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TECHNOLOGY INSTITUTE

APPELIED ENGINEERING DEPARTMENT

# Final study project

## To obtain a professional Bachelor’s degree in specialty Health, Safety and Environment.

# Theme :

# *Evaluation of the safety barriers of an industrial system: application of the “Bow Tie” method*

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# Abstract:

This work includes how to apply the method for analyzing and evaluating the security barriers of an industrial system (the storage sphere of liquefied petroleum gas) using the Bow Tie that gives a logical and high-accuracy sequence of possible causes and consequences, as well as security barriers in both FTA and ETA in order to deal with threats and avoid dangerous phenomena. We found that the existing barriers are considered appropriate and permissible, also the top event frequency contributed in a positive way to reduce the probability of dangerous phenomena, and the most critical barrier affecting the system is the relief valves due to the results obtained.



**Key words:** Risk Analysis, LPG, LPG Sphere, Quantitative Analysis, bow tie



## الملخص:

يتضمن هذا العمل كيفية تطبيق طريقة تحليل وتقييم الحواجز الأمنية لنظام صناعي (حاوية تخزين غاز البترول المميع) باستخدام (عقدة الفراشة) التي تعطي تسلسلًا منطقيًا وعالي الدقة للأسباب والنتائج المحتملة، بالإضافة للحواجز الأمنية في كل من شجرة احتمال العطب وشجرة احتمال الأحداث من أجل التعامل مع التهديدات وتجنب الظواهر الخطيرة. وجدنا أن الحواجز الأمنية الوقائية تعتبر مناسبة ونستطيع اعتبارها مسموحة، كما أن احتمال او تردد الحدث الخطير الاوسط ساهم بشكل إيجابي في تقليل احتمالية حدوث الظواهر خطيرة (كالانفجار)، وأهم حاجز يؤثر على النظام هو صمامات الأمان من خلال النتائج المتحصل عليها.



**الكلمات المفتاحية:** تحليل المخاطر، غاز البترول المميع، حاوية غاز البترول المميع، التحليل الكمي للمخاطر، عقدة الفراشة.



## Résumé :

Ce travail comprend comment appliquer la méthode d'analyse et d'évaluation des barrières de sécurité d'un système industriel (conteneur de stockage de gaz de pétrole liquéfié) en utilisant le (Nœud papillon) qui donne une séquence logique et de haute précision des causes et des résultats possibles, en plus des barrières de sécurité dans l'arbre de probabilité de défaillance et dans l'arbre de probabilité des événements afin de faire face aux menaces et d'éviter les phénomènes dangereux. Nous avons constaté que les barrières existantes sont considérées comme appropriées et autorisées, que la fréquence de l'événement redouté central(ERC) a également contribué de manière acceptable à réduire la probabilité des phénomènes dangereux, et que la barrière la plus critique affectant le système est les soupapes de décharge en raison des résultats obtenus.



**Mots Clé :** Analyse des risques, GPL, Sphère de GPL, Analyse quantitative, Noeud papillon

# ACKNOWLEDGEMENTS

*We express our gratitude to Allah for granting us the determination, the bravery, and the essential endurance to accomplish this humble task.*

*Our beloved parents for their efforts from the moment of our birth until these blessed moments. To everyone who advised us, guided us, contributed or directed us in the preparation of this research and linked us to the required references and sources in any of the stages it went through,*

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# DEDECATIONS

We would like to dedicate this memory to:

To our parents who supported us with everything they had.

To our teachers who gave us the necessary knowledge and guidance.

To our friends and our colleagues and all those who helped us in this journey of three years of hard work.

# Summaries :

# List of figures:

# List of tables:

# List of Abbreviation:

FTA: Fault tree analysis.

ETA: Event tree analysis.

LPG: Liquefied Petroleum Gas.

CNG: Compressed Natural Gas.

UVCE: Unconfined Vapor Cloud Explosion.

BLEVE: Explosion of Boiling Liquid Expansion Vapor.

DP: Division of production.

TOE: Ton of oil equivalent.

HBK: Haoud Berkaoui.

GLA: Geullala.

BKH: Benkahla.

GTU: Gas treatment unit.

GID: Gas Indicator detector.

PID: Piping and Instrumentation Diagram.

RGA: Residual gas analyser.

PSV: Pressure safety valve.

PI: Pressure Indicator.

TI: Temperature Indicator.

PIC: Pressure Indicator Controler.

T: Tank (Spheres T-701A/B).

HAZOP: Hazard and Operability.

# GENERAL INRODUCTION:

Today, the world is going through many changes as a result of the continuous development of technology and modern technologies that facilitate the daily human life. These tools consume energy from various sources in order to complete their tasks. It is not hidden from us that the energy production process differs according to the methods of its production, and the most widespread of them is the consumption of raw materials such as coal, gas or oil in large facilities in order to produce energy, and despite its risks, it is considered the most common method efficiency for energy production.

This method has undergone many changes since its inception. It used coal as a raw material at its inception, but today it exploits natural gas and liquefied petroleum gas, which is stored in spherical containers in a liquid state with strict procedures and advanced safety systems, because the manipulation of these The material is extremely dangerous as it is fast and easy to ignite, and these measures are the results of what is known as the risk analysis.

Risk analysis methods vary at the level of LPG storage facilities, and several factors can affect the selection of facility officials, including the availability of the necessary data and many other influences. The Bow Tie method is one of those methods used, which is characterized by its ability to link the causes and results that result. Backlogs in the form of different scenarios, in order to identify weaknesses and elements most affecting the protection system and suggest improvements.

# *I. First chapter:*

## *Methodology" Bow Tie"*

# 1)INRODUCTION:

There are many methods of analyzing risks in order to predict and prevent them from occurring, although there are some shortcomings in these studies, including their non-absolute results and the fluctuation in the existing data due to the change of the environment and the place from which it is taken, but it enables us to know the weaknesses in our facilities and Thus strengthening and ensuring the protection of workers, the environment and the interests of the enterprise.

The Bow Tie method that we will use combines two different methods of risk analysis, FT and ET, which explain the causes of the proposed event and the possible scenarios for the results with the probability of each of them, which can be considered a very effective method in order to avoid possible risks.

# 2)Concepts and definitions:

## a) Danger:

"An operation, activity or material with the potential to cause harm to people, property, the environment or business or simply, a potential source of harm."[1]

## b) Risk:

"Risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives. Risk is quantified in terms of likelihood and impact, and a risk may have one or more causes and, if it occurs, it may have one or more impacts." [2]

## c) HAZOP :

"Hazard and operability Study. A systematic qualitative technique to identify and evaluate process hazards and potential operating problems, using a series of guidewords to examine deviations from normal process conditions."[1]

## d) Barrier:

"A control measure or grouping of control elements that on its own can prevent a threat developing into a top event (prevention barrier) or can mitigate the consequences of a top event once it has occurred (mitigation barrier). A barrier must be effective, independent, and auditable. See also Degradation Control. (there possible names Control, Independent Protection Layer, Risk Reduction Measure)."[1]

## e) Top Event:

"In bow tie risk analysis, a central event lying between a threat and a consequence corresponding to the moment when there is a loss of control or loss of containment of the hazard. The term derives from fault Tree Analysis where the unwanted event lies at the 'top' of a fault tree that is then traced downward to more basic failures, using logic gates to determine its causes and likelihood."[1]

## f) Fault Tree analysis:

"Fault tree analysis (FTA), sometimes known as event tree analysis, is a method of identifying the possible causes of a system failure. A fault tree is used to graphically illustrate the different potential causes of a failure in the form of a diagram. By using FTA, you can determine what factors contributed to an event (known as a failure), and the probability of it occurring. Once the major causes are identified and addressed, FTA can help maintenance teams prioritize corrective actions." [3]

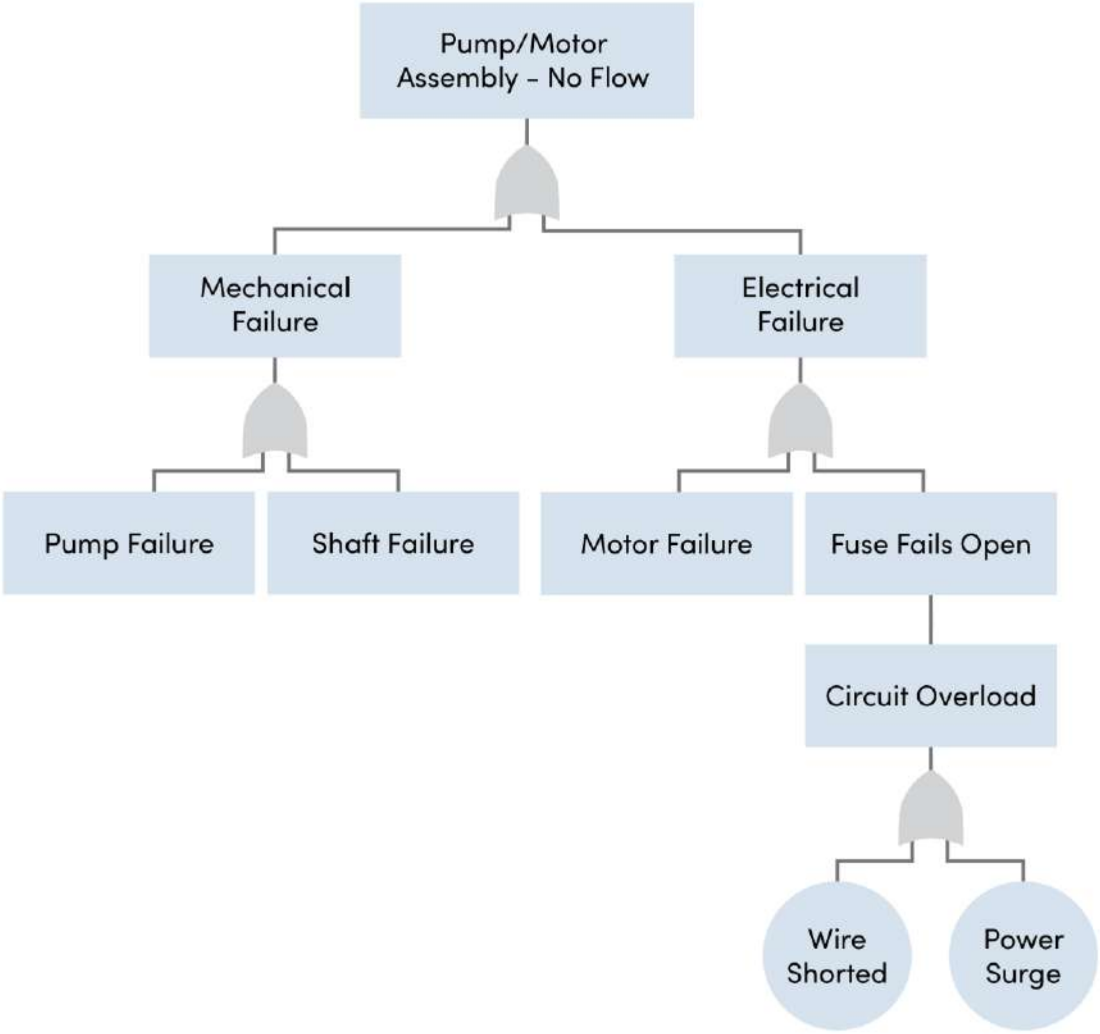


*Figure 1 Fault Tree exampel[3]*

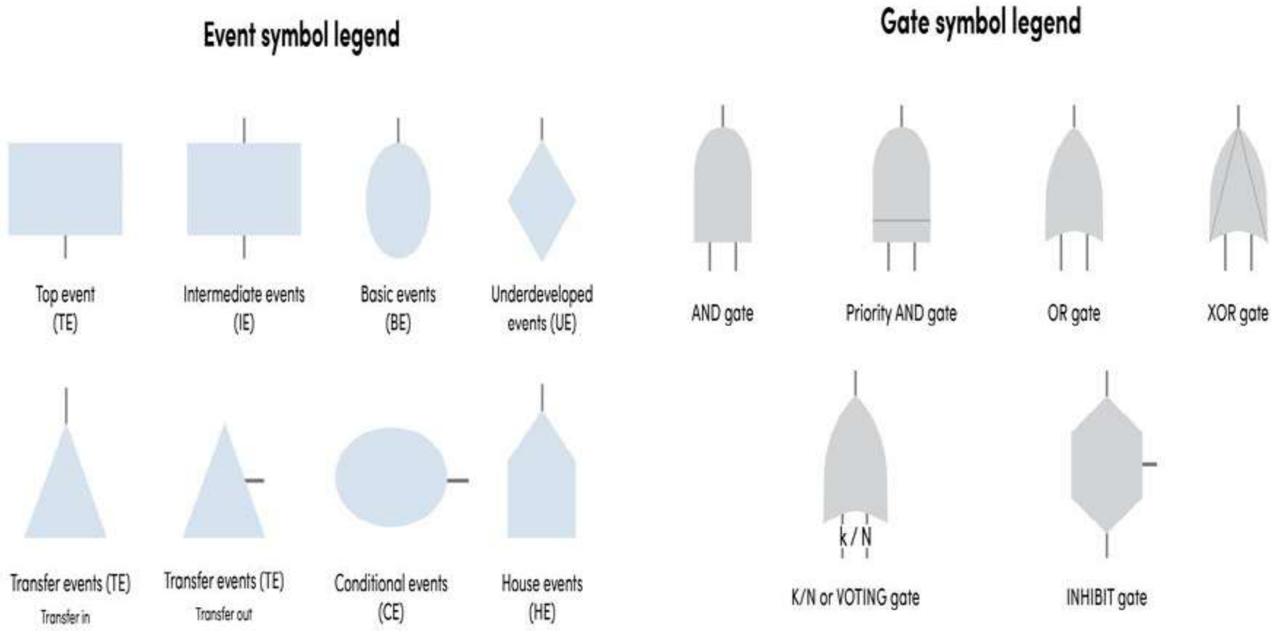


*Figure 2 FTA events & gates symbols [3]*

## g) Event Tree analysis:

"An event tree analysis (ETA) is an inductive procedure that shows all possible outcomes resulting from an accidental (initiating) event, taking into account whether installed safety barriers are functioning or not, and additional events and factors." [4]

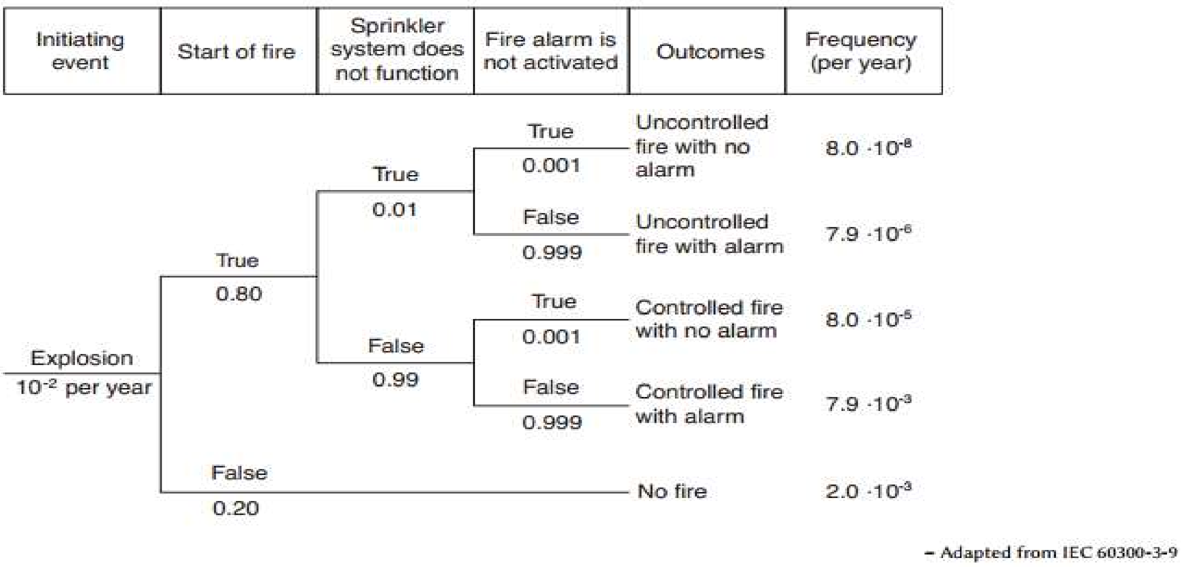


*Figure 3 Event Tree example[4]*

## h) Bow Tie Model:

“A risk diagram showing how various threats can lead to a loss of control of a hazard and allow this unsafe condition to develop into a number of undesired consequences. The diagram can show all the barriers and degradation controls deployed. The bow tie diagram is shown in figure 4 with the following elements:

(Hazard / Top Event / Threats / Consequences / Prevention Barriers / Mitigation Barriers /Degradation Factors / Degradation Controls)."[1]

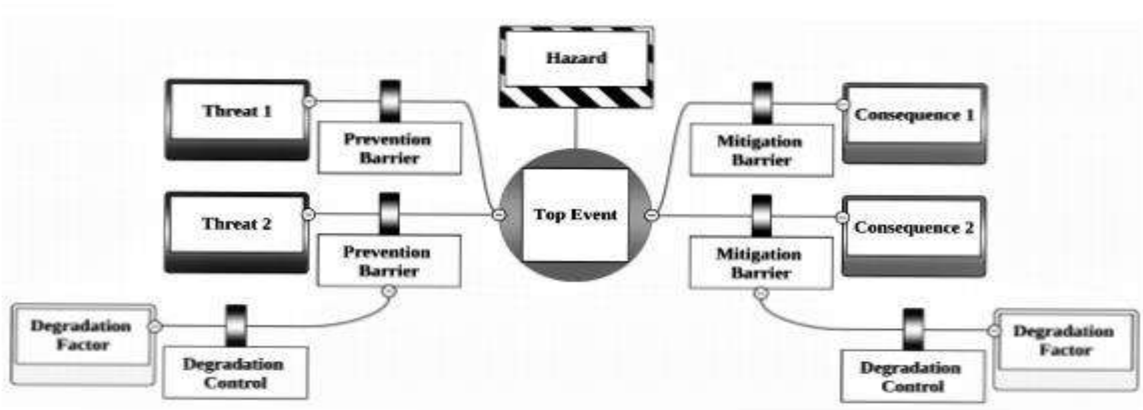


*Figure 4Bow Tie model[1]*

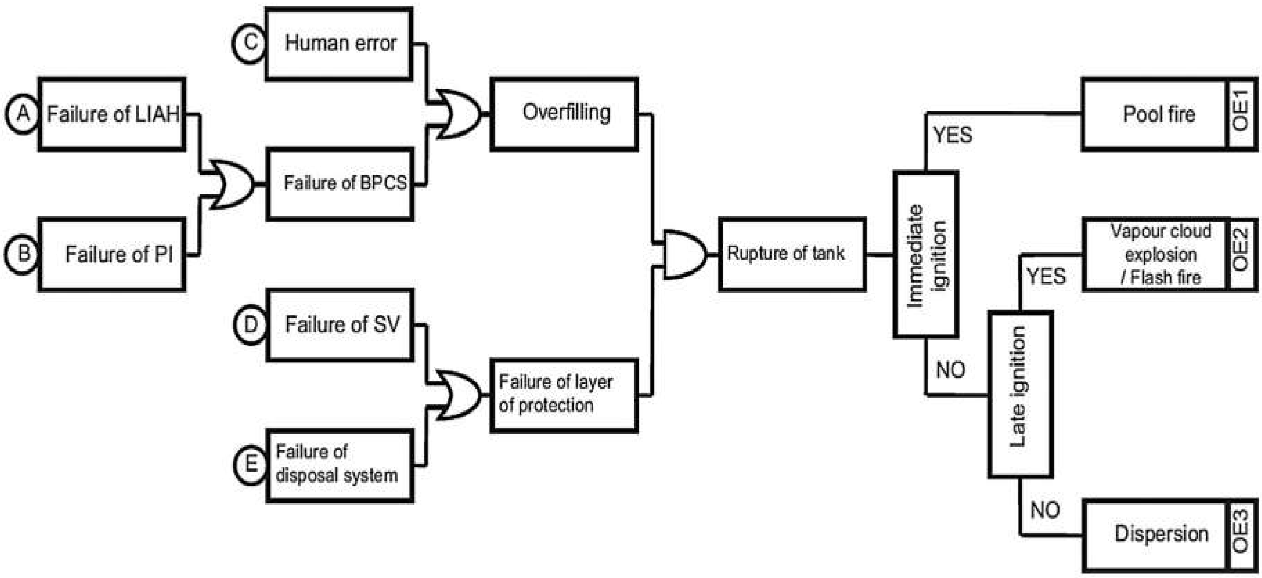


*Figure 5 Bow Tie without barriers [5]*

# 3)Objectives of the <Bow Tie> method:

"The purpose of the bow tie methodology in risk management is to visually represent the potential hazards, their causes, and the controls that can be implemented to manage and mitigate those risks. It helps organizations to understand the risks they face, assess their likelihood and impact, and make informed decisions about risk management strategies." [6]

“This approach offers several tangible benefits, including:

- Visualizing the connections between hazards, their causes, and their effects.
- Evaluating the level of risk posed by each cause and the severity of each hazard.
- Implementing preventative and protective measures to mitigate risk.
- Identifying factors that may weaken these measures and increase risk.
- Measuring the effectiveness of these measures in reducing risk.
- Assessing the overall impact of these measures on risk levels.” [7]

# 4)Bow Tie Principle:

“The "Bow Tie" method is a widely used probabilistic approach for risk assessment in the industrial environment. It combines a fault tree and an event tree, both focused on the same potential hazard. By providing a comprehensive model for risk management, the Bow Tie approach has gained popularity. The method derives its name from the graphical representation that resembles a bow tie.” [7]

# 5)Advantages and disadvantages of Bow Tie:

## a) Advantages:

- “Provide a systematic analysis of the barriers along threat and consequence pathways that can prevent or mitigate a major Accident Event. This can support the design process, or the operational or maintenance activities to raise awareness and understanding of the barriers in place and the role of individuals in operating or maintaining barriers.

- Provide a cumulative picture of risk through the visualization of the number and types of barriers and degradation controls and their condition. This can support the identification and prioritization of actions to strengthen degraded barriers and degradation controls.

- Provide a structured process where identified hazards, threats and consequences can be related in cause and effect scenarios, and to assist in the development and understanding of how unwanted events can occur.”[1]

### b) Disadvantages:

- “Simplification: The Bow Tie diagram oversimplifies complex systems and may not capture all nuances. This can lead to an oversimplified understanding of risks and potential hazards.” [6]

- “Lack of data: The Bow Tie method relies on reliable data to accurately identify and assess risks. However, incomplete or limited data can lead to inaccurate risk assessment and management.

- Resource-intensive: Developing comprehensive Bow Tie diagrams can be time-consuming and resource-intensive, particularly when identifying and assessing all potential risks and hazards.” [8]

- “Subjectivity: The identification and assessment of threats and hazards in Bow Tie diagrams can be subjective, relying on the knowledge and experience of analysts. This subjectivity may introduce inconsistencies in the analysis and risk assessment.” [9]

- “Limited scope: Bow Tie diagrams mainly focus on the top event, its causes, and consequences, potentially neglecting other factors that could impact the system. This limitation may restrict the effectiveness of the risk management approach.” [10]

# 6)Conclusion:

The Bow Tie risk analysis and management methodology has been widely adopted across various industries for several years, consistently demonstrating its effectiveness. This methodology establishes a clear connection between causes and effects, illustrating how threats can result in a loss of control and ultimately lead to undesirable outcomes. Moreover, it offers the ability to incorporate supplementary details, including the efficacy, nature, ownership, and status of protective barriers. This comprehensive approach greatly enhances the prevention and control of potential risks.

# ***II. Second chapter:***

## ***LPG's Properties, Handling and Storage.***

# 1)INRODUCTION :

Since its discovery, hydrocarbons have played a major and important role in several fields, including energy and chemicals. With the development of this industry, it has become the economy of entire countries, which has led to the emergence of conflicts around it.

Liquefied petroleum gas is one of the hydrocarbon derivatives that are extracted from petroleum. It is a group of gases that have been compressed at low temperatures in order to convert them from a gaseous state to a liquid for the purpose of storing them or transporting them over long distances. Usually, liquefied petroleum gas consists of propane and butane.

The storage of liquefied petroleum gas represents a great danger because it is highly flammable, as well as the fact that it requires constant high pressure and low temperature that prevent it from returning to the gaseous state, and this requires the joining of several systems in order to maintain the required cycle, including firefighting systems and many other safety measures. These procedures are determined through methods risk analysis of the prevention and safety unit.

# 2)General information on LPG:

## a) Physical and chemical characteristics of LPG:

“Liquefied petroleum gas (LPG) is a group of hydrocarbon gases, mainly composed of propane, normal butane, and iso-butane. It is obtained from crude oil refining or natural gas processing and can be sold either as individual gases or as a mixture.

Also, LPG is a versatile and efficient fuel option that is commonly used for heating, cooking, and transportation, but it is important to handle and store it properly due to its flammable nature

And one of the main advantages of LPG is its ability to be easily liquefied through pressurization, which allows for convenient transportation and storage without the need for cryogenic refrigeration. (The U.S. Energy Information Administration)” [11]

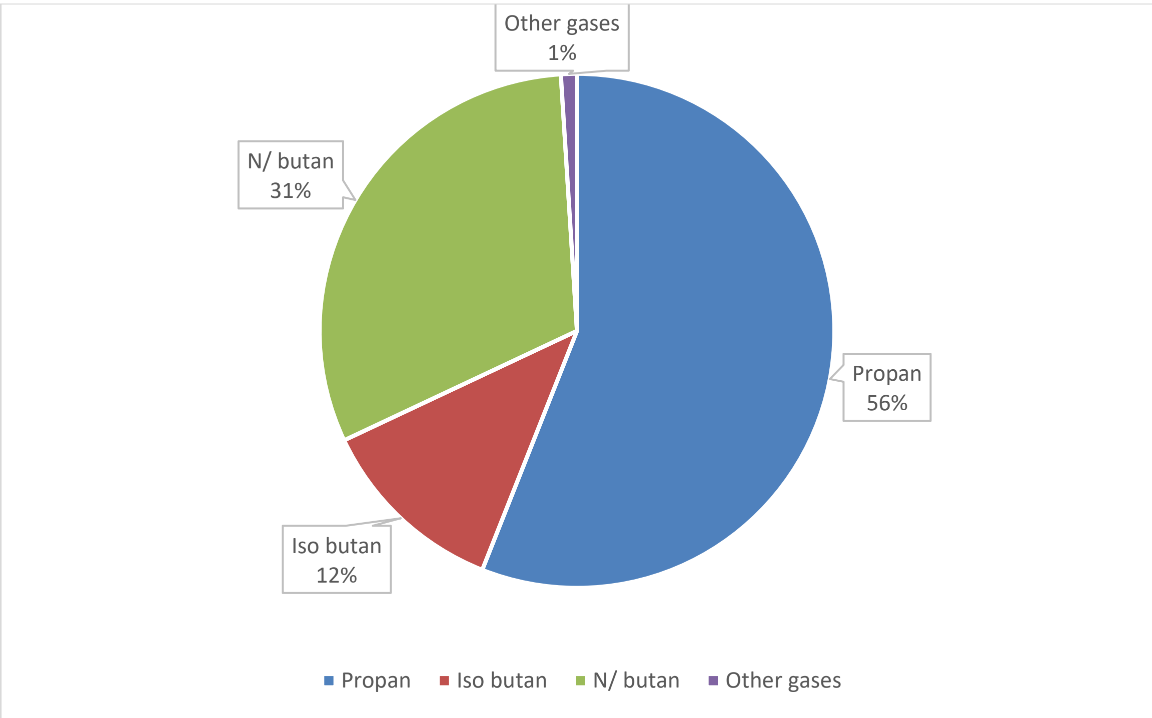


*Figure 6 LPG components in persentage[12]*

| Property | LPG |
|---|---|
| Heating value (KJ/Kg) | 50000 |
| Self-ignition temperature (°C) | 525 |
| Boiling point range (°C) | -34 |
| Flame propagation rate (cm /s) | 52/58 |
| Flame temperature (°C) | 1985 |
| Molecular weight (Kg/Kmol) | 44.1 |
| Upper flammability limit in air (% vol) | 74.5 |
| Lower flammability limit in air (% vol) | 4.1 |
| Density at 15°C (Kg/l) | 0.507 |

*Table 1 Charactristics of LPG[13]*

## b) Advantages and disadvantages of liquefied petroleum gas (LPG):

❖ *Advantages:*

"Liquefied Petroleum Gas (LPG) is a clean burning efficient fuel and a vital source of energy for of millions of people around the world and it is portable and can be transported, stored and used virtually anywhere.

From the benefits there are:

- LPG is a clean lower carbon energy source.

- LPG is one of the cleanest conventional fuels available.
- LPG emits about 20% less $CO_2$ than heating oil and 50% less than coal.
- LPG enables the transition from high carbon conventional fuels to renewable energy sources.
- LPG is energy efficient as a high proportion of the energy content of LPG is converted to heat.
- LPG replaces chemicals in agriculture including sanitizing livestock stalls and flame weeding." [14]

- *Disadvantages:*

"The existence of the benefits of liquefied petroleum gas did not preclude the presence of some disadvantages, which we mention below, which are:

- LPG requires a specialized fuel system to be installed in a car.
- The storage tank used for LPG is heavy, which can add weight to the car and potentially impact its performance.
- LPG is an inflammable gas, which means it poses a risk of fire and explosion.
- LPG is heavier than air, and in case of leakage, it can cause suffocation.
- LPG has a lower energy density than some other fuels, which can result in higher consumption rates.
- Compared to Compressed Natural Gas (CNG), LPG is generally more expensive.
- The ignition temperature of LPG is higher than that of gasoline, which may have implications for engine design and operation." [15]

# 3) Storage of LPG:

## a) Types of storage of LPG:

- *Spheres:*

"Very resistant, use in the factories of production and the refineries.

*Figure 7 LPG spherical storage [16]*

- ***Cigars:***

Capacity limited to 500$m^3$, use in repository commercial or stations.

*Figure 8 LPG storage cigars [16]*

- ***Tanks under bank:***

The walls are covered with a protective cover (earth, sand) from thermal and mechanical effects.

*Figure 9 LPG storage tank under bank [16]*

- ***Refrigerated storage:***

refrigerated storage under pressure where LPG are near or less than 0°C this allows a reduction significant pressure of storage this requires installing and device operation refrigeration.

*Figure 10 LPG refrigerated storage [16]*

### ❖ *Underground storage:*

LPG are stored in large quantities in cavities dug in rock (limestone, chalk, etc.).

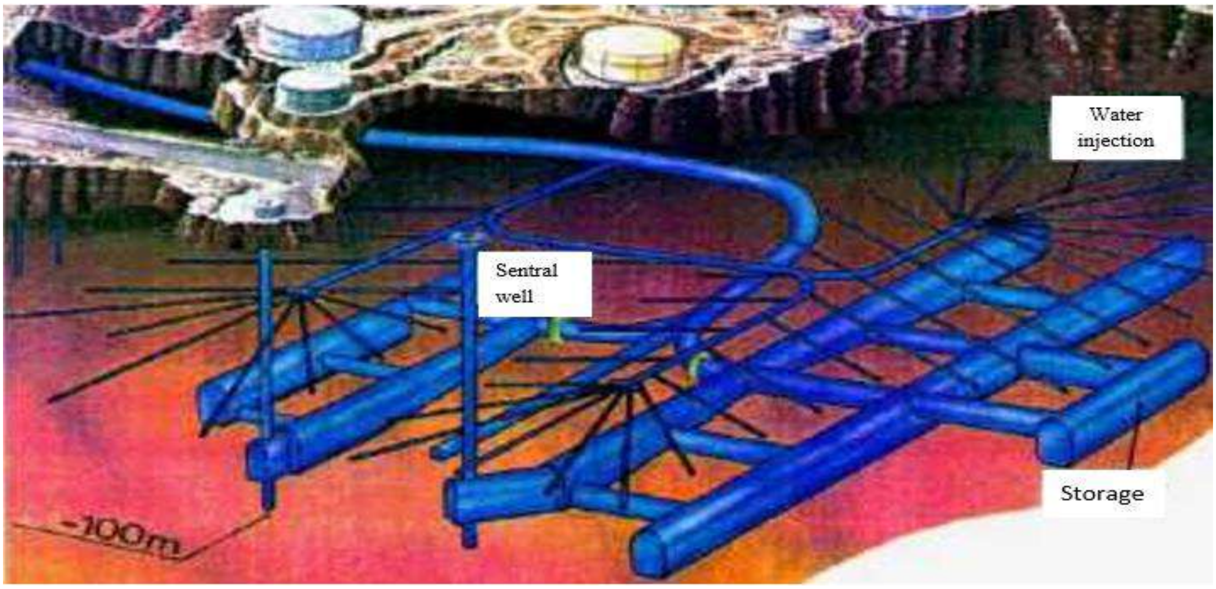


*Figure 11 LPG underground storage [16]*

## b) Risks of LPG storage:

### ❖ *LPG leaks:*

An LPG leak is characterized by the formation of a cloud gas, with the formation of a highly flammable clear layer enveloping this cloud, in addition to the formation of a gel at the source of the leak.

➢ LPG leak in the gas phase:

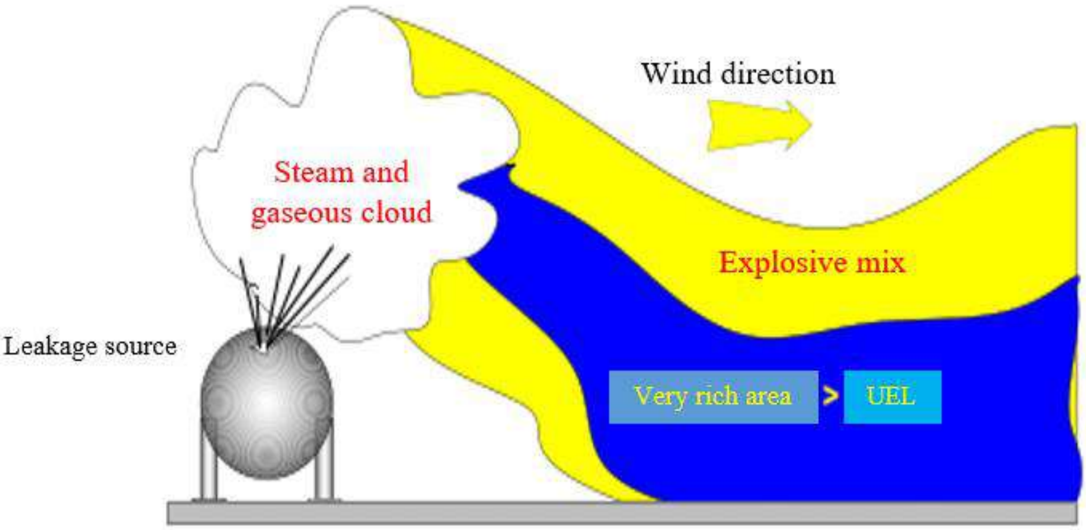


*Figure 12LPG leak in the gas phase simulation [16]*

➢ LPG leak in the liquid phase:

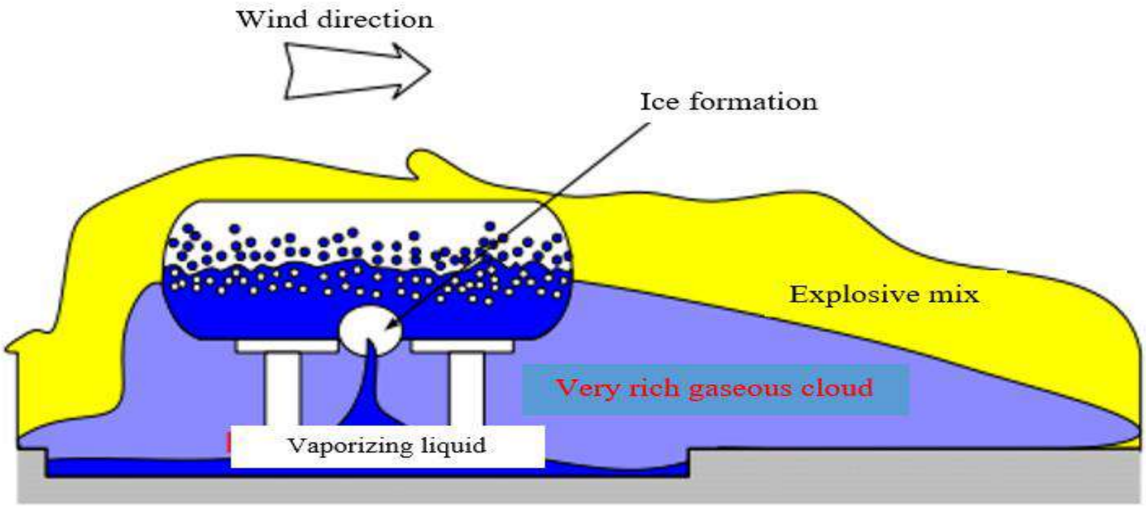


*Figure 13 LPG leak in the liquid phase simulation [16]*

## ❖ *LPG Fires:*

An accidental LPG leak causes the formation of a flammable cloud, if it encounters a source of ignition, a fire occurs with the instantaneous spread burning in the flammable cloud. Features of this fire varies according to the leak scenario and results in:

- Flash.
- Jet fire.
- Pool fire.
- BLEVE (explosion of boiling liquid expansion vapor).
- UVCE (Unconfined Vapor Cloud Explosion).

➢ Flash:

A flash occurs immediately following the occurrence of a leak, resulting in the formation of a torch fire. This type of fire is typically caused by factors such as the presence of sparks, gravel, or other ignitable materials.

*Figure 14 Flash example [16]*

➢ Jet Fire:

Typically, it does not involve an explosion. However, it becomes hazardous when the torch flame approaches nearby equipment, which may rapidly weaken and break due to the intense radiation. This can lead to additional release of LPG and hydrocarbons, potentially triggering a domino effect.

*Figure 15 Jet Fire example [16]*

➢ Pool fire:

These fires endure for a longer duration compared to HC cloud fires. They emit long, smoky flames. The radiation near the pools is highly intense and gradually decreases within a range of 3 to 5 times the diameter of the pool.

*Figure 16 Pool fire example [16]*

➢ BLEVE:

It is a highly dangerous and destructive phenomenon: it occurs when a LPG (liquefied petroleum gas) container burns or being near to flames.

It happens in parts or stages such as:

- Pressure increases.
- Rupture of the metal above the liquid level.

- Sudden vaporization of the liquids and formation of an aerosol that instantly ignites.
- Formation of a fireball that rises into the air.

In the case of its Consequences there are:

- Intense radiation (thermal effect).
- Overpressure waves.
- Toxic effect.
- Projection of fragments (up to 1200m).

*Figure 17 Stages of BLEVE [17]*

- <u>UVCE:</u>

It occurs following a loss of containment, or when large volumes of flammable combustible/air clouds develop before ignition. The extremely rapid ignition of the mixture in open space will cause shockwaves with high thermal radiation and overpressure. “[16]

*Figure 18 UVCE example [16]*

# Conclusion:

Liquefied petroleum gas is one of the excellent and indispensable energy resources in the world of industry, and despite the risks involved, such as its rapid ignition and the possibility of causing a large explosion such as (BLEVE), it is still used in homes and in cars, and this indicates that it is an important substance for humans in their daily lives.

# *III. Third chapter:*

## *Application of the "Bow Tie" method*

# 1) Definition of the company and the installation:

## a) Definition of the company and their activity:

### ❖ *SONATRACH (DP):*

"SONATRACH is the Algerian national company responsible for research, production, pipeline, transportation, processing, and commercialization of hydrocarbon derivatives. Additionally, the company is involved in other sectors such as electricity generation, renewable and new energies, and seawater desalination. It operates in Algeria and worldwide where opportunities arise.

As the first company in Africa, it holds a prominent position globally, with a total production of 230 million TOE (Ton of oil equivalent) in 2006. Its activities contribute approximately 30% to Algeria's Gross Domestic Product (GDP), and it employs 120,000 people within the group.

SONATRACH is divided into three business units: Upstream, Downstream, Pipeline Transportation, and Commercialization. The Production Division (PD) is an integral part of the upstream business unit. The production sites of the Production Division are distributed across three areas based on their geographic location. Area 1 includes the regional directions of Hassi Messaoud (CINA, CIS, satellite units, Borma, Mesdar), Hamra, Rhourde Nouss, and Gassi Touil. Area 2 comprises the regional directions of Hassi R'Mel (Center, North, South, Djebel Bissa, Oued Noumer, and Ait Kheir) and Haoud Berkaoui (Guellala and Benkahla). Area 3 includes the regional directions of In Amenas, Stah (Alar, Stah, Mereksen), Tin Fouye Tabankort, and Ohanet.

### ❖ *THE REGION OF HAOUD BERKAOUI (HBK):*

Haoud Berkaoui, managed by Sonatrach's Upstream Production Division, has been operating since the commissioning of its first oil treatment center in 1967. Currently, there are five oil treatment units and one gas treatment unit. The region has 95 producing wells, with 49 utilizing gas lift technology for secondary recovery. To enhance recovery capacity, there are 28 water injection wells in operation.

Each production center receives crude oil from multiple wells, where it is stabilized, stored in bins, and prepared for shipment. Gas recovered during the stabilization process is compressed and transferred to the gas treatment plant in Guellala (GTU/GLA), which extracts LPG, sales gas, and gas-lift.

As of today, the Haoud Berkaoui region has an oil processing capacity of 26,100$m^3$/d (5800T/d), 1,236,000 $Sm^3$/d for gas treatment, 500T/d for LPG, and 90T/d for condensate. The region also has an oil storage capacity of 28,300 $m^3$ and a gas storage capacity of 3,400 $m^3$." [18]

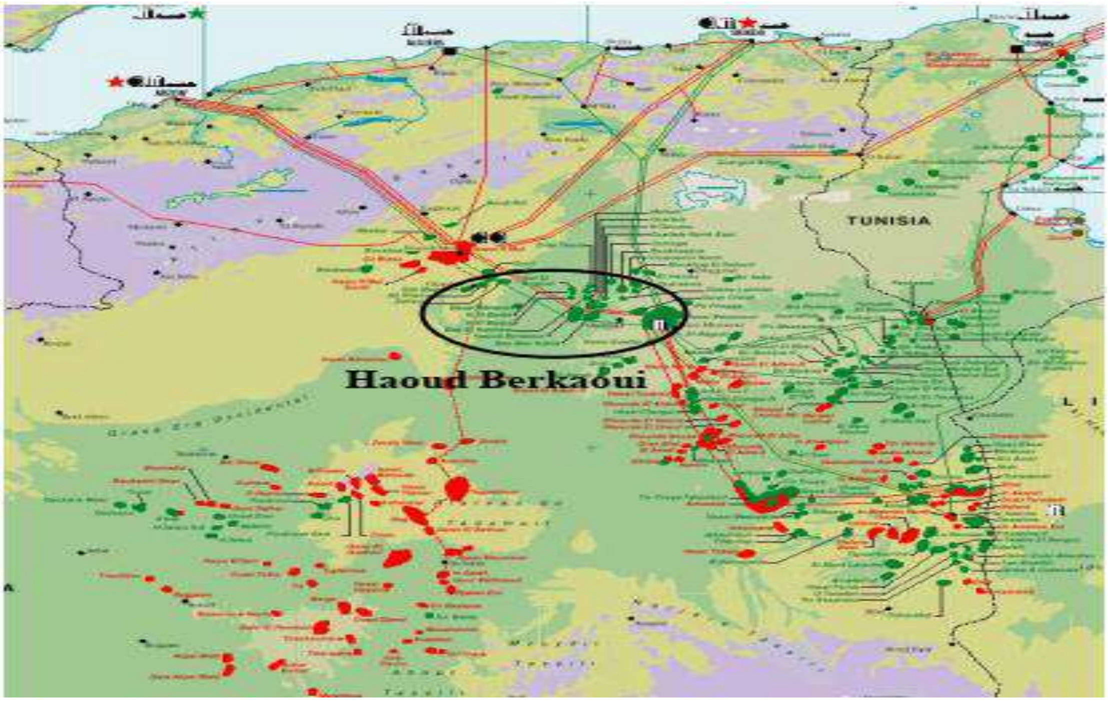


*Figure 19 Location plan of the Haoud Berkaoui regional directorate [18]*

| **Units** | **Date of implementation service** | **Oil ($m^3$/d)** | **Gas (106$Sm^3$/d)** | **Condensate (T/d)** | **GPL(T /d)** |
|---|---|---|---|---|---|
| **HBK** | 1967 | 8000 | - | - | - |
| **BKH** | 1971 | 2880 | - | - | - |
| **GLA** | 1976 | 7500 | - | - | - |
| **GLA (NE)** | 1978 | 2400 | - | - | - |
| **DRT** | 1979 | 1200 | - | - | - |
| **GTU (GLA)** | 1993 | - | 1236 | 90 | 228 |

*Table 2 Processing Capabilities [18]*

| **Units** | **Oil ($m^3$)** | **Condensate ($m^3$)** | **LPG ($m^3$)** |
|---|---|---|---|
| **HBK** | 13000 | - | - |
| **BKH** | - | - | - |
| **GLA (NE)** | 15000 | - | - |
| **GLANE** | 150 | - | - |
| **DRT** | 150 | - | - |
| **GTU (GLA)** | - | - | 2x 1700 |

*Table 3 Storage capacities [18]*

## b) DESCRIPTION OF THE GUELLALA PRODUCTION CENTER:

“In 1992, the GTU GUELLALA gas processing plant was commissioned with the aim of recovering associated gases resulting from the separation of high, medium and low pressure crude oil from the HBK, GLA and BKH fields. Instead of being flared, these gases are re-injected into the wells.

*Figure 20 Picture of GTU / GUELLALA from above [18]*

- **Date of commissioning:**
  - Oil treatment unit in 1976.
  - GTU gas in 1992.

- **Activities:**

- Oil treatment, separation, storage and raw shipping.
- Gas treatment, compression, separation, drying, cooling, Fractionation (C5), storage (C3+), LPG shipping (C3+).
- Oily water treatment.

- **Storage capacities:**

- Fixed roof tank at atmospheric pressure (4x5000$m^3$).
- LPG sphere (2x1700$m^3$).

- **Storage conditions:**

- Atmospheric pressure for crude.

- 11 bars and 30°c for LPG.

- **Main facilities:**
- Oil separation and treatment units.
- Guellala gas treatment unit + RGA station.
- Boosting units.
- Water injection unit.
- De-oiling stations.
- Storage and shipping.
- **Production capacity:**
- Crude 1424 (t/d)
- LPG 228 (t/d)” [19]

*Figure 21 Picture of GTU / GUELLALA [19]*

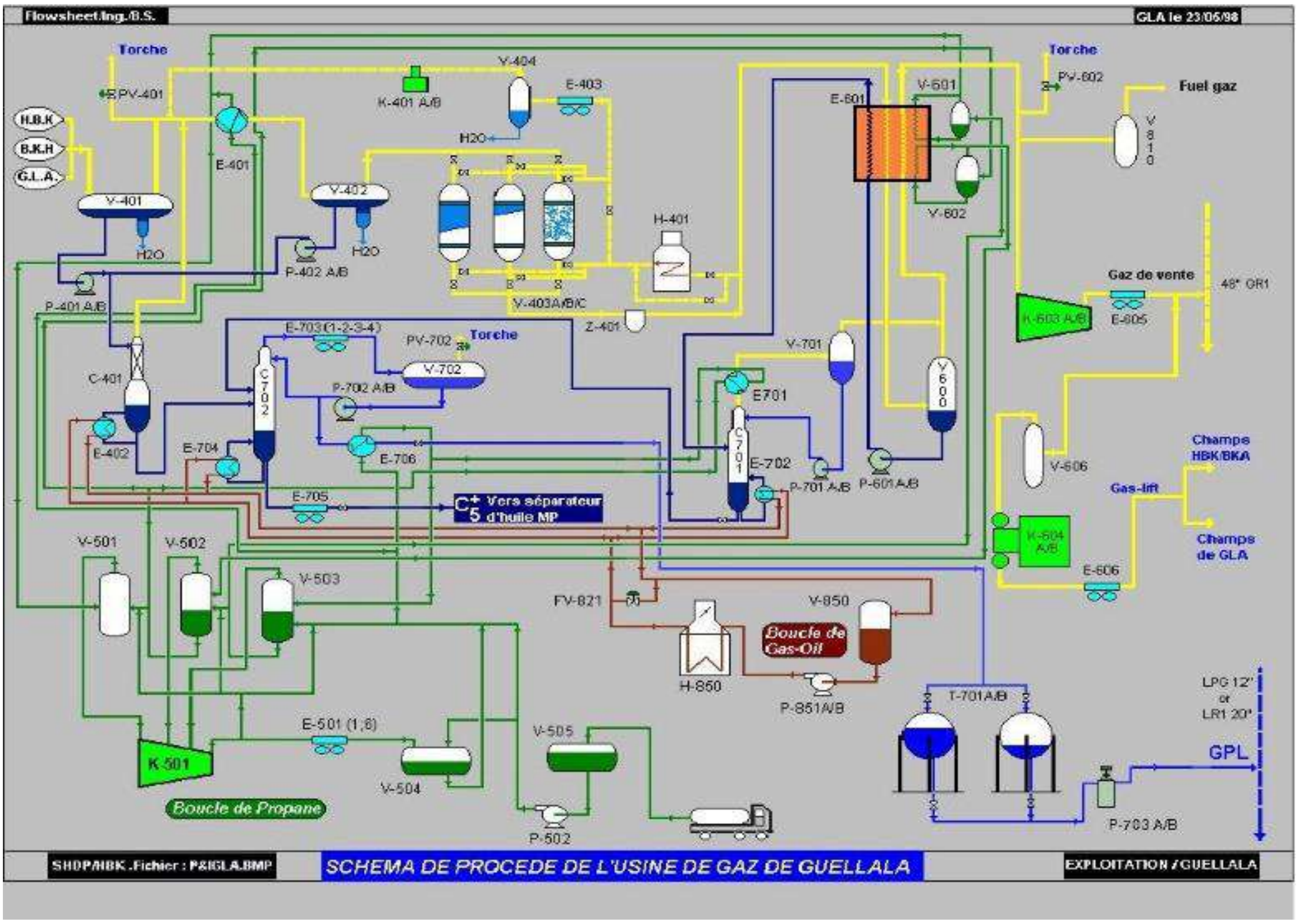


*Figure 22 Guellala gas treatment unit PID diagrams [20]*

# 2) LPG Storage System:

## a) Storage system components:

❖ *Two LPG storage sphere :*

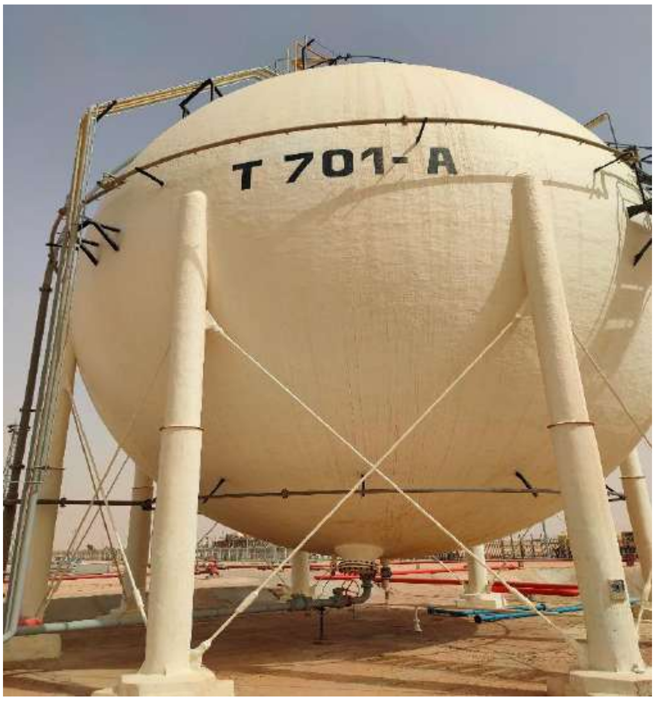


*Figure 24 picture of sphere T 701-A*


*Figure 23 picture of sphere T 701-B*

| | |
|---|---|
| Fluids | LPG |
| Calculation pressure | 12.3BarG |
| Temperature calculation | 70°C |
| Max service pressure | 11BarG |
| Operating temperature | 45°C |
| Thicknesses | 27.5 / 29 / 30.5 mm |
| Corrosion allowance | 1.5 mm |
| Volume | 1697.4$m^3$ |
| Empty weight | 218000 Kg |
| Total weight | 1916000 Kg |

*Table 4 sphere T 701(A-B) characteristics[21]*

❖ *Two electric pumps:*

*Figure 25 LPG  pumps (P 703A-B)*

| | |
|---|---|
| Capacity | 65.4 $m^3$/h |
| Height | 878 m |

*Table 5 Pumps  P 703(A-B) characteristics [22]*

## b) Storage System P&IDs:

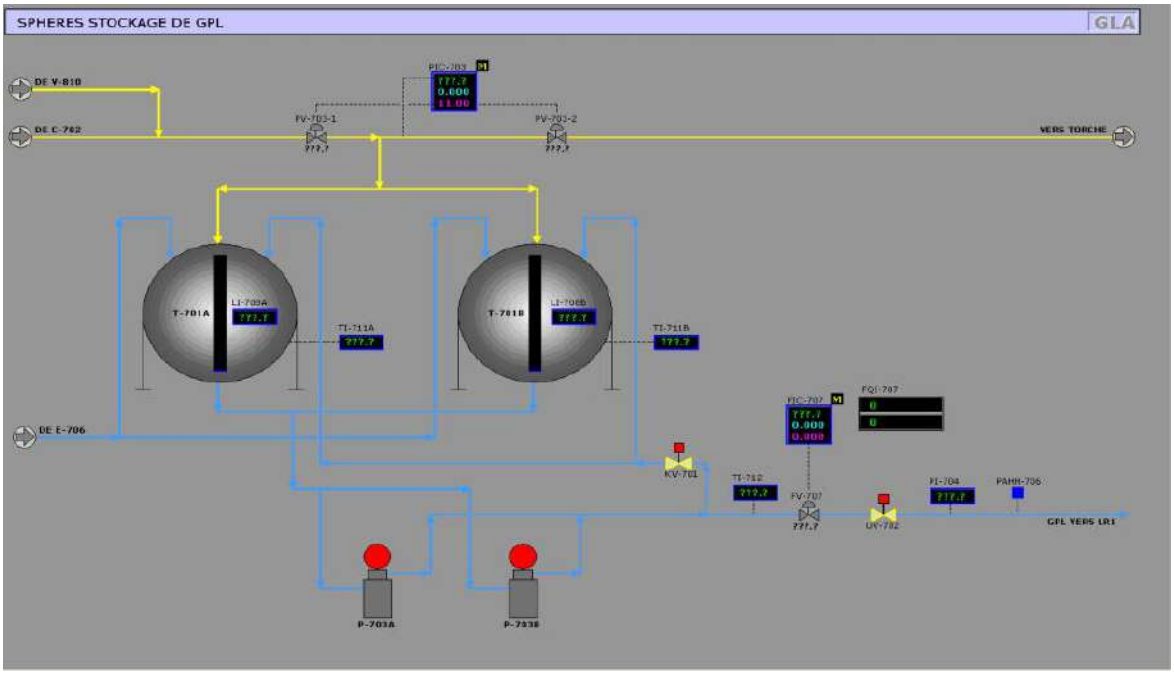


*Figure 26 System diagram from controlling room [23]*

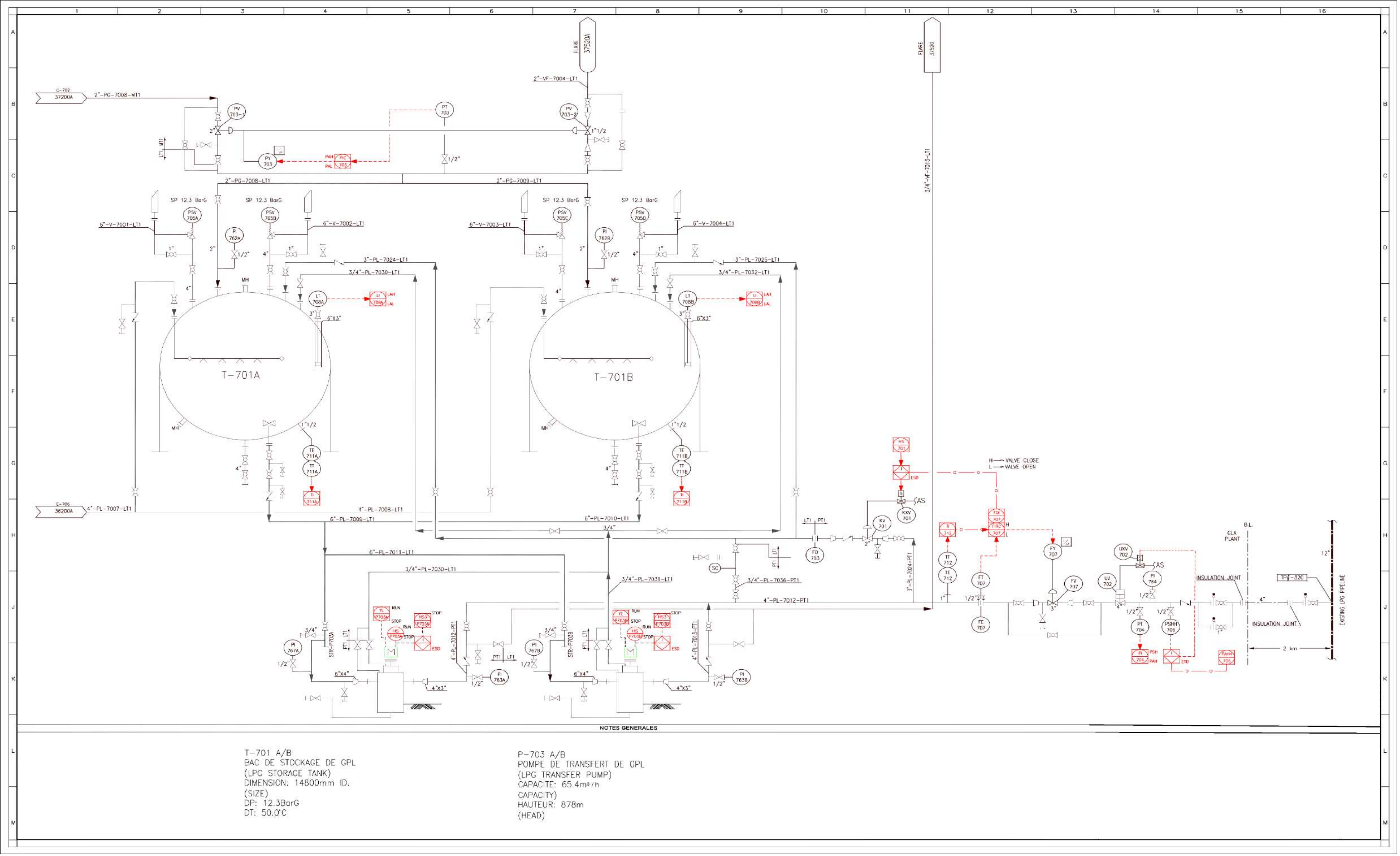


*Figure 27 Storage System P&IDs [22]*

| Type of system function | The purpose of the function |
|---|---|
| Filling | LPG storage at sphere T701 (A and B). |
| Recycling | Protection of the pipeline from the increase in pressure.<br>The sphere is safeguarding against a decrease in pressure. |
| Dispatch | Injection of LPG to the existing LPG pipeline. |

*Table 6 LPG storage system states*

## c) Existing means of security:

### ❖ *PSV (pressure safety valve):*

There are two PSV above the sphere with a bypass for each, which opens at a pressure of 12.3 bar.

*Figure 28 PSV above the sphere*

### ❖ Fireproofing:

“Fireproofing is a layer of paint or concrete that resists flames for a well-defined period.

This fireproofing can ensure a protection:

• Along the implementation time of the deluge system.

• Areas of the structure not soaked of water.

• In case of system failure deluge.

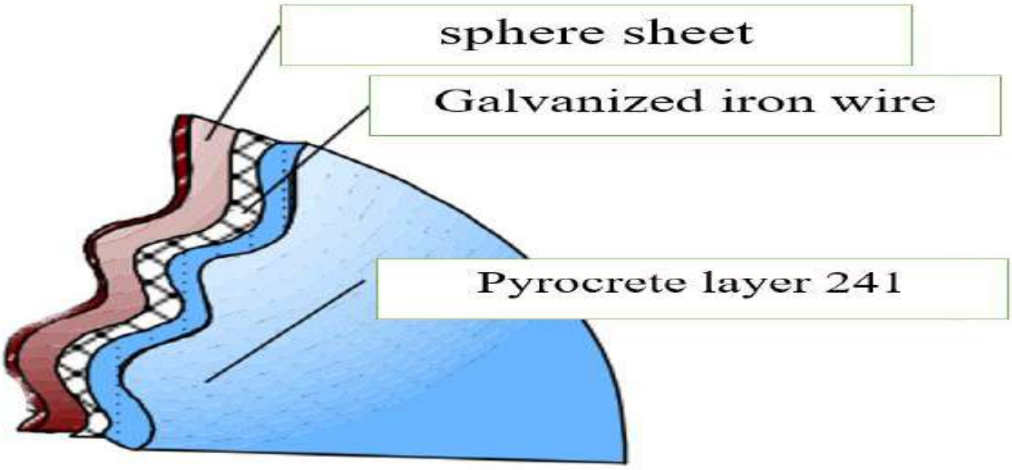


*Figure 29 the sphere fireproofing [16]*

❖ *Fire and gas detectors:*

➢ **Gas detection:**

One of the protections against risk of LPG leakage is gas detection.

• Point gas detectors: installed near sources leaks (flange seal, mechanical seal) or a heat sources (motors, furnaces).

• Linear gas detectors: usually installed in storage areas.

*Figure 30 GID [16]*

### ❖ *Water deluge system:*

The purpose of the deluge system is to preserve the integrity of the equipment she protects against thermal radiation from a nearby disaster. Commissioning can be automatic or manual.” [16]

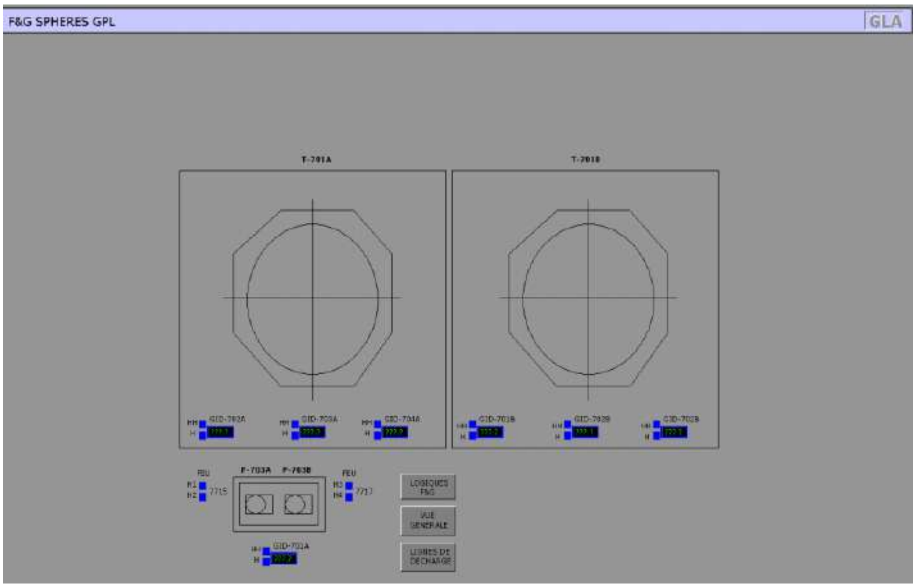


*Figure 31 Water deluge system diagram [23]*


*Figure 32 Sphere T 701-B*

# 3)HAZOP method application:

- Company: Sonatrach.
- Facility: LPG storage Tank (T-701 A/B).
- Drawing: 8578-GLA-PID-DW-37300A.

| Parameter | Guide Word | Deviation | Causes | Consequences | Safeguards |
|---|---|---|---|---|---|
| Pressure | More | Higher pressure | -PV- 703-1 failure open, PV -703-2-failure close & Manual valve bypass PV- 703-2 failure close. | -Excessive overpressure in T-701A.<br>-Possible damage of equipment.<br>-Possible rupture of T-701A (possible BLEVE explosion). | -Alarm PAH-703 & Operators.<br>-PI-762A.<br>-PSV-705A/B. |
| | | | - External fire around T-701A. | | -PIC-703A loop & Operators.<br>-Alarm PAH-703.<br>-Fireproofing.<br>-Water deluge system.<br>-PSV-705A/B. |
| | | | - Manual valve of T-701A flare line maloperation close | | -PSV-705A/B. |

| | | | | | |
|---|---|---|---|---|---|
| | | | during the filling operation. | | |
| | Less | Lower pressure | -PV-703-1 failure close & PV-703-2 failure open. | -Excessive evaporation of LPG.<br>-Possible P-703A/B cavitation and damage (during shipment).<br>-Possible off-spec product. | -Alarm PAL-703 & Operators.<br>-PI-762A. |
| | | | -PSV -705 A/B failure open. | | - PIC-703A & Operators.<br>-PI-762A. |
| | | | - Manual valve of T-701A flare line maloperation close during shipment operation (Human error). | | -PI-762A. |
| Level | More | Higher Level | - Manual valve of T-701A filling line failure open. | -LPG overfilling in T-701A.<br>- Possible flare damage.<br>- Possible rupture & BLEVE. | -Alarm LAH-708A & Operators.<br>-LT-708A.<br>- PSV-705A/B. |
| | | | - Level transmitter LT-708A failure. | | -Operators.<br>- PSV-705A/B. |
| | Less | Lower Level | - Manual valve of T-701A shipment line maloperation open. | - Lower level of LPG in T-701A.<br>- Possible P-703A/B cavitation & damage. | -Alarm LAL-708A & Operators.<br>-LT-708A. |
| | | | - Level transmitter LT-708A failure. | | -Operators. |
| Temperature | More | Higher Temperature | -External fire around T-701A. | -Excessive evaporation of LPG.<br>-Excessive overpressure in T-701A.<br>-Possible equipment damage.<br>- Possible rupture (possible BLEVE explosion). | -TI-711A.<br>-PIC-703A.<br>-Alarm PAH-703.<br>-Operators.<br>-PI-762A<br>-Fireproofing.<br>-Water deluge system.<br>-PSV-705A/B. |
| | | | -LPG cooler E-706 stop. | | -TI-711A.<br>-PIC-703A & Operators.<br>-PI-762A.<br>-PSV-705A/B. |

| | | | | | |
|---|---|---|---|---|---|
| | Less | Lower Temperature | No significant cause identified. | | |

*Table 7 HAZOP method*

# 4) Application of <<Bow Tie>> on a selected scenario:

In this study it was decided to adopt the scenario "Loss of confinement".

- *Events and their abbreviations:*

| Events | Abbreviations |
|---|---|
| Small external fire around T-701A. | EX |
| PIC-703A loop failure. | PIC |
| Alarm failure. | AF |
| Human error. | HE |
| PSV-705A/B failure close. | RV |
| Water deluge system failure. | WDS |
| PV-703-1/2 failure. | PV |
| Internal failure of manual valve by-pass PV-703-2. | IF-1 |
| LPG cooler E-706 stop (internal failure). | IF-2 |
| Internal failure of manual valve of T-701A filling line. | IF-3 |
| Level transmitter LT-708A failure (internal failure). | IF-4 |
| Instant ignition. | Ii |
| Delayed ignition. | Di |
| Loss of confinement. | LC |
| Overheat. | OH |
| Overpressure. | OP |
| High level (LPG overfilling in T-701A). | HL |
| PAH-703A & operators failure. | PAO |
| Control valves failure. | CVF |
| Manual valve by-pass PV-703-2 failure close. | BP |
| Level increase. | LI |
| Manual valve of T-701A filling line failure open. | FIL |
| LAH-708A & operators failure. | LAO |

*Table 8 Events and their abbreviation*

❖ *Probability of Failure on Demand (PFD) of events:*

| Events | PFD | Source |
|---|---|---|
| EX | $10^{-2}$ | Layer of Protection Analysis SIMPLIFIED PROCESS RISK ASSESSMENT. |
| PIC | $10^{-1}$ | |
| AF | $10^{-3}$ | L'ANALYSE DE RISQUE FRÉQUENCE DES ÉVÉNEMENTS INITIATEURS D'ACCIDENT GROUPE D'ÉCHANGE "FRÉQUENCE DES ÉVÉNEMENTS". |
| HE | $10^{-1}$ | |
| RV | $10^{-2}$ | |
| WDS | $10^{-2}$ | |
| PV | $10^{-1}$ | |
| IF-1 | $5.36\times10^{-2}$ | Nonelectronic Parts Reliability Data 1995. New York, Reliability Analysis Center, Griffiss AFB. |
| IF-2 | $10^{-1}$ | Glenn G. Young & Glenn S. Crowe, Modifying LOPA for Improved Performance. |
| IF-3 | $5.36\times10^{-2}$ | Nonelectronic Parts Reliability Data 1995. New York, Reliability Analysis Center, Griffiss AFB. |
| IF-4 | $1.98\times10^{-1}$ | Guidelines for Process Equipment Reliability Data. 1989 New York, AIChemE Center for Chemical Process Safety. ISBN 0-8169-0422-7 |
| Ii | $7\times10^{-1}$ | Due to INERIS (RAPPORT D'ÉTUDE N° DRA-13-133211-12545A) 22/06/2015. |
| Di | $10^{-1}$ | |

*Table 9 PFD of the possible events*

❖ *Barriers and their abbreviations:*

| Barriers | Abbreviations |
|---|---|
| PIC-703A loop. | SB1 |
| Water deluge system. | SB2 |
| PAH-703A & operators. | SB3 |
| LAH-708A & operators. | SB4 |
| PSV-705A/B. | SB5 |

*Table 10 Barriers and their abbreviations.*

a) Application of Fault Tree analysis (FTA):

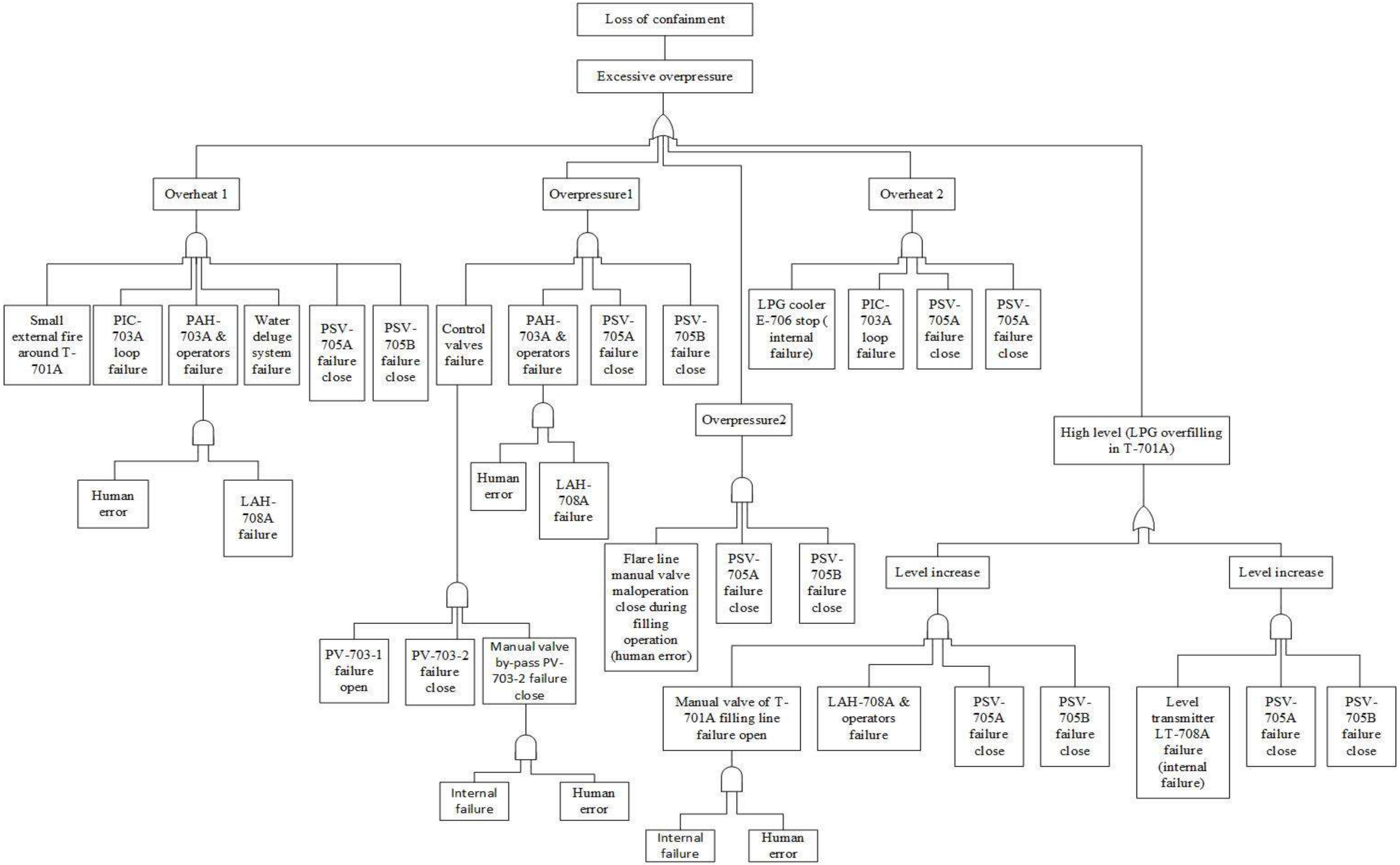


*Figure 33 FTA method*

| Events | The results |
|---|---|
| LC | $2.789\times10^{-5}$ |
| OH1 | $1.009\times10^{-11}$ |
| OH2 | $10^{-7}$ |
| OP1 | $10^{-7}$ |
| OP2 | $10^{-5}$ |
| HL | $2.781\times10^{-5}$ |
| PAO | $1.009\times10^{-1}$ |
| CVF | $1.483\times10^{-3}$ |
| BP | $1.482\times10^{-1}$ |
| LI1 | $10^{-5}$ |
| LI2 | $1.979\times10^{-5}$ |
| FIL | $1.483\times10^{-1}$ |
| LAO | $1.009\times10^{-1}$ |

*Table 11 Intermediates & top event results*

### *Critical Importance (CIF):*

The Critical Importance Factor (CIF) is often called the Fussell-Vesely Importance. CIF indicates the risk associated with a given event, that is, how much the event occurrence is contributing to system failure.

The CIF is defined as:

$$\text{CIF}x(\text{t}) = \frac{qx(t)MIFx(t)}{Q(t)} = \frac{Q(t)-Q(t)|qx=0}{Q(t)}$$

$Q(t)$=System (or Gate) Unavailability.

$qx(t)$=Unavailability of event$x$.

$MIFx(t)$=Marginal Importance Factor.

$Q(t)|qx = 0$ =Unavailability with $qx = 0$

| Element | Critical Importance |
|---|---|
| RVA | 100,00% |
| RVB | 100,00% |
| IF4 | 63,80% |
| HE | 28,73% |

| | |
|---|---|
| IF2 | 0,26% |
| PV1 | 0,00% |
| PV2 | 0,00% |
| IF3 | 0,01% |
| IF1 | 0,00% |
| PIC | 0,26% |
| EX | 0,00% |
| WDS | 0,00% |
| AF | 0,01% |

*Table 12 Importance of elements*

**Note:**

The most critical element and effective on the system is RVA RVB (Relive valve) from the results that say the importance is 100%, and if we suppose that its availability is one then it will make a safety condition and an effective protection to the system.

| Minimal Cut Set | Order | Unavailability | Contribution |
|---|---|---|---|
| IF4.RVA.RVB | 3 | $1,98.10^{-5}$ | 66,20% |
| HE.RVA.RVB | 3 | $1.\ 10^{-5}$ | 33,45% |
| IF2.PIC.RVA.RVB | 4 | $1.\ 10^{-7}$ | 0,33% |
| AF.IF3.RVA.RVB | 4 | $5,36.10^{-9}$ | 0,02% |
| AF.IF1.PV1.PV2.RVA.RVB | 6 | $5,3610^{-11}$ | 0,00% |
| AF.EX.PIC.RVA.RVB.WDS | 6 | $1.\ 10^{-13}$ | 0,00% |

*Table 13  Minimal cuts*

## b) Application of Events Tree analysis (ETA):

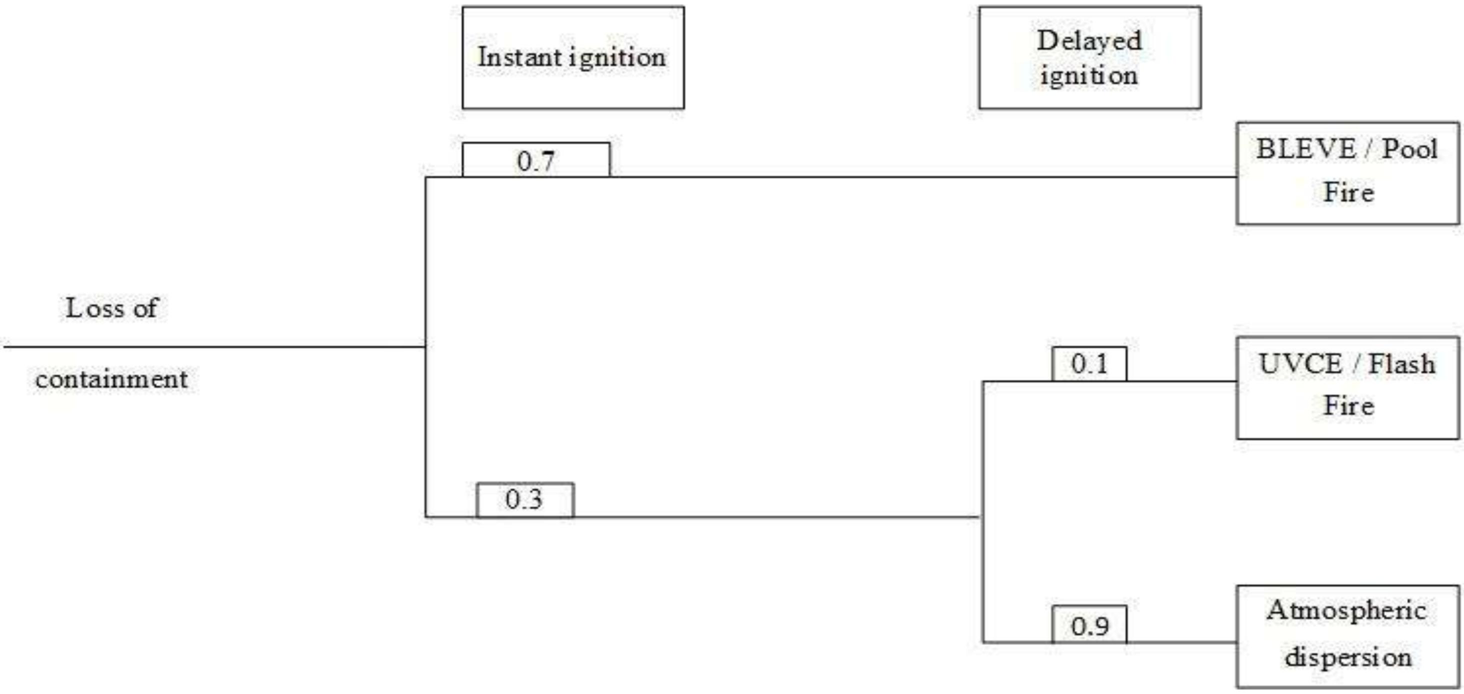


*Figure 34 ETA method*

### ETA results:

F (BLEVE) = 2.78864*$10^{-5}$*0.7=1.95204*$10^{-5}$/y

F (UVCE/Flash fire) = 2.78864*$10^{-5}$*0.3*0.1 = 8.36592*$10^{-7}$/y

F(ATM dispersion) = 2.78864*$10^{-5}$*0.3*0.9 = 7.52932*$10^{-6}$/y

### Interpretation:

The possibility of dangerous phenomena is less because the Top Event frequency is permissible and not high due to the good contribution to the protective barriers.

c) Simplified Bow Tie analysis:

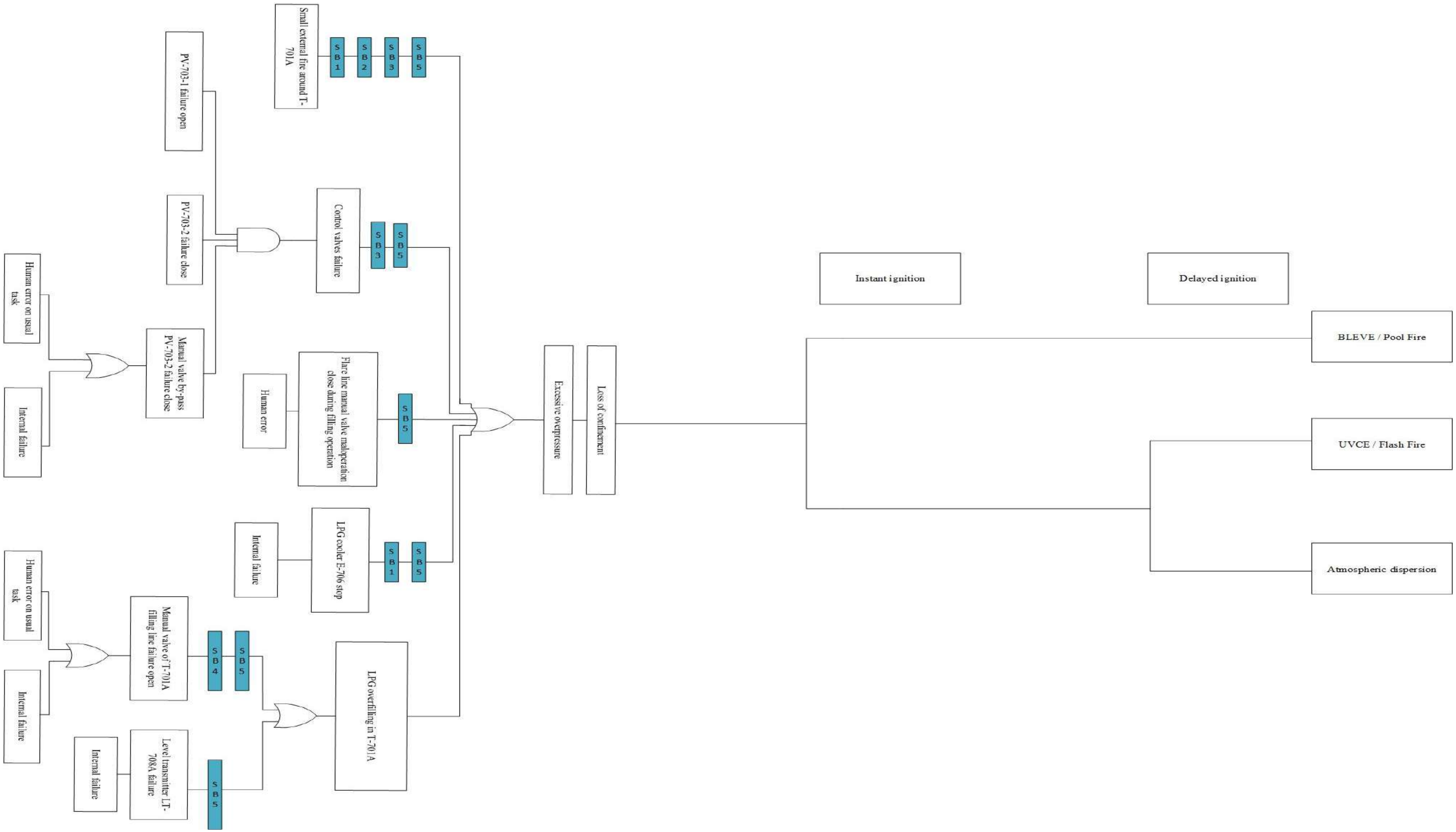


*Figure 35 Simplified Bow Tie analysis*

## d) Bow Tie analysis:

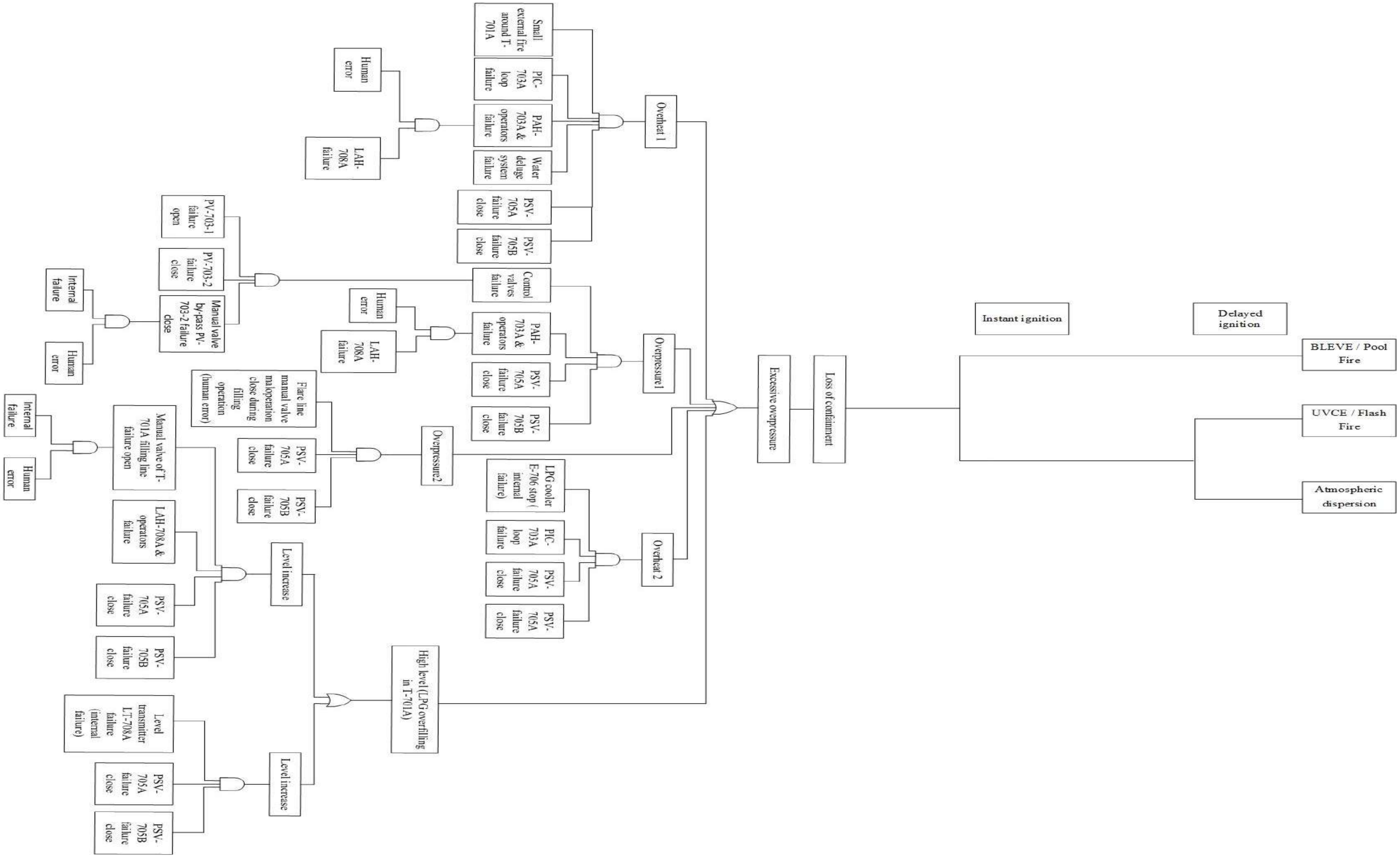


*Figure 36 Bow Tie analysis*

# Sources:


[1] BOW TIES IN RISK MANAGEMENT A Concept Book for Process Safety, CENTER FOR CHEMICAL PROCESS SAFETY OF THE.
[2] Project Management Institute. (2017). A Guide to the Project Management Body of Knowledge (PMBOK® Guide) – Sixth Edition.
[3]https://www.fiixsoftware.com/glossary/fault-tree-analysis/
[4]System Reliability Theory Models, Statistical Methods, and Application
[5]The bowtie method: A review (Markowski et al. (2009)
[6] Health and Safety Executive (HSE). (2018). Bowtie Methodology: A Review and Recommended Good Practice. Retrieved from https://www.hse.gov.uk/research/rrpdf/rr1146.pdf
[7] https://www.infoqualite.fr/methodologie-dattenuation-des-risques-bowtie-ou-noeud-papillon/
[8] HSE. (2018). Bowtie Methodology: A Review and Recommended Good Practice.
[9] Van der Schalk, J., & de Kort, J. (2017). Comparison of risk assessment methodologies used in the process industries. Safety Science, 97, 60-76.
[10] Reason, J. (2008). The human contribution: unsafe acts, accidents and heroic recoveries. Ashgate Publishing.
[11]https://www.eia.gov/tools/glossary/index.php?id=Liquefied%20petroleum%20gases%20%28LPG%29#:~:text=Liquefied%20petroleum%20gases%20(LPG)%3A,be%20marketed%20individually%20or%20mixed.
[12] Laboratoire de GTU / GUELLALA.
[13] Azeez, S. A. (2016). "Comparison of Performance Characteristics of LPG and Gasoline - Fuelled Single Cylinder SI Engine." Tikrit Journal of Engineering Science 23: 96-104.

[14]elgas company https://www.elgas.com.au/welcome-to-elgas/lpg-exceptional-energy/
[15]MECHANICALFUNDA https://www.mechanicalfunda.com/2020/07/advantages-disadvantages-lpg.html
[16] SONATRACH, Direction Régionale de Rhourde Nouss, Division Sécurité (Les risque des GPL / A, Remini / Décembre 2005)
[17] https://monde.ccdmd.qc.ca/ressource/?id=127072&demande=desc
[18] Rapport EDD Haoud Berkaoui.
[19] Manuel sécurité GLA.
[20] Rapport de stage.
[21] Sphere nameplate.

[22]Storage System P&IDs.

[23] ABB LSTK-SONATRACH GLA (Pages graphiques).