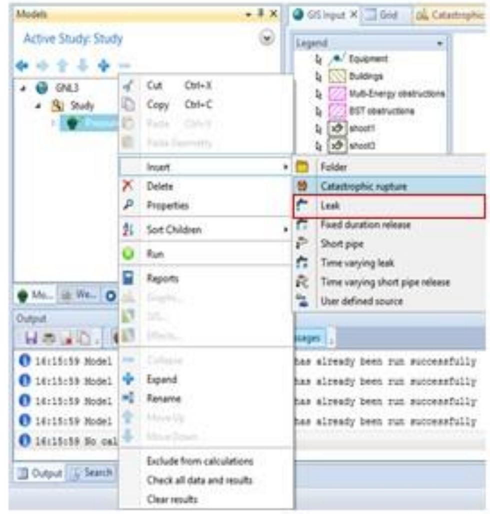


04 Insert equipment on GIS

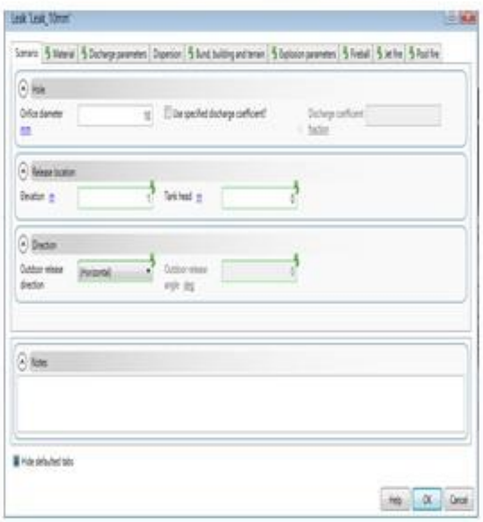
06 Fill in the necessary information



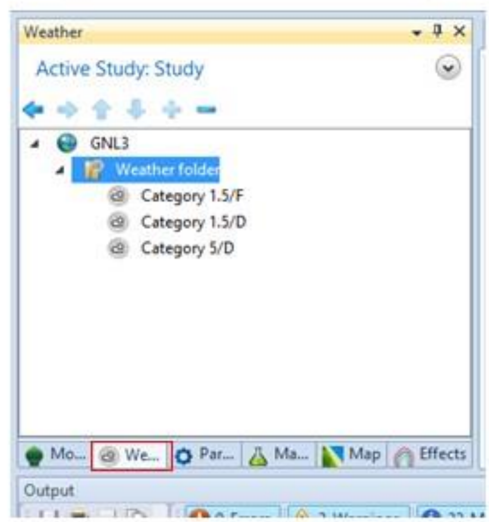
07 Choose the type of catastrophe



08 Fill in the necessary information



09 Enter climatic data



10 Choose the mode and run the simulation

Annexes E

The code source of FICS and its explanation

```
1 from imageai.Detection.Custom import CustomVideoObjectDetection2
2 import os
3 import telebot
4 import numpy as np
5 import cv2
6 import tensorflow as tf
7 execution_path = r"E:\Imsi Project\Fire"
8 ################################# Load models
```

The first 6 lines for importing the necessary libraries

Line 7 for the directory where we saved the recorded video

```
9     def load_models():
10    global video_detector
11    global bot
12    global interpreter
13    global input_details
14    global output_details
15    import telebot
```

################# fire detection model

```
16    ################# fire detection model
17    video_detector = CustomVideoObjectDetection()
18    video_detector.setModelTypeAsYOLOv3()
19    video_detector.setModelPath(Path_detection_model)
20    video_detector.setJsonPath(Path_object_json)
21    video_detector.loadModel()
```

################# telegram bot

```python
################## telegram bot
bot = telebot.TeleBot(token)
```

################# classification model loading and configuration

```python
################## classification model loading and configuration
interpreter = tf.lite.Interpreter(path_classification_model)
interpreter.allocate_tensors()
input_details = interpreter.get_input_details()
output_details = interpreter.get_output_details()
```

#################################### returned frame information

```python
###################################### returned frame infos
def forFrame(frame_number, output_array, output_count,detected_frame):
    for detection in output_array :
        if detection["percentage_probability"] > 30 :
            crop_fire_zone= detected_frame[detection["box_points"][1]:detection["box_points"][3],detection["box_points"][0]:detection["box_points"][2]]
            cv2.imwrite('detected_frame.jpg', detected_frame)
            classification(crop_fire_zone)
    cv2.imshow("test",detected_frame)
    cv2.waitKey(1)
```

```
######################################## Classification function
```

```python
######################################## Classification function
def classification(crop_fire_zone,detected_frame) :
    img=cv2.resize(crop_fire_zone,(224,224))
    img=img.astype('float32')
    if len(img.shape) == 3:
        img = np.expand_dims(img, 0)
    interpreter.set_tensor(input_details[0]['index'], img)
    interpreter.invoke()
    output_data = interpreter.get_tensor(output_details[0]['index'])
    classification_prob = []
    classification_label = ['FIRE BALL','JET FIRE', 'NONE']
    total = 0
    for index, prob in enumerate(output_data[0]):
        if prob != 0:
            classification_prob.append(prob * 100)
            total += prob
    scenario=str(classification_label[classification_prob.index(max(classification_prob))])+" : "+str(max(classification_prob))
    alert(scenario)
```

```
################################################# Alert Function
```

```python
################################################# Alert Function
def alert(scenario,detected_frame) :
    bot.send_message(chat_id, text=scenario)  #### send catastrophic scenario name
    bot.send_photo(chat_id,photo=open('detected_frame.jpg','rb')) # send the frame which contains catastrophic scenario
```

start the detection

```
65 ############################################## start the
detection
66 def start_detection():
67
 video_detector.detectObjectsFromVideo(camera_input=camera,
68
 69output_file_path=os.path.join(execution_path, "detected"),
70
 frames_per_second=10,
71
 per_frame_function=forFrame,
72
 73minimum_percentage_probability=30,
74                                         log_progress=True,
75
 return_detected_frame=True)
76
77 if __name__ == "__main__" :
78     load_models()
79     camera = cv2.VideoCapture(0)
80     start_detection()
```

Line 77: The program starts

Line 78: Loading the models and making the necessary configuration like load detection and classification models and login to Telegram bot.

Line 79: We start the camera (0 or 1 if you have a second camera).

Line 80: Calling the start detection function for starting detection from the camera.

Start detection function: the function read the frame from the camera and start detection:

- camera_input: as we mentioned in the line 76.
- output_file_path: the directory (path) of where the recorded video detection will be saved.
- frames_per _second: the recorded video will be loaded with 10 fps.

- minimum_percentage probability: is the minimum probability for detection.
- per_frame_function: each frame we call forFrame.
- return_detected_frame (True): allows to return the detected frame to make some operations on frame with the forFrame function.

forFrame function: this function called by per_frame_function and gives some information about the detection:

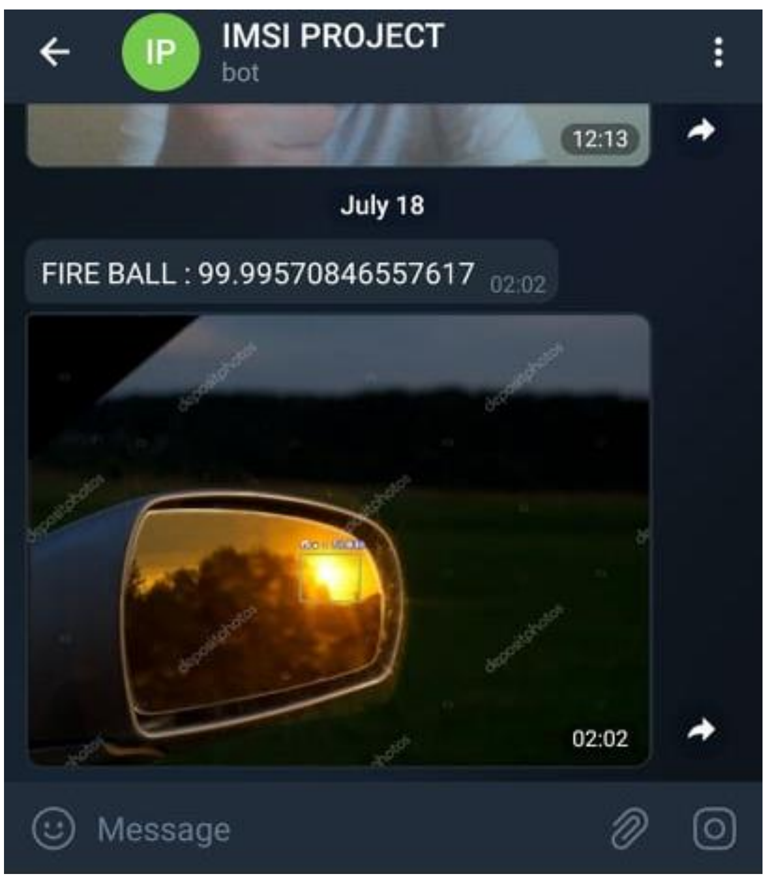
- output_array: a list contains the detected object (fire) , the percentage probability of fire and coordinates of the zone containing fire.
- returned_frame: the frame with the probability and box around the fire.
- In line 33: if the probability is above 30 % we will make some operations like crop the zone of fire from all the frame (Line 34) for facilitate the classification save the detected frame as jpg image to use it in alert function (Line 35) and call classification function (Line 36) with this crop_fire_zone which is a frame contains only the detected fire
- Line 37 and 38: Show the frame in a window which named “test”.

Classification function: this function called in forFrame function the goal of this function is to classify the fire if it FIREBALL, JETFIRE or None and call **Alert()** function with the predicted scenario .

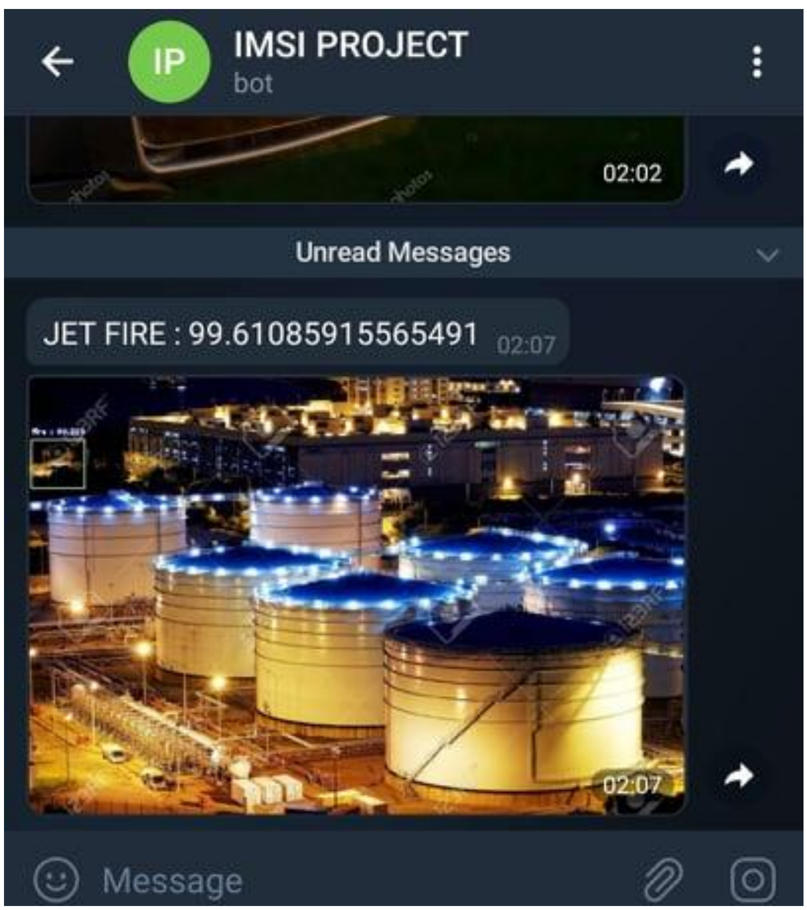
Alert function: this function called in Classification function, the goal is to alert with a message containing the predicted scenario (Line 62) and image saved in Line 35 which contains fire (Line 63).

Annexes F


fire : 70.830
depositphotos


IP
IMSI PROJECT
bot
12:13
July 18
FIRE BALL : 99.99570846557617 02:02
02:02
Message


fire : 60.223


IMSI PROJECT
bot
02:02
Unread Messages
JET FIRE : 99.61085915565491
02:07
02:07
Message