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RISK ASSESSMENT IN THE DEBUTANIZER AND ON-SPEC CONDENSATE STORAGE UNIT

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ÉVALUATION DES RISQUES DANS L'UNITE DE DEBUTANISEUR ET DE STOCKAGE DE CONDENSAT CONFORME

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Table of Contents :

General Introduction 01

CHAPTER I : DESCRIPTION OF THE TIGUENTOURINE GAS PROCESSING PLANT

Introduction:.....03

I.1. Geographical Location:..... 04

I.2. Presentation of the SH-ENI-EQUINOR Partnership 04

I.3.Company organization:.....06

I.3.6 HSE Division (Health, Safety, and Environment): 07

I.4. Process Overview – Gas and Condensate Treatment Facility: 08

I.5. Safety (HSE): 12

I.5.1.Measures include..... 13

I.5.2. HSE Objectives 13

I.5.3 HSE Charter:..... 13

I .5.3.1 Your rights include: 13

I .5.3.2 The In Amenas Project Counts on You To.....14

I.5.4.Life-Saving Rules..... 14

Conclusion 16

Chapter II: Risk Assessment

Introduction..... 17

II.1.Definition:..... 18

II.2. Task Risk Assessment: 20

II.2.1.LEVELS OF Task Risk Assessment: 21

II.2.2. ORA (Operational Risk Assessment): 22

II.2.3. Roles And Responsibilities: 22

II.2.4. Fire Zones: 23

II.2.5. Fire & Gas System: 23

II.2.6. Fire And Gas Detectors: 24

II.3. Hydrocarbon-Related Hazards: 26

II.3.1.Health Risks Associated With Hydrocarbons:.....26

II.3.2. Environmental Risks Associated With Hydrocarbons: 27

II.3.3. Economic Implications And Risks Associated With The Hydrocarbon Industry: 28

Conclusion: 29

CHAPTER III:RISK ANALYSIS AND EVALUATION METHODS

Introduction..... 30

III. 1.Risk Analysis and Evaluation Methods..... 31

III.1.1. Qualitative Methods..... 31

III.1.2. Semi-Quantitative Methods..... 31

III.1.3. Quantitative Methods..... 32

III .2 The Complementarity of Risk Analysis Methods..... 32

III .3 Preliminary Hazard/Risk Analysis (PHA/APR)..... 34

III .4 Failure Modes, Effects, and Criticality Analysis (FMEA/AMDEC)..... 34

III .5 Fault Tree Analysis (FTA/ADD)..... 35

III .6 Event Tree Analysis(ETA/ADE)..... 36

III .7 HAZOP Method (Hazard & Operability Study).... 37

III .7.1 Principle of the HAZOP Method.... 37

III .7.2 Steps of the HAZOP Method. 38

III .7 .3 HAZOP Sequence... 39

III .7.4 HAZOP Formalism... 40

III .7.5 Advantages of the HAZOP Method..... 41

III .8 Layer of Protection Analysis (LOPA) 42

III .8 .1 What is layer of protection analysis (LOPA).... 42

III .8 .2Protection layers..... 42

III.8.3 Independent protection layers (IPLs): 43

III.8.4Layer of protection analysis (LOPA) application..... 44

III.8.5 Layer of protection analysis (LOPA) study team..... 46

III.8.6Layer of protection (LOPA) method steps..... 48

III.8.7Advantages and limitations..... 49

Conclusion 52

CHAPTER IV :HAZOP &LOPA Method Application

Introduction..... 53

IV.1 Deviations..... 54

IV.2 Drawings..... 55

IV.3 Risk Ranking..... 61

IV.4 Recommendations..... 61

Conclusion..... 80

General Conclusion 81

References

Annexes

List of Figures

Figure I.1 The 6 Divisions Within In Amenas----------06

Figure I.2. The HSE Division----------07

Figure I.3.Life Saving-Rules ----------15

Figure II.1.Task Risk Assessement ----------20

Figure III.1 Sequential Use of Various Risk Analysis Methods----------32

Figure III.2 : Sequential Use of Various Risk Analysis Methods----------33

Figure III.3 **:** HAZOP sequence----------40

Figure III.4 : Examples of safeguards (protection layers)----------43

Figure IV**.**1**:** P&ID DC-PS-01-23-21175- REV Z15----------56

Figure IV**.**2**:** P&ID DC-PS-01-23-21174- REV Z09----------57

Figure IV**.** 3:P&ID DC-PS-01-23-21177- REV Z08----------58

Figure IV**.**4**:** P&ID DC-PS-01-22-21170- REV Z13----------59

Figure IV **.**5**:** P&ID DC-PS-01-22-21448- REV Z08----------60

List of Tables

Table II.1: Two Types Of Work Permits.....21

Table III.1: FMEA Formalism. 35

Table III .2: HAZOP Formalism.....40

Table IV.1: Deviations**:** 54

Table IV.2: Drawings**:** 55

Table IV.3 : Team Members. 61

Table IV.4 : Master HAZOP Worksheet. 62

Table IV.5: Master LOPA Worksheet**:** 71

Lists Of Annexes :

Annexe03: Likelihood Of Risk Event

Annexe02: Risk Framework – Business Impact Levels

Annexe01: Risk Framework -HSE Impact Levels

Annexe 4: Overview of PHA-Pro Software.

List of Abbreviations:

Abbreviation	English Meaning	French Equivalent
HSE	Health, Safety and Environment	Santé, Sécurité et Environnement
TRA	Task Risk Assessment	Évaluation des Risques de Tâches
PTW	Permit To Work	Permit de Travail
ORA	Operational Risk Assessment	Evaluation des Risques Opérationnels
ESD	Emergency Shutdown	Arrêt d'Urgence
ESDV	Emergency Shutdown Valve	Soupape d'Arrêt d'Urgence
BDV	Blowdown Valve	Soupape de Décharge
HAZOP	Hazard and Operability Study	Étude des Risques et de la Fonctionnalité
LOPÄ	Layer of Protection Analysis	Analyse des Couches de Protection
IPL	Independent Protection Layer	Couche de Protection Indépendante
SIL	Safety Integrity Level	Niveau d'Intégrité de Sécurité
FSC	Fail Safe Control	Système de Sécurité à Échec Sécurisé
FMEA/AMDEC	Failure Modes and Effects Analysis	Analyse des Modes de Défaillance, de leurs Effets et de leur Criticité
FTA/ADD	Fault Tree Analysis	Analyse Arborescente de Défaillances
ETA/ADE	Event Tree Analysis	Analyse Arborescente d'ÉvénementS
PHA/APR	Preliminary Hazard Analysis	Analyse Préliminaire des RisqueS
CPF	Central Processing Facility	Installation Centrale de Traitement
TA	Technical Authority	Autorité Technique
PA	Performing Authority	Autorité Exécutante
AA	Area Authority	Autorité de Zone
AO	Area Owner	Responsable de Zone

IA	IN AMENAS	In Amenas (site industriel algérien)
SIF	Safety Instrumented Function	Fonction Instrumentée de Sécurité
TMEL	Tolerable Maximum Event Likelihood	Probabilité Maximale Tolérable d'un Événement
C&E	Cause and Effect (diagrams)	Schémas Causes et Effets
P&ID	Piping and Instrumentation Diagram	Schéma de Tuyauterie et d'Instrumentation
HVAC	Heating, Ventilation and Air Conditioning	Chauffage, Ventilation et Climatisation
CCTV	Closed Circuit Television	Caméra de Surveillance Vidéo
IR/UV	Infrared/Ultraviolet Detectors	Détecteurs Infrarouge/Ultraviolet
VESDA	Very Early Smoke Detection ApparatuS	Appareil de Détection Très Précoce de Fumée
TAR	Turnaround	Arrêt Technique Planifié
ETA	Estimated Time of Arrival	Temps Estimé d'Arrivée

Abstract

This master's thesis presents a comprehensive risk assessment conducted on the Debutanizer and On-Spec Condensate Storage Unit within a hydrocarbon production facility. The study focuses on identifying potential hazards, evaluating their severity, and proposing effective mitigation measures to ensure the safety of personnel, equipment, and the environment. The research begins with a theoretical overview of industrial risks, followed by a detailed analysis of the unit in question. Risk assessment tools such as Task Risk Assessment and Permit to Work systems were employed to evaluate operational dangers associated with handling flammable and toxic substances.

Additionally ,the study explores the broader impacts of hydrocarbon-related risks: Environmental, Human, Economic

The findings highlight the necessity of implementing technical, organizational, and procedural safety measures. Emphasis is also placed on fostering a proactive safety culture and integrating continuous monitoring systems

This work contributes to enhancing industrial risk management strategies and encourages the adoption of safer practices in the hydrocarbon sector.

Keywords: Risk assessment , safety ,HAZOP ,LOPA

Résumé

Ce mémoire de master présente une évaluation approfondie des risques réalisée sur l'unité de déséthanisation (Debutanizer) et de stockage des condensats conformes dans une installation de production d'hydrocarbures. L'étude vise à identifier les dangers potentiels, évaluer leur gravité et proposer des mesures de prévention et de protection adaptées afin d'assurer la sécurité du personnel, des équipements et de l'environnement.

Une approche méthodique a été adoptée, s'appuyant sur des outils comme le Task Risk Assessment et le Permit to Work pour analyser les risques opérationnels liés à la manipulation de substances inflammables et toxiques.

L'étude examine également les impacts globaux des risques liés aux hydrocarbures :Environnementaux, Humains, Économiques.

Les résultats démontrent l'importance de mettre en œuvre des mesures techniques et organisationnelles solides, et d'ancrer une culture de sécurité proactive dans les pratiques industrielles.

Ce travail contribue à renforcer les stratégies de gestion des risques industriels et encourage l'adoption de pratiques plus sûres dans le secteur des hydrocarbures.

Mots-Clés : Évaluation des risques , Sécurité ,HAZOP ,LOPA .

الملخص

يتناول هذا البحث تقييمًا شاملًا للمخاطر في وحدة نزع البيوتان وتخزين المكثفات المطابقة للمواصفات ضمن منشأة لإنتاج الهيدروكربونات. يهدف هذا العمل إلى تحديد الأخطار ألمحتملة تقييم خطورتها، واقتراح حلول مناسبة للتقليل منها وضمان سلامة الأفراد والمعدات والبيئة.

اعتمدت الدراسة على أدوات تحليل معروفة مثل تقييم مخاطر المهام و تصريح العمل من اجل فهم و تقدير المخاطر التشغيلية الناتجة عن التعامل مع المواد القابلة للاشتعال والسامة .

كما تناولت الدراسة تأثيرات المخاطر المرتبطة بالهيدروكربونات على البيئة ،الانسان،الاقتصاد.

اظهرت النتائج ضرورة تدابير وقائية و تقنية و تنظيمية فعالة ، مع تعزيز ثقافة السلامة فهي جزء لا يتجزأ من بيئة العمل الصناعية.

يسهم هذا العمل في تعزيز استراتيجيات إدارة المخاطر الصناعية ويُشجّع على اعتماد ممارسات أكثر أمانًا في قطاع الهيدروكربونات

الكلمات المفتاحية : تقييم المخاطر ،السلامة ، دراسة المخاطر وقابلية التشغيل (هازوب) ، تحليل طبقات الحماية (لوبا).

General Introduction

General introduction

In the context of the industrial sector, particularly within oil and gas facilities, ensuring safety and managing risks have become imperative for protecting workers, assets, and the environment. This master's thesis focuses on a comprehensive risk assessment conducted on the Debutanizer and On-Spec Condensate Storage Unit located in the Tiguentourine gas processing site, a strategic component of Algeria’s energy infrastructure.

The study aims to systematically identify hazards associated with the handling of hydrocarbons, evaluate their impact across multiple dimensions — health, environmental, and economic — and implement effective control measures. By using established safety methodologies such as Task Risk Assessment (TRA), Hazard and Operability Study (HAZOP), and Layer of Protection Analysis (LOPA), the research enhances understanding of operational risks and improves decision-making for safer operations.

The research is grounded in real-world data and industrial practices. It not only identifies deviations and failure points but also recommends improvements that contribute to sustainable and safe plant management. This work reinforces the importance of fostering a proactive safety culture within industrial operations, especially in high-risk environments such as oil and gas processing facilities.

Problem Statement

Despite advancements in industrial safety protocols, oil and gas processing units remain inherently hazardous due to the nature of the materials handled. In the Debutanizer and On-Spec Condensate Storage Unit, multiple operational and environmental risks persist — from fire and explosion to chemical exposure and system failures.

So ,The central problem addressed in this thesis is:

How can a comprehensive, integrated risk assessment methodology be applied to effectively identify, evaluate, and mitigate the complex risks present in hydrocarbon processing operations, specifically in the Debutanizer and condensate storage systems?

CHAPTER I :

DESCRIPTION OF THETIGUENTOURINE GAS PROCESSING PLANT

Introduction:

In this chapter, we present the TIGUENTOURINE gas site, highlighting the importance of its production capacity and its ability to process wet gas through the various treatment sections at the CPF. This includes the initial stages of fluid collection and reception (Trunk-Lines, Admission Manifold, Slug-Catcher), followed by the new gas compression system (Boosting), then the three treatment trains, and finally the storage and dispatch section. And the importance of the HSE in the site to ensure the security of workers.

I.1. Geographical Location:

The In Amenas region falls under the administrative authority of the Illizi Wilaya:

• It is positioned 1,600 km southeast of Algiers, 820 km from Ouargla, and 240 km to the northeast of Illizi.

• The TIGUENTOURINE gas site is located 60 km southwest of In Amenas, about 100 km from the Libyan border.

I.2. Presentation of the SH-ENI-EQUINOR Partnership (formerly SH-BP-STATOIL) :

The Tiguentourine field has been jointly operated since 2006 by the British oil and gas company BP, the Norwegian company Equinor, and the Algerian state-owned oil company Sonatrach. These companies formed a strategic partnership to explore, develop, and extract natural gas resources in the region.

The gas extracted from the Tiguentourine field is transported to the In Amenas Gas Treatment Center via a collection network with a capacity of 30 million standard cubic meters per day. From there, it is transferred to Sonatrach's distribution network through three dedicated pipelines.

This partnership between Sonatrach, BP, and Equinor serves as an example of international collaboration in the energy sector, combining the expertise and resources of different companies to maximize the efficiency and exploitation of the region's natural resources.

Since September 2022, Eni’s acquisition of BP's operations in Algeria, including those in the gas fields near In Amenas, has marked a significant shift in the country’s energy sector. As the main operator of the Tiguentourine gas field, Eni brings its expertise, technology, and commitment to operational excellence, driving growth and sustainability in the region and reshaping Algeria's energy landscape

I.2.1. SONTARACH:

Sonatrach, the Algerian national company for the exploration, production, transportation, transformation, and commercialization of hydrocarbons, plays a central role in the country's oil and gas industry. Recognized as a pillar of the Algerian economy, it is involved in every stage of hydrocarbon exploitation, from exploration to the sale of finished products. In addition to its core activities, Sonatrach is also diversifying into sectors such as petrochemicals, electricity production, renewable energy, seawater desalination, and mining.

I.2.2. ENI :

Eni is a leading Italian energy company, founded in 1953. Specializing in the exploration, production, refining, and distribution of oil and natural gas, Eni is renowned for its technological expertise and commitment to energy innovation. The company plays a vital role in global energy security. 1.2.3.

I .2.3 EQUINOR:

Founded in 1972, Equinor, formerly known as Statoil, is the largest company in Norway, with approximately 29,000 employees. Although it is listed on the Oslo Stock Exchange and the NYSE, the Norwegian government retains the majority of the company's shares, holding 70.26%, with 3.26% owned by Folketrygdfondet, the national pension fund. Headquartered in Stavanger, Norway's oil capital, the name Statoil is derived from the combination of "state oil," reflecting its status as a state-owned company.

I.3. Company organization:

There are 6 divisions within the In Amenas organization, as follows:

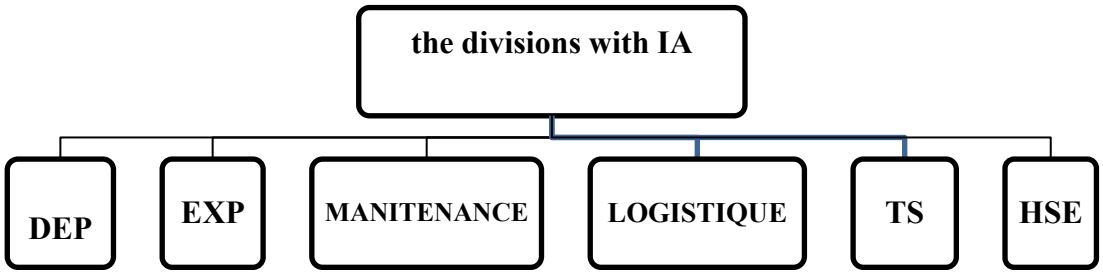


Figure I.1.the 6 divisions within in amenas

I .3.1 DEP Division (Division of Engineering Production):

The Well Operations Division is responsible for the operational management of wells, as well as the production and gathering system. It also ensures the transportation of crude oil to the CPF for processing.

I.3.2 EXP Division (Operations Division):

The Operations Division is responsible for the overall management of the Central Processing Facility (CPF). It ensures the proper functioning of all processing equipment and machinery.

I .3.3 Maintenance Division:

The Maintenance Division, comprising four departments (mechanical, electrical, instrumentation, and planning), is responsible for preparing and executing all mechanical and electrical operations. It operates both within the Central Processing Facility (CPF) and on the gathering system, including the wells, ensuring both preventive and corrective maintenance.

I .3.4 Logistics Division:

The Logistics Division is responsible for providing and ensuring the availability of all necessary resources for operations, including work equipment, transportation, and spare parts.

I .3.5 TS Division (Technical Support):

The Technical Support Division is responsible for monitoring production, preparing performance reports, planning and scheduling shutdowns through the TAR service, studying and managing modifications through the E&M service, and providing multidisciplinary technical support to maintenance through the "Technical Authorities" service.

I.3.6 HSE Division (Health, Safety, and Environment):

Through the implementation of robust policies and practices, the HSE division ensures a safe and conducive working environment for all. To achieve these objectives, the department operates through five essential teams: Prevention, Environment, Intervention, Transportation, and Medical Support. These teams are the pillars of individual protection, minimizing environmental impact, and ensuring effective emergency response. In the following sections of this document, we will take a closer look at each of these teams, exploring their specific functions and contributions.

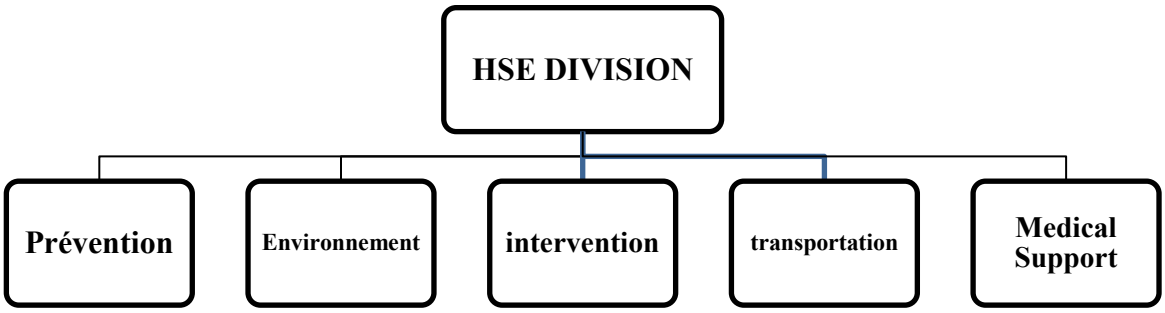


Figure I.2. the HSE division

I .3.6.1 Prevention Service:

The Prevention team plays a key role in maintaining a safe working environment and prioritizing employee well-being. Through proactive measures and unwavering commitment to safety, they foster a culture of safety and mitigate risks. Their efforts help create an environment conducive to employee growth, thus contributing to the overall success of the organization.

I.3.6.2 Intervention Service:

The Intervention team within the IA project holds a critical position in ensuring the safety, well-being, and operational integrity of our site. Committed to upholding the highest standards of health, safety, and environmental protection, the intervention team plays a vital role in emergency response and mitigation. Their diverse responsibilities include providing first aid to injured workers, extinguishing fires, protecting equipment in case of emergency, and responding to chemical spills. The team demonstrates exceptional professionalism, expertise, and preparedness.

I.3.6.3 Environment Service:

The environmental team within the IA project plays a key role in promoting sustainability, environmental management, and the preservation of our natural environment. Committed to adhering to the highest standards of environmental protection and conservation, the team plays a crucial role in mitigating the impact of our operations on the ecosystem. The team takes on a range of responsibilities, actively contributing to environmental preservation.

I.4. Process Overview – Gas and Condensate Treatment Facility:

I.4.1. Reception Facility:

The production fluid arriving from the inlet manifold is first directed to a slug catcher, which performs initial three-phase separation into gas (vapor), liquid hydrocarbons, and produced water. This unit also acts as a buffer, managing flow fluctuations and temporarily storing liquids caused by surges in the gathering system.

• The separated gas is routed under pressure control to the processing trains.

• Liquid hydrocarbons are sent to pre-flash separators at the inlet of each train.

• Produced water is discharged under level control to the degassing vessels of the respective trains

I.4.2. Inlet Gas Cooling and Separation :

The gas from the slug catcher is maintained at around 71.3 bar. In summer, gas temperatures can rise to 82°C and are reduced to 60°C using an air cooler. During winter, with ambient temperatures as low as -5°C, the cooler is bypassed to prevent hydrate formation. The cooled gas is mixed with VRU gas and sent to the inlet separator, where liquids are removed and routed to appropriate units for hydrocarbons and water separation

I.4.3. Desulfurization and Mercury Removal :

Wet gas can contain up to 5 ppm of H_2S and 200 ng/Sm^3 of mercury. About 75% of the gas is treated in an absorber containing PURASPEC 1038 catalyst, which removes both H_2S and mercury. The remaining 25% is treated in a mercury-only absorber with PURASPEC 1156. The treated gas streams are recombined, filtered, and meet sales specifications: less than 2 ppm H_2S and 10 ng/Sm^3 mercury, protecting downstream aluminum exchangers

I.4.4. Decarbonation :

To reduce CO_2 levels, approximately 60% of the desulfurized gas is processed in an amine absorber operating at 69.2 bar and 58°C. The gas flows upward through packed beds, contacting a lean amine solution. CO_2-rich amine is collected at the bottom, while treated gas exits at the top and passes through a knockout drum to remove amine droplets. Treated gas is then blended with untreated and regeneration gas to ensure CO_2 remains below 2 mole%

I.4.5. Amine Regeneration:

The amine regeneration unit removes absorbed CO_2 from the rich amine solution, restoring it for reuse in the absorption cycle

I.4.6. Gas Dehydration:

Drying is essential to prevent hydrate formation. Dehydration is done via three molecular sieve vessels operating in parallel. Typically, two are in service while the third regenerates. The gas must exit with less than 0.1 ppmv water. About 12% of the dry gas is used for regeneration, compressed to 72.5 bar, cooled, and water is removed before reuse

I.4.7. Cold Box and Initial Separation :

The dry gas is cooled to around 12.5°C using a brazed aluminum heat exchanger (Cold Box), with cooling from deethanizer overhead vapors. Partial condensation occurs, and the gasliquid mixture is sent to a drum where condensed liquids are separated and reheated. A portion of the gas is subcooled to -69°C for further processing

I.4.8. Turbo-Expander :

Roughly 74% of the gas is expanded to 17.8 bar through a turbo-expander, which also drives a compressor for deethanizer off-gas. If the expander is offline, a Joule-Thomson valve maintains operation, though with reduced liquid recovery and increased deethanizer pressure (27 bar) to ensure compressor feed pressure is maintained at 23 bar

I.4.9. Deethanizer :

The deethanizer separates ethane and lighter gases from heavier components (C_3+). Cold feed enters at the 15th tray; a hot stream enters at the 27th tray. The column operates at - 72°C and 17.3 bar. If using the J-T valve, these conditions change to -16°C and 27 bar. Reflux is generated via heat exchange and pressure reduction

I.4.10. Condensate Stabilization :

Liquid hydrocarbons from the slug catcher and wet gas treatment are pressurized (~30 bar) and fed to a pre-flash separator to remove light gases. After coalescing filters remove free water, the liquids feed a stabilizer column operating at 19.7 bar. The stabilizer separates C_2 components from heavier hydrocarbons. Any free water collected is sent to the water degassing system

I.4.11. Debutanizer :

The debutanizer receives heavier fractions from the stabilizer and deethanizer. It separates LPG from condensates. The overhead product is partially recycled as reflux; the remainder is sent to storage. The bottom product is also sent to storage after heat exchange. The column features 36 trays and receives two feed streams: a preheated stream at the 16th tray and another from the stabilizer at the 26th tray

I.4.12. Condensate and LPG Storage:

At this processing facility, there are two types of storage systems: Condensate is stored in tanks. LPG is stored in bullet tanks ("cigars").

I .4.13 LPG Storage:

The LPG storage tanks are cylindrical pressurized vessels (commonly referred to as “cigars”) operating at a pressure of 16.3 bar and temperatures ranging from 60°C to 91°C. There are 8 LPG storage bullets, divided into two groups of four:

4 for on-spec LPG

4 for off-spec LPG

Each group shares common inlet and outlet lines, as well as a vapor balancing line, which connects the vapor space of each tank. Fuel gas is used to maintain vapor equilibrium

I .4.14 Condensate Storage:

There are two floating roof tanks used to store on-spec condensate, each with a capacity of 7,950 m^3, providing 24 hours of autonomy. The condensate is stored at atmospheric pressure and approximately 56°C.

Off-spec condensate, produced during upsets or abnormal operating conditions, is routed to the condensate degassing drum and then sent to a fixed-roof storage tank designated for off spec product.

I.5. Safety (HSE):

The safety of personnel and the integrity of equipment are among the company's highest priorities.

In addition to process safety measures (such as PSVs, BDVs, and Emergency Shutdown Systems), the organization has implemented a structure specifically tailored to address the potential risks associated with operating a gas processing facility

I.5.1.Measures include:

• Personnel training and qualification.

• Strict adherence to procedures.

• Provision of personal protective equipment (PPE) to all personnel.

• Enforcement of golden safety rules.

• Continuous risk assessment and improvement.

I.5.2. HSE Objectives :

• Zero accidents

• Zero injuries

• Zero environmental impact

I.5.3 HSE Charter:

At the In Amenas project, no work shall be authorized if it poses a risk to safety or the environment. Everyone is responsible for promoting excellence in health, safety, and environmental performance

I .5.3.1 Your rights include:

• A safe working environment.

• Being informed about HSE procedures and trained to perform tasks safely.

• The right to stop work if conditions are deemed unsafe.

• The right to participate in incident investigations and request feedback.

• Immediate corrective actions for any reported deficiencies.

• The right to report unsafe or negligent behavior.

I .5.3.2 The In Amenas Project Counts on You To:

• Observe and comply with all HSE rules.

• Be aware of the risks and precautions before starting any task.

• Follow procedures and always adhere to the conditions of the work permit.

• Stop work immediately if there is a danger or risk to the environment

• Report any incidents or unsafe acts immediately.

• Use only equipment that is in proper working condition.

• Inform others to help carry out the work safely.

• Keep the work area clean and dispose of waste properly.

• Know what to do in case of an emergency.

• Be personally involved in HSE managemen1.t.

I.5.4.Life-Saving Rules:

The Life-Saving Rules, developed by the International Association of Oil & Gas Producers (IOGP), are a set of fundamental safety principles designed to prevent serious incidents and save lives in the oil and gas industry. These rules outline specific actions and behaviors that individuals must follow, regardless of their role or location, to minimize risks and ensure both their own safety and that of others. They serve as a universal standard across the industry, emphasizing the importance of consistent safety practices and promoting a culture of safety excellence.

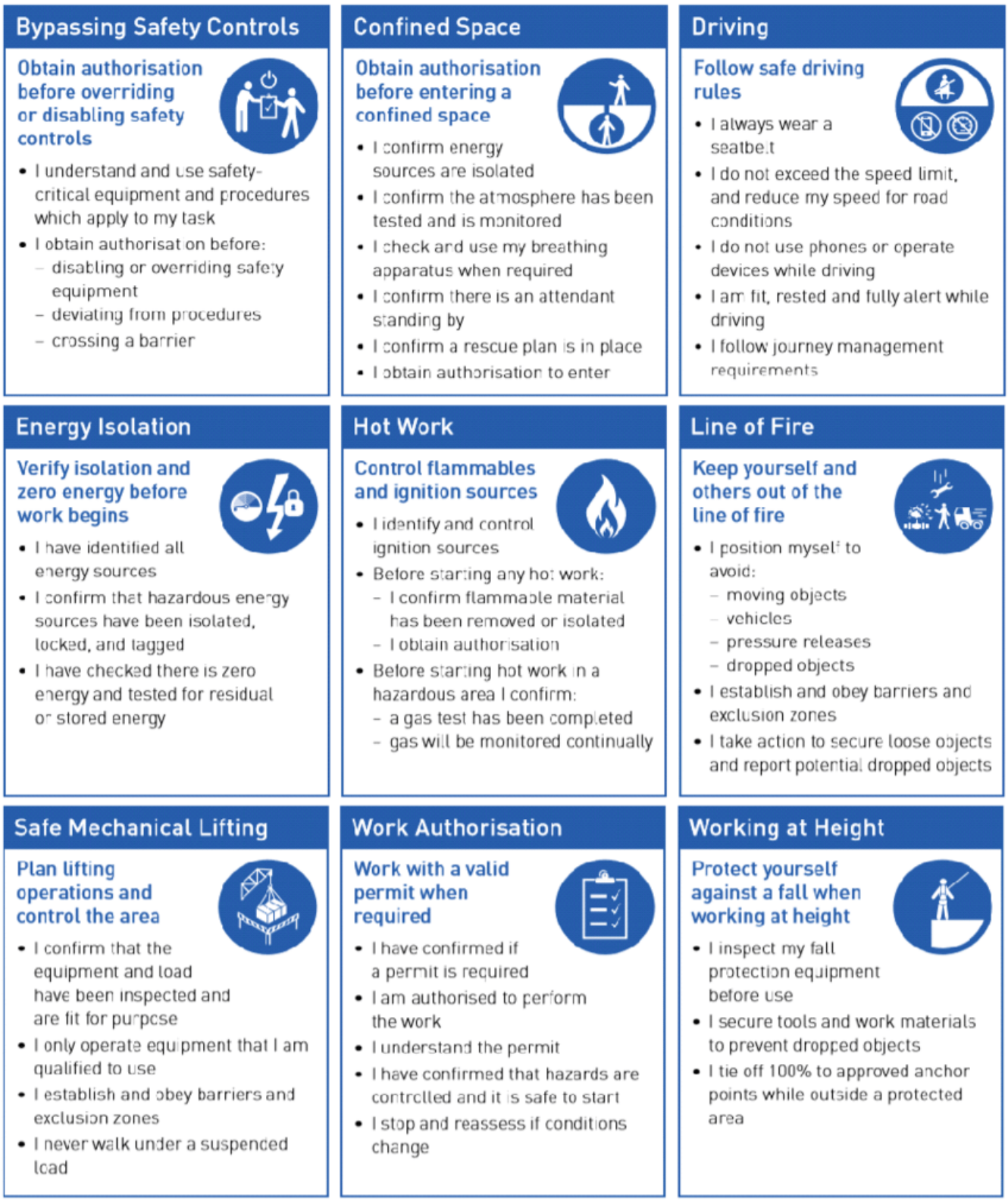


FIGURE I.3 : Life Saving Rules

CONCLUSION:

The TIGUENTOURINE gas site plays a crucial role in Algeria's gas production, with an efficient CPF system handling all stages from reception to dispatch. Its strong HSE commitment ensures the safety of personnel, equipment, and the environment. Given the high-risk nature of gas operations, continuous risk evaluation and hazard control are essential to maintain safe, reliable, and sustainable operations.

CHAPTER II:

RISK ASSASSEMENT

Introduction:

In industrial environments, particularly within the oil and gas sector, managing occupational health and safety is a critical priority. Task Risk Assessment (TRA) is a systematic process used to identify, evaluate, and control risks associated with specific tasks or operations. This proactive approach aims to prevent accidents, protect workers, and ensure compliance with safety standards.

II.1.Definition:

II.1.1 Risk Assessment:

A systematic process used to identify hazards and assess risks associated with a specific task /operation and implement control methods to minimize risk to as low as reasonably practicable PRIOR to the start of the activity.

II.1.2 Hazard:

The inherent property or ability of something to cause loss, damage or harm.

II.1.3 Hazard Effect:

The consequences which could result from a Hazard being not controlled

II.1.4 Severity:

The amount of harm, injury, damage or loss that a particular hazard could cause given regard to the circumstances prevailing at the time the event occurs.

II.1.5 Probability:

The likelihood of a Hazard effect being realized.

II.1.6 Risk:

The potential for loss, damage or injury for a given hazard at a particular time and Circumstance.

Risk= severity x probability.

II.1.7Significant:

Indicates that a Hazard or a Risk is anything other than trivial. A significant risk is one which requires some form of positive safeguard to eliminate it or reduce it to an acceptable level.

II.1.8 Competent Person:

A person who, by reason of his training, knowledge, experience and judgement, is considered by management to be capable of adequately assessing health and safety risks for the activity in question.

II.1.9 Reasonably practicable:

This term implies that cost effectiveness estimation must be made. If the cost or difficulty of a precaution is grossly out of proportion to the reduction in risk likely to be achieved by implementing it, the precaution can be considered not reasonably practicable.

Any additional risks which may arise while implementing or removing the precaution must also be taken into consideration in determining what is reasonably practicable.

II.1.10 Safeguard:

A precautionary measure which prevents or reduces a risk, safeguards can be classified as physical, procedural, human, time-related or contingency.

II.1.11 Contingency:

A Safeguard which is intended to control or mitigate a Hazard Effect

II.1.12 Task:

An individual work assignment carried out by one or more persons.

II.1.13 Environmental Risk Assessment:

an environmental analysis applied when handling chemicals during a task or project that may directly impact the environment.

II.2. Task risk assessment:

Risk analysis is part of the risk management decision-making process, which includes three main stages: risk analysis, risk evaluation, and risk control. The goal of this process is "risk control," which depends on "risk evaluation," itself based on "risk analysis." This highlights the central role that risk analysis plays within the overall process.[1][14].

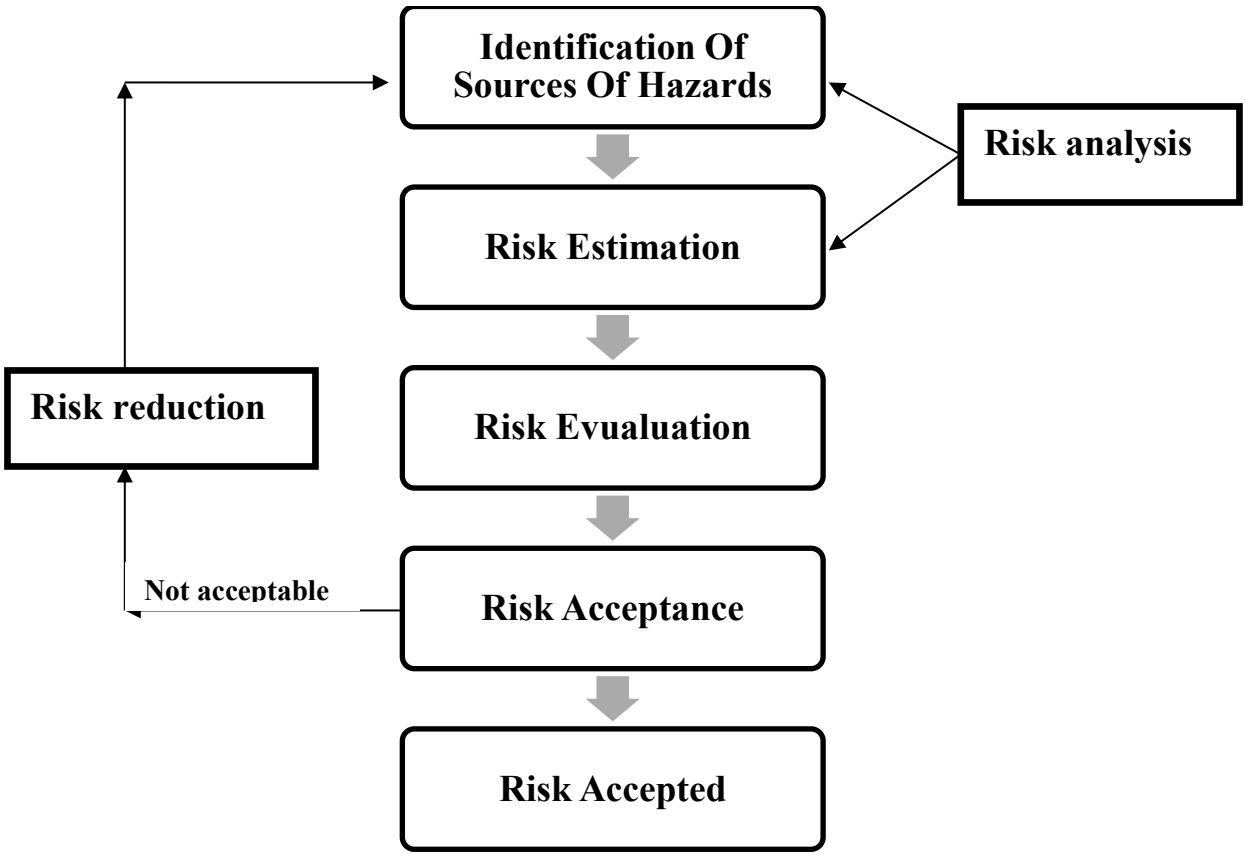


Figure II.1.Task Risk Assessment

II.2.1. Task risk assessment:

There are two levels of risk assessment:

II.2.1.1. Level 01:

A competent person must evaluate whether potential hazards may be present, based on their knowledge and experience, and using a hazard checklist if needed. It is important to note that the risk assessment associated with a Work Permit (PTW) is considered a Level 1 assessment. [1][6].

Table II.I : Two types of work permits:

Hot Work Permit	Cold Work Permit
For temporary operations that could result in fire, open flames, elevated temperatures, or sparks, such as welding, cutting, burning, grinding, brazing, etc.	For tasks that do not generate ignition sources, open flames, or sparks. Examples: construction work, long-term maintenance, and repair in operational areas that involve the breach of hydrocarbon containment or isolation systems, etc.

II.2.1.2. Level 02:

A Level 2 TRA must be conducted when the competent person determines that the risks cannot be adequately managed without additional safety measures or precautions.
Conditions that may require escalation to Level 2 include:

-the task physically cannot comply with hse procedures .
-the task is new or unusual and requires further analysis.
-confined space entry is involved.
-a complex lifting operation is required.

II.2.2. ORA (Operational Risk Assessment):

This assessment is used when:

• Equipment or systems are operating outside of their design parameters, or

• A critical safety system is not functioning or has been bypassed.

It also applies when significant risks are not adequately controlled without additional safeguards, or when deviations from established procedures or operating parameters are necessary.

• ORA must be renewed every 30 days.

• ORA must not be used for task-based assessments (TRA) or environmental assessments (ERA). [2][6]

II.2.3. Roles and Responsibilities:

• The In Amenas Operations Manager (IA Operations Manager) is responsible for ensuring that this procedure is followed and must approve all Operational Risk Assessments (ORA).

• The Area Owners (AO - Appointed Division Heads) are responsible for ensuring that this procedure is applied within the work control system.

The AO, in consultation with the Area Authority (AA), must approve all risk assessments within their designated area of responsibility.

• The AO is also responsible for ensuring that safe working practices are implemented and followed, and that Area Authorities are competent in using this procedure.

• The Area Authority (AA) is responsible for ensuring that the Task Risk Assessment form, along with other relevant permits and certificates, are properly completed in accordance with IA Ops procedures.

• The Area Authority (AA) is also responsible for ensuring that all control measures identified through this process are implemented both before and during all work activities.

• The Performing Authority (PA) is responsible for:

• Preparing all Task Risk Assessments (Level 1 and Level 2),

• Understanding the required controls and requirements arising from this process,

• Communicating them to all individuals involved in the task or work activity.
• The HSE Division will provide expert or technical input during the Level 2 Task Risk Assessment process (see team structure below, if applicable).
• The Technical Authority (TA) will contribute expertise or technical input in the Task and Operational Risk Assessment process.
• The HSE Division Head will:
• Provide assurance by reviewing the effectiveness of this process on an annual basis, and • Approve all Operational Risk Assessments in consultation with the Operations Manager and the Area Owner.

II.2.4. Fire Zones:

In order to identify the risks of fire and detected gases, all areas of the unit and associated facilities are divided into fire zones. In general, a fire zone is defined either by a physical barrier or by the function of the equipment.
This separation must also take into account electrical isolation, hydrocarbon system isolation, as well as the different protection systems of the unit such as fire and gas detection, Emergency Shutdown (ESD), rapid depressurization, functions, physical locations, and building boundaries

II.2.5. Fire & Gas System:

The fire and gas detection system is designed to detect, indicate, and alert in the presence of smoke, fire, or flammable or toxic gas, trigger the general alarm, and activate the firefighting system. It consists of:
• Fire and gas detectors.
• Safety system (FSC: Fail Safe Control).
• Firefighting network (fire pumps, deluge system, and the CO_2 system at the turbine level).

II.2.6. Fire and Gas Detectors:

II.2.6.1. Fire Detectors:

The following fire detection means are installed at CPF:

• Heat detectors (rate-compensated).

• Flame detectors:

• IR/UV: process areas and gas turbine enclosures (combustion).

• CCTV: process areas.

• Smoke detectors:

• High-performance optical: offices, BDV, control center, and military camp.

• Combined Optical/Heat – Point: CPF laboratory, laundry, HVAC, etc.

• Ionization – Point: main substation, compressor substation, etc.

• Aspirating smoke detection systems (VESDA): CCR, turbine LERs.

• Fusible link detectors in the wells

2.2.6.2. Flammable Gas Detectors:

Point IR type: Installed near specific high-risk local process equipment (compressors, pumps), gas turbine compartments, HVAC / air intake ducts, and hydrocarbon pump pits. IR (optical path): Installed in CPF process areas

II.2.7. Emergency Shutdown System (ESD):

The Emergency Shutdown (ESD) system is the primary hazard control measure
to reduce accidents affecting personnel, equipment, and the environment.

It consists of:

• Transmitters

• Safety system (FSC: Fail Safe Control)

• Emergency Shutdown Valves (ESDV) and Blowdown Valves (BDV)

II.2.8. Emergency Shutdown System Philosophy (ESD):

There are four emergency shutdown levels, called ESD1, ESD 2A, ESD 2B, ESD3, and ESD4.

Activation of a higher ESD level will trigger all associated actions of the lower levels in addition to the actions of the specified level [2][4][12].

Level 1: CPF Shutdown and Abandonment *:*

This is the highest shutdown level and is manually triggered from the control room. The following actions are initiated:

• Shutdown of gas wells and complete shutdown of CPF, including depressurization of the 3 trains.

• Inhibition of the backup generator startup.

• Electrical isolation of CCTV and UPS systems.

Level 2A: Emergency Production Shutdown:

Level 2A will be automatically triggered by the ESD system in the following cases:

• Very high level in the HP fuel gas scrubber (set at 88%)

• Very high level in the HP flare knockout drum (set at 86%)

• Very high level in the slug-catcher (set at 84%)

• Very low instrument air pressure (set at 5.6 bar)

• Loss of electrical power

Triggered actions:

• Shutdown of gas production wells and the three (3) treatment trains

• Shutdown of IGC, RGC, GTG systems and shipping facilities

• Automatic CPF depressurization upon fire or gas confirmation

Level 2B: Fire Zone Shutdown:

• Isolation and shutdown of the affected fire zone (isolation, shutdown, and depressurization of related machines, and electrical outlet isolation)

Level 3: Process System Shutdown :

• Isolation and shutdown of the equipment in the corresponding train system

• Shutdown of the associated turbo-compressor.

Level 4: Equipment Shutdown :

• Shutdown and/or isolation of the corresponding system or equipment

II.3. Hydrocarbon-related hazards:

II.3.1.Health Risks Associated with Hydrocarbons:[5][10]

II.3.1.1 Respiratory Effects:

Inhalation of hydrocarbon vapors can irritate the respiratory tract and lead to breathing difficulties such as coughing, shortness of breath, asthma, and, in severe cases, lung damage.

II.3.1.2 Carcinogenic Potential:

Certain hydrocarbons—such as polycyclic aromatic hydrocarbons (PAHs) and volatile organic compounds (VOCs)—are classified as potential carcinogens. Prolonged exposure can increase the risk of developing cancers including lung cancer, skin cancer, and bladder cancer.

II.3.1.3 Neurological Effects:

Exposure to specific hydrocarbons like benzene can have toxic effects on the nervous system. Symptoms may include headaches, dizziness, impaired coordination, and long-term damage to nerve cells.

II.3.1.4 Skin Irritation:

Extended contact with hydrocarbons may cause skin irritation, including redness, itching, rashes, and chemical burns.

II.3.2. Environmental Risks Associated with Hydrocarbons:

II.3.2.1fire risk :

Fire risk is a major concern in the hydrocarbon industry. For hydrocarbons to burn, oxygen, a fuel (the hydrocarbon), and a heat source are required. Combustion only occurs when these elements are present in specific proportions and at a sufficient temperature. If the fuel concentration is too high, the mixture is too rich to burn; if it is too low, it is too lean to burn.
Due to their high calorific value, even a small amount of the mixture can ignite the neighboring layers and spread heat. When the liquid catches fire, the heat produces vapor, accelerating the combustion process.

II.3.2.2 explosion risk:

An explosion is a combustion reaction that occurs at a very high speed, accompanied by a significant rise in pressure and the release of large amounts of energy. The presence of explosive mixtures in the atmosphere is a key factor in the explosion process, especially when the concentration of the involved substance in the air falls between the lower and upper explosion limits (LEL and UEL). [5][11]

II.3.2.3The release and spread of toxic substances:

In the event of a major accident, such as an explosion, fire, or significant leak, pollutants can contaminate the air, water, and soil, leading to fatal outcomes (such as the 1984 Bhopal disaster) or long-term soil contamination with potential health risks (such as the 1976 Seveso disaster).
The dispersion of a toxic substance is considered a long-term yet immediate phenomenon. The triggering event is the loss of containment, which is brief in duration. Following the loss of containment, the effects are immediate and can last from several minutes to several hours, depending on the dispersion conditions (such as the nature of the leak, weather conditions, etc.).

II.3.3. Economic Implications and Risks Associated with the Hydrocarbon Industry:

II.3.3.1 Price Volatility*:*

The price of hydrocarbons (oil and natural gas) is highly volatile, influenced by global supply-demand dynamics, geopolitical tensions, natural disasters, and market speculation. This volatility can lead to economic instability for countries and companies dependent on hydrocarbon exports and imports, affecting national economies and consumer prices.

II.3.3.2 Employment and Economic Dependency:

Many economies are highly dependent on the hydrocarbon industry for jobs, revenue, and economic growth. A sudden downturn in the industry can lead to widespread job losses, especially in oil-producing regions, and can affect the broader economy, causing unemployment and social instability.

II.3.3.3Investments and Financial Risks:

Investments in the hydrocarbon sector can carry financial risks due to the fluctuating prices and the potential for long-term market decline as renewable energy technologies become more competitive. Companies may face stranded assets, where investments in hydrocarbon reserves or infrastructure lose value if the world moves towards cleaner energy solutions.

II.3.3.4Supply Disruptions:

Hydrocarbon industries are vulnerable to supply disruptions caused by geopolitical conflicts, natural disasters, or accidents (e.g., oil spills or pipeline explosions). These disruptions can lead to energy shortages, price hikes, and economic losses across various sectors, particularly in regions heavily reliant on oil and gas imports.

II.3.3.5 Public Health Costs:

The extraction and burning of hydrocarbons are linked to significant public health risks, including respiratory diseases and cancer, especially in regions where fossil fuels are extracted or refined. The resulting healthcare costs can strain government budgets and reduce economic productivity. [10][13]

Conclusion:

In conclusion, task risk assessment is a fundamental tool for anticipating hazards and reducing incidents in the hydrocarbon industry. Given the complexity and severity of the risks associated with these substances, a rigorous and structured approach is essential. It not only helps protect workers and the environment but also ensures the continuity and performance of industrial operations within a controlled safety framework.

CHAPTER III:

RISK ANALYSIS AND EVALUATION METHODS

Introduction :

In the field of industrial safety and risk management, the identification, analysis, and evaluation of potential hazards are essential steps in ensuring the integrity of operations and the protection of people, assets, and the environment. Chapter III provides an in-depth exploration of the principal methods used for risk analysis and evaluation. These methods are categorized into qualitative, semi-quantitative, and quantitative approaches, each offering unique advantages and applications depending on the complexity of the system under study. Special attention is given to widely recognized methodologies such as the Hazard and Operability Study (HAZOP) and the Layer of Protection Analysis (LOPA), both of which play a critical role in systematically identifying risks and establishing effective safeguards. By understanding and applying these methods, this chapter aims to build a comprehensive foundation for robust risk assessment practices in engineering and industrial contexts

III. 1.Risk Analysis and Evaluation Methods:

The main methods used in a risk analysis approach are generally classified into three main categories:

Qualitative-methods.

Semi-quantitative-methods.

Quantitative methods. [1][9]

III.1.1. Qualitative Methods:

Qualitative risk analysis serves as the foundation for all other types of risk assessments. It enables a comprehensive understanding of the system under study and its individual components. This approach does not rely explicitly on numerical data; instead, it is based on relevant observations of the system's condition, expert judgment, and feedback from past experiences.

Commonly used qualitative methods include Preliminary Hazard Analysis (PHA) and HAZOP (Hazard and Operability Study).

III.1.2. Semi-Quantitative Methods:

Semi-quantitative risk analysis occupies a middle ground between purely qualitative and fully quantitative approaches. Its objective is to reduce the high subjectivity typically associated with qualitative assessments by introducing greater precision and accuracy.

Several semi-quantitative tools and methods have been developed for this purpose, one of the most notable being Layer of Protection Analysis (LOPA).

III.1.3. Quantitative Methods :

Quantitative risk analysis is often regarded as the most robust approach for informed decision-making regarding risk. This method involves using probabilistic measures to characterize the various parameters in a risk assessment.
These measures are typically derived through mathematical processing, using data related to the parameters being evaluated, along with other quantitative information.
Widely used quantitative techniques include Event Tree Analysis (ETA) and Fault Tree Analysis (FTA).

III .2 The Complementarity of Risk Analysis Methods :

In the context of a safety study, risk analysis methods are often used in combination to ensure a thorough and effective assessment. This integration of different methods illustrates their complementarity, where each approach enhances and supports the others to provide a more comprehensive understanding of risks.[1][9]

A first example of this combined use of risk analysis methods is provided by figure 1

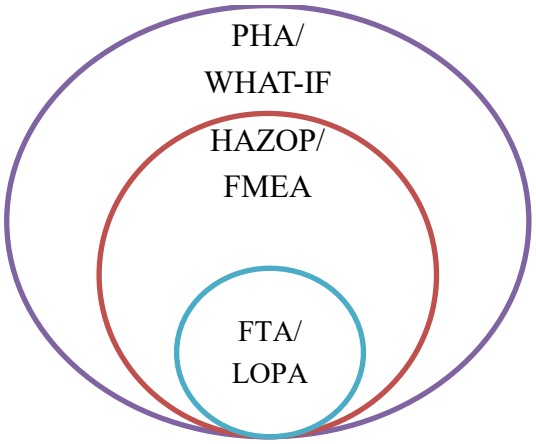


Figure III. 1 – Sequential Use of Various Risk Analysis Methods

Figure 2 also illustrates another example of the combined (sequential) use of various risk analysis methods, where:

- The first level of risk analysis allows for a so-called "macroscopic" assessment.
- If a more detailed analysis is required, a second level analysis is performed, treating the identified failures as independent.
- To account for the interdependence of these failures (in the form of accident scenarios), a third level of analysis becomes essential.[14][15]

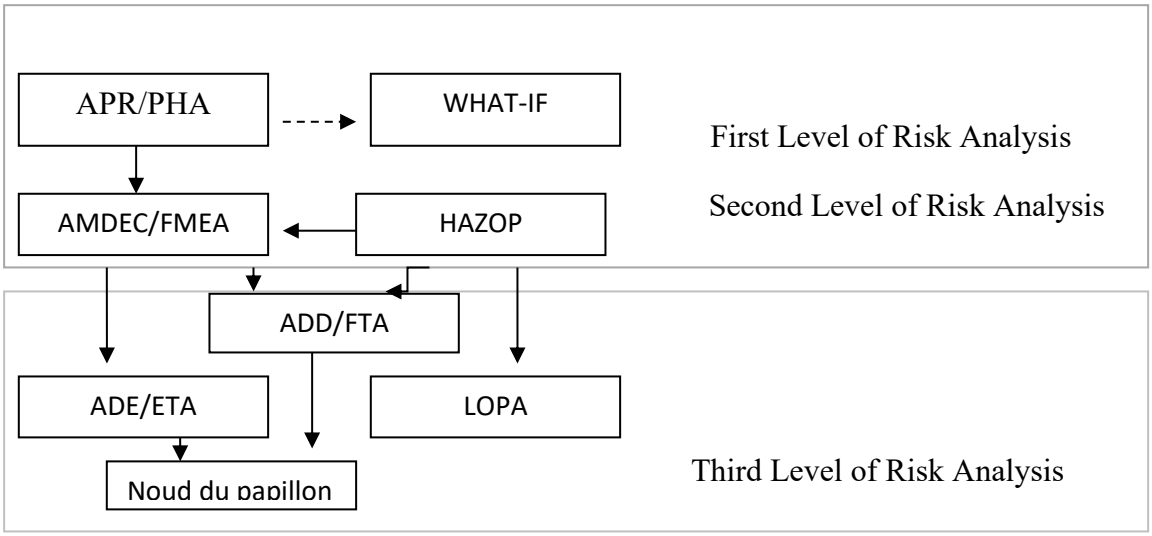


Figure III. 2 – Sequential Use of Various Risk Analysis Methods

III .3 Preliminary Hazard/Risk Analysis (PHA/APR)

This technique is commonly used to identify potential risks at the early stages of designing a facility or project. As such, it generally does not require an in-depth or detailed understanding of the system being studied. The objectives of this method are to:

- Integrate safety considerations from the research and design phases of a facility;
- Anticipate, in advance, all risks inherent to products, processes, equipment, and site layout;
- Recommend corrective actions;
- Identify risks that require further, more detailed analysis.

However, PHA is not suitable for thoroughly characterizing the sequence of events that could lead to a major accident in complex systems. As its name suggests, it is a preliminary analysis method aimed at identifying critical points that should be the focus of more detailed studies. It helps highlight systems or equipment that may require deeper analysis using more advanced tools such as FMEA (Failure Modes and Effects Analysis), HAZOP (Hazard and Operability Study), or Fault Tree Analysis (FTA).[3][9]

III .4 Failure Modes, Effects, and Criticality Analysis (FMEA/AMDEC)

FMEA is a natural extension of Fault Tree Analysis (FTA), where the probability of occurrence for each failure mode is considered along with the severity of the effects of these failures. This approach ensures that failure modes with significant effects have sufficiently low probabilities of occurrence, thanks to design methods, various verifications, and testing procedures.[9][10]

The FMEA method consists of four main steps:

1. Define the system's main functions, components, and specifications.
2. List the failure modes and determine their causes for each component of the system.
3. Study the effects of the failure modes.
4. Assess the criticality**.**

5. This method allows for listing the potential sources of failures in order of importance, highlighting those that could lead to critical scenarios.
   The results of the FMEA analysis are typically presented in the form of a table.

Table III.1:Fmea Formalism:

Component	Function	Failure mode	Possible Cause(s)	Effect of Failure	Severity (S)	Occurrence (O)	Detection (D)	Risk Priority Number (S×O×D)

S (Severity): Impact level of the failure (scale 1 to 10, 10 = catastrophic impact).

O (Occurrence): Estimated frequency of the failure.

D (Detection): Ability to detect the failure before it causes damage.

Risk Priority Number (RPN): Calculated as Severity × Occurrence × Detection

III .5 Fault Tree Analysis (FTA/ADD) :

Fault Tree Analysis (FTA) was historically the first method developed for systematically examining risks.
FTA is a deductive method; unlike inductive methods, it allows for the consideration of failure combinations and ensures that all potential causes have been accounted for.

This analysis traces causes step by step, starting from the basic event(s) that could lead to the feared event. Fault trees are used to produce the minimal combination of independent basic events that, if they occur simultaneously, will cause the undesirable event.

FTA enables the estimation of the probability of an event occurring and ensures that all possible measures have been considered to prevent the risk associated with this event.

The main advantage of Fault Tree Analysis is its strong alignment with past accident analysis, which shows that major accidents often result from the combination of several events that, individually, would not have led to such disasters. Additionally, the technique:[7][8]

- Allows for quantification of the probability of system failure,
- Evaluates the most common causes of vulnerability,
- Helps optimize the allocation of resources necessary to control a system's vulnerability.

III .6 Event Tree Analysis (ETA/ADE) :

Event Tree Analysis (ETA) is used to analyze the probability of different outcomes identified during a safety analysis.
Starting from the initiating event or an initial failure, ETA systematically estimates the system's drift by considering the operation or failure of detection, alarm, prevention, protection, or intervention devices, among others.
In contrast to Fault Tree Analysis (FTA), Event Tree Analysis is a method that examines, starting from an initiating event, the sequence of events that may or may not lead to a potential accident, along with the behavior of safety barriers, in particular.
ETA is particularly useful for studying existing or potential safety measures (prevention, protection, intervention) at a site.
It helps visualize the event chains following an accidental event and the barriers, as well as the order in which they are activated. It provides a solid foundation for evaluating the need for new or improved safety procedures and functions.[7][8]
An event tree progresses from cause to effect and provides a wide range of possible outcomes.

III .7 HAZOP Method (Hazard & Operability Study) :

The HAZOP method was developed by Imperial Chemical Industries (ICI) in the early 1970s.

In 1980, the Union of Chemical Industries (UIC) published a French version of this method in its safety guide No. 2, titled "Safety Study on Fluid Flow Diagrams." It was later translated into French in IEC 61882 standard.

The method is particularly suited to complex systems of a thermo-hydraulic nature, commonly found on industrial sites involving hazardous products and/or processes. These systems rely heavily on parameters such as flow rate, temperature, pressure**,** level, concentration, etc., which are crucial for the safety of the installation. Any deviation in these parameters could lead to serious immediate consequences for personnel, the population, assets, and the environment.

The method primarily focuses on the systematic identification of parameter deviations in order to pinpoint their causes and consequences.

The method requires the review of flow diagrams and P&ID (Piping and Instrumentation Diagrams).

III .7.1 Principle of the HAZOP Method:

HAZOP follows a procedure quite similar to the one developed for FMEA (Failure Modes and Effects Analysis).

HAZOP does not focus on failure modes but on potential drifts (or deviations) in the key parameters related to the operation of the installation.

It is focused on the system as a whole, in contrast to FMEA, which is centered on the components.

For each constituent part of the system under examination (e.g., a line or loop), the generation (conceptual) of potential deviations is carried out systematically through the combination of:

Guide words such as "No," "More," "Less," "Too much,"

Parameters associated with the system being studied, such as temperature, pressure, flow rate, concentration, time, or operations to be performed.

Guide Word + Parameters = Deviation

III .7.2 Steps of the HAZOP Method :

III .7.2 .1 Form a HAZOP Team :

Create a multidisciplinary HAZOP team, consisting of a team leader and members capable of collaborating and bringing different perspectives based on their areas of expertise. This team will identify risk sources and potential deviations from the design. HAZOP team members can include design engineers, personnel familiar with operations, the HAZOP facilitator, and safety professionals.

III .7 .2.2 Identify Processes, Nodes, and P&ID:

When starting a HAZOP study, it is important to identify the processes involved, familiarize oneself with the process flow diagram (P&ID), and understand all the nodes.

P&ID (Piping and Instrumentation Diagrams**)** are drawings or diagrams that provide a visual representation of the processes, equipment, and controls interconnected in the physical plant. HAZOP nodes are sections of the overall process where changes occur. These need to be examined alongside safety data sheets (SDS) to define parameters and identify deviations

.

III.7 .2 .3 Define Parameters, Determine Deviations, and Select Guide Words:

Define the parameters or safe operational limits during the examination of the nodes to determine potential deviations and select appropriate guide words.

Using guide words, hazards can be clearly identified, as they represent deviations beyond acceptable parameters or safe operating limits.

III.7 .2 .4 Control Deviations and Establish Safety Monitoring:

Once hazards are identified, corresponding strategies for hazard mitigation or elimination should be applied to maintain workplace safety.

For ongoing processes and production, a monitoring system should be established to ensure that protective measures remain effective and safety procedures are followed.

III .7 .2 .5 Communicate HAZOP Study Results and Improve Processes:

The results of the HAZOP analysis can be used to improve safety within the plant. Improvements in safety practices and processes should be communicated to employees, all stakeholders, and relevant parties.

III .7 .3 HAZOP Sequence:

The HAZOP study shall follow the sequence illustrated in Figure

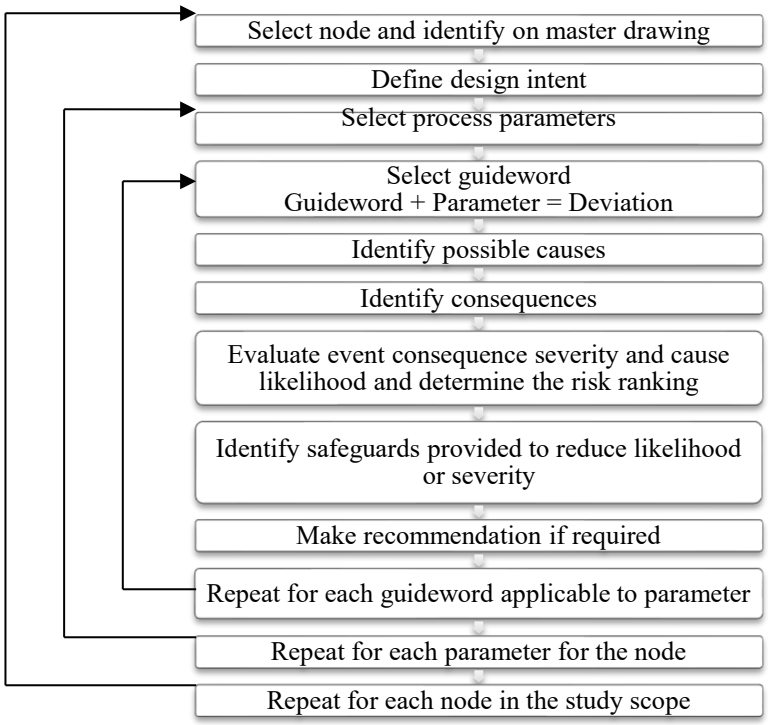


Figure III. 3 - HAZOP sequence

III .7.4 HAZOP Formalism:

Table III .2: Hazop Formalism

Guide word	parameters	deviation	causes	consequences	safeguards	remarks	Recommendations

III .7.5 Advantages of the HAZOP Method:

III .7.5.1 Systematic Examination:
HAZOP ensures a thorough, structured review of the entire process, systematically analyzing each part and identifying potential risks.

III .7.5.2 Multidisciplinary Study:
The method involves a team with a broad range of expertise, ensuring that all relevant aspects of the process are considered, from engineering to operations to safety.

III .7.5.3 Utilizes Operational Experience:
HAZOP leverages the collective experience of the team, ensuring that real-world operational knowledge is applied to identify practical hazards and issues.

III .7.5.4 Covers Safety and Operational Aspects:
The method takes into account both safety features and operational procedures, providing a holistic view of the process and its potential risks.

III .7.5.5 Identifies Solutions for Identified Problems:
For every risk or hazard identified, HAZOP encourages the team to propose corrective actions or improvements, offering tangible solutions to address potential issues.

III .7.5.6 Considers Operational Procedures:
The method doesn’t just focus on hardware and design; it also accounts for the operational procedures that could affect the system's safety, ensuring a complete assessment.

III .7.5.7 Addresses Human Errors:
HAZOP systematically considers the potential for human error, helping to identify and mitigate risks associated with incorrect operations or decision-making.

III .7.5.8 Independent Study:

HAZOP studies are typically conducted by an independent facilitator, ensuring an objective and unbiased approach to risk analysis.

III .7.5.9 Documented Results:

The findings from HAZOP are thoroughly documented, ensuring that results can be reviewed, acted upon, and tracked over time for continuous improvement.

III .8 Layer of Protection Analysis (LOPA) :

III .8 .1 What is layer of protection analysis (LOPA) :[2][4][12]

LOPA is a method for evaluating the adequacy and effectiveness of independent protection layers in reducing the frequency and/or consequence severity of hazardous events.

LOPA provides criteria and restrictions for evaluation of IPLs, reducing the subjectivity of qualitative methods.

LOPA can be used to determine the target SIL for a SIF, but that is just one outcome of LOPA.

LOPA also evaluates whether protection layers can be considered independent and determines their required risk reduction.

III .8 .2Protection layers :

As shown in Figure 4, a scenario can have multiple protection layers depending on the complexity of the process and potential consequence severity.

LOPA typically focuses on protection layers that are preventive, that can include:

1. BPCS.

2. SRAs.

3. SIS.

4. Active mechanical and passive protection layers.

Mitigation layers such as deluge, gas detection, emergency response systems, are typically not considered in LOPA since these systems become active after an event has occurred.

LOPA provides a consistent basis for determining if protection layers achieve the required risk reduction target.

III.8.3 Independent protection layers (IPLs):

LOPA evaluates safeguards that meet IPL criteria.

LOPA only takes credit for IPLs whereas a HAZOP can include safeguards that are not independent.

IPLs shall be functional in the operating mode for which they are credited

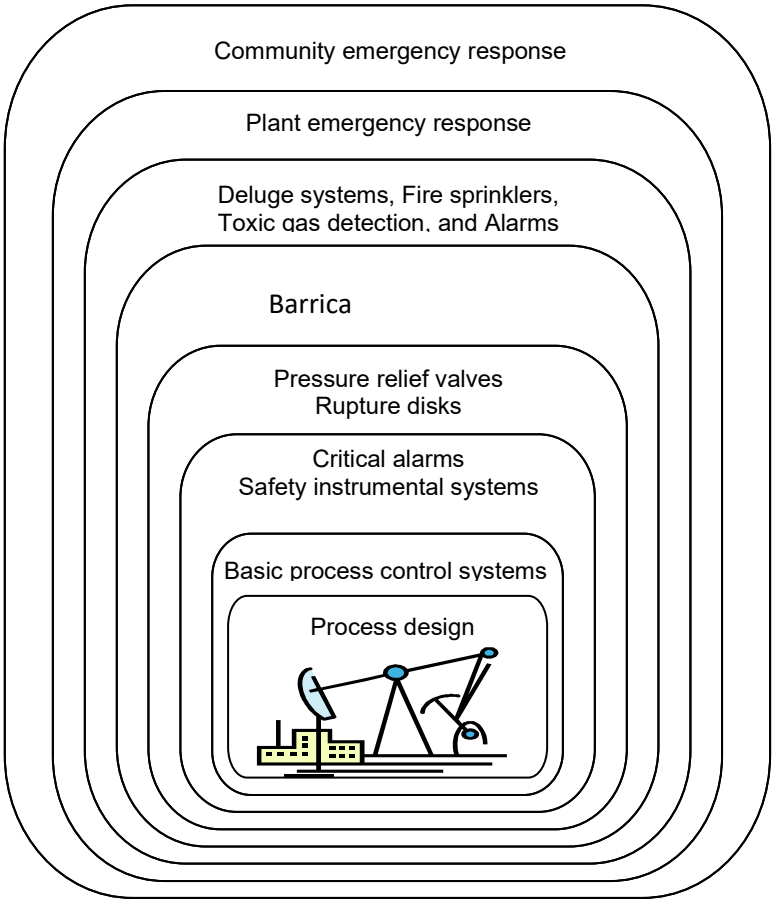


Figure III. 4- Examples of safeguards (protection layers)

IPLs shall conform to the following criteria:

III.8.3.1 Specificity (Functionality):

IPL is designed to prevent a postulated accident sequence, potentially from multiple initiating causes, from proceeding to a defined, undesirable endpoint.

III.8.3.2 Independence:

IPL is independent of all other protection layers associated with the identified potentially hazardous event. Independence requires that performance not be affected by the failure of another protection layer or by conditions that caused another protection layer to fail. Protection layers are also independent of initiating cause.

Guidance on independence requirements where more than one SIF applies can be sought from the relevant SETA.

III.8.3.3. Dependability (Reliability):

protection provided by IPL reduces risk by a known and specified amount.

III.8.3.4 Auditability:

IPL is designed to enable periodic validation of the protective function such as by periodic testing and maintenance of the IPL.

Instrumented functions, designated as an IPL in LOPA, shall have controlled access to changes. Access security can include administrative and/or physical measures (locks, keys, passwords, etc.) to prevent unmanaged changes to set points for example.

III.8.4Layer of protection analysis (LOPA) application :

-For operating facilities, LOPAs shall be started either in conjunction with the

HAZOP or within 90 days of issue of the final HAZOP report.

- For projects, a LOPA shall be performed in time to meet the stage gate

requirements.

There can be potential efficiencies in coordinating HAZOP and LOPA studies by conducting a LOPA either immediately following or in conjunction with these studies.

- LOPA shall be performed for each safety, health or environmental scenario progressed from HAZOP or alternative methodology if:

Severity level is C to E (inclusive) .

At severity level C, it is normal to use diverse IPLs instead of relying on a single IPL to achieve the TMEL.

- For severity level A and B, scenarios, LOPA is not an adequate risk analysis method.

Other techniques such as ISD, FMEA, FMECA, event tree, fault tree analysis, and/or QRA shall be applied (either separately or in support of LOPA) in pursuit of risk reduction .

The proposed method(s) shall be subject to approval by the segment EA.

- LOPA may be performed for hazard scenarios of severity levels F to H.

A HAZOP team can opt to progress a severity F-H qualifying scenario to LOPA if uncertain of the adequacy of protection layers provided.

III.8.5 Layer of protection analysis (LOPA) study team:

III.8.5.1 Leader :

III.8.5.a LOPA leader (also referred to as facilitator or chairman):

1. Shall be independent of the project team for projects.

Leaders from the same design engineering contractor are not normally preferred.

2. Should be independent of the project team and the process unit or plant area affected by the change, for a study in support of an MOC.

3. Should be independent of the subject process unit, for revalidations on operating facilities.

III.8.5.b Qualified LOPA leader, shall:

1. Have successfully completed the respective segment competency assessment process identified by the relevant process safety SETA.

2. Be agreed for the entity or project by the relevant EA.

The development path of a new leader will normally involve formal classroom training, participation as team member/scribe followed by co-leading.

The LOPA can be more efficient if the leader has experience in the type of facility being reviewed or similar facilities.

III.8.5.c LOPA facilitator should:

1. Advise the BP operations or project leader of issues that could affect the integrity of the study and work with them to develop an effective solution.

2. Be alert to time pressures so that the quality, thoroughness, or integrity of the review is not compromised.

3. Advise project and/or site leadership of the need to delay or postpone the LOPA until issues affecting the integrity of the study can be resolved. Such issues can include but are not limited to:

- Inadequate experience, expertise or makeup of the LOPA team.

- Lack of attendance or contribution by team members.

-Team fatigue.

-Required PSI is inaccurate or not available.

III.8.5.2 Other team members :

III.8.5.2.a Company representation shall be included on LOPA teams

The level of representation can vary between HAZOPs but is set consistent with the fact that BP is responsible for enabling studies that conform to this Practice.

III.8.5.2.b LOPA shall be performed using a multidisciplinary team.

III.8.5.2 c. Technical expertise of the LOPA team .

1. The core LOPA team shall include personnel with understanding of and experience with:

-Process or facility design and process intent.

- Equipment, design limits, materials of construction, and condition of equipment being reviewed.

- Day to day operations.

- Process safety.

This is typically a process safety engineer or a process (or other) engineer with process safety competency consistent with the hazards and complexity of the system being studied.

- Instrumentation and controls - control and shutdown hardware and logic solvers.

2. Other specialist expertise, whose attendance may be limited to relevant sessions, should include, if applicable:

- Scribe.

- Corrosion and materials.

- Maintenance, instrumentation and/or mechanical.

- Mechanical. This can include static and/or rotating equipment expertise.

-Inspection.

- Technical representative for licensed technologies and/or vendor package.

- Other disciplines.

For projects, it can be beneficial to include expertise from other similar facilities.

- Core team members or delegates agreed in the TOR shall be present for all LOPA sessions.

-The team should be as small as practical for each review session.

- Changes to the core team shall be agreed by the BP operations or project leader and LOPA leader.

- Core team member changes should be avoided during the study.

III.8.6Layer of protection (LOPA) method steps :

1. Identify hazardous scenarios with potential consequence levels requiring a

LOPA.

2. Obtain the following information from the HAZOP or other BP approved

hazard identification method:

- LOPA scenario description (including consequence description).

- Consequence ranking.

- List of initiating causes.

- List of safeguards for evaluation as IPLs.

Preloading the HAZOP scenario data into the LOPA documentation tool prior to start

of the LOPA team meeting provides a more efficient approach.

3. Confirm initiating causes of the LOPA scenario and determine the initiating

cause frequency .

4. Determine or confirm the consequence severity level of the LOPA scenario

in terms of health, safety, and environmental, and optionally, in terms of

equipment damage and business value.

5. determine the TMEL for the corresponding severity level.

6. List the safeguards that meet IPL requirements and that mitigate the initiating causes.

7. Determine if the intermediate event likelihood is less than or equal to the relevant TMEL.

-If it is, proceed to the next scenario.

-If not, proceed to the next step.

8. Evaluate whether there is a viable inherently safer design option.

III.8.7Advantages and limitations :

Advantages and limitations of the LOPA process include the following:

III.8.7.1 LOPA advantages :

1. LOPA is effective in agreeing layers of protection to manage risk.

2. LOPA conforms to industry standards. IEC 61511.

3.LOPA facilitates the analysis of protective layers addressing health and safety and environmental, and can also be applied to risks due to equipment damage and business value lost.

III.8.7.2 LOPA limitations:

1. LOPA is not a method:

-For identifying hazards.

- To analyses escalation events.

- To analyses risks associated with escape and evacuation.

2. LOPA can be:

- Excessive for simple or low risk decisions.

-Overly simplistic for complex systems.

3. For LOPA that indicates a gap for SIL 3 or higher SIFs:

-Other methods of risk evaluation agreed by the relevant EA shall be applied to better understand the risks.

-Alternatives should be sought that include inherently safer design strategies and alternative risk management approaches.

III.8.7.3 Scenarios and initiating cause exclusions :

1. Escalation events (e.g. external fire, domino effects from other parts of the unit or adjacent plants).

2. General fires not associated with a specific process parameter deviation.

3. Activities governed by Control of Work (e.g., lock out/tag out, confined space entry, crane lifts, and vehicle impacts).

4. Industrial hygiene and occupational safety hazards (e.g., slips, trips, and falls, pinch points, ergonomics, accessibility, hot surfaces, etc.).

5. Design error (e.g., wrong sizing, wrong material selection, wrong instrumentation, etc.) as an initiating cause. However, LOPA may be utilized to identify interim risk reduction measures while a design is being corrected.

6.General corrosion, erosion, improper maintenance, inspection, or other integrity management issues.

7. Natural phenomena such as: floods, earthquakes, tornadoes, storms, lightning strikes, etc.

8. Terrorism and sabotage

Conclusion :

This chapter has outlined the major approaches to risk analysis, demonstrating how qualitative, semi-quantitative, and quantitative methods can be effectively employed to assess and manage potential hazards. Through detailed explanations and structured methodologies, it has been emphasized that risk assessment is most powerful when multiple methods are integrated to complement one another, ensuring a thorough and resilient evaluation process.

In the course of the next chapter, I have applied both the Hazard and Operability Study (HAZOP) and the Layer of Protection Analysis (LOPA) methodologies to illustrate their practical application in identifying deviations, assessing risks, and designing independent protection layers. This integrated application highlights the value of combining different analytical tools to achieve a deeper, more precise understanding of operational risks, ultimately supporting the development of safer and more reliable industrial systems.

CHAPTER IV :

HAZOP &LOPA Method Application

Introduction:

This chapter presents the application of both Hazard and Operability Study (HAZOP) and Layer of Protection Analysis (LOPA) methodologies. The primary objective is to systematically identify potential hazards, evaluate operability concerns, and verify the adequacy of existing safeguards to effectively manage identified risks.

HAZOP serves as a foundational tool in ensuring safe operations within process facilities. It employs a structured and well-established approach to hazard identification, supporting the assessment of safety, environmental, and commercial risks.

Following the HAZOP, a LOPA was conducted to evaluate the effectiveness of current safeguards and determine the need for additional layers of protection. Each scenario was analyzed quantitatively to assess residual risk levels and ensure alignment with defined risk acceptance criteria.

The LOPA study was carried out in accordance with BP Engineering Technical Practices, ensuring adherence to industry standards and best practices.

IV.1 Deviations:

The objective of HAZOP study is to identify ways in which the design intent or operability of the process under consideration could be compromised. To do this, the project documents, particularly the Piping & Instrumentation Diagrams (P&IDs), are examined by a multidisciplinary team for ways in which deviations in the principal process parameters (e.g. flow, pressure, temperature) could occur, usually as a result of equipment failure, failure to correctly carry out procedures or other human error. The deviations studied are generated by applying guidewords (e.g. more, less) to the parameter. A typical deviation would therefore be "Flow, More". In addition, some aspects of the design (e.g. materials of construction, instrumentation) are applied as deviations to trigger. the study team to consider whether the equipment and facilities shown on the P&IDs are appropriate to the process. A standard set of deviations was applied, as follows:

Table IV.1: deviations

Deviations	Comment
1. High Pressure	
2. Less Pressure	
3. High Temperature	
4. Low Temperature	
5. High Level	
6. Low Level	

IV.2 Drawings:

Table IV.2: drawings:

Drawing	Place(s) Used
DC-PS-01-23-21175- REV Z15	Nodes: 1
DC-PS-01-23-21174- REV Z09	Nodes: 1
DC-PS-01-23-21177- REV Z08	Nodes: 1
DC-PS-01-22-21170- REV Z13	Nodes: 1
DC-PS-01-22-21448- REV Z08	Nodes: 1

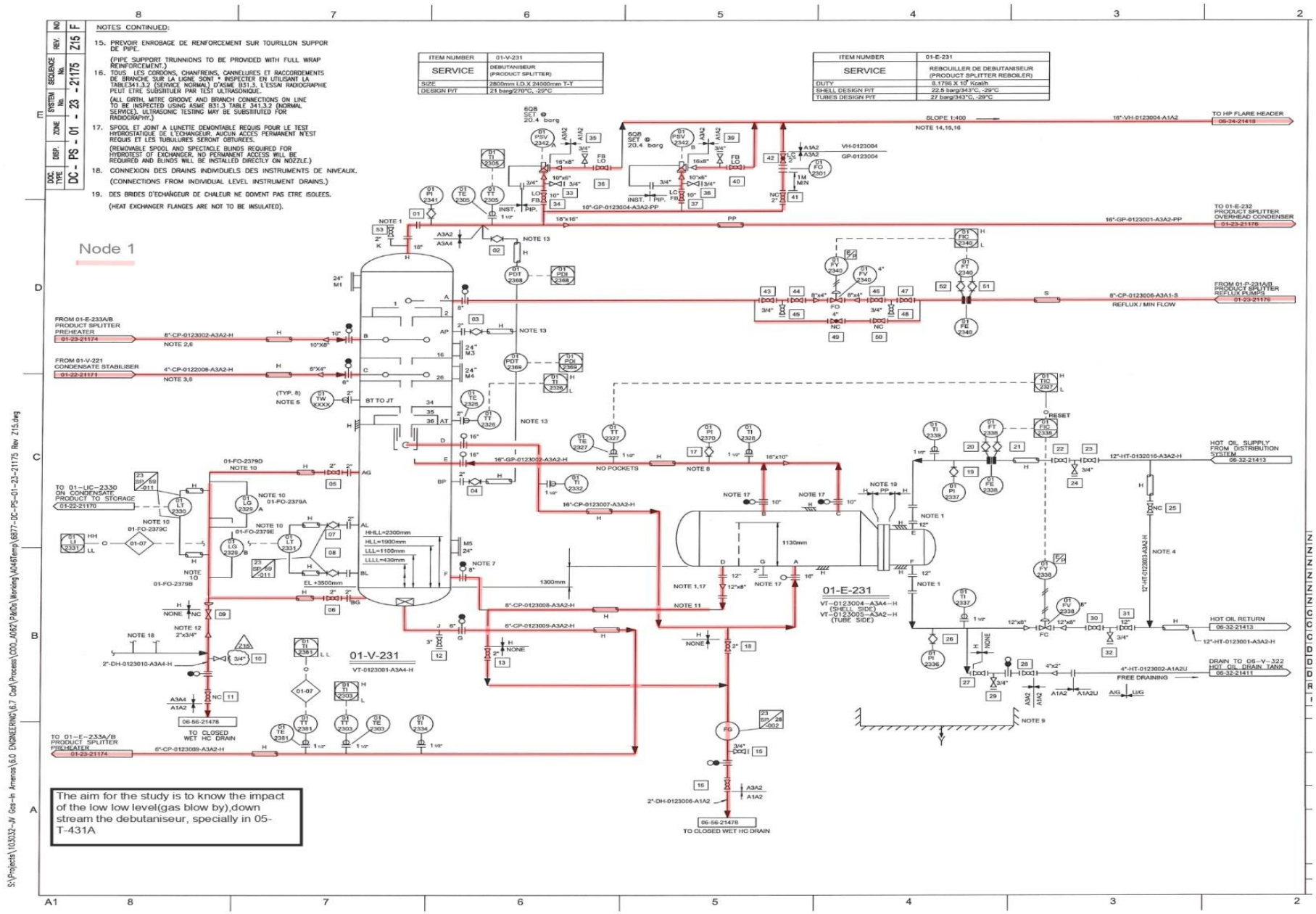


Figure IV.1 DC-PS-01-23-21175- REV Z15

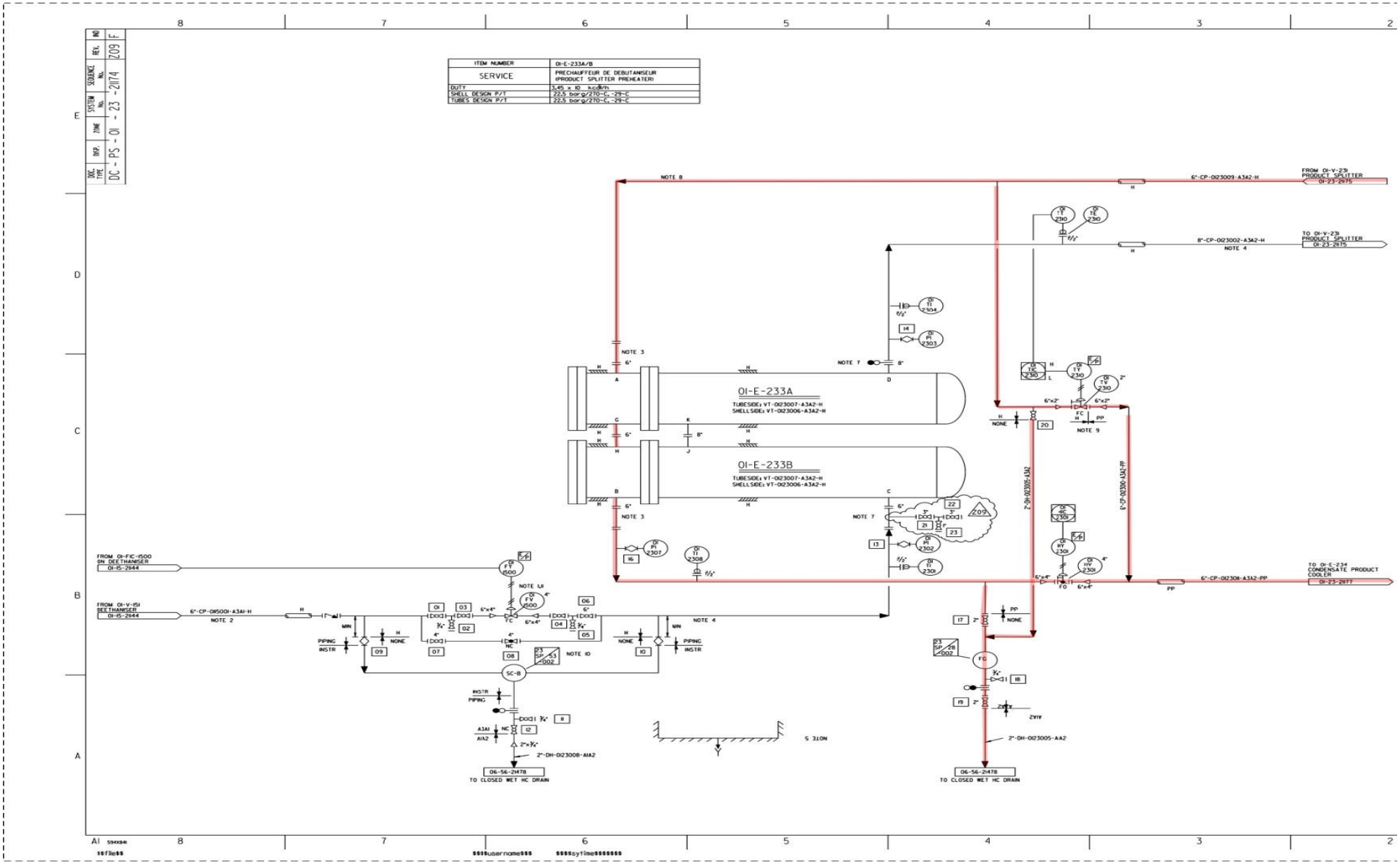


Figure IV.2 DC-PS-01-23-21174- REV Z09

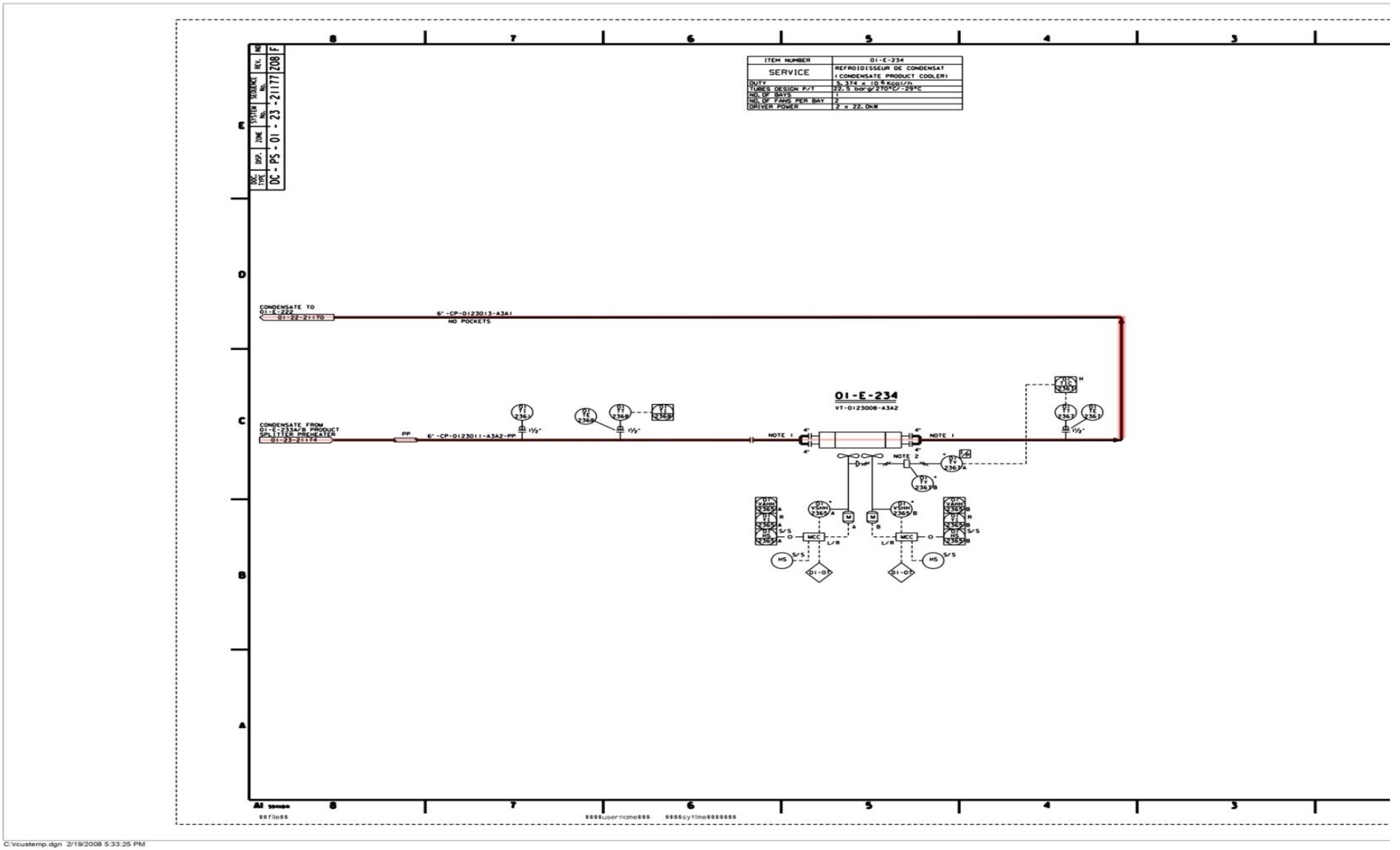


Figure IV.3 DC-PS-01-23-21177- REV Z08

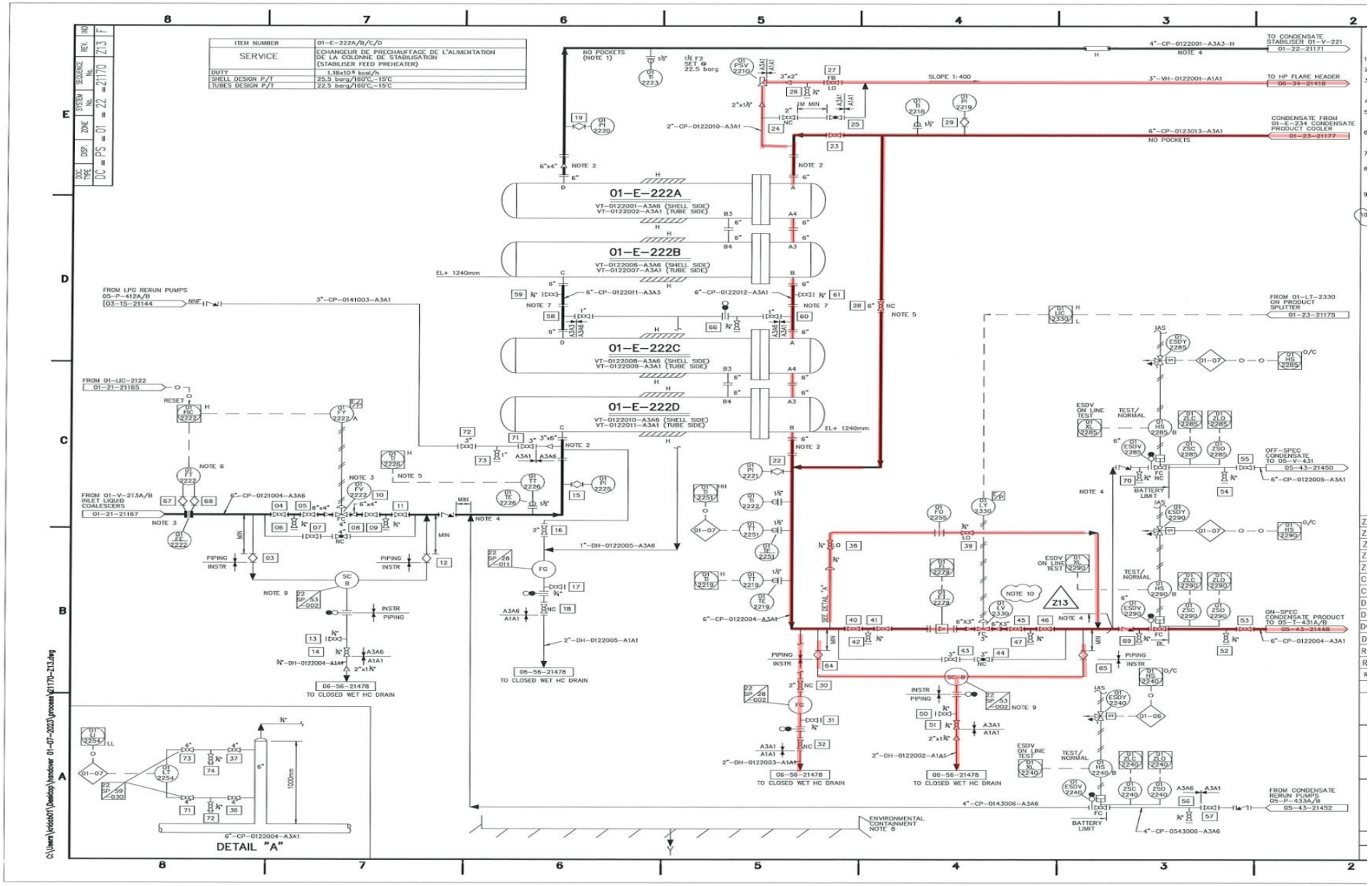


Figure IV.4 DC-PS-01-22-21170- REV Z13

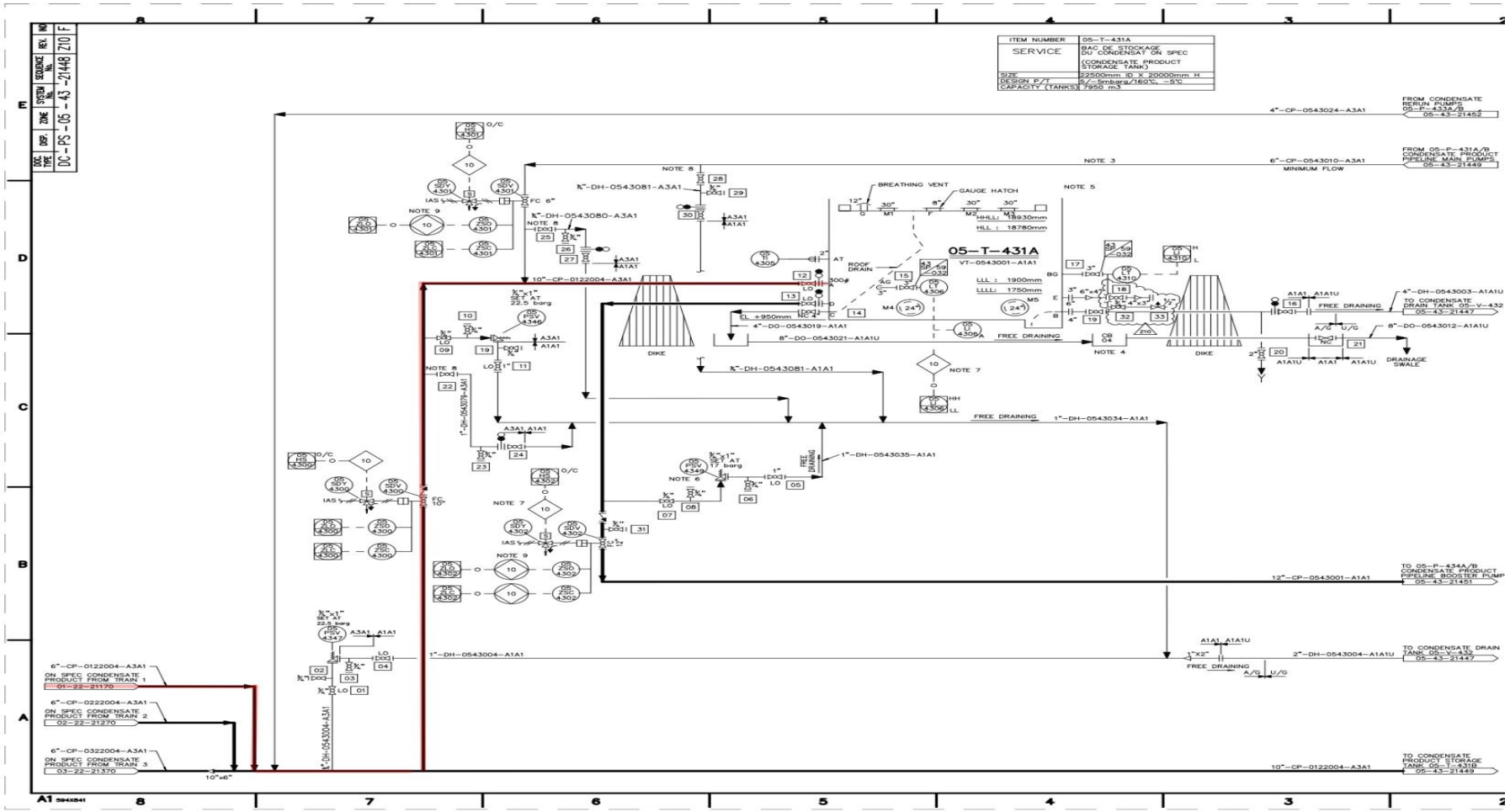


Figure IV .5 DC-PS-01-22-21448- REV Z08

IV.3 Risk Ranking:

Where adverse consequences of deviations were identified, these were assessed for severity and likelihood (frequency) based on this study, there was some consequences were identified which were sufficiently severe (severity E and higher), which is required LOPA study Severity & Likelihood Rankings, risk matrix used in the HAZOP are presented below:

Table IV.3 : Team Members:

First Name	Last Name	Company	Expertise	E-Mail Address
Maroua	Messaif	Interns	Student	
Sorour	Belhadj	Interns	Student	

IV.4 Recommendations:

Based on the outcomes of the HAZOP & LOPA study, Risk reduction measure equivalents to a SIL 1 is required.

Table IV.4 : Master HAZOP Worksheet :

Node: 1. Debutanizer and cooling condensate to on spec storage

Deviation: 1. High Pressure

Causes	Consequences	CAT	Risk Matrix			Safeguards
			S	L	RR	
No causes identified	Refer to no flow-deviation					

Node: 1. Debutanizer and cooling condensate to on spec storage

Deviation: 2. Less Pressure

Causes	Consequences	CAT	Risk Matrix			Safeguards
			S	L	RR	
No causes identified	Refer to no flow-deviation					

Node: 1. Debutanizer and cooling condensate to on spec storage

Deviation: 3. High Temperature

Causes	Consequences	CAT	Risk Matrix			Safeguards
			S	L	RR	
1-High Ambient Temperature (Summer)	No significant impact					
2- Failure to Open Bypass Valve (170-V-28): High temp flow from wells to shell side of exchanger 01-E-222 A/B/C/D (>60C)	High condensate temp to floating roof tanks (05-T-431 A/B), possible LOPC, fire, fatalities(1-2), loss of one tank, environmental damage.	S	E	2	5	1-Alarms (01-TAH-2219)
		C	E	2	5	2- Alarms (01-TAHH-2251)
		E	G	2	3	3- Fire &Gas detection
						4- Firefighting systems
						5- ignition source control
3- Hot Oil Valve 01-FV-2338 Left Open	High temp at bottom of debutanizer C5+ in LPG off-spec product.	C	H			
4-Condensate Product Cooler Failure (01-E-234)	(01-E-234) High condensate temp to storage tanks seal failure, fire, fatalities(1-2), commercial and environmental losses	S	E	3	6	1-Alarms (01-TAH-2219)
		C	E	3	6	2- Alarms (01-TAHH-2251)
		E	G	3	4	3- Fire &Gas detection
						4- Firefighting systems
						5- ignition source control
5-01-TV-2310 Valve Failure (Stuck Closed)	High temp off-spec LPG to debutanizer poor separation, off-spec product.	C	H			

Node: 1. Debutanizer and cooling condensate to on spec storage

Deviation: 4. Low Temperature

Causes	Consequences	CAT	Risk Matrix			Safeguards
			S	L	RR	
1- Low ambient temperature (winter)	No significant consequences identified.					
2- Overcooling in Condensate Product Cooler (01-E-234) fin fans (loss of control)	No significant consequences identified.					
3-Bypass valve 170-V-28 across 01-E-222 A/B/C/D opened or left open in error.	Low temperature condensate to storage. Loss of efficiency in Condensate Stabilizer. No significant effects identified.					
4- 01-TV-2310 (FC) driven open	Low temperature LPG flow to Debutanizer causing process upset and less efficient separation. Minor production loss (Off spec product).	C	H			

Node: 1. Debutanizer and cooling condensate to on spec storage

Deviation: 5. High Level

Causes	Consequences	CAT	Risk Matrix			Safeguards
			S	L	RR	
1- Manual Valves e.g. 170-V-40 closed in error	Increase in level in Debutanizer and overfill. Process upset. Liquid droplet carryover with LPG and off spec LPG Product.	C	G			
2- 01-LV-2330 (FC) manually or driven closed	Increase in level in Debutanizer and overfill. Process upset. Liquid droplet carryover with LPG and off spec LPG Product.	C	G			
03-HV-2301 (FO) manually or driven closed	Increase in level in Debutanizer and overfill. Process upset. Liquid droplet carryover with LPG and off spec LPG Product.	C	G			
01-ESDV-2285 and 01-ESDV-2290 manually or fail closed (e.g. loss of instrument air or power)	Increase in level in Debutanizer and overfill. Process upset. Liquid droplet carryover with LPG and off spec LPG Product.	C	G			

Node: 1. Debutanizer and cooling condensate to on spec storage

Deviation: 6. Low Level

Causes	Consequences	CAT	Risk Matrix			Safeguards
			S	L	RR	
1- The manual valves by pass 170-V-43 and 170-V-44 manually or left open	Loss of level in Debutanizer and potential gas blow-by to On-Spec Floating Roof Tank (05-T 431 A or B). LOPC through Floating Roof Tank from lifted floating roof. Jet Fire, Explosion, Pool fire in the bund area and potential fatalities (1-2 fatalities) remote area. Commercial loss based on loss of online On-Spec Floating Roof Tank (05-T-431 A or B) and loss of production for 1-2 weeks for investigation/repair. Significant Environmental incident.	S	E	3	6	01-LT-2330 low alarm to bordeman
		C	E	3	6	01-LALL-2254 on Outlet of Debutanizer to storage closes 01-ESDV-2290 and opens01-ESDV-2285 to protect theOn-spec Condensate Tank from high TVP.
		E	F	3	5	01-LT-2331 low low alarm closed 01-ESDV-2290and01-ESDV2285to protect the down stream equipment (05-T-431 A and B)
						fire and gas detection
						training and competence person
2- 01-LV-2330 manually or driven open	Loss of level in Debutanizer and potential gas blow-by to On-Spec Floating Roof Tank (05-T 431 A or B). LOPC through Floating Roof Tank from lifted floating roof. Jet Fire, Explosion, Pool fire in the bund area and potential fatalities (1-2 fatalities) remote area. Commercial loss based on loss of online On-Spec Floating Roof Tank (05-T-431 A or B) and loss of production for 1-2 weeks for investigation/repair. Significant Environmental incident.	S	E	3	6	01-LT-2330 low alarm to bordeman
		C	E	3	6	01-LALL-2254 on Outlet of Debutanizer to storage closes 01-ESDV-2290 and opens01-ESDV-2285 to protect the On-spec Condensate Tank from high TVP.
		E	F	3	5	01-LT-2331 low low alarm closed 01-ESDV-2290and01-ESDV2285to protect the down stream equipment (05-T-431 A and B)
						fire and gas detection
						training and competence person

Table IV.5: Master LOPA Worksheet:

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
1. 01-LV-2330 manually operable error by Boardman	BP (GP 48-03 Table 2	1.00E-01	S	E	Loss of level in Debutanizer and potential gas blow-by to On-Spec Floating Roof Tank (05-T-431 A or B). LOPC through	1. 01-LAL-2330 alarm on Debutanizer via BPCS. Not claimed as we need to know the sil related to SIF 01-LT-2331.	01-LT-2331	3. C&ECLOSED ESDV-2285 and 01-ESDV-2290 via ESD Doc numeber 05183 need to know the SIL For this SIF	C&E doc 05183	1.00E+00	1	1. Occupancy for 1 to 2 fatalities within flash fire and explosion foot print (assumed 50m x 50m) estimated as 10%. Does not include TAR and is averaged over the year for	1.00E-01	S	1.00E-03

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
					Floating Roof Tank from lifted floating roof. Jet Fire, Explosion, Pool fire in the bund area and potential fatalities (1-2 fatalities) remote area. Commercial loss based on loss of online On-Spec Floating							normal operations.1.00E-01			
						2. 01-LALL-2331 on Debutanizer closes 01-ESDV-2285 and 01-ESDV-2290 via ESD(The aim for the LOPA study.						2. Ignition probability assuming immediate ignition. GP-48-03 Table 4.	1.00E-01		
							01-LT-2331	4. C&ECLOSED ESDV-2285 and 01-ESDV-2290	C&E doc 05183	1.00E+00	1	1. Occupancy N/A	1.00E+00	C	1.00E-02

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:

Severity: E

TMEL: 1.00E-04 **MEL (/yr):** 3.00E-03

LOPA Ratio: 3.333E-02 **RRF:** 30

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Environmental:

Severity:

TMEL: **MEL (/yr):**

LOPA Ratio: **RRF:**

LOPA Result:

Commercial:

Severity: E

TMEL: 1.00E-03 **MEL (/yr):** 3.00E-02

LOPA Ratio: 3.333E-02

RRF: 30

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
			C	E	Roof Tank (05-T-431 A or B) and loss of production for 1-2 weeks for investigation/repair. Significant Environmental incident.	3. 01-LALL-2254 on standpipe downstream of 01-E-222 A/B/C/D closes 01-ESDV-2290 to On-spec Floating Roof Storage Tank and opens 01-ESDV-2285 to Off spec Storage Tank via		via ESD Doc numeber 05183 need to know the SIL For this SIF							
								7.				2. Ignition probability assuming immediate ignition. GP-48-03 Table 4.	1.00E-01		

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
						Degasser. Not claimed as we need to know the sil related to sif 01-LT-2331									
2. 01-LV-2330 spuriously open by BPCS	BP (FC) GP48-03 driven BPCS failure Table1	1.00E-01	S	**E**	Loss of level in Debutanizer and potential gas blow-by to On-Spec Floating Roof Tank (05-T-431 A or B).	1. 01-LAL-2330 alarm on Debutanizer via BPCS. Not claimed as we need to know the	01-LT-2331	5. C&ECLOSED ESDV-2285 and 01-ESDV-2290 via ESD Doc numeber 05183 need to know the SIL For this SIF	C&E doc 05183	1.00E+00	**1**	1. Occupancy for 1 to 2 fatalities within flash fire and explosion foot print (assumed 50m x 50m) estimated as 10%. Does not include TAR and is averaged over the year for	1.00E-01	**S**	**1.00E-03**

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
					LOPC through Floating Roof Tank from lifted floating roof. Jet Fire, Explosion, Pool fire in the bund area and potential fatalities (1-2 fatalities) remote area. Commercial loss based on loss of online On-	sil related to SIF 01-LT-2331						normal operations.1.00E-01			
						2. 01-LALL-2331 on Debutanizer closes 01-ESDV-2285 and 01-ESDV-2290 via ESD(The aim for the LOPA study.						2. Ignition probability assuming immediate ignition. GP-48-03 Table 4.	1.00E-01		
							01-LT-2331		C&E doc 05183	1.00E+00	1	1. Occupancy N/A	1.00E+00	C	1.00E-02

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
			C	E	Spec Floating Roof Tank (05-T-431 A or B) and loss of production for 1-2 weeks for investigation/repair. Significant Environmental incident.	3. 01-LALL-2254 on standpipe downstream of 01-E-222 A/B/C/D closes 01-ESDV-2290 to On-spec Floating Roof Storage Tank and opens 01-ESDV-2285 to Off spec Storage Tank via		6. C&ECLOSED ESDV-2285 and 01-ESDV-2290 via ESD Doc numeber 05183 need to know the SIL For this SIF				2. Ignition probability assuming immediate ignition. GP-48-03 Table 4.	1.00E-01		

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
						Degasser. Not claimed as we need to know the sil related to sif 01-LT-2331									
3. Bypass 170-V-43 and 48-44 opened in error	BP3GP 48-03 Table 2 operator inside	1.00E-01	S	E	Loss of level in Debutanizer and potential gas blow-by to On-Spec Floating Roof Tanks (05-T-431 A/B) and	1. 01-LAL-2330 alarm on Debutanizer via BPCS. Not claimed as we need to know the	01-LT-2331	2. C&ECLOSED ESDV-2285 and 01-ESDV-2290 via ESD Doc numeber 05183 need to know the SIL For this SIF	C&E doc 05183	1.00E+00	1	1. Occupancy for >3 fatalities within flash fire and explosion foot print (assumed 50m x 50m) estimated as 10%. Does not include TAR and is averaged over the year for	1.00E-01	S	1.00E-03

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
					Off spec Storage Tank (05-T-432). LOPC through Floating Roof Tank rim seals and damage to floating roof. Fire on floating roof and into bund area and potential injury. Commercial loss based on single	sil related to SIF 01-LT-2331.						normal operations.1.00E-01			
						2. 01-LAL-2330 alarm on Debutanizer via BPCS. Not claimed as we need to know the sil related to SIF 01-LT-2331.						2. Ignition probability assuming immediate ignition. GP-48-03 Table 4.	1.00E-01		
							01-LT-2331		C&E doc 05183	1.00E+00	1	1. Occupancy N/A	1.00E+00	C	1.00E-02

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:		**Environmental:**		**Commercial:**	
Severity: E		**Severity:**		**Severity:** E	
TMEL: 1.00E-04	**MEL (/yr):** 3.00E-03	**TMEL:**	**MEL (/yr):**	**TMEL:** 1.00E-03	**MEL (/yr):** 3.00E-02
LOPA Ratio: 3.333E-02	**RRF:** 30	**LOPA Ratio:**	**RRF:**	**LOPA Ratio:** 3.333E-02	
LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.		**LOPA Result:**		**RRF:** 30	

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
			C	**E**	tank loss. Environmental damage based on contained fire	3. 01-LALL-2254 on standpipe downstream of 01-E-222 A/B/C/D closes 01-ESDV-2290 to On-spec Floating Roof Storage Tank and opens 01-ESDV-2285 to Off spec Storage Tank via		1. C&ECLOSED ESDV-2285 and 01-ESDV-2290 via ESD Doc numeber 05183 need to know the SIL For this SIF				2. Ignition probability assuming immediate ignition. GP-48-03 Table 4.	1.00E-01		

Study:

Node: 1. Debutanizer and cooling condensate to on spec storage

Scenario: 1. 11-SC4 Gas blowby causing tank roof damage and LOPC

Safety:

Severity: E

TMEL: 1.00E-04 **MEL (/yr):** 3.00E-03

LOPA Ratio: 3.333E-02 **RRF:** 30

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Environmental:

Severity:

TMEL: **MEL (/yr):**

LOPA Ratio: **RRF:**

LOPA Result:

Commercial:

Severity: E

TMEL: 1.00E-03 **MEL (/yr):** 3.00E-02

LOPA Ratio: 3.333E-02

RRF: 30

LOPA Result: Risk reduction measure equivalents to a SIL 1 is required.

Initiating Events			**Consequence**				Tag #	**Independent Protection Layers**				**Frequency Modifier**		**IEL (/yr)**	
Initiating Event	Data Source	Freq. (/yr)	CAT	S	Consequence	IPL for consideration		Description	Data Source	PFD	RRF	Description	Prob	CAT	IEF (/yr)
						Degasser. Not claimed as we need to know the sil related to sif 01-LT-2331									

Conclusion

The application of the HAZOP and LOPA methodologies in this chapter has enabled a comprehensive and systematic evaluation of potential operational hazards and associated risks within the studied process unit. The HAZOP analysis effectively identified critical deviations, their underlying causes, and potential consequences, highlighting areas where safety and operability could be compromised. Subsequently, the LOPA approach allowed for a quantifiable assessment of residual risk by evaluating the performance and independence of existing safeguards.

The findings demonstrated that while numerous protective layers are in place, certain scenarios—particularly those involving high-temperature excursions, gas blow-by, and instrumentation failures—require additional risk reduction measures. The LOPA outcomes confirmed the need for safety integrity level (SIL) 1 equivalent protections for specific high-severity scenarios to meet acceptable risk thresholds.

This integrated analysis underscores the importance of adopting industry-recognized best practices, such as those outlined in BP's Engineering Technical Practices, in driving continuous improvement in process safety. Through collaborative assessment by a multidisciplinary team, actionable recommendations have been proposed to enhance safety performance, reduce operational risks, and safeguard both personnel and the environment.

GENERAL CONCLUSION

General Conclusion

This thesis has demonstrated the importance of comprehensive risk assessment in the oil and gas sector. Through the application of TRA, HAZOP, and LOPA, a clear understanding of operational hazards in the Debutanizer and condensate storage units was developed.

The findings highlight the necessity of implementing technical, organizational, and procedural safety measures to mitigate risks. Beyond technical solutions, fostering a culture of safety and vigilance is essential to prevent incidents and ensure sustainable operations.

In conclusion, integrated risk management not only enhances operational efficiency but also safeguards human lives and the environment, which must remain a priority in any industrial context.

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ANNEXES

Annexe01: Risk Framework -HSE Impact Levels:[16]

SEVERITY	HEALTH AND SAFETY	ENVIRONMENTAL
A	Comparable to the most catastrophic health/ safety incidents ever seen in industry. The potential for 100 or more fatalities (or onset of life threatening health effects) shall always be classified at this level	• Future impact, e.g., unintended release, with widespread damage to any environment and which remains in an "unsatisfactory" state for a period > 5 years. • Future impact with extensive damage to a sensitive environment and which remains in an "unsatisfactory" state for a period > 5 years. • Future impact with widespread damage to a sensitive environment and which can only be restored to a "satisfactory"/agreed state in a period of more than 1 and up to 5 years.
B	Catastrophic health/ safety incident causing very widespread fatalities within or outside a facility. The potential for 50 or more fatalities (or onset of life threatening health effects) shall always be classified at this level	• Future impact with extensive damage to a non-sensitive environment and which remains in an "unsatisfactory" state for a period > 5 years. • Future impact with extensive damage to a sensitive environment and which can only be restored to a "satisfactory"/agreed state in a period of more than 1 and up to 5 years. • Future impact with widespread damage to a non-sensitive environment and which can only be restored to a "satisfactory"/agreed state in a period of more than 1 and up to 5 years. • Future impact with widespread damage to a sensitive environment and which can be restored to an equivalent capability in a period of around 1 year
C	Catastrophic health/ safety incident causing widespread fatalities within or outside a facility. The potential for 10 or more fatalities (or onset of life threatening health effects) shall always be classified at this level.	• Future impact with extensive damage to a non-sensitive environment and which can only be restored to a "satisfactory"/agreed state in a period of more than 1 and up to 5 years. • Future impact with widespread damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of around 1 year. • Future impact with extensive damage to a sensitive environment and which can be restored to an equivalent capability in a period of around 1 year. • Future impact with widespread damage to a sensitive environment and which can be restored to an equivalent capability in a period of months
Levels A-C maintain the visibility of risks with the potential for catastrophic impact even if their probability of occurrence is extremely low. The upper level of this framework is defined by the most severe level of impact ever seen in industry		
BP's commitment to health, safety and the environment is paramount; this is reflected in BP's HSE goal of "No Accidents, No Harm to People, and No Damage to the Environment". No accident, injury, or loss of containment causing damage to the environment is ever "acceptable" to BP. BP is using this framework (equivalents of which are used throughout industry) to support the consistent prioritization of actions to eliminate or mitigate HSE risk and as part of BP's Performance Improvement Cycle to deliver continuous risk reduction.		

D	Very major health/ safety incident The potential for 3 or more fatalities (or onset of life threatening health effects) shall always be classified at this level. 30 or more injuries or health effects, either permanent or requiring hospital treatment for more than 24 hours.	• Future impact with extensive damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of around 1 year. • Future impact with localized damage to a sensitive environment and which can be restored to an equivalent capability in a period of around 1 year. • Future impact with widespread damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of months. • Future impact with extensive damage to a sensitive environment and which can be restored to an equivalent capability in a period of months.
E	Major health/ safety incident 1 or 2 fatalities, acute or chronic, actual or alleged. 10 or more injuries or health effects, either permanent or requiring hospital treatment for more than 24 hours	• Future impact with localized damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of around 1 year. • Future impact with extensive damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of months. • Future impact with localized damage to a sensitive environment and which can be restored to an equivalent capability in a period of months. • Future impact with extensive damage to a sensitive environment and which can be restored to an equivalent capability in a period of days or weeks.

SEVERITY	HEALTH AND SAFETY	ENVIRONMENTAL
F	High impact health/ safety incident Permanent partial disability(ies) Several non-permanent injuries or health impacts. Days Away From Work Case (DAFWC)	• Future impact with localized damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of months. • Future impact with immediate area damage to a sensitive environment and which can be restored to an equivalent capability in a period of months. • Future impact with extensive damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of days or weeks. • Future impact with localized damage to a sensitive environment and which can be restored to an equivalent capability in a period of days or weeks.
G	Medium impact health/ safety incident Single or multiple recordable injury or health effects from common source/event.	• Future impact with immediate area damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of months. • Future impact with localized damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of days or weeks. • Future impact with immediate area damage to a sensitive environment and which can be restored to an equivalent capability in a period of days or weeks
H	Low impact health/ safety incident First aid Single or multiple over-exposures causing noticeable irritation but no actual health effects	• Future impact with immediate area damage to a non-sensitive environment and which can be restored to an equivalent capability in a period of days or weeks.

Annexe02: Risk Framework – Business Impact Levels:

SEVERITY*	Non-Financial Impact	Financial Impact (EQUIPMENT DAMAGE, BUSINESS VALUE LOST)
A	Public or investor outrage on a global scale. Threat of global loss of license to operate.	>$20 billion
B	Loss of license to operate a major asset in a major market – US, EU, Russia. Intervention from major Government – US, UK, EU, Russia. Public or investor outrage in major western markets – US, EU. Damage to relationships with key stakeholders of benefit to the Group.	$5 billion - $20 billion
C	Loss of license to operate other material asset, or severe enforcement action against a major asset in a major market. Intervention from other major Government. Public or investor outrage in other material market where we have presence or aspiration.	$1 billion - $5 billion
D	Severe enforcement action against a material asset in a non-major market, or against other assets in a major market. Interventions from non-major Governments. Public or investor outrage in a non-major market, or localised or limited “interest-group” outrage in a major market. Prolonged adverse national or international media attention. Widespread adverse social impact. Damage to relationships with key stakeholders of benefit to the Segment.	$100 m to $1 billion
E	Other adverse enforcement action by regulators. Limited “interest-group” outrage in non major market. Short term adverse national or international media coverage. Damage to relationships with key stakeholders of benefit to the SPU.	$5m -$100 m
F	Regulatory compliance issue which does not lead to regulatory or other higher severity level consequence Prolonged local media coverage. Local adverse social impact. Damage to relationships with key stakeholders of benefit to the Performance Unit (PU).	$500k-$5m
G	Short term local media coverage. Some disruption to local operations (e.g., loss of single road access less than 24 hours).	$50k -$500k
H	Isolated and short term complaints from neighbours (e.g., complaints about specific noise episode).	<$50k

Annexe03: Likelihood Of Risk Event :

	1	2	3	4	5	6	7	8
Severity level	A similar event has not yet occurred in our industry and would only be a remote possibility	A similar event has not yet occurred in our industry	Similar event has occurred somewhere in our industry	Similar event has occurred somewhere within the BP group	Similar event has occurred or is likely to occur ,within the lifetime of 10 similar facilities	Likely to occur once or twice in the facility lifetime	Event likely to occur several times in the facility lifetime	Common occurrence (at least annually) at the facility
A	8	9	10	11	12	13	14	15
B	7	8	9	10	11	12	13	14
C	6	7	8	9	10	11	12	13
D	5	6	7	8	9	10	11	12
E	4	5	6	7	8	9	10	11
F	3	4	5	6	7	8	9	10
G	2	3	4	5	6	7	8	9
H	1	2	3	4	5	6	7	8
frequency	10^{-6}/yr or lower	$> 10^{-6}$to 10^{-5}/yr	$> 10^{-5}$to 10^{-4}/yr	$> 10^{-4}$to 10^{-3}/yr	$> 10^{-3}$to 10^{-2}/yr	$> 10^{-2}$to 10^{-1}/yr	$> 10^{-1}$to 1/yr	> 1to /yr
probability	10^{-6} or lower	$> 10^{-6}$to 10^{-5}	$> 10^{-5}$to 10^{-4}	$> 10^{-4}$to 10^{-3}	$> 10^{-3}$to 10^{-2}	> .01 to 0.1	> .1 to 0.25	> .25

Annexe 4: Overview of PHA-Pro Software:

What is PHA-Pro?

PHA-Pro is a specialized software tool developed by Dyadem / IHS Markit, designed to facilitate and document Process Hazard Analysis (PHA) studies, including HAZOP (Hazard and Operability Study) and LOPA (Layer of Protection Analysis**)**. It provides a structured interface that enables safety teams to systematically identify, analyze, and manage risks associated with industrial operations.

How PHA-Pro Works

1. Study Creation: Users can initiate a new project, defining the scope, system boundaries, and analysis parameters.
2. Node-Based Structure: The process is divided into logical sections called **"**Nodes**"** for focused analysis.
3. Guide Word Application**:** The software applies standard guide words such as *No, More, Less, Reverse*, etc., to stimulate hazard identification.
4. Deviation Analysis: For each guide word and process variable, the following are evaluated:
    - Cause
    - Consequence
    - Existing Safeguards
    - Recommended Actions
5. Automated Documentation: PHA-Pro generates detailed worksheets and reports for PHA, HAZOP, and LOPA.
6. Team Collaboration: The software supports recording participant names and tracking inputs during workshop sessions.

How PHA-Pro Was Used in Our Study :

In the context of our risk assessment study on the Debutanizer and On-Spec Condensate Storage Unit at the Tiguentourine Gas Processing Facility, PHA-Pro was utilized in the following manner:

- The system was divided into functional Nodes based on the P&ID diagrams.
- Each node was analyzed using guide words to identify potential deviations in key variables such as pressure, temperature, flow, and level.
- Causes and consequences of each deviation were identified, and existing safeguards were recorded.
- Where safeguards were deemed insufficient, technical and procedural recommendations were proposed using the software's framework.
- The LOPA module of PHA-Pro was used to assess the adequacy of Independent Protection Layers (IPLs) and determine whether additional risk reduction measures were needed