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HAZOP Revalidation Processes.

A New Approach

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Abstract

Process safety discipline has become increasingly important and critical in the design and operation of modern industrial installations that store or process toxic or flammable chemicals.

*Sustainable, competitive, and effective organizations take safety as an increasingly important management tool. They safeguard employees, facilities and neighbouring communities in terms of risk and significant environmental, legal, regulatory and financial impacts. The strength of these organizations is not only measured by what they have done in the past, but by what they do in the present and what they can guarantee in the future**: a vision in which safety is seen as an investment and never as a cost.***

Hazard and Operational Studies (HAZOP) are a structured and systematic way of identifying and analysing potential threats associated with the design, process and/or handling of hazardous chemicals. These studies and their revalidation processes must take place every five years, as they are mandatory requirements defined by the Process Safety Management (PSM) of the refining and petrochemical industry.

Specialists typically carry out these hazard studies, using different and in-depth technical knowledge of the process, mechanics, instrumentation, and safety. These efforts are complex, challenging, time-consuming, and consequently, expensive.

Based on the many HAZOP carried out in the modernization process of the Galp Refinery located in Matosinhos and in the subsequent revalidation studies of the hazard analyses, a new methodology was studied, maintaining the necessary safety requirements, with a reduction in time and costs of carrying out the meetings.

In this context, the concept of "super-nodes" appears to optimize the Revalidation HAZOP methodology based on a different identification of the P&ID circuits of the units. It consists of a structural change in the approach of a complex process, changing its form *of "waterfall" analysis (part by part) to something more agile, fast and safe (end to end package analysis) that can be replicated in new Revalidation risk analyses.*

The Diesel Hydrotreatment unit design HAZOP is presented in this work as a standard methodological analysis, showing all its preparation, execution and reporting steps in detail. The test run is intended to collect a set of information that can be compared with the result obtained in the Revalidation process of the same unit, through the identification of circuits in "super-nodes".

This procedure was also applied in the Gas Treatment Units, Sulphur Production Units and in the comparison between the Revamping HAZOPs of the Matosinhos Refinery and their Revalidation processes. With this information, it was possible to confirm the success of the proposed methodological approach for Revalidation processes and the significant reduction that, in some cases, corresponds to about a third of the initial sessions of the HAZOP study.

Keywords: *Process Safety, Process Safety Management, Process Hazard Analysis, HAZOP, Revalidation Approach, Galp Matosinhos Refinery.*

Resumo

A disciplina de segurança de processo tornou-se cada vez mais importante e crítica no projeto e operação de modernas instalações industriais que armazenam ou processam produtos químicos tóxicos ou inflamáveis.

*Organizações sustentáveis, competitivas e eficazes têm a segurança como uma ferramenta de gestão cada vez mais importante. Elas protegem os seus colaboradores, as instalações e as comunidades vizinhas em termos de risco e impactos ambientais, legais, regulatórios e financeiros significativos. A força dessas organizações mede-se não só pelo que fizeram no passado, mas também pelo que fazem no presente e, sobretudo, pelo que podem garantir no futuro**: uma visão em que a segurança seja vista como um investimento e nunca como um custo.***

Os Estudos de Perigos e Operacionalidade (HAZOP) são uma forma estruturada e sistemática de identificar e analisar as ameaças potenciais associadas ao projeto, processo e/ou manuseio de produtos químicos perigosos. Esses estudos e seus processos de revalidação devem ocorrer a cada cinco anos, pois são requisitos obrigatórios definidos pela gestão de segurança de processo (PSM) da indústria de refinação e petroquímica.

Os especialistas tipicamente realizam esses estudos de risco, usando conhecimentos técnicos diferentes e aprofundados do processo, mecânica, instrumentação e segurança. Esses esforços são complexos, desafiadores, demorados e, consequentemente, caros.

Com base nos vários HAZOP efetuados no processo de modernização da Refinaria Galp localizada em Matosinhos e nos estudos de revalidação subsequentes das análises de perigos, foi estudada uma nova abordagem mantendo os necessários requisitos de segurança, com uma redução de tempo e dos custos de execução das reuniões.

Neste contexto, o conceito de "super-nós" surge para otimizar a metodologia de Revalidação HAZOP a partir de uma identificação diferenciada dos circuitos P&ID das unidades. Consiste em uma mudança estrutural na abordagem de um processo complexo, alterando sua forma de análise "cascata" (parte por parte) para algo mais ágil, rápido e seguro (análise de pacote de ponta a ponta) que pode ser replicado em novas Revalidações de análises de risco.

O HAZOP da unidade de Hidrotratamento de Gasóleo é apresentado como uma análise metodológica padrão, mostrando detalhadamente todas as suas etapas de preparação, execução e relatório. O teste run destina-se coletar um conjunto de informações que permitam ser comparadas com o resultado obtido no processo de Revalidação da mesma unidade, através da identificação dos circuitos em "super-nós".

Este procedimento foi também aplicado nas Unidades de Tratamento de Gás, Produção de Enxofre e na comparação entre os HAZOPs do Revamping da Refinaria de Matosinhos e os seus processos de Revalidação. Com esta informação, foi possível confirmar o sucesso da abordagem metodológica proposta para os processos de Revalidação e a redução significativa que, em alguns casos, corresponde mesmo a cerca de um terço da duração das sessões do estudo HAZOP.

***Palavras-chave**: Segurança do Processo, Gestão de Segurança de Processo, Análise de Perigos de Processo, HAZOP, Processos de Revalidação, Refinaria de Matosinhos da Galp*

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To the management and my colleagues at Galp, for all the information support and for allowing me to participate in so many HAZOP studies throughout the projects I was involved in, which provided me with the critical tools for elaborating the criteria used in this work.

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Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

ACRONYM	MEANING
AIChE	American Institute of Chemical Engineers
ALARP	As Low As Reasonable Practicable
ANSI	American National Standard Institute
APCER	Associação Portuguesa de Certificação
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASSE	American Society of Safety Engineers
ASTM	American Society for Testing and Materials
BAT	Best Available Technique
CAER	Community Awareness & Emergency Response
CCPS	Center for Chemical Process Safety
CEI	Chemical Exposure Index
CIA	Chemical Industries Association
CMA	Chemical Manufacturers Association
COMAH	Control of Major Accidents Hazards
CSB	Chemical Safety and Hazard Investigation Board
CSC	Car Seal Close
CSO	Car Seal Open
DCS	Distributed Control System
EPA	Environmental Protection Agency
ESD	Emergency shutdown
EPSC	European Process Safety Center
ETA	Event Tree Analysis

FIC	Flow Indicator Control
FMEA	Failure Mode and Effect Analysis
FTA	Fault Tree Analysis
F&G	Fire & Gas
HAZAN	hazard analysis
HAZOP	Hazard and Operability Analysis
HSE	Health, Safety and Environmental
IChemE	Institution of Chemical Engineers
ICI	Imperial Chemical Industries
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IHAS	Integrated Hazard Analysis System
IPL	Independent Protection Layers
ISA	International Standards Association
LIC	Level Indicator Control
LO	Lock Open
LC	Lock Close
LOPA	Layer of Protection Analysis
MAPP	Major Accident Prevention Policy
MOC	Management of Change
MSDS	Material Safety Data Sheet
NSC	National Safety Council
NFPA	National Fire Protection Agency
ORA	Optimal Risk Analysis
OSHA	Occupational Safety and Health Administration
P&ID	Piping and Instrument Diagram
PES	Programmable Electronic Systems
PFD	Process Flow Diagram
PHA	Process Hazard Analysis
PIC	Pressure Indicator Control
PLC	Programmable Logic Controller
PPE	Personnel Protective Equipment
PSI	Process Safety Information
PSM	Process Safety Management

PSV	Pressure Safety Valve
QRA	Quantitative Risk Analysis
SIL	Safety Integrity Level
SIF	Safety Integrity Function
SIS	Safety Integrity System
RMP	Risk Management Plan
SRA	Society of Risk Analysis
TF	Toxicity Factor
TSO	Tight Shut Off

1 Introduction

Guedes de Carvalho (1998) wrote in his book “História do Ensino de Engenharia Química na Universidade do Porto (1762-1995)” [1]:

“The First Statement of Chemical Engineering - According to James Weil, it was Arthur D. Little who, in 1915, invented the first Chemical Engineering Statement, establishing that the base of the Chemical Engineering education will be the focus in the “process operations”: a common step to the majority of the industrial processes, such as heat transfer, distillation, fluid mechanics, milling and crystallization. With this statement, chemical engineers had to design different types of equipment, installation layouts and process flow connections and propose new operation activities.

As the Second Statement of Chemical Engineering – The focus of the evolution was changed in 1960, when R. B. Bird, W.E. Stewart and E, N. Lightfoot of the University of Wisconsin published their book entitled “Transport Phenomena”. Instead of studying process operations empirically, the authors try to understand the bases more scientifically, as well as other basic principles, namely: transport phenomena, thermodynamics, kinetics, process project and theory of the control. Almost simultaneously start to appear the computers and consequently an increase in the mathematical modelling.

The search for the Third Statement - The majority of actual analysts, as says Weil, “are all ready for the third statement, a work that indicates the future directions with authority and clarity and for a new rupture of vitality in the education and investigation”. This new statement should be guided by the needs of the society, such as environmental protection or process production efficiency? Or then more guided for the new sciences, such as biology, computers, and materials? Or then more guided for the people as workgroups, communications, etc.?”

Process Safety is a discipline that focuses on preventing operational failures (e.g., fires, explosions, and accidental chemical releases) at chemical process facilities.

However, it excludes classic worker health and safety issues involving working surfaces, ladders, protective equipment, etc. [2]

This work is dedicated to process safety, being a contribution to the constant search of chemical engineers to meet the needs of modern societies, where the present state-of-art management includes process hazard analysis as a critical path to providing proactive information about plant risk and how to deal with it.

1.1 Work Presentation

The proximity of housing areas surrounding industrial facilities, as a result of population migration and society development, necessarily increases the social awareness of the environmental impact and safety of all the affected parts.

On some occasions, this distance is so short that it increases the possible domino effect, raising the probability and consequences of a severe accident in any establishments (see Figure 1.1).

Figure 1.1 Matosinhos Refinery and surrounding areas.

Furthermore, the transportation of chemical products or fuel from the facility to cities, hospitals, shopping malls, or airports is also a dangerous factor in creating and using operational safety protocols.

Many industrial severe accidents have caused human and economic losses, long-term operational shutdowns, contractual reassessments, insurance increases, and additional research and audits.

The discipline of process safety aims to prevent incidents by optimizing process technology, updating operation or maintenance procedures, as well as implementing management systems. Those responsible must conduct a thorough investigation of the incidents to determine and analyse the facts that caused the consequences. The primary objective is to learn lessons by revealing the real root that causes problems.

In the 1960s, it became evident that the future of the process industry lay in increasingly large chemical plants with significant inventories of toxic and flammable chemicals. There was concern that the historical system of learning from incidents would become increasingly unacceptable as the scale of potential was likely to be inadmissible to continued operation by a commercial company [3].

Industrial disasters are more than just safety issues that must be addressed. They are also significant because they provide valuable opportunities to learn about the "fit" between society, technology, and the environment, and how that fit might be reinforced or impaired by unforeseen events. This kind of knowledge is priceless to humanity in a period of profound societal and environmental transformation. However, to make the best use of such possibilities, it is important to change how we think about industrial disasters [4].

As a response to the severe accidents registered between 1970 and 1980 (see Figures 1.2 (Seveso) and 1.3 (Bhopal)), process modifications and potentially dangerous industrial changes demand now a much deeper understanding of the design and operation of the units.

The incident in Seveso, the Italian city where an accidental emission of dioxins occurred in 1976, contaminating a wide area of Italy, was critical in the origin of the first European regulation for the prevention of accidents with dangerous substances, laying the foundations for a strongly oriented system for the protection of the community surrounding the industrial units.

According to the Seveso directive, the industrial operator now must show to the authorities, at any time, what measures have been taken to prevent incidents, restricting their consequences for society and the environment. It is a directive that aims to guarantee high levels of protection across the European Union.

Figure 1.2 Seveso accident in 1976.

Figure 1.3 Bhopal accident in 1984.

To meet these legal obligations, petroleum and chemical industries currently use Process Hazard Analysis (PHA) to identify weaknesses and minimize threats during projects' execution or even during the operation of the installations. They must be considered unfinished exercises, as they always depend on the experience and knowledge of the people involved.

Hazard and Operability Analysis (HAZOP) is one of the most well-known and applied PHA tools, which systematically identifies potential threats and problems caused by deviations in the design or operation of facilities. This analysis allows:

- Assess the applicable control measures and alert to the need for additional ones;
- Identify dangerous products to minimize their quantity;
- Identify hazardous materials, leading to their replacement by less dangerous ones;
- Moderate the operating conditions (temperature, pressure, and composition) to minimize the impact of any leakage or high energy release;
- Detect new dangers from layout changes, new equipment, new raw materials and/or products, changes in the operation variables and/or procedures, etc.
- Simplify the project, reducing unnecessary complexities and operational errors.

As a result of this process safety analysis, there has been a decrease in the frequency and severity of accidents at work, which provide the company and the surrounding communities with an increasing guarantee of safety and full compliance with environmental requirements. The supervisory authorities, on the other hand, through periodic audits, accompany and monitor the safety systems, checking not only the protocols in progress but also any new opportunities to reinforce the safety of the installations.

In the United States, the Occupational Safety and Health Administration (OSHA) already imposes national companies, which operate with dangerous or highly toxic products, producing over 10000 lb (4356 kg) of flammable products per year, to perform process hazard analysis by experts in engineering and process operations. The employer is responsible for addressing the team's findings and safety suggestions in a timely way and documenting their resolution. Finally, the PHA also needs to be updated and revalidated at least every five years after completing the initial process hazard analysis to ensure that the process hazard analysis is consistent with the current process [5].

In Europe, companies also have a similar “standard” with the Seveso directives, to revalidate the Major Accident Prevention Policy (MAPP) every five years to demonstrate their continuous improvement process and prove it to the competent authority.

From the Seveso directives, the operator is also responsible for creating a safety management system to prevent possible serious accidents involving dangerous substances. This system must be written and include the objectives and general principles of action, defined by the operator, on controlling major hazards and accidents involving dangerous substances. It must integrate the organizational structure, responsibilities, safety procedures (management of change, planning for emergencies, performance monitoring, audits, reviews, hazard Revalidations, etc.), processes, and resources to implement the system of preventing major accidents involving dangerous substances.

The PHA Revalidations aim to guarantee the consistency of the process with the current operating conditions and to identify and control new risks through an exhaustive verification of the engineering project. This reassessment is particularly critical in cases where companies do not have a Management of Change (MOC) procedure in place and changes can be made without a detailed safety study.

In the risk assessment to revalidate the PHA, all changes made to the process in the previous PHA must be carried out, thus confirming that the respective safeguards have been recognized and incorporated in the final report. Identifying a large volume of changes may even result in a new PHA from scratch to ensure that the analysis is up to date and that they reflect all the risks of the process.

Incident investigation reports and recommendations from previous PHA should be revisited. The respective analysis should focus specifically on how to process modifications, human factors and/or layout problems that may have affected the safety of the equipment or the installation in general.

Unit operators should discuss the risks involved in operating procedures that do not constitute routines, such as starting up, stopping, maintenance, and sampling the unit, to help identify deficiencies in procedures or equipment that may contribute to human error. These instructions must be executed as "guidewords" during the HAZOP analysis.

Following this approach, Galp Energia, SGPS, S.A (Galp) implemented the necessary measures to comply with legal safety requirements. In particular, the periodic hazard analysis after new projects or after detecting new dangers of layout changes, new raw materials and/or products, changes in operating variables and/or procedures, etc.

1.2 Galp Company

Galp is a holding company based in Portugal that is dedicated to the oil and gas industry. Its activity is divided into three business segments: Gas and Energy, Exploration and Production and Refining and Marketing.

In the Gas and Power segment, Galp is dedicated to the distribution and marketing of natural gas and the generation and sale of electricity. The Exploration and Production segment explores, develops, and produces oil and natural gas, operating in around 40 projects worldwide. In the Refining and Distribution area, Galp is active in operating oil and gas to produce and market petroleum products.

In 2020, Galp's refining system could process 330 thousand barrels of crude oil per day from the Matosinhos and Sines refineries to supply the entire Portuguese market with different petroleum products such as fuels and petrochemicals lubricants, paraffins, and bitumen.

At the end of December 2020, Galp decided to discontinue refining operations in Matosinhos and continue to supply the regional market from the site, maintaining access to the maritime terminal, storage and distributing facilities. As a result, the production of electricity, fuels, oils (bases, bitumen and paraffins), aromatics and solvents at this refinery was cancelled and some of these products are now transferred from Sines Refinery or imported from other countries.

Figure 1.5 shows the actual crude oil process and product capacities of Galp's refining system [6].

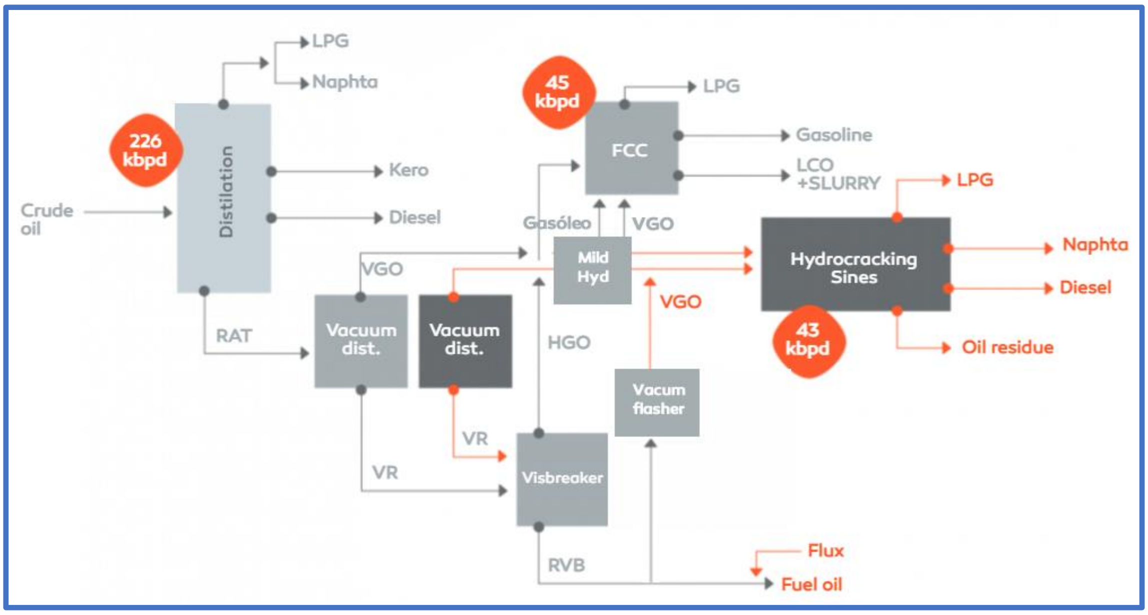

Figure 1.4 Actual Galp refining system.

According to the Galp website, the productions are shown in Figure 1.4 [6].

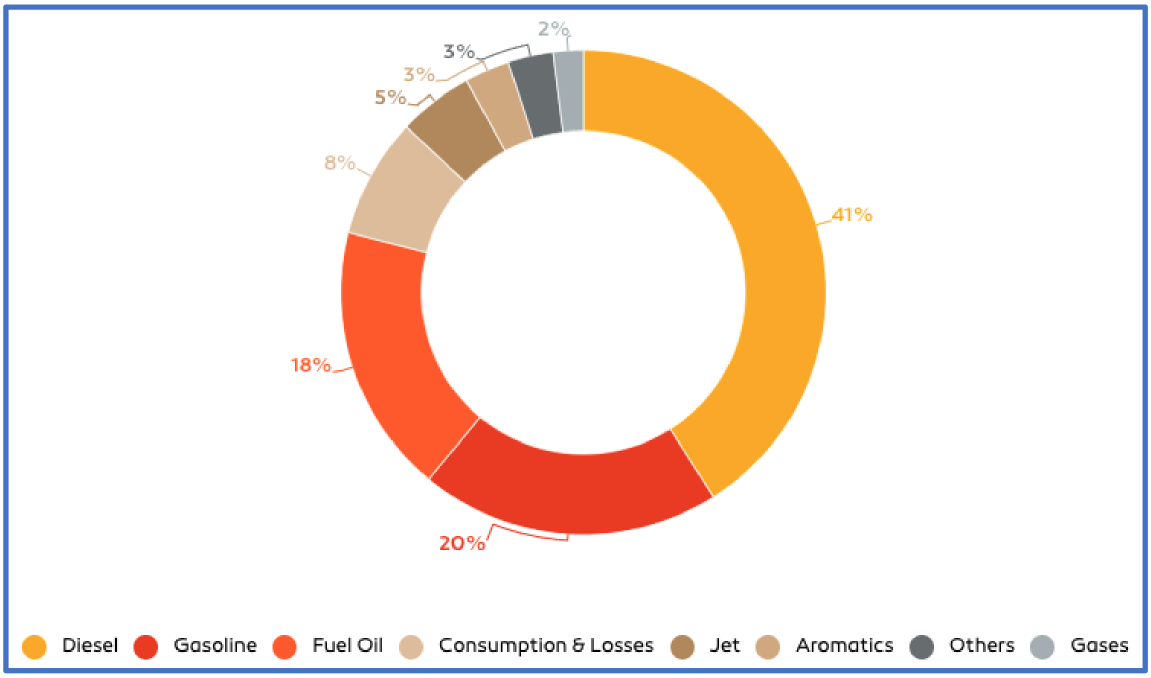

Figure 1.5 Galp productions in 2020

Despite assuming that oil still plays an important key role in the company's sustainability, Galp has been increasingly investing in energy efficiency and renewable energy, considering it is important to have strong participation in the energy transitions.

To reduce its environmental impact, at the Sines refinery alone, Galp invested 4.4 million euros in energy efficiency projects, potentially reducing 81 thousand tons of carbon dioxide, corresponding to 4 % of the total emitted by this facility [7].

Another 2020 objective was that 247000 m^3 of biofuels were to be incorporated into the fuels sold in Portugal and Spain, including 30000 m^3 of biodiesel from waste produced by Enerfuel (Galp). The integration of these low-carbon fuels avoided the emission of more than 650 kton CO_2 compared to the fuel of exclusively fossil origin [8].

With an investment of approximately 330 million euros, also in 2020, a joint venture was created with the Spanish group ACS. Galp holds 75% of the joint venture and has become the main producer of solar energy in the Iberian Peninsula. It currently has a generating capacity of 914 MW and is expected to reach 2.9 GW by 2024 [9].

Galp is evaluating the development of a 100 MW electrolyser in the first phase, with the ambition to expand this capacity over the decade to 0.6 - 1.0 GW, consuming green hydrogen instead of the grey hydrogen produced in Sines [10].

1.2.1 Matosinhos Refinery

The Matosinhos Refinery started its activity in 1969 and was inaugurated in September of the following year. Figure 1.6 shows one old photo from the construction of the piperacks phase.

Figure 1.6 Refinery construction in 1969.

The Refinery is located on the northwest coast of Portugal, in the municipality of Matosinhos, between Leça da Palmeira and Perafita, occupying an area of about 290 hectares. The refinery layout installations can be seen in Figure 1.7 [11].

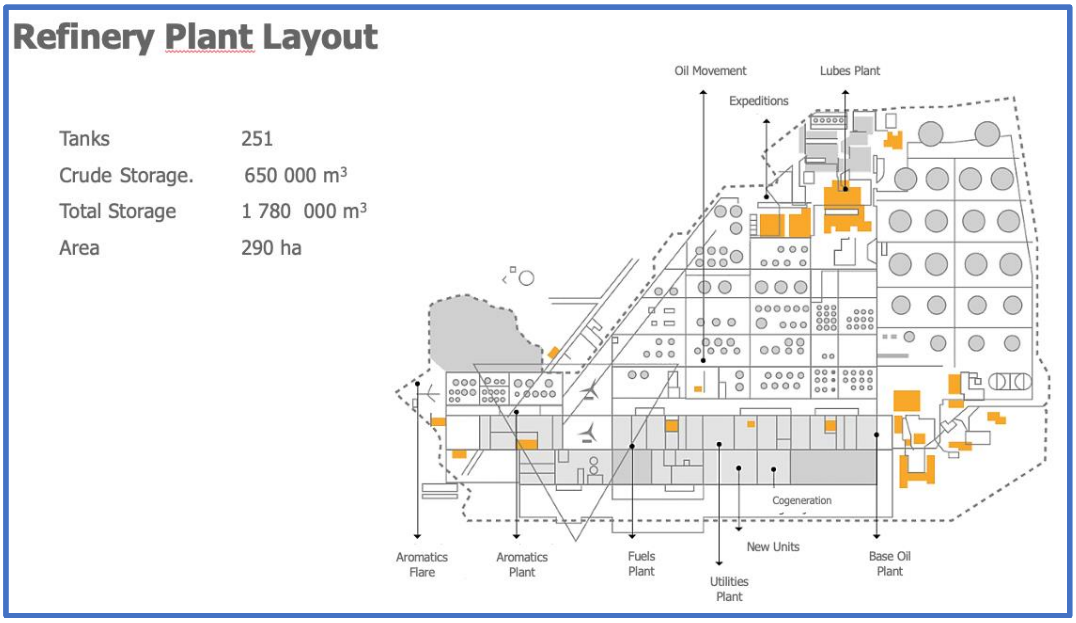

Figure 1.7 Refinery plant layout installations.

The refinery receives its raw materials through the ocean terminal (mono-buoy) through a buried pipeline 3.2 km long and through the port of Leixões, to which several pipelines about 2 km long connect it. This interconnection network also makes sending some intermediate and final products for dispatch by ship possible. The refinery is also connected with a pipeline to Francisco Sá Carneiro airport to supply jet fuel, a pipeline to an LPG gas station (Pergás) and an installation for filling tank vehicles for fuel, bitumen and chemical products in bulk - see Figure 1.8 [6].

Figure 1.8 Matosinhos Refinery interfaces.

The refining complex started its activity with the Fuels (FCO), Base Oils (FOB), Lubricants (LUB) plants and, in 1981, with an Aromatics plant (FAR). The refinery also integrated the Utilities plant (FUT) that produced and distributed steam, demineralized water, and cooling water, compressed air, and electricity to the other units of the refinery. A Waste Water Treatment (WWT) also treated the generated liquid effluents and an Oil Movement plant (MOV) that managed the storage and movement of raw materials, intermediate products, and final products, both between the different units abroad.

Matosinhos Refinery was a typical hydroskimming configuration until 2010 when the new units were built and others were revamped. With this project, the crude distillation and other associated treatments were expanded with the vacuum and visbreaker units to produce vacuum gasoil (VGO) for hydrocracking and fluid catalytic cracking (FCC) plants installed at the Sines Refinery, increasing the distillation capacity of the Matosinhos Refinery to 5.5 million ton/year. All the process unit changes implemented can be seen in the block diagram in Figure 1.9.

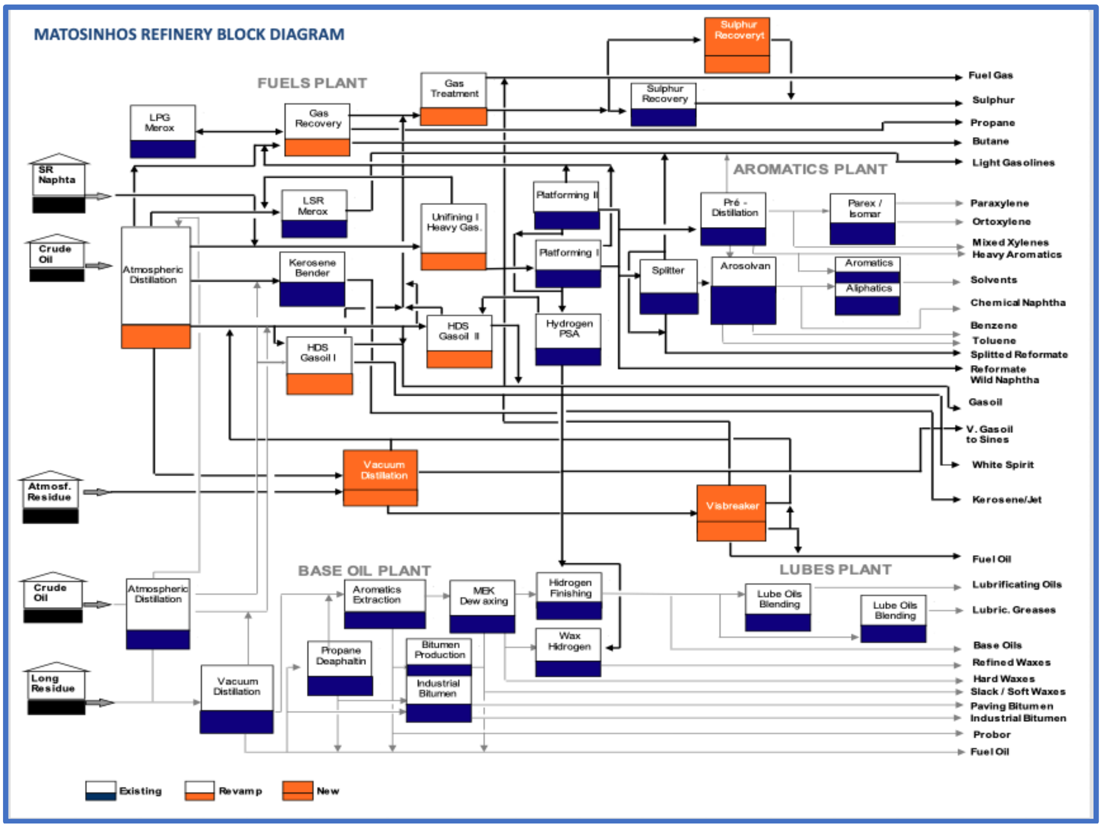

Figure 1.9 Matosinhos Refinery block diagram.

These process units produced fuels (liquefied petroleum gas (LPG), gasoline, Jet/petroleum, diesel, and fuels), base oils and lubricants, paraffins, bitumen, solvents and aromatics, making this facility the only specialized refinery in Portugal.

Oils, Lubes, Aromatics, and Solvents were produced exclusively at the Matosinhos Refinery and were intended for both the national market and export to more than 40 countries spread over four continents.

Domestically, solvents and aromatics were sold to the manufacturing industry, emphasizing the supply of benzene to Bondalti's aniline production unit in Estarreja. Also important was the supply of hexane and heptane to Hovione, one of the main Portuguese companies in the pharmaceutical area. The paint, varnish, and coatings industry, with a strong presence also in the north, was one of the main customers for the solvents produced at the refinery, with companies such as CIN and Barbot paints standing out. The product portfolio of the refinery is shown in Figure 1.10 [6].

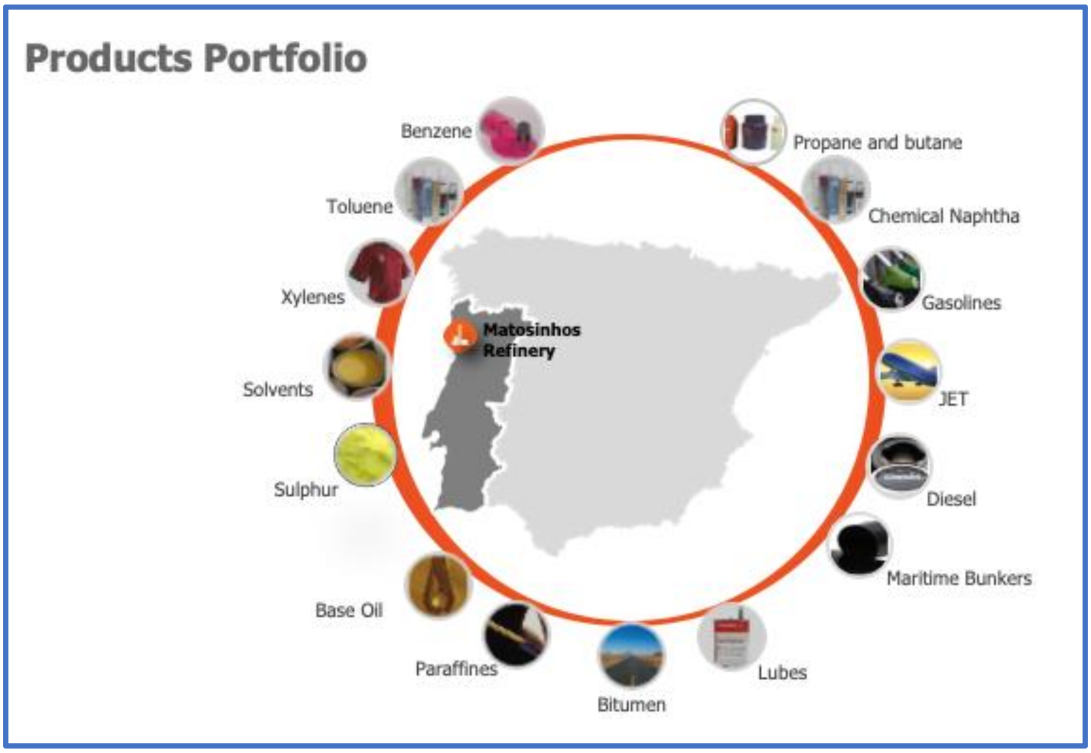

Figure 1.10 Refinery portfolio products.

The refinery was characterized by its high degree of integration, technological adequacy and versatility. Due to its process flexibility, it allows the treatment of different crude oil grades from many places worldwide.

1.2.2 Fuel Plant

The Fuel Plant, in which location some of the units are studied in this work, uses crude oil as a raw material to produce fuels. It consists of several process units, with a simplified diagram shown in Figure 1.11.

The crude is separated into fractions (cuts) in an atmospheric distillation column. These intermediate products must be treated to give rise to different fuels with the necessary specifications for their commercialization.

The lighter, gaseous fraction is treated to remove hydrogen sulphide (hydrogen sulphide) and mercaptans in several units, obtaining propane, butane, liquefied petroleum gas (LPG) and fuel gas for use in the refinery. The hydrogen sulphide is sent to the sulphur recovery unit, where it is obtained as a final product.

Light gasoline is treated to reduce the mercaptan content at the Merox unit and can then be integrated into other products.

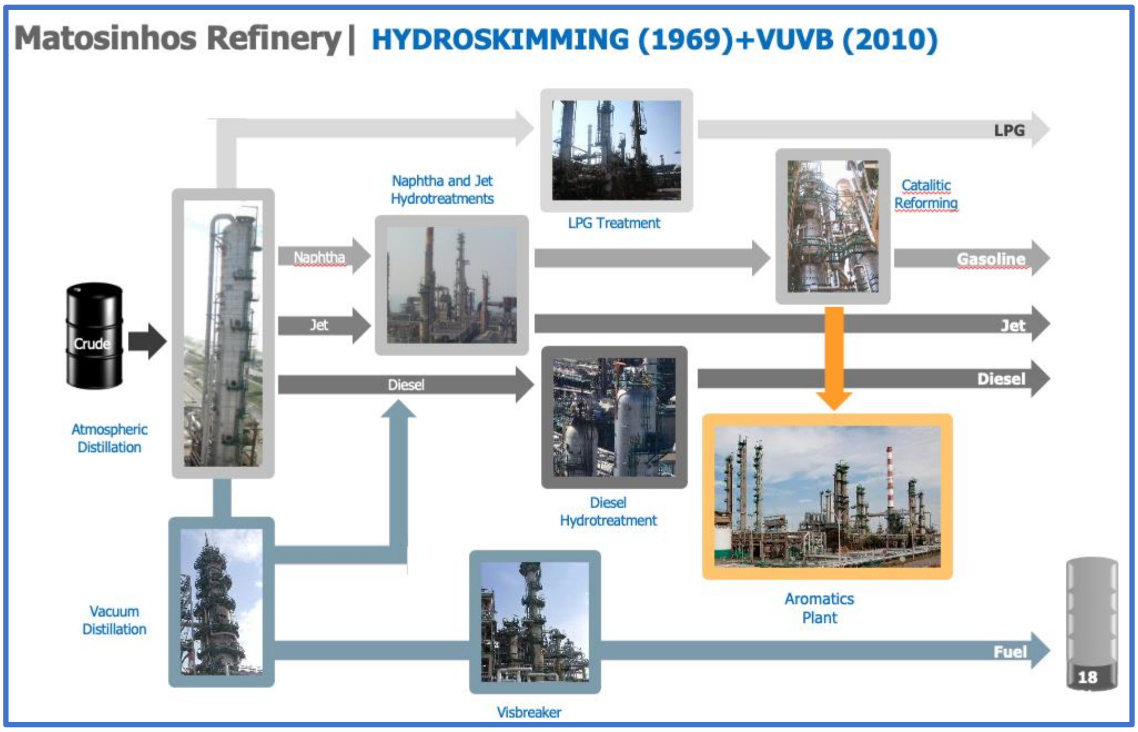

Figure 1.11 Fuels plant block diagram.

The heavy gasoline is initially treated to remove sulphur and other contaminants, after which it is sent to the catalytic reforming units, where a high-octane product, the reformed, is obtained, which is destined for the blending of gasolines and constitutes the raw material for the aromatics plant (FAR).

In the process, a stream rich in hydrogen is also produced, which, after purification in the PSA unit, is used in other reaction units of the base oil plant (FOB) and the fuel plant (FCO).

Petroleum (kerosene) and diesel are treated to reduce their sulfur content in two hydrodesulfurization units to meet specifications. Kerosene is used as aviation fuel (Jet) and in the blending of diesel, where desulfurized diesel is also sent.

The heaviest fraction of the distillation, the atmospheric residue, will be vacuum distilled to separate it into higher-value products. Two main streams are obtained: heavy vacuum gas oil (HVGO), used at the Sines refinery as a feedstock for hydrocracking and catalytic cracking unit (FCC), and vacuum residue. This last stream is treated in the Visbreaker unit, where its viscosity will be reduced by heat treatments, obtaining products that can be used as fuel oil.

1.3 Motivation and Main Contributions

My professional career began in 1984, at the Galp de Matosinhos Refinery, after completing the Chemical Engineering course at the University of Porto.

During my career at the company, as a process and project engineer, I held the most varied positions in the management, production and technology of fuels and petrochemicals. With these responsibilities I participated, in some cases led, the operation of several facilities and several industrial projects, namely in their design, construction, commissioning and start-up phases of several units of the Matosinhos and Sines Refineries. In the basic and detailed engineering of the various projects, involving complex process units and equipment of different characteristics, where the risks had to be carefully studied, I was able to identify the appropriate safety measures to safeguard everyone involved in their installation and operation.

The experience and perspectives presented here are the result of my multidisciplinary experience. During this trip, I paid special attention to safety, given the responsibilities related to such roles. In this context, I had the opportunity to participate in several process risk analysis, where most were HAZOPs, in the design and Revalidation phase, which allowed me to acquire expertise in the creation of their methodology and verify that this technique is fundamental for success term of an installation.

During these studies, it was possible to observe that in the HAZOP methodology, the subdivision of P&ID's into "nodes" presented a variability that depended on the technical experience of the team, its leader and the global knowledge of the process. During the Revalidation process, the "nodes" often corresponded to bigger circuits of a unit, involving more complex equipment such as distillation columns and auxiliary equipment, furnaces, compressors, turbines, etc. This orientation proved to be a potential way to reduce the execution time of HAZOPs, namely in the Revalidation phase, whenever an experienced multidisciplinary team is present, it ensures that all risks are addressed and all safeguards duly identified.

This work aims to deepen and optimize the safety analysis methodology of the HAZOP process, during its Revalidation process, through new criteria for identifying nodes, allowing a consistent and safe analysis of the causes, consequences and necessary safeguards. Through this strategy, models (e.g., distillation column package) will be created that can be used for safety analysis in similar installations and operating conditions.

During the HAZOPs Revalidation at the Fuel Factory of the Matosinhos Refinery, I had the opportunity to prepare, lead the meeting and make the respective report of the Diesel Hydrotreatment Unit, using the methodology and conventional identification of nodes. An experience that allowed me to collect all the information presented in chapter 4 of this work.

A new approach to identifying nodes, called "super-nodes", studied, and applied in the following chapters, was also tested in the Gas and Sulphur Treatment units and again in the Diesel Hydrotreatment unit, during a second Revalidation study. A comparative analysis was made between the two different node approaches to extract conclusions.

From all the information collected during the Fuel Plant Revamping project in 2010 and during the HAZOPs Revalidation process of the same units, it was possible to draw final conclusions about the application of this new approach to the methodology applied in the HAZOP study.

For the success of this work, given the specificity of the technical information, the collaboration, availability, knowledge, and complementarity of GALP's technical resources involved were fundamental. My sincere thanks to them for all their collaboration.

1.4 Work Outline

This work analyses the framework and procedure of one of the most used methods for hazard analysis - the HAZOP study - proposing an optimization to its mandatory revalidation process. This methodology has been used to identify hazardous scenarios while meeting the requirements of the US and European Directives.

Is organized into the following seven chapters:

1 – Introduction:

This chapter highlights the importance of safety in the industry to prevent incidents and accidents and optimize process technology. The most recent history is provided as the most important legal achievements. The Galp company and its refinery in Matosinhos are presented, which served as the basis for all information collected in this work. Special emphasis is given to the Fuel Plant, where risk analyses and their respective Revalidation were carried out. Finally, this chapter also explains my motivation for carrying out this work, which results from my professional experience in the chemical and petrochemical industries, namely in operation and design, where safety is fundamental for the installations.

2 – Process Safety:

This chapter introduces Process Safety as a critical discipline for preventing and mitigating episodic chemical releases that could cause disasters in the workplace and the surrounding community. Establishes the connection between the historical tragic events and their consequences with numerous lessons and regulations that have helped the understanding of dangers and risks in a modern process industry.

3- Process Hazard Analysis:

This chapter presents the PHA as a process safety management tool or guideline, highlighting the skills and information needed to perform these safety reviews. Objectives, opportunities, rules, planning and selecting the most appropriate techniques applied during the project or the operation of a process installation are presented. The Management Change (MOC) procedure is also highlighted as a critical requirement in companies to ensure that all changes are managed within a plant.

4– Hazard and Operability Study:

This chapter describes the purpose, procedure, methodology, advantages, disadvantages, the types of results and the HAZOP methodology's resource requirements. Additionally, current HAZOP limitations will be emphasized, and thus, the research requirements that should be considered for the improvement and advance. To classify and analyse the research carried out over several years and define the state of the art of the HAZOP methodology, successive data on the topic of Hazard and Operability were revised based on books, standards and, the main magazines and conferences on school subjects. A particular focus will be given to the risk classification criteria due to the severity and probability of a HAZOP and its general rules typically applied and that allow the standardization of these studies. The Diesel Unit HAZOP Revalidation study will be presented, showing all the steps from the preparation and meeting to the report of the safety analyses.

5 – A New Approach to HAZOP Revalidation:

This chapter reviews the actions and rules that must be implemented to ensure good planning and execution of HAZOP studies during the Revalidation processes. Revalidating and updating the results of a PHA risk assessment are critical and essential steps in keeping process safety information up-to-date and reliable. Different methodologies for breaking down a P&ID will be discussed, along with their respective implications for the time and cost of the HAZOP. The division of a P&ID corresponds to one of the most fundamental parts of the methodology and constitutes a critical theme of this work. A new concept of "super-nodes" will be presented, discussed and applied in the Revalidation of Diesel and LPG Treatment Units The main focus will be given to the Sulphur Recovery Unit (Claus Unit) as an application of the lesson learned, showing the strategy risk analysis methodologies that can be applied in revalidation of process facilities. It is intended to extract guidelines, criteria and conclusions to allow a faster and more economical way to perform a HAZOP without loss of quality in these safety analyses.

6 – Refinery Global HAZOPs Indicators:

This chapter compares the data collected at Galp's Matosinhos Refinery during the HAZOP studies in the design phase and later during the Revalidation process of the same risk analyses. The obtained results, namely the number of P&ID’s, number of nodes, and execution time of risk analyses are presented and commented on for later presentation of the conclusions.

7 – Conclusions and Future Objectives:

This chapter presents the main conclusions of this current research and the proposal for future work, such as systems capable of improving the overall HAZOP methodology.

Finally, a list of the References used and cited throughout the work is presented and a Glossary of the main terms related to the topic of Process Safety.

Annex A - HAZOP Risk Matrix
Annex B – Typical Modifications
Annex C – Case Study #1 Diesel Unit First Revalidation Worksheets
Annex D – Case Study #2 Diesel Unit First Revalidation Worksheets
Annex E – Case Study #3 Gas Treatment Revalidation Worksheets
Annex F – Case Study #4 Claus Unit HAZOP Design vs Revalidation

2 Process Safety

Unsafe activities are unacceptable in today's societies due to its impact on people, facilities, the environment and, not least, on the companies' reputation. Achieving the goal of "zero accidents" requires more than meeting exacting standards of safety and health at work. It involves the management of all aspects associated with the safety of various processes and operations.

Process Safety is a fundamental and critical discipline for designing and operating modern industrial facilities that handle hazardous chemicals. It represents an important proactive and systematic approach to protecting the environment of employees, contractors and neighbouring citizens. It is an identification and mitigation (or prevention) approach that integrates all aspects of risk associated with process industries to reduce the frequency and severity of incidents. It helps to improve company culture in terms of safety through more efficient operation, more effective industrial process design and more qualified management.

This discipline considers:

• Proactive management system focused on preventing incidents;

• Reduction of the risk of environmental impact;

• Safer workplace for employees and nearby communities;

• Reduction of downtime and losses;

• Compliance with industry codes, standards, and practices;

• Integration with existing quality, environment, and safety management systems;

• Continuous improvement of system performance measurement metrics;

• The full involvement of employees in implementing the system makes the system sustainable.

2.1 History and Regulations

Sustainable and competitive organizations manage safety efficiently and transparently, conducting their activities only when suitable safety conditions.

Who does not remember Flixborough-UK (1974), Seveso-Italy (1976), Bhopal-India (1984) and explosions platform Piper Alpha-UK (1988) and the Texas City US refinery (2005), or the case of Macondo in the Gulf of Mexico in 2010?

History has a long list of examples where inadequate safety management originated catastrophic accidents (see Table 2.1).

Table 2.1 Some catastrophic accidents and fatalities since 60s.

WHEN	WHERE	WHAT	FATALITIES
1966	Feyzin, France	LPG Bleve	18
1974	Flixborough, UK	Cyclohexane	28
1976	Seveso, Italy	Dioxin	1
1979	Bantry Bay, Ireland	Crude ship	50
1982	Ocean Ranger, Canada	Platform	84
1984	México	LPG Bleve	600+
1984	Bhopal, India	Methyl isocyanate	20000+
1986	Challenger	Space shuttle	7
1986	Chernobyl, USSR	Nuclear powerplant	100+
1986	Sandoz, Basel, Switzerland	Warehouse	0
1987	Texas City	HF	0
1987	Grangemouth, UK	HCK HP, LP interface	1
1988	Piper Alpha Platform	Propane	167
1988	Norco, USA	FCCU/ Propane	7
1989	Pasadena TX, USA	Ethylene/Isobutane	23
1992	La Mede, France	Gasoline/LOG/FCCU	6
1994	Milford Haven, UK	FCCU feedstock	0
1998	Longford, Australia	LPG, brittle fracture	2
2001	Toulouse, France	Ammonium Nitrate	30
2001	Petrobras	Platform	11
2003	Columbia	Space shuttle	7
2004	Skikda, Algeria	LNG	27
2005	Texas City, USA	Gasoline ISOM	15
2005	Buncefield, UK	Gasoline/tank Farm	0
2005	Bombay High. India	Platform	13

WHEN	WHERE	WHAT	FATALITIES
2010	Macondo, Gulf Mexico	Deep Water Drilling	0
2010	Harbin, China	Benzene & Nitrobenzene	20
2011	Devecser, Hungary	Toxic Substances	10
2011	Fukushima, Japan	Radioactive Gases	0
2013	Texas, USA	Ammonium nitrate	15
2013	Gumi, Korea	Hydrofluoric acid	5
2014	Kaohsiung, Taiwan	Propylene	23
2014	Sofia, Bulgaria	Vinyl, Polyvinyl chloride	17
2015	Tianjin, China	Sodium cyanide	173
2016	Ludwigshafen, Germany	Ethylene and Propylene	3
2016	Coatzacoalcos, Mexico	Vinyl Chloride	28
2016	Louisiana, USA	Isobutane	0
2018	Zhangjiakou, China	Chemical explosion	22
2019	Rouen, France	Chemical Products	0
2020	Visakhapatnam, India	Styrene	11
2020	Beirut, Lebanon	Ammonium nitrate	220
2021	Hallein, Austria	Sulphur dioxide	1
2021	Leverkusen, Germany	Unknown	7
2021	Georgia, USA	Liquid nitrogen	6

Marsh's report [12], which catalogues the loss of assets in the oil industry, indicates that the sum of the 100 largest losses occurring in the last 40 years exceeds 33 billion USD only in material loss, not even mentioning the devastating losses of lives.

The first concerns with public health and safety had started in the food industry in the United States, in 1920's, and toxicology laboratories industries, beginning in the decade of 1930, with toxic properties evaluation of the potentially dangerous products.

United State Center for Chemical Process Safety (CCPS), which provides leadership and infrastructure to promote and advance Process Safety Management (PSM), suggests that process safety was born on the banks of Brandywine River in the early 19th century at E.I. du Pont black powder works. Recognizing that even a minor incident could precipitate considerable damage and loss of lives, DuPont directed the works to be built and operated under very specific safety conditions [13].

In the middle of the decade 1960, it became evident that it had considerable differences in the actuation of the companies regarding the occupational health, risks of injuries and losses. Moreover, chemical, and petrochemical industries had started great modifications in the existing operating conditions, increasing the energy stored, creating a critical and bigger danger to the society. At the same time, process installations had started to grow and interconnect with other plants for product exchange, becoming much more complex, with a significant increase in the risks.

In 1963, three people gathered for four months, three days a week, to research the design of a new phenol plant. They began with a technique known as critical examination, which asked for alternatives but was later modified to seek deviations. When the first detailed design was developed, the corporation modified the process under the name operability studies. It became the third stage of its hazard analysis procedure (the first two being done at the conceptual and specification stages) [14].

Concawe was established in 1963 by a small group of leading oil companies to carry out research on environmental issues relevant to the oil industry. Its membership has broadened to include most oil companies operating in Europe. The scope of Concawe's activities has gradually expanded in line with the development of societal concerns over environmental, health and safety issues. These now cover areas such as fuels quality and emissions, air quality, water quality, soil contamination, waste, occupational health and safety, petroleum product stewardship and cross-country pipeline performance [15].

The Occupational Safety and Health Administration (OSHA) was established in 1970 and approved by the United States Congress with the primary objective of establishing and strengthening "safety standards." Its main goal was to ensure that companies provide employees with a safe working environment free of known hazards, including hazardous substances, high noise levels, mechanical threats, heat or cold stress, or unhygienic conditions.

The Institution of Chemical Engineers (IChemE) held a one-week safety training at Teesside Polytechnic in 1974. The training, which took place immediately after the Flixborough accident, was fully booked, as were those scheduled in the following years. The first paper in the open literature was also published in the same year [16].

Following the Seveso catastrophe, the Chemical Industries Association produced "A Guide to Hazard and Operability Studies" in 1977. The term HAZOP had never been used in a formal publication before. Kletz was the first to do so in 1983, with the revised and updated course notes from the IChemE courses. Hazard and operability investigations had become a standard feature of chemical engineering degree programs in the UK [17].

Following BHOPAL, in 1984, the American Institute of Chemical Engineers (AIChE) was tasked with developing methods to eliminate catastrophic process incidents by expanding state-of-the-art technology and managing new practices. Thus, in 1985, the AIChE created the "Center for Chemical Process Safety" with 17 founding companies, having started its activities with the publication of "Guidelines for Hazard Evaluation Procedures", the first book on process safety, and the creation of the Safety and Chemical Engineering Education Program (SACHE), to teach process safety in the chemical engineering curriculum at universities.

Also in 1990, the American Petroleum Institute, with the objective of establishing a safety management system for processes with the potential for catastrophic release of poisonous and/or explosive materials, published the standard "API RP 750 - Management of Process Hazards", which it still regulates many American and European companies today.

With new catastrophic accidents in 1992, particularly with the Texas isobutane release, companies were forced to change their paradigms and safety requirements significantly. New regulations emerged: "USA OSHA: 29 CFR 1910.119 - Process Safety Management of Highly Hazardous Chemicals" - and overlaying "USA EPA: 40 CFR Part 68 (1996 the final approval) - Risk Management Programs for Chemical Accidental Release Prevention".

Process Safety Management focuses on protecting the installation, workers, contractors, and visitors. On the other hand, Risk Management is more focused on protecting the community, the population, or nearby facilities such as schools and hospitals.

The historical industrial accidents with significant impact had put in evidence the necessity to develop the area of risk evaluation and losses prevention and the need to establish stricter rules, regulations, and legislation to reduce or prevent the occurrence of bigger industrial accidents (see Table 2.2)

Each of these accidents reminds us of the importance of being ambitious, demanding, and rigorous in applying process safety management.

Looking for the causes of these accidents, it should be investigated where they can occur, the lessons that can be learned, and what necessary safeguards should be implemented.

Table 2.2 Safety regulation and legislation since 60s.

YEAR	REGULATIONS
1966	First LPG prescriptive regulations
1982	EU Seveso I Directive
1985	US Chemical Emergency Preparedness Program
1986	US Emergency Planning and Community
1986	US EPA Emergency Planning & Community Right-to-Know Act
1986	US Chemical Accident Prevention Program
1987	EU Seveso I Directive Update
1990	US Clean Air Act Amendments
1992	UK HSE Offshore Installations – Safety Case Regulations
1992	US OSHA 1910-10 – Process Safety Management
1996	US EPA Risk Management Program
1996	EU Seveso II Directive
1999	UK Control of Major Accident Hazard (COMAH) Regulations
2002	EU Seveso II Update
2005	UK HSE Offshore Installations – Safety Case Regulations
2007	US Petroleum Refinery Process Safety Management National Emphasis Program
2011	US *Act on Special Measures concerning the handling of Environment Pollution*
2011	*CHINA Regulations on Safe Management on Hazardous Chemicals (Decree 591)*
2012	*US Process safety management of highly hazardous chemicals.*
2014	*US National Emphasis Program – Primary Metal Industries (CPL 03-00-018)*
2015	*EU Seveso III (Decreto-lei n.º 150/2015)*
2017	*US PSM Covered Chemical Facilities National Emphasis Program (CPL 03-00-021)*
2020	*US National Emphasis Program – Respirable Crystalline Silica (: CPL 03-00-023)*

The time that passes without an incident is not necessarily an indication that everything is well. There is always a series of failures that can lead to an accident. If nothing is done, all systems will deteriorate continuously over time and events may occur when large defects pass through several risk control systems simultaneously.

After an accident, the organizations tend to reinforce their barriers. However, the prolonged absence of catastrophic accidents can lead to a false sense of safety, leading to relaxation and erosion barriers. For this reason, organizations must provide mechanisms, standards, guidelines, codes, programs, and procedures that can be assessed in real-time the status of each line of defence, ensuring the proper management of process safety - see Table 2.3.

Table 2.3 Most Important Industrial Organizations

AIChE: American Institute of Chemical Engineers	ANSI: American National Standard Institute
Center for Chemical Process Safety (CCPS) Design Institute for Physical Data (DIPPR) Loss Prevention Symposia (Health and Safety Division)	Consensus Standards on Various Subjects Special Publications Handbook Monthly Newsletter – ANSI Newsletter
API: American Petroleum Institute	**ASSE: American Society of Safety Engineers**
Process Hazard and Process Safety Seminars Technical Standards and Recommended Practices Operator and Maintenance Iteming	Education Courses in System Safety and Accident Prevention Seminars (e.g., Safety Management, Chemical Process Safety) CSB: US Chemical Safety and Hazard Investigation Board
ASTM: America Society for Testing and Materials	**Investigation of Industrial Chemical Accidents**
Standard Development Standard Technology Iteming Courses CHETAH Program for Estimating Physical Properties	Reports, paper about lessons learned Videotapes with accidents anatomy IChemE: The Institution of Chemical Engineers
IEEE: Institute of Electrical/Electronic Engineers	**Loss Prevention Bulletin**
IEEE Transaction on Reliability, Safety, and Risk Management Journals and Conference Publications	Training Modules and Information exchange. Conference on Major Accident Prevention
CMA: Chemical Manufacturers Association	**NFPA: National Fire Protection Association**
National Chemical Referral and Information Center Community Awareness and Emergency Response (CAER) Management Guidelines (e.g., Manager's Guide to QRA) Responsible care	Consensus Standards Related to Fire and Explosion prevention Fire safety seminars Training materials
NSC: National Safety Council	**SRA: Society for Risk Analysis**
CAMEO software for emergency response management accident prevention manual for industrial operations	Conference on Risk Assessment. Journal

2.2 What are Industries Doing Related to Process Safety?

Many business leaders may not be aware of the potential limitations of their safety management programs. As a result, hazard and operability identifications constitute a critical tool, which must be periodically reviewed due to constant change in the organization, processes, people or technologies.

Despite the great advances made during the last century, the industry has grown and changed every day, placing new regulations and more difficult safety challenges to managers and operators of facilities that handle hazardous materials (see Table 2.4).

Table 2.4 Safety Regulations Requirements.

SEVESO III	PSM (OSHA 1910.119)	EPA RMP (PROGRAM 3)
Process description	Employee participation	Employee participation
Neighbourhood environment	Training	Training
Management system	Process Hazard Analysis (PHA)	Process Hazard Analysis (PHA)
Safety policy	Mechanical integrity	Mechanical integrity
Organization	Process safety information	Process safety information
Process	Operating procedures	Operating procedures
Risk assessment	Hot work permits	Hot work permits
Work authorization	Management of change (MOC)	Management of change (MOC)
Management of change (MOC)	Pre-start-up review	Pre start-up review
Performance measures	Emergency response plans	Emergency response plans
Audits & reviews	Incident investigation	Incident investigation
Risk identification	Contractors	Contractors
High risk assessment	Compliance audits	Compliance audits
Demonstration of:	Trade secrets	
• Prevention		
• Control		
• Mitigation		
• Emergency response plans		
• Security reports		

Whether project teams or operating facilities, all organizations face the dichotomy of balancing process safety with production, cost, and schedule demands. Many companies implement behaviour-based safety programs, balancing different compromises, and effectively reducing injuries and accidents.

In United States, the Process Safety Management (PSM) has become the standard applied to hazardous processes. It is an effective tool to increase the safety of the operation and the efficiency, quality, and cost-effectiveness of companies. This mandatory requirement, currently, is being extended all over the world in oil and gas companies.

European companies normally follow and apply the requirements established at the EU level for the Prevention of Serious Accidents (SEVESO) with hazardous substances. They incorporate in their management systems the guidelines issued by the regulatory bodies in safety matters. They systematically analyse accidents in their sector, integrating lessons learned in operations and promoting an interdisciplinary discussion of accident reports.

In 2013, within the scope of Galp's PSM supervision program, the company DUPONT, considered to be at the forefront in the area of safety, proposed several key performance indicators (KPI) for subsequent auditing of incidents and accidents related to the process. In Figure 2.1. some images of the safety culture promoted among the company's workers are shown [18].

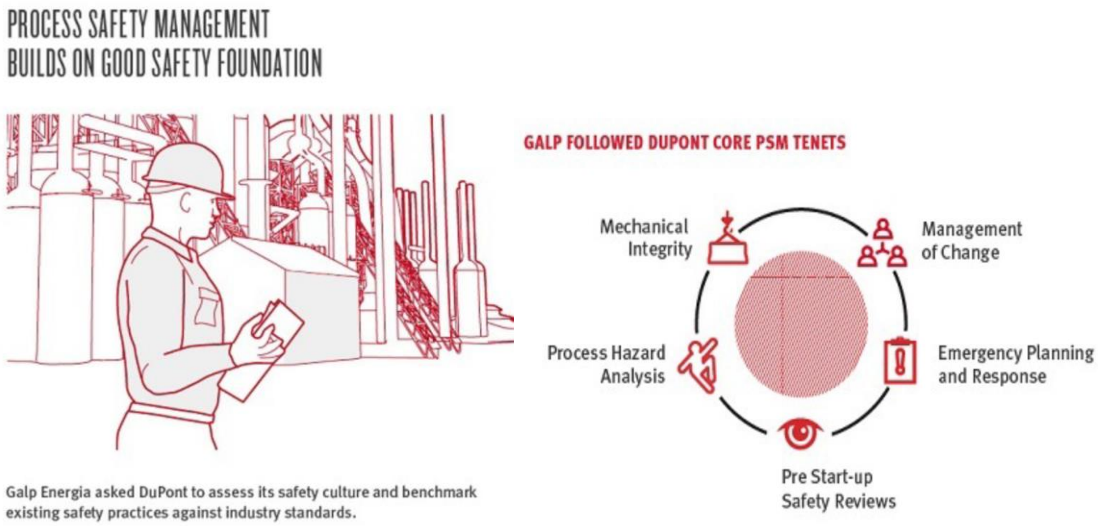

Figure 2.1 Safety Culture proposed by DUPONT (2013).

2.3 What is Process Safety Management?

Process Safety Management (PSM) is an analytical technique aimed at preventing the discharge of any substance designated by OSHA as a "very hazardous chemical". PSM is a series of interconnected approaches to managing hazards in the process industries to reduce the frequency and severity of accidents resulting from chemical and other energy source releases (US OSHA 1993). These standards are based on organizational and operational procedures, design guidelines, audit programs, and different ways.

The U.S. Occupational Safety and Health Administration (OSHA) 1910.119 define the 14 elements of the PSM program [19], which are:

- Process Safety Information (PSI);
- **Process Hazard Analysis;**
- Operating Procedures;
- Training;
- Contractors;

- Mechanical Integrity;
- Hot Work;
- **Management of Change;**
- Incident Investigation;
- Compliance Audits;
- Trade Secrets;
- Employee Participation;
- Pre-startup Safety Review;
- Emergency Planning and Response.

All elements are interconnected and are required to complete the PSM picture. Every element provides information for completing other elements or uses information from other elements to complete itself. These standards comprise organizational and operational procedures, design guidelines, audit programs and other data.

The major purpose of PSM for extremely hazardous compounds is to minimize unintended releases of dangerous chemicals, especially into areas where personnel and others may be at risk. A successful PSM program requires a systematic strategy for evaluating the entire chemical process. It takes a while to complete the review. PSM aims integrity of systems, equipment, and processes through applying appropriate design principles and best practices of engineering and operation, preventing the release of hazardous substances and/or energy in an uncontrolled way, and avoiding accidents with serious human consequences, material and environmental. In other words, this is the way to design, maintain and operate the assets, keeping dangerous substances and energy subsidiaries away from people and preventing serious accidents.

2.4 European Industries – Regulations and Control

The Seveso disaster in 1976 pushed Europe to pass rules to prevent and control catastrophic accidents. The goal was to ensure a high level of safety and protection for people and the environment from hazardous chemical accidents across the European Union.

The directive on the prevention of these major accidents is known as Seveso Directive and has undergone several changes:

- In June 1982, the first EU Directive 82/501/EEC [20] was adopted – known as Seveso Directive.

- In December 1996, this directive was replaced by Council Directive 96/82/EC [21], resulting in the Seveso II Directive. New standards have been established to prevent major accidents involving dangerous substances and the consequences for people and the environment.

- In December 2003, this directive was extended by Directive 2003/105/EC [22], which included a revision and extension of the scope. The Member States must implement new requirements for safety management systems, emergency planning, land-use planning and strengthen inspection provisions. When hazardous substances are present in concentrations that exceed the directive's standards, this requirement has been implemented at hundreds of industrial sites.

- In July 2012, the new Directive 2012/18/EU [23], known as “Seveso III”, was published to include:

- Adoption of the European System of Classification of Substances.

  Substance’s alignment is subject to the new European classification system that will improve the identification of hazards and risks to health and the environment;
- Information and public participation.

  Strengthening the provision of providing information to the public. The new rules provide for the provision of online information "understandable" about the establishments and public participation in case of emergency planning and expansion of facilities;
- Inspections.

  Introduction of stricter rules regarding the inspection facilities. All establishments with a higher level of dangerousness should be inspected at least once a year and at the lower level every three years. The new revision also allows for additional inspections by the competent authorities in cases of abuse or non-compliance with the requirements.

According to the Seveso III directive, the Member-States must ensure that the goals of preventing major accidents are in their land-use policies. This includes controls on the siting of new establishments, modifications to existing establishments and new developments (transport links, residential areas, etc.) in the vicinity of existing establishments. They must evaluate the requirement to maintain or develop suitable spacing between establishments and residential areas in the long run.

The Member-States must guarantee that information on safety measures and required behaviour in the event of an accident is provided to anyone likely to be affected by a serious accident without them having to ask for it. They must also ensure that safety reports are available to the public at all times.

European CONCAWE company has been playing an increasingly active role, bringing the views and experience of the oil industry to the debates around safety, contributing to a reduction of accidents and consequently to an industrial activity ever safer.

The CONCAWE statistics demonstrate the oil industry's dedication to safety, with incident rates continuously lower than the industry. Member companies can also share useful information regarding accidents and lessons learned through this activity.

Following the reporting requirements created by the American Petroleum Institute, the CONCAWE Safety Management Group increased the scope of industry-wide safety performance indicators to include process safety in the 2009 CONCAWE report. Expanding the focus to include process safety and personal safety is expected to result in a further drop in major injury rates in the industry.

This large list of Process Safety Performance Indicators (PSPI) and the gathering and analysis of accidents is now required for a modern European safety management system. CONCAWE, for example, collects a large number of personal incidents labour statistics, which it publishes in an annual report (see Table 2.5 and Figure 2.2 from "European downstream oil sector safety performance - Statistical overview of reported events – 2020") [24].

Table 2.5 Number of reported fatalities since 2011.

Fatalities over 10 years by sector			
Year	Manufacturing	Marketing	Total
2011	10	1	11
2012	7	6	13
2013	4	2	6
2014	6	1	7
2015	5	3	8
2016	2	0	2
2017	1	1	2
2018	7	3	10
2019	3	0	3
2020	1	1	2
Total	46	18	64

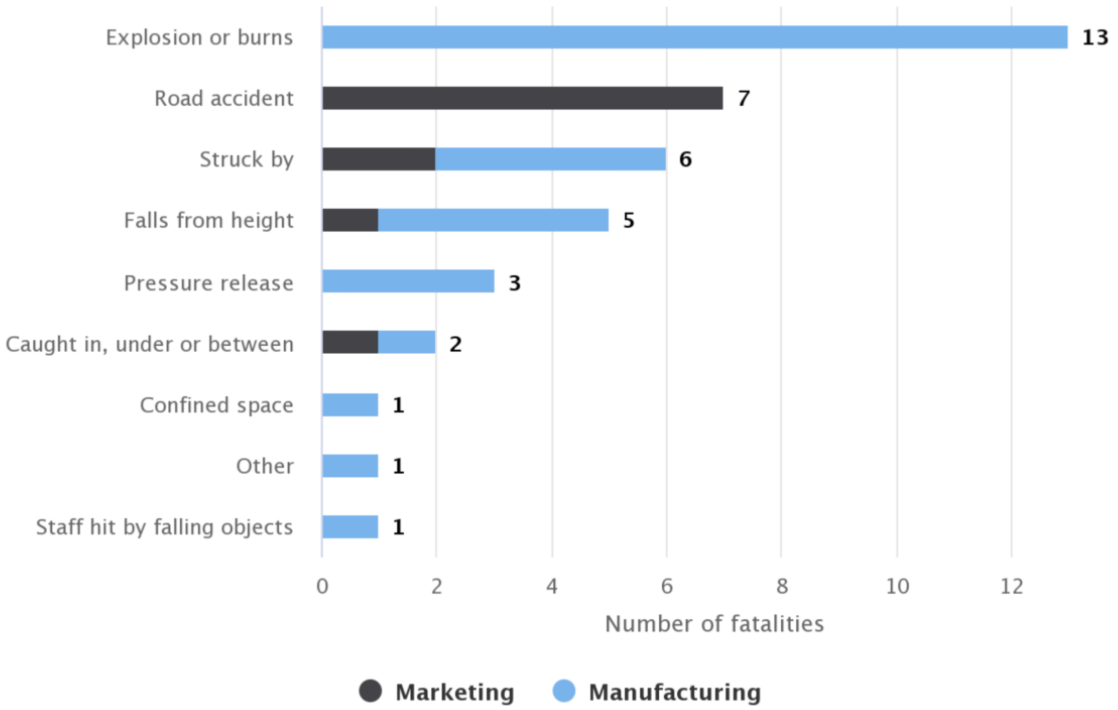

Figure 2.2 Number of fatalities by incident type 2013-2020.

CONCAWE shows that the oil industry widely recognizes safety management systems as essential for collecting and analysing safety incident data and continually improving the safety of employees and contractors.

To support this effort, the CONCAWE has been compiling statistical safety data for the European downstream oil industry to:

- Provide member companies with a benchmark against which to compare their own company's safety performance; and
- Demonstrate how responsible approaches to safety management can help ensure that accidents stay at low levels despite the hazard intrinsic to refinery and distribution operations.

Most importantly, CONCAWE's annual safety data report enables companies to evaluate the efficacy of their management systems, identify any shortcomings and take corrective actions as quickly as possible.

2.5 Portuguese Industries

In December 2010, the Portuguese Environment Agency (APA) in the report "Guia para a integração da prevenção de acidentes graves na avaliação ambiental estratégica dos planos municipais de ordenamento do território" [25], identified in Portugal 55 establishments, according to the number of hazardous substances that store and which are considered "Higher Level of Hazard", of which 14 are operated or with the participation of Galp.

Seveso Directives lay down rules for preventing major accidents involving dangerous substances and limiting their consequences for people and the environment, transposing into Portuguese laws several European Directives according to Table 2.6 (adapted from [26].

Table 2.6 Seveso Directive - Legislative evolution.

EUROPE	PORTUGAL
Directives 82/501/EC and 87/216/CEE - Seveso I	Decreto-Lei nº 224/87
Directive 88/610/EC - Seveso I modification	Decreto-Lei nº204/93
Directive 96/82/EC - Seveso II	Decreto-Lei nº164/2001
Directive 2003/105/EC - Seveso II extended	Decreto-Lei nº254/2007
Directive 2012/18/EU - Seveso III	Decreto-Lei nº150/2015

For establishments with a higher level of danger, policies to prevent major accidents involving dangerous substances and the obligation to submit a safety report are two of the most critical requirements that the operator has to notify the national authorities since Seveso I.

Considering that the proximity between hazardous establishments and residential areas represents an increased risk, the Seveso law provides that the appropriate safety distances must be established when drawing up, reviewing, and amending municipal land use plans. Residential areas, roads, and places frequented by the public and environmentally sensitive areas are considered covered by this ordinance to prevent severe accidents with dangerous substances.

Matosinhos Galp Refinery is a facility covered by the Seveso Directive. The Seveso Prevention Safety System (SGPAG - Safety System for the Prevention of Serious Accidents) was implemented, which has been audited annually, since 2008, by an auditor of the Environmental Portuguese Agency (Agência Portuguesa Ambiente). This exercise aims to ensure that the installation has a visible commitment and effectiveness of a Prevention Policy against Major Accidents, which was audited and went far beyond the risk management and protection levels applied to the oil & gas industries process.

In 2018, Galp completed the DRIVER project, which had as its main objective the implementation of an Integrated Management System (IMS) of Environment, Quality, Safety, Energy, and Social Responsibility.

In 2020, APCER renewed the Certification of the IMS in the five aspects, namely Environment, Quality, Safety, Energy and Social Responsibility, and certified the Business Continuity aspect according to NP EN ISO 22301:2017. In Portugal, Galp was the first energy company to achieve certification in these six dimensions [27].

3 Process Hazard Analysis

One of the most significant parts of a safety management program is the Process Hazard Analysis (PHA). It is a safety evaluation applied to the design and operation of the processes, by teams of qualified professionals, in defined stages of the development of a facility. It allows complying with corporate and national safety standards and best practices for operating and developing a safe project.

PHA is defined as a structured effort to identify and analyse the significance of potential risks associated with manufacturing or handling very hazardous substances in the chemical industry. PHA provides data to assist companies and employees in making decisions about improving safety and mitigating the effects of accidental or unplanned hazardous chemical discharges. The PHA investigates fires, explosions, poisonous or flammable chemical discharges and major hazardous chemical spills.

Detecting dangerous circumstances requires a multidisciplinary team of professionals who can apply the rules rigorously, thoroughly, and methodically. Success depends on identifying and analysing possible scenarios that could result in varying degrees of severity. A process that includes multiple unit operations of varying sizes, complexities and ages, each operation may also employ different approaches and team members. Results can then be included in a single survey and final assessment.

As a PHA technique, HAZOP has been the first systematic hazard identification methodology used in process industries, from which other techniques were developed to solve specific problems or provide faster assessments.

3.1 Introduction

Over time, different types of PHAs have been applied with different coverage and detail of information. Figure 3.1 shows its evolution over time.

1960	1960	1965	1970	1970	1974
SAFETY REVIEW	CHECKLISTS	RELATIVE RANKING	PreHA	WHAT If	HAZOP
Walk Through Inspection	Historical Lists	ICI Mond Index	Preliminary Hazard Analysis	Brainstorming	Hazard Operability Analysis

Figure 3.1 Different PHA applications over the time

All PHAs are focused on conditions that lead to changes in the chemical process, technology and/or facilities, such as raw materials, equipment, utilities, human actions (routine and non-routine procedures) and other external factors that may affect the processes.

These modifications must be properly managed by identifying and reviewing before implementing them. Materials of construction, equipment specifications, piping arrangements, alarms, and interlocks, i.e., all these items must have means and methods to detect and analyse both technical and mechanical changes. Operating outside of design, new procedures and/or parameters (pressure limits, temperature ranges, flow rates, etc.) requires a PHA review to ensure safe plant operation.

Changes in process technology also require a review in terms of safety as they can result in changes in production rates, raw materials, experimentation, unavailability of equipment, new equipment, development of new products, changes in catalysts and operating conditions to improve performance or quality.

The temporary modifications must also be subject to hazard analysis to avoid accidents that can produce catastrophes with equipment and human losses. They must have a time limit set and monitored. Otherwise, they will tend to become permanent if not controlled. In addition, a formal procedure must be employed to ensure that, at the end of the temporary change, the equipment and procedures are returned to their original or designed circumstances.

Typically, for minor and well-understood changes, the execution of a checklist may be sufficient when reviewed by an authorized person and communicated to others who are affected. Other hazard evaluation methods, including approvals from operations, maintenance, and safety departments, are required for more sophisticated or major design changes, such as P&ID’s, raw materials, operating procedures, mechanical integrity programs and electrical classifications.

All reports and drawings, with updated information, must be available to operate, maintenance and technical personnel as well as to the process hazard team members when a PHA is being prepared or modified.

3.2 Hazard Identification Techniques

Many factors, including how much is known about the process, will influence the choice of a PHA strategy or technique. More than 1000 relevant references were identified through a literature review conducted by Health and Safety Executive Information Services for references to hazard identification techniques [28].

This is why the PHA technique selected must be chosen according to the complexity of the process and should be able to identify, evaluate and control the hazards involved.

There are Qualitative and Quantitative PHA techniques and to selecting between both, the following points should be taken into account:

- type of process;
- main objectives;
- limitations of the technique;
- what level of effort is typically associated;

The main PHA qualitative techniques are (adapted from [28]):

Preliminary Hazard Analysis (PreHA) is a method based on the United States Military Standard System Safety Program requirements. As a precursor to more detailed hazard analysis studies, PreHA is typically used to analyse and prioritize hazards early in the life of a process. It is typically used during conceptual design or R&D when limited information on design details or operating procedures are available. It is most commonly used as a design review tool before a P&ID is created. It comes in use while making site selection judgments and studying big facilities when other methods are not possible.

Checklist (traditional): A hazard evaluation checklist uses pre-prepared lists of questions on process safety to identify issues and motivate analysts to determine whether existing measures are adequate. Checklists are used to identify common hazards and ensure that procedures, standards of practice and regulations, among other things, are followed. The questions on the checklist are based on experience and knowledge of the process's safety issues, as well as applicable codes, standards and regulations. Checklists can be used for almost any part of a process, including equipment, materials and procedures. Their use necessitates comprehension of the process and its protocols and the significance of the checklist questions. Checklists might become obsolete with time; thus, they should be audited and updated regularly.

What-If Analysis: A brainstorming method in which a group of experts familiar with the topic process asks questions or expresses worries about potential negative outcomes. It can be used to investigate almost any process area, including equipment, processes, control systems and management practices, among other things. Because the technique gives less structure than other PHA methods, team leaders should be familiar with it. The method does not employ the usage of guidewords to aid the brainstorming process.

What-If/Checklist Analysis: The method is similar to What-if alone, except that the study is structured around broad categories of concerns.

Hazard and Operability (HAZOP) Analysis: This is a set of formal hazard identification and elimination procedures designed to identify hazards to people, processes plants and the environment. Studies are to be conducted by teams that brainstorm to systematically identify hazards or operability problems throughout a source through the use of certain guidewords such as "no flow" and "no cooling". The consequences of the deviation associated with the guidewords are assessed and credible deviations are identified and addressed.

Failure Modes and Effects Analysis (FMEA): is a process for evaluating and documenting the consequences of known component failures (e.g., open, closed, on, off, leaks, etc.). Both electrical and mechanical systems are affected in this way. It can also be employed in flow systems with high dependability requirements (such as fire-fighting water supply systems).

Quantitative Techniques: These techniques do not identify potential accident scenarios; instead, they enhance risk assessment by providing more thorough, statistical assessments of the probability of a specific scenario.

Layer of Protection Analysis (LOPA): is a strategy for determining if the combination of occurrence frequency and severity of consequences matches a company's risk tolerance when evaluating high-consequence scenarios. It offers an estimated order-of-magnitude of risks. This method uses pre-defined values for initiating events, separate protective layers, and repercussions. LOPA is only applicable to a single cause-and-effect pair. Other scenarios have been identified (typically in a qualitative hazard evaluation).

Dow Fire and Explosion Index (F&EI): Dow Chemical Company created a system for rating the relative potential fire and explosion risk effect radius and property damage/business interruption implications of a process. Analysts develop multiple hazards and exposure indexes using material attributes and process data.

Dow Chemical Exposure Index (CEI): Consider the following five categories of factors that can have an impact on the effects of material release: (1) acute toxicity, (2) volatile fraction of material that could be discharged, (3) distance to areas of concern, (4) molecular weight of the substance and (5) numerous process parameters such as temperature, pressure and reactivity, among others. The CEI is the sum of the values assigned to each variable of concern using arbitrarily set numerical scales.

Fault Tree Analysis (FTA): It uses deductive reasoning to determine the reasons for a certain incidence (referred to as a top event). It's frequently employed when other PHA techniques suggest that a specific type of accident is of particular concern and that a deeper knowledge of the causes is required. As a result, it's a solid addition to other PHA approaches. FTA is sometimes used in incident investigations to breakdown what happened. FTA is also used to calculate the probability of the top event. It's best for analysing systems with high redundancy.

Event Tree Analysis (ETA): Standard PHA methods are not very similar to ETA. It does not provide a complete list of hazard scenarios for a given procedure. Instead, it is used to determine the probable outcomes following the success or failure of protection mechanisms following a specific starting event and quantify the frequencies of the outcomes. Beginning with a starting event, event trees graphically depict the flow of event sequences, from control and safety system reactions through event sequence outcomes.

3.3 Hazard Technique Selection

Choosing a suitable hazard technique approach might be challenging for the inexperienced professional because the "optimal" technique may not be obvious. As a safety responsible gain experience with multiple hazard techniques, selecting the most appropriate becomes easier and more natural.

The appropriate approach and methodology for hazard assessment are normally defined by the team responsible for a study. The methodology to be used should depend on factors such as the size and complexity of the installation, the credible hazards, the perceived severity of the potential consequences, the degree of uncertainty, the level of perceived risk, the number of people exposed to the risk and the proximity to environmentally sensitive areas, but also the time and information available.

The management team should outline the fundamental document for a hazard study, including the research's principal purpose, the sort of decision-making information required and the work's starting resources and timelines.

Figure 3.2 presents a flowchart to help determine the best qualitative technique for hazard assessment. A team's safety leader can use it as a guide, but based on his and the team's experience, he is free to decide on alternative options that prove to be suitable. As an example, the case of a process unit can be considered, where potential accidents can occur due to multiple events without an exhaustive list of all failure reasons, which leads to the application of the HAZOP methodology for safety review. For a pump failure, which is a much simpler situation, a checklist, a What If, or even a combination of both, may suffice for an effective safety assessment.

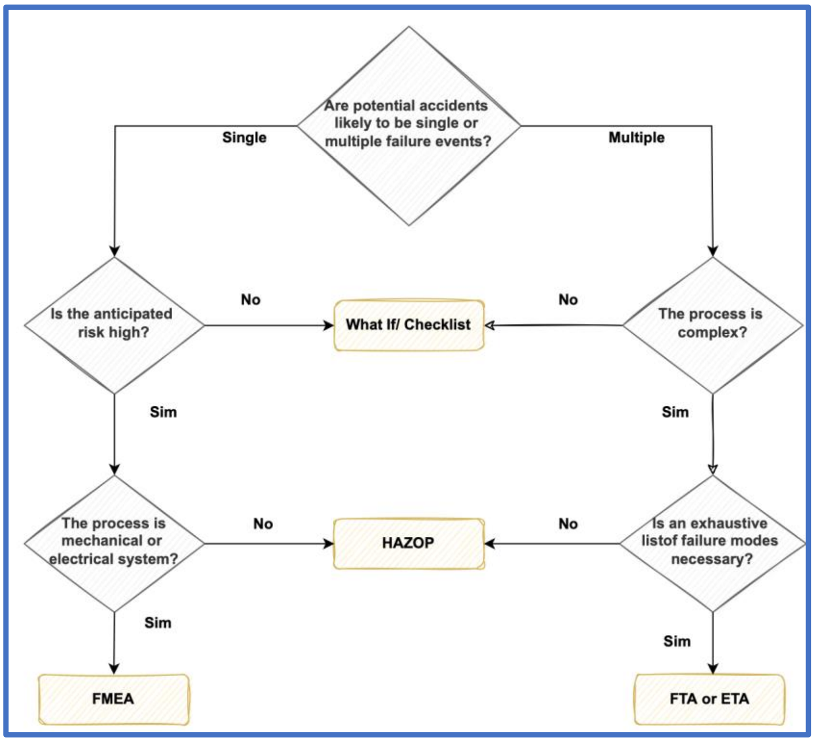

Figure 3.2 Choice of qualitative hazard assessment technique.

HAZOP investigations are a typical process hazard analysis technique utilized in the industry today, covering a wide range of industries and jurisdictions. This methodology is normally chosen for operational activities, including the handling, storage, or use of hazardous substances, in the amounts established in the Seveso directive, which may cause the risk of multiple deaths and/or significant environmental impact or high levels of damage, whether inside or outside the facilities. Includes all facilities covered by the Seveso serious accident prevention regime.

For new installations that are a repetition of previous designs, the assessment methodologies carried out for the original design may be used. They meet current objectives, standards, and criteria, consider new knowledge and technology, and adequately cover any significant differences that affect risk management.

The relevance of the process selection may differ from one facility to the next, from one company to the next and from one sector to the next. To fulfil the study, the technical project manager and/or the hazard team leader should propose the most appropriate approach using several factors that can influence the choice:

- study motivation;
- type of results needed;
- type of information available to conduct the study;

- analysis of the problem characteristics;
- perceived hazard associated with the subject process or activity; and
- resource availability and analyst/management preference.

Safety improvement efforts are likely to be wasted without a clear objective and understanding of why risk analysis is needed. Another reason, no less important, is the precise type of information needed to achieve the study's objective. It is a critical and crucial component in deciding on the choice of the best risk technique to be used. Outdated information, for example, can jeopardize the quality of the study carried out.

Two factors can determine the standard techniques accessible to the hazard evaluation team:

(1) the life stage of the process or activity where research is needed, from the design phase of the project to its final decommissioning (see Figure 3.3 adapted from [29]);

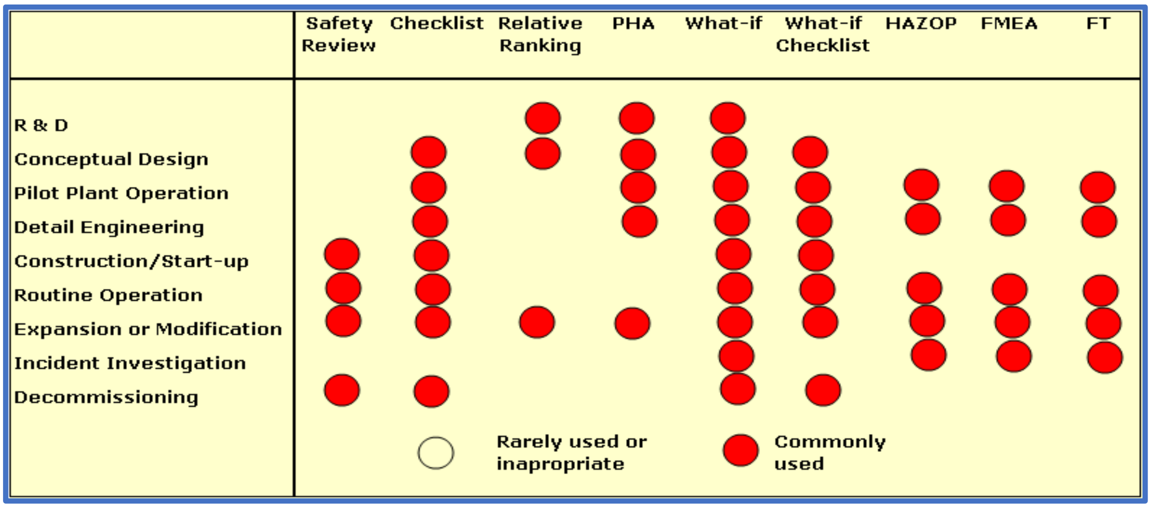

Figure 3.3 Techniques used for hazard studies during the lifetime of a facility.

(2) And the quality and accuracy of the available documentation. Figure 3.4 (adapted from [29]) presents the information that becomes accessible as the plant evolves through its life cycle.

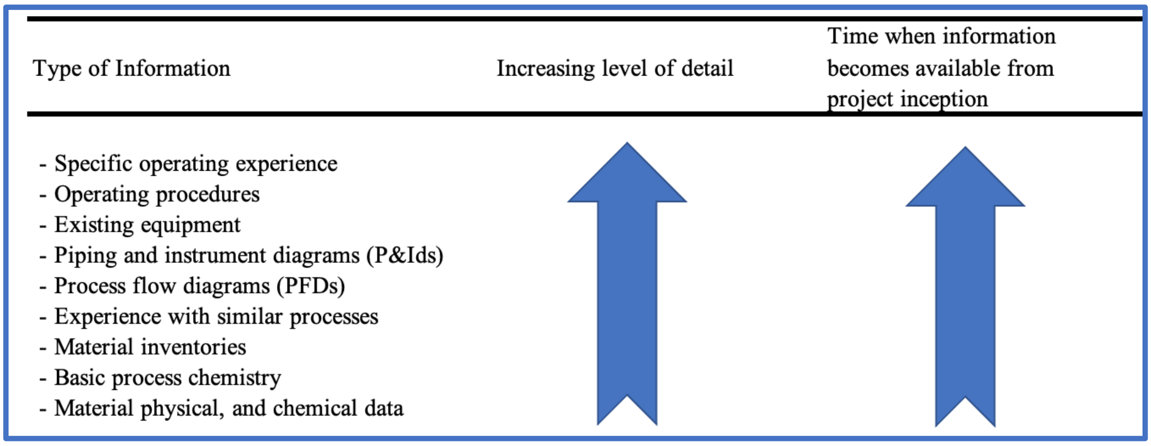

Figure 3.4 Typical information available from hazard analysis.

Various types of data can be provided, depending on the hazard study objectives:

- A list of hazards;
- A list of possible accident scenarios;
- A list of alternatives for reducing risk or areas that need more investigation;
- A list of outcomes that should be prioritized;
- A list of input for quantitative risk analysis.

Finally, human resource availability is also an important factor to consider when deciding on a hazard technique. In general, two categories of persons must be present in a hazard study: skilled leaders and practitioners of the hazard technique chosen and those familiar with the process or activity under investigation.

Some hazard evaluation procedures necessitate a creative collaboration of team members, while others can be completed solely by individuals working alone. Ideally, hazard studies should be conducted using approaches that are most familiar with the methodological experience of the team leader and other study participants.

There are several limits and disadvantages to all PHA techniques. The checklist methodology, for example, is useful when the process is highly stable, and no substantial changes are made. Still, it is less effective when the process has undergone significant changes. The checklist may miss the most recent modifications, as a result, they will not be reviewed. Another constraint that can be critical is the team's or analyst's assumptions, which can sometimes have catastrophic impacts on the installations in the event of serious errors.

HAZOP is a formally organized method of thoroughly evaluating each system element to see how crucial parameters can deviate from the intended design conditions to cause hazards and operability difficulties.

3.4 Management of Change Procedure

A company's Management of Change procedure (MOC) is the document that guarantees that any changes that occur within its facilities are properly managed and evaluated in terms of safety, health, environment, and quality.

The CCPS defines MOC as "a procedure to ensure that changes do not accidentally introduce new hazards or enhance the risk of existing hazards" [30]. MOC includes a review and authorization process for evaluating proposed changes to facility design, operations, organization, or activities before they are implemented to ensure that no new hazards are introduced and the risk of existing hazards to employees, the public, or the environment is not unintentionally increased.

These are the causes of changes in technology, process, facilities, equipment, environment, or even human resources specified in more detail in Annex B.

This procedure must include, at a minimum, the following aspects:

- Criteria for identifying and classifying the type of changes;
- Hazard identification technique to evaluate, plan and control changes;
- Responsibilities relating to the change management process;
- The process of communicating changes;
- Period for Revalidation of the hazard analysis.

In this procedure (MOC), the safety reviews determine the criteria for selecting the best risk assessment technique. It is intended to ensure that all potential risks associated with a modification are identified and controlled, whether temporary, permanent or urgent, of technology or processes, in facilities/equipment or people. These risks result from the dynamism and diversification existing in an installation, from operational needs, legal requirements or even imperatives of another nature.

It is also understood that all new projects/installations and partial dismantling, even if they have an independent project, as long as they are integrated into existing installations, must be framed by this standard.

In most companies, the safety team may want to create a suitable form to assist in the changes and formalize it through the change management standard. This typical form may include a description of the change and its purpose, the technical basis for the change, safety and health considerations, material safety data sheet, documentation of changes to operating procedures, maintenance procedures, inspection and testing approaches, P&ID's, electrical rating, training and communications, pre-start inspection, duration and approvals and related authorizations.

In addition, it must also be explained whether it is a temporary or permanent change, as well as its degree of priority, according to the criteria eventually established in the company.

At Galp, the MOC procedure is designated by "NT-P-028 Serious Accident Risk Management" [76], and all information and decisions are documented and controlled but with the flexibility to regulate both major and minor changes. Galp specifies that, for each process modification, the following must be attained:

- Identification of the type of modification (permanent, temporary, or urgent);
- Identification of any impact, in terms of the Seveso Directive or equivalent;
- Identification of the aspect of the modification: Technology or Process, Equipment / Infrastructure, People or surroundings;
- Definition of the new operating conditions that are intended to be achieved with the modification;
- Identification of the risk analysis methodology to be applied;
- Verification of aspects related to legal compliance;
- Approval of the modification process by appropriate hierarchical level;
- Ensure that all persons possibly affected by the modification are subject to sufficient training and/or information regarding the modification;
- Information to entities under the applicable legal requirements.

According to the same standard, any proposed modification must conduct a risk analysis by the applicable policy and internal risk management regulations. Considering the nature and extent of the proposed amendment, the type of risk assessment to be carried out and the competencies to be gathered for this purpose are defined early.

3.5 PHA Section for the Studies

Considering the facilities that will be analysed in this work, the Diesel Desulphurization Unit, the LPG Treatment Unit, and the Sulphur Recovery Unit (Claus Unit), the HAZOP methodology was selected for the comparative study of risk analysis carried out between the project phases and their respective Revalidation processes. This choice took six important factors:

- The problem's complexity and magnitude;
- The type of process;
- The sort of operation that will be performed as part of the process;
- The accident events or circumstances to be concerned about.
- The nature of the inherent hazard and;
- The existent Management of Change data.

Many factors, including how much is known about the process, will influence the choice of a PHA strategy or technique. All the standards agree that HAZOP is the most thorough and auditable method for hazard identification in chemical process plants.

The HAZOP methodology is a PHA technique utilized worldwide to investigate a system's hazards and its operability issues by investigating the impacts of any deviations from design conditions. It is required for more sophisticated or major design changes, such as P&ID's, raw materials, operating procedures, mechanical integrity programs and electrical classifications. HAZOP relies on good judgment and the assumptions established throughout the many studies are well documented and understood by the teams and reviewers over the years.

4 Hazard and Operability Study

This technique was developed by ICI in the UK in the mid-1960s, after Flixborough catastrophe in 1974, but it became more widely used in the chemical process industry. The explosion at this chemical plant killed 28 people and injured dozens more, many of whom lived nearby – see Figure 4.1.

This technique was then adopted by the oil industry, which has a similar potential for major disasters. This was followed by the food and water industries, where the hazard potential is similar but of a different nature, with concerns being more related to contamination than explosions or chemical releases.

Figure 4.1 Flixborough UK in June 1974.

4.1 Literature Review

Due to the increasing complexity of new processes that could not be properly assessed using then-conventional methodologies focused on equipment-oriented procedures, Lawley [31] developed and characterized the concepts needed to conduct hazard assessments and operability studies in 1974.

This author explained the technical and management ideas behind HAZOP research two years later [32] and the elements that had to be considered to successfully build the HAZOP. The study's design, the leader's skills, the study protocol, the appraisal of probable difficulties and assessing the proposed modifications in the examined units were all meticulously laid out. He also offered new instances from the study to show how HAZOP functioned.

The Chemical Industries Association in the United Kingdom released the first guideline on HAZOP, a strategy used in the process industries for detecting risks and developing safety measures, just one year later (1977) [33].

Many other guidelines and publications have emerged since then, highlighting the most essential and extensively used documentation for understanding the basic HAZOP concept and its evolution (adapted from 34):

- Knowlton [35], in 1981, was the first to create a book devoted exclusively to HAZOP applications.
- Nolan [36], in 1994, provided his practical expertise on specific subjects for both HAZOP and What If procedures. He published the book "Application of HAZOP and What-if Safety Reviews to the Petroleum, Petrochemical and Chemical Industries";
- Kletz [37-40], ICI Safety Chemical Engineering (company's adviser from 1968 to 1982), was one of the most prominent authors on several process-safety themes. From 1984 to 1999, he wrote various books and journal articles with a complete set of HAZOP technical definitions, experiences and information. The most known books are the "HAZOP & HAZAN Identifying and Assessing Process Industry Hazards (first edition)" with four editions;
- Lees [41] and Wells [35], 1996, applied the concepts of HAZOP to a wide variety of areas of hazard detection and loss prevention;

- European Process Safety Centre (EPSC) [43], in 2000, formulated new HAZOP guidelines, adapting the approach to the introduction of new technologies;
- Venkatasubramanian [44], also in 2000, examined how an intelligent system approach can be used to leverage human hazards analysis techniques and procedures to decrease time, effort and expense, as well as increase the consistency and thoroughness of the study;
- British Standard [45], in 2001, established the standard BS IEC 61882 "HAZOP Studies (Application Guide)" and defined additional requirements for conducting a HAZOP, demonstrating its relevance as the most extensively utilized technique in process plants and other types of facilities;
- Hyatt, in 2003, through CRC Press [46], published a book that teaches fault and event trees and consequence modelling, as well as assessments of several HAZOP approaches and their relative merits and is useful for both beginner and experienced risk professionals;
- Macdonald [47], in 2004, updated the field with the most recent data on the characteristics of HAZOP, outlining how to conduct a HAZOP and connecting it to future studies focusing on SIL assignments;
- Garcia-Serna [48], in 2007, introduced a HAZOP technique for the first systematic green engineering guidance tool for engineers to design, assess and implement processes by the highest industrial requirements for environmental improvement;
- EPSC [49], in 2008, updated his bestselling title – HAZOP Guide to Best Practice. This second edition describes and illustrates the HAZOP study method, highlighting a variety of proven uses and approaches;
- Nolan [50-52], in 2008, 2012 and 2014, updated his practical experience, publishing three new editions of his first book in the area. With the fourth and actual edition, he expands the scope to include maintenance, exploratory drilling and governmental regulation updates;
- Adhitya et al., in 2009 [53], proposed a new approach that presents a structured methodology for risk identification;
- Wiley-VCH, in 2013 [54], present a number of case studies and exercises that help to put the principles and theories of loss prevention engineering into proper day-to-day perspective;

- EPSC [55], in 2015, updated again the book entitled “HAZOP Guide to Best Practice”. This third and actual edition brings additional experience with which to assist the reader in delivering optimum safety and efficiency of performance of the HAZOP team;
- Guo and Kang [56], also in 2015, proposed an extended hazard and operability (HAZOP) analysis approach with dynamic fault tree to identify potential hazards in chemical plants. According to them, using a case study the approach can provide a reliable basis to improve process safety;
- Baybutt [57], 2016, published an article that describes the meaning and use of design intention to encourage HAZOP Study practitioners to address it fully during studies;
- Ahn and Chang [58], also in 2016, proposed a fuzzy-based HAZOP for analyzing process hazards. The fuzzy theory was used to express uncertain states. This theory was found to be a useful approach to overcoming the inherent uncertainty in HAZOP analysis;
- Cameron et al., in 2017 [59], present an article that summarizes the tentative that has been made over the last 30 years to automate HAZOPs that has started in the mid-1980s. Although full automation has never been achieved, semi-automation has been achieved using qualitative process modelling and expert system reasoning.
- Taylor [60], also in 2017, in a newspaper article, presents why HAZOP analysis techniques, after being introduced in the 1970s, still cannot eliminate manual approaches. Reasons for this were investigated and conclusions were draw. Over more than 30 years, the author's experience with automated HAZOP processes is thus revisited;
- Wu and Lind [61], in 2018, published a paper with research that enlightens the importance of understanding system complexity in the oil and gas industry and thereby gradually changing old-fashioned HAZOP industrial practice and improving safety performance;
- Baybutt [62], also in 2018, provides a pragmatic view of cognitive biases and guidance on how to address them in hazard and risk analysis;
- Kummer and Varga [63], in 2019, explain how HAZOP can help the experts explore all hazard situations in a technology-based on dynamic process simulation, therefore a framework for exploring hazard events is suggested in this work;

- Danko et al. [64], also in 2019, within a generic layer of protection analysis, a methodology is given that uses raw process design and basic process management as the first layer of protection (LOPA). A series of dynamic simulations on various failures were used to test the protection layers;
- Willey et al. [65], in 2020, wrote a paper reviewing how chemical engineering students are learning hazard analysis methodologies at the undergraduate and graduate levels. Examples of how students were presented to the checklist and bowtie analysis methods, as well as how to conduct a HAZOP, were covered. The many resources that can be used were also discussed with examples.
- Single et al. [66], also in 2020, present a knowledge-based framework for the automatic generation of HAZOP worksheets by a semantic reasoning method to identify risks and operability difficulties. Using the example of an hexane storage tank, according to the author the quality and quantity of the automatically generated results agree with the original worksheets.
- Mokhtarname et al. [67], in 2022, introduced the use of multivariable process monitoring (MPM) algorithms that are very popular for early detection of unusual situations and diagnosis of the process conditions to guarantee the plant safety, reliability and productivity, with HAZOP. This combination can improve the HAZOP by performing a more certain and effective evaluation of the process safeguarding strategy;
- Marhavilas et al. [68], also in 2022, conducted a case study in the petrochemical industry on the implementation of a hybrid technology that utilizes HAZOP-DMRA (Decision-Matrix Risk-Assessment) Analytical-Hierarchy-Process (AHP), that is classified in a Multi-Criteria-Decision-Making (MCDM). Using this methodology makes it possible to produce Safety Level Coloured Maps (SLCM). Those maps are intended to pinpoint crucial issues and ranking risk.

These data show that most safety information collected over the recent chemical industry history was addressed to standardization of HAZOP methodology to obtain a design and operation more efficient and safer design and operation.

Traditional HAZOP is a systemic safety examination procedure that evaluates the safety and operability of complex process equipment or manufacturing processes. Its main purpose is to identify potential risks and process operability issues and make recommendations for prevention. However, there are disadvantages to this so-called traditional HAZOP, such as [69]:

- The need for a long time (depending on the size of the technology);
- The need for a clear definition of objectives;
- The high demands on the technical knowledge;
- The HAZOP study participants' skills (because a good HAZOP study cannot be done without a good HAZOP team and HAZOP leader).

Most publications have been dedicated to developing expert systems, particularly in recent years, using new and advanced strategies to allow automation of the HAZOP technique, reducing the probability of errors and saving time and human resources.

This wide range of applications demonstrates how HAZOP has evolved into a valuable tool for improving safety systems. HAZOP has progressed to the point where it can be identified as the most comprehensive and most widely used systematic hazard identification methodology in the design and operation of facilities.

With this literature review, it was possible to identify the effort made over several decades by the scientific community and the industry to reduce the risks to human health, environmental impacts and damage to equipment.

4.2 HAZOP Methodology

The HAZOP study is the most widely utilized process hazard analysis method in today's world. It is one of the techniques that regulators typically accept as a standard in the refining, petrochemical, and chemical industry.

From the Basic Engineering Design Package (BEDP), through the Front-End Engineering Project (FEED), detail design, construction, commissioning, start-up and normal operation of a facility, HAZOP is expected to produce numerous recommendations/actions, which must be closed as soon as possible to safeguard the safety of the facility and that of all its stakeholders.

The European document “EN 61882:2016, Hazard and operability studies (HAZOP studies) - Application guide” [70], presents the methodology that allows reviewing the design and operation of a process facility to identify the potential deviations from the normal safe operation. Figure 4.2 (adapted from [70]) shows the sequencing procedure that can be carried out in any of these phases of an installation's life.

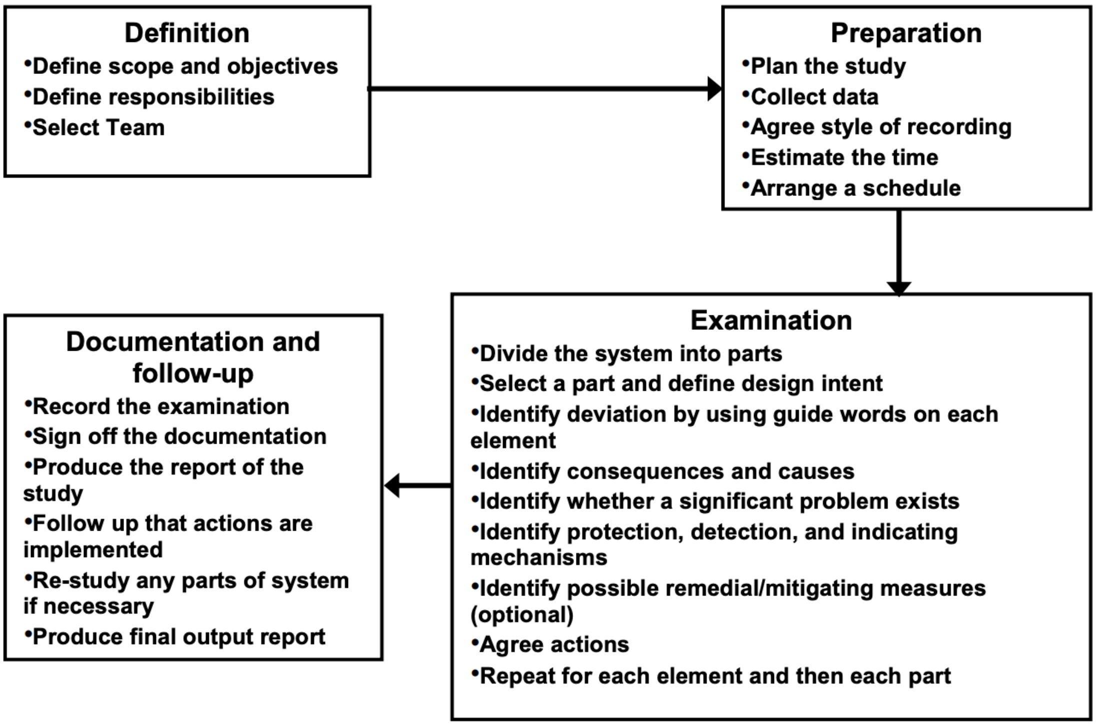

Figure 4.2 HAZOP Sequence procedure.

The person in charge of the plant or project, with the help of the research leader, usually sets the goals. The scope should be stated as clearly as possible.

This connection is needed to legitimise the study and ensure that the study is focused. While the overall goal is to discover dangers and operability issues, the team should concentrate on the study's underlying aim or justification.

A study could be conducted for a variety of reasons, including:

- Evaluate a design's safety;
- Determine whether and where to construct;
- Make a list of questions to ask a potential supplier;
- Examine the operational and safety protocols;
- Enhance the safety of a current facility;
- Check if the safety instrumentation is responding to the best parameters;
- Revalidate a safety assessment during construction, commissioning and decommissioning.

It is also crucial to specify which precise implications should be considered:

- Employee safety (at the factory or a nearby research facility);
- Plant or equipment loss;
- Production loss (loss of competitive advantage in the market);
- Liability or Insurability;
- Public safety;
- Environmental implications.

For example, a HAZOP might evaluate where a factory should be built to have the least amount of influence on public safety. The HAZOP in this scenario should be focused on deviations that result in off-site dangers. The HAZOP is done by a multidisciplinary team of experts with relevant knowledge of the evaluation process's design, operation, and maintenance. The idea is to assess the plant through brainstorming sessions, during which the team analyses all plant designs using the structure supplied by guide words. The main benefit of brainstorming is that it stimulates creativity and generates new ideas. The interaction of the team and their different backgrounds leads to this innovation (see Figure 4.3 (adapted from [71]).

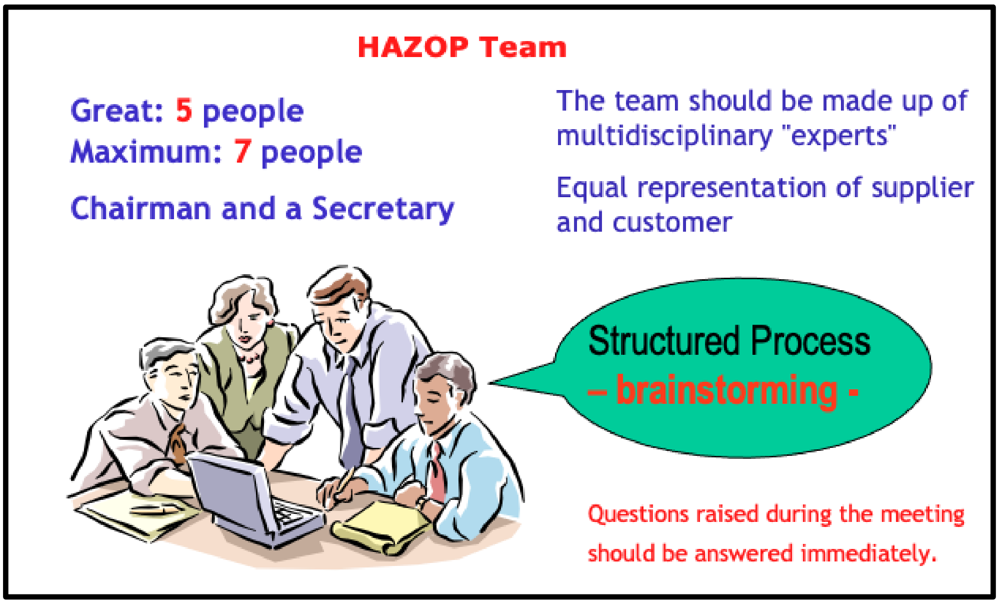

Figure 4.3 HAZOP Team composition.

A team of five to seven persons is ideal, but a smaller group may be acceptable for a smaller plant. The group strategy fails if the team is too large. On the other hand, if the group size is too small, it may lack the breadth of knowledge required to ensure completeness.

The team leader should have been knowledgeable about the plant's operations. A team might, for example, consist of the following individuals:

- Project engineer;
- Process engineer;
- Operations supervisor;
- Instrument project engineer;
- Chemist;
- Maintenance supervisor;
- Safety engineer (if HAZOP leader is not present).

The role and the responsibility of the various stakeholders in the HAZOP sessions can be analysed in Table 4.1 (adapted from [70]).

Table 4.1 Review roles & responsibilities

Position / Role	**HAZOP**
Chairman / Team Leader	Prepare documentation, mark-up System nodes. Facilitate review meeting. Prepare report.
Scribe	Record meeting in line with facilitators' requirements.
Process Engineer	Provide process input
Instrumentation & Control System engineer	Provide input concerning instrumentation, control system specifications and requirements, process control and safeguarding functionality/ intended design.
HSE Engineer	Provide safety input.
Process Engineer	Provide process input

Position / Role	HAZOP
Instrumentation & Control System engineer	Provide input concerning system control.
Operations	Provide operations input on how a plant is operated in line with normal procedures.
Maintenance	Provide experience on how systems are maintained.
HSE Engineer	Provide safety input.
Specialist Engineers: Mechanical, Piping Materials and Electrical.	Provide specialist input as required.

The most important job of the team leader's is to keep the team focused on the key task: identifying problems, not necessarily solving them. Engineers have a strong tendency to launch into a design or problem-solving mode as soon as a new problem comes to light. This mode should be avoided until there are obvious answers, as it will detract from the core aim of HAZOP, which is hazard identification. In addition, the team leader must remember a few key points to ensure a good meeting:

- Do not compete with members;
- Pay attention to all members;
- Do not put anyone on the defensive during meetings;
- Take pauses as needed to maintain a high level of energy.

During the study, important aspects are also considered:

- To set the priorities for a full safety analysis;
- To provide preliminary information on probable hazards, their sources and implications;
- To suggest some risk-mitigation system strategies.

It can be used at any point in the design process and during operations. Provides the first stages in maintaining the overall risk assessment. If a technology solution emerges during the identification of potential issues, it must be documented as part of the HAZOP report.

4.3 Preparation issues

The success of a HAZOP depends on all previous work to the meeting. This can be divided into four different stages:

- Obtaining the required information (support documents);
- Converting data into a usable format and devising a study nodes sequence;
- Scheduling meetings.

Obtaining the necessary data usually entails using line diagrams, flowsheets, plant layouts, isometrics and fabrication drawings, among other things. Operating instructions, instrument sequence control charts, logic diagrams and computer programs may also be included. Plant manuals and equipment manufacturer's manuals are occasionally available. The data must be examined to ensure that they are relevant to the study's objectives and that there are no inconsistencies or ambiguities - see Figure 4.4.

HAZOP Preparatory support documents

- Basis of design and process description
- Process flow diagrams (PFD's) and Plot-Plan
- Mass and enthalpic balances
- Verification of “as-built” P&IDs
- Checking Battery Limits - "marked-up" P&IDs
- Control and security narratives
- Cause-Effect Diagrams and ESD System Description
- Operating manuals / procedures
- Process materials information
- Equipment specifications
- HSE (Health, Safety & Environmental) information

Figure 4.4 Support documents for a typical refinery HAZOP.

Figure 4.5 shows the main actions performed before executing a HAZOP session and are crucial for its proper functioning.

HAZOP Preliminary work

- Appointing the **team leader & appropriate experts team**
- Collect all supporting **information**
- Estimated **schedule of time** to be spent by P&ID's
- Establishing the **PHA software** or data sheet
- Prepare **meeting room** conditions
- List of **guidewords & key parameters**
- Establishing **Risk Ranking Criteria**
- **Briefings with the team** before work starts (to get to know team members and brief training on the HAZOP methodology if necessary)

Figure 4.5 HAZOP preliminary work.

All process lines and systems that are part of, or maybe affected by, the projects or process facilities are covered by the HAZOP Study as a manageable section called "node". The preliminary identification of deviations, from the operation or design intention by applying guidewords, such as No, More and Less, to aspects of intention (such as flow, temperature, pressure, addition, reaction, etc.) within parts of the process, is a critical requirement for the success of the subsequent meeting. It will facilitate the identification of the causes of each deviation within each node and make it easier to guide the resulting sequence of events, including consequences and safeguards.

The process designers' set of needed or preferred process behaviours is known as "design intention". Parameters like flow and pressure are used to express distinct aspects of a node's intention design purpose. In general, each node has several relevant parameters. The HAZOP technique focuses on deviations from design intention because they represent possible difficulties, such as a lack of flow in a transfer line or overpressurizing a tank, which could lead to hazard and operability scenarios.

There is no single criterion for what should be included in a process's design intention. The definition of design intention for a process may appear simple in theory, but it is difficult to implement in practice. The design goal is usually complicated, with some subtle characteristics. Of course, a HAZOP study does not have to cover all areas of design intention, but it does have to decide which ones should be included.

HAZOP studies must identify and consider all areas of design intention for which variations could result in scenarios within the study's scope and goals. If the design goal is not sufficiently articulated and a comprehensive set of deviations is not examined, scenarios will be overlooked.

Unfortunately, HAZOP Study teams frequently establish the design intention by selecting process characteristics from a checklist without considering all important components of design intention. This strategy is likely to result in scenarios being ignored. To ensure that scenarios are identified as completely as possible, research teams must comprehend the meaning of design intention and include all crucial factors in investigations. Defining the design purpose for each process node as it is considered and collecting parameters is a preferable technique. This method enables a more thorough examination of the design purpose.

4.4 Schedule Estimation

Due to a lack of resources and necessary expenses, there are always time constraints for the leader and team members to complete a HAZOP investigation with many P&ID’s.

Some meetings can take months to complete a large process. Sessions, however, should be limited to three hours a day (preferably in the morning).

Very long sessions are undesirable because their effectiveness usually declines, especially for those who do not fully understand the methodology or process under study. Under extreme time pressure, only sessions can be held on consecutive days in exceptional circumstances, thus not complying with the basic recommendations.

Making resources available for HAZOP sessions usually involves taking experienced staff out of their routine activities, travel expenses, accommodation, and other costs, which create serious difficulties in allocating needed resources for an adequate period. As a result, these sessions are held by the HAZOP team for a very limited period, which is not adequate considering the number of P&ID’s, their complexity and workload.

The HAZOP team leader must successfully manage sessions while keeping study objectives and timelines permanently in mind. The HAZOP study leader must be technically capable and experienced and team participants must have a wide range of professional knowledge and experience

Since fatigue can affect the team's overall effectiveness, HAZOP is a brainstorming technique; it will be necessary to schedule adequate time for the predefined workload and conduct the HAZOP study sessions as planned. Table 4.2 gives a conventional HAZOP schedule estimate with different steps and work hours.

Table 4.2 Conventional HAZOP study time estimation.

HAZOP Schedulle Preparation - 5 Persons (Team Leader, Secretary, Process, Instumentation and HSE Engineers)	Time (hours)
Assemble Plant Data (3 days): Process Flow Diagrams (PFD's) and Plot-Plan Heat & Mass balances Verification of “as-built” P&Ids Checking Battery Limits - "Tagged" P&Ids Control and safety narratives Cause-effect diagrams and description of the ESD system Operating manuals / procedures Process materials information Equipment specifications HSE (Health, Safety and Environment) Information	120
Meeting Preparation (3 days): Define HAZOP Team Process descripton study Divide and mark-up all P&I's into sections and nodes Plant analysis sequence (from the first to the last node) Make the list of keywords for each section Meeting room preparation	120
SUB- TOTAL (5 persons)	240
HAZOP Schedulle Examination - 20 Persons (FLUOR+GALP) - Team Leader, Secretary, Process, Projects and HSE Engineers and Shift Supervisers)	Time (hours)
Examination: equivalent to 13 days. Vacuum Visbreaker Units Study. Apply guidewords to first node Identify all consequences Repeat until all nodes are considered (47 P&I and 57 nodes) Study second and subsquent sections until all are studied	
SUB- TOTAL (20 persons)	2080
HAZOP Schedulle Report - 5 Persons (Team Leader, Secretary, Process, Instumentation and HSE Engineers)	Time (hours)
Pos-Meeting: 10 days Scope of study Brief description of the process under study Keyword combinations and their meanings Description of Actions ("Action Response Sheets" containing information on actions taken General comments (which was not available or not reviewed or that the team had alread Results (the number of recommended actions)	
SUB- TOTAL (5 persons)	400
TOTAL HAZOP manhours	2720

4.5 Examination

Nodding begins at the start of the procedure. In the unit's P&ID’s, the identified preliminary nodes must be confirmed to allow a joint analysis with the team, thus consolidating the sequence of process circuits to be carried out in the study.

Each major vessel included in the scope of the investigation should be identified. The traditional approach starts with the main inlet line of the first vessel; each of its inlet lines in the primary process flow path to the vessel is noded. The vessel is then noded. Then, each outlet line is noded in the primary process flow path. This is done for all vessels in the major process flow channel. Any moment during the nodding process that makes sense, vessels and lines and other process flow pathways are noded.

In Chapter 5, different approaches to identifying nodes and their impacts will be discussed in more detail, as this issue is particularly important in the new approach to the HAZOP methodology that is intend to develop in this work.

Existing upstream and downstream circuits that may be affected by new facilities should also be included in the study. At the very least, the following nodes should be researched:

- Process lines;
- Process vessels;
- Process equipment;
- Emergency Shutdown Systems (ESD);
- Isolation at battery limits;
- Interface with other installations.

The goal is to review rather than resolve action items to find credible departures from the project's or process's original goal. The method detects hazards and hypothesizes possible accident sequences resulting from these hazards. Creative thinking identifies the outcomes of these situations. The work procedure must show that all precautions and safeguards have been taken to provide a safe and functional installation.

The technique is based on the idea that no hazards exist if the process does not depart from the design goal. The team determines whether the deviation could realistically occur and, if so, assesses whether the consequences constitute hazard and/or operability issue. The team then assesses whether safeguards, either hardware or procedures, are adequate considering the causes and consequences of the deviation. If necessary, the team makes an improvement recommendation.

Double jeopardy hazards are typically excluded. When justified, the double jeopardy for some scenarios should be accepted if the hazard is extremely high. In general, serious accidents are the result of combined factors.

4.5.1 Guidewords

To stimulate discussion or ensure the integrity of the process, guidewords appropriate for the study and, not too specific (limiting ideas and discussion) or too general (allowing for the loss of focus) should be chosen.

Guideword application, during the work sessions, will be registered in a worksheet as shown in Figure 4.6:

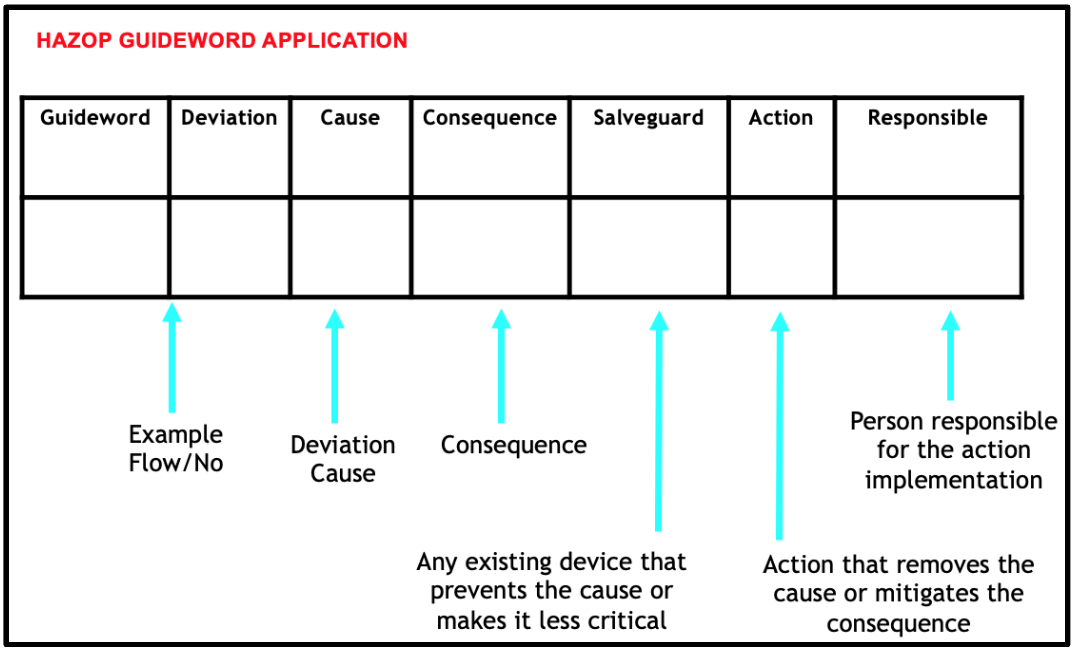

Figure 4.6 HAZOP guidewords application.

Each guideword is a combination of words that describe a system's critical property or parameter and how it could deviate from expected behaviour. System features such as 'Feed', 'Temperatures,' and so on are frequently associated with key parameters. 'No or not', 'more', 'less', 'as well as', 'part of', 'reverse' and 'other than' are frequent expressions used to describe deviations - see Figure 4.7 (adapted from [71]).

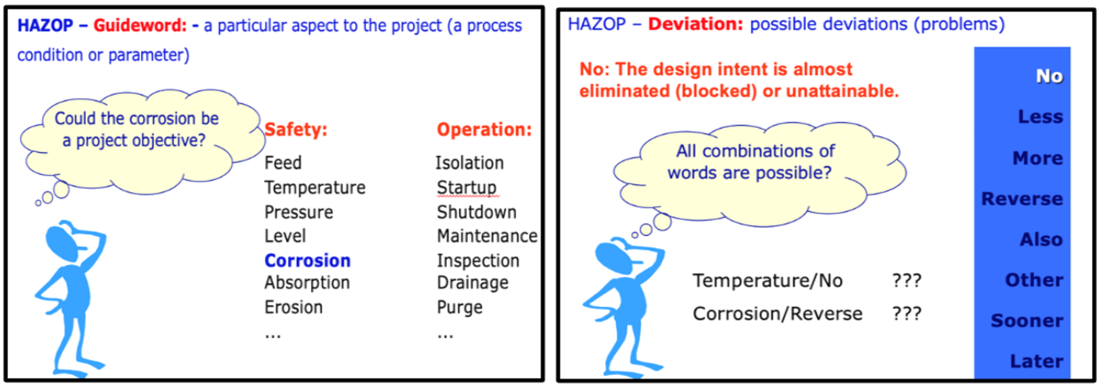

Figure 4.7 Guidewords and secondary words examples.

Table 4.3 (adapted from [70]) shows the guidewords application and the common interpretation during the HAZOP procedure.

Table 4.3 Overview guideword parameter and common interpretation.

Parameter / Guide Word	More	Less	None	Reverse	As well as	Part of	Other than
Flow	high flow	low flow	no flow	reverse flow	deviating concentr.	Contam..	deviating material
Pressure	high pressure	low pressure	vacuum		delta-p		explosion
Temperat.	high temperat.	low temperat.					
Level	high level	low level	no level		different level		
Time	too long / too late	too short/ too soon	sequence step skipped	Back wards	missing actions	extra actions	wrong time
Agitation	fast mixing	slow mixing	no mixing				
Reaction	fast reaction / runaway	slow reaction	no reaction				unwanted reaction
Start-up / Shut-down	too fast	too slow			actions missed		wrong recipe
Draining /Venting	too long	too short	none		deviating pressure	wrong timing	
Inertizing	high pressure	low pressure	none			Contam..	wrong material
Utility failure (instrum. air, power)			failure				
DCS failure			failure				
Mainten.			none				
Vibrations	too low	too high	none				wrong frequency

The HAZOP methodology uses a group of guidewords to define abnormal conditions and analyse their consequences. These guidewords ensure that the process or the project nodes are explored in detail, identifying many deviations and their possible causes and consequences.

4.5.2 Study Flowchart Sequence

During the HAZOP study, the team leader must help the other members to apply the list of guidewords and the respective deviations at each node. Some of them, because they are irrelevant, can be omitted. In each case, the team must discuss:

- What can cause the circumstances described by the guideword;
- The nature and extent of consequences if this situation occurs;
- The existence or not of safeguards;
- Necessary action and the person responsible for its implementation in case of non-existence of safeguard.

During the mitigation survey of identified hazards, the HAZOP team should:

- Eliminate or reduce identified process hazards by selecting an inherently safe design or implementing specific barriers with the same objective;
- Make a preliminary identification of critical process equipment related to the identified hazards;
- Make an initial identification of potentially dangerous events for which the protection by Safety Instrumented Functions is advisable.
- Assess the consequences of identified hazards by using the severity axis of the Risk Matrix (Annex A) to characterize and classify all identified hazards and hazardous events according to their possible consequence.
- As a result of the risk analysis activities, recommendations are identified, resulting in an action plan that must be prioritized. Once the recommendations are established, the team should also propose any temporary actions or controls that should be considered to mitigate the risk of the event in question until the recommendation can be implemented.

The procedure for performing a HAZOP study is shown in Figure 4.8 (adapted from [70]).

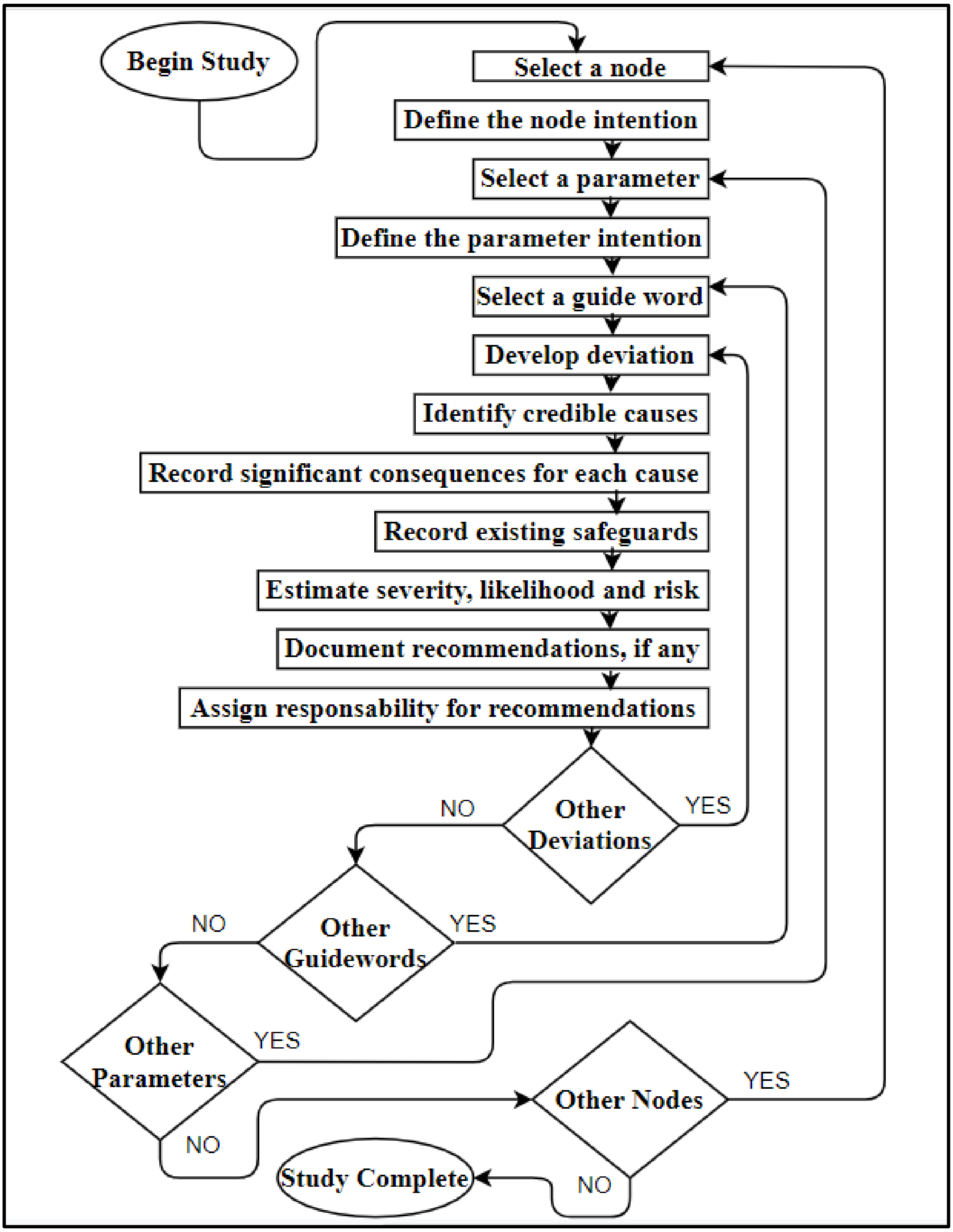

Figure 4.8 HAZOP methodology sequence.

4.5.3 Risk ranking criteria

Depending on company or project requirements, typically, detecting hazards are ranked in terms of risk. With a standard risk matrix, risk ranking qualitatively identifies the risk as a combination of severity and likelihood. Risk prioritization is carried out based on this combination.

The severity should be established for health and safety, environmental, financial, asset damage and reputational effects. The likelihood is the number of times an event occurs each year, which should be determined by the company and historical datasets. Various risk matrices are employed in different sectors (Annex A).

The team leader must address the likelihood of causes and the severity of effects of the hazard scenarios identified with the team before initiating the HAZOP sessions (criteria agreed upon by management). Prioritizing situations based on their level of risk allows for a more effective reaction to any recommendations that may be made.

The process dangers must be addressed during the identification of the whole scenario. Identification, assessments of similar occurrences, engineering studies of control failures, facility localisation, human aspects, and public effects evaluation, among others, are all regarded as crucial for a thorough description.

After identification, the entire team must determine if the project and/or operational changes have the relevant safeguards considering only a qualitative risk assessment or if corrective actions derived from the study are necessary.

There are, however, some cases in which potential problems are identified that require additional corrective action or possible process alternatives to eliminate hazards or reduce existing risks.

Safety Integrity Level (SIL) classification is an exercise that determines the required level of safety integrity (reliability) to be provided by safeguarding instrumentation for a process scenario or equipment condition, or event which requires a Safeguarding Function/ Instrumented Protective Function to take action to prevent a hazardous situation for each safeguarding loop. The required level of safety is expressed in a SIL rating. A failure is the consequence of extreme process conditions (i.e., high pressure, high temperature, low/no flow, etc.) if the provided safety function does not work or is not present. For each consequence group, the consequences are categorized from Cat 0 (no or negligible effect) to Cat 5 (catastrophic effect).

To comply with the standard IEC 61511(2003) [72], Galp Company develops corporate risk rating schemes to evaluate the severity and likelihood of hazardous scenarios and combine them to provide general risk estimation in the matrix, grid, or table form.

4.5.4 General Notes and Assumptions

Some assumptions were made as a basis for applying the HAZOP methodology. These assumptions and rules have to be agreed upon by the HAZOP study team and subsequently applied to the review, namely (adapted from Galp internal HAZOP meetings):

HAZOP REVIEW RULES

- HAZAP sessions must identify hazard and operability problems, considering process and control loop deviations, human actions, and external events as credible causes.
- No effort should be employed for developing detailed solutions for the recommendations (such as prevention measures, safeguards, or mitigations systems); only writing clear the proper recommendation is required.
- Safeguards can be divided into prevention safeguards (reducing likelihood) as interlocks, PSV, or blowdown systems, and also can be for mitigation measures, which reduce severity (such as F&G, Fire Fighting systems, Emergency Plans, etc.).
- The causes may be inside the node, the consequences can be everywhere, including outside the node.
- The causes may be outside the node for interfaces. Deviations on the other side of the interfaces must be included.
- All reliable causes must be included as the adequacy of protection may influence the causes.
- Double risk is excluded. Unidentified latent failures do not pose a double risk. Also, common-mode failures are considered as "single risk".
- Spontaneous escape is excluded; it may be a result of another deviation. However, tube breakage of exchangers must be included as a reliable cause.

HAZOP REVIEW PERMISSIONS

1. Not to be considered:
    - Simultaneous occurrence of two unrelated incidents or simultaneous failure of more than one independent protection device (double risk - "double jeopardy")
    - Operator negligence (except for common human error)
    - Natural event (flood, earthquake), except where a project case
    - Sabotage.

2. HAZOP analysis is not performed for normal operating equipment/units only. HAZOP results should also be applied to spare/standby units/equipment (e.g., compressor trains of the same type).

3. Comments and observations written on the original copy are considered included in the project (if not accepted, required modifications to the P&ID's should be recorded as a recommendation).

4. When analysing control circuit failures, it is assumed that any one of the control circuit elements (e.g., transmitter/controller/control valve) is failing, leading to one or more consequences. Alarms linked to this control loop will not be considered protection.

5. Human error can be considered the cause of deviation during normal operation: Furthermore, human error is considered more frequent during start and stop activities, which will require a specific safety procedure.

6. Local indicators will not normally be considered as safeguards. Any sensor instrument to be considered protection must have a dedicated alarm in the DCS Control Room.

7. It is assumed that a pressure safety valve (PSV) can escape. Still, without significant consequences, if the PSV is connected to a flare system or directed to a safe location, so we did not study in HAZOP.

8. The cause "unexpected opening of the PSV" is not an initiator of significant deviations (such as "incorrect flow" / "low pressure", etc.).

9. The dangerous failure of a PSV "does not open when needed" is considered a double hazard if there is low flow and proper design. When PSVs are the only layer of protection, it can be considered a dangerous failure of the PSV.

10. To be considered an alarm as a protection, in the Distributed Control System (DCS) Control Room, the operator must have at least 10 minutes for proper intervention after the alarm is activated.

11. Manual intervention is considered a safeguard only if activated by dedicated independent alarms of the specific deviation, provided there is sufficient time and means for the operator to take action and bring the process to a safe state ("the operator must have sufficient time and independent facilities to eliminate the hazard. Normally, credit should not be claimed unless the time available between the alarm and the hazard exceeds 20 min (as suggested by IEC61508, part 5: 2010 [73]). Unnecessary alarms should be followed as a general philosophy.

12. All manual valves installed in automatic valve bypass or equipment maintenance bypass should be considered closed, provided that the start-up and maintenance procedures have been followed. However, critical manual valves must be considered (e.g., for important pumps or suction compressors or discharge lines).

13. For shell and tube heat exchangers, the scenario of overpressurization due to tube rupture (and the relevant requirement for an appropriately sized PSV) is not considered if the equipment involved has been designed by the ASME rule 10/13.

14. In the case of manual shut-off valve specified CSO /CSC (or LO /LC), incorrect operation, such as incorrect opening or closing of the mentioned valves, is not considered a possible cause of one or more deviations.

15. It is assumed that check valves allow 10% leakage in the case of reverse flow for liquids and even more for gases. They are not backpressure protection.

16. Check valves are not considered a suitable isolation device in the face of possible backflow of the gas/vapour phase leading to overpressurization.

17. Safeguards to be valid need to comply with the requirements of IEC 61511-2016 [74] (be Specific, be Auditable, be Independent and, finally, Fully Prevent Risk).

18. All drains, vents and bleed points are assumed to be fitted with plugs, covers, or double hand valves at the open ends, where they can cause any damage in the event of an accidental opening. Therefore, they are not considered open in this HAZOP.

19. For sampling and maintenance matters, suitable methods, personnel protection equipment, and procedures are considered to be in place to ensure personnel safety and process integrity. Therefore, they are not considered in this HAZOP.

20. The F&G system normally alarms the DCS at a lighthouse near the area with a leak to the alarm field operators. It could be mitigation protection if assumed 10 m for proper action for leaks. In the event of a major leak disruption (flammable or toxic event), the F&G system only reduces the size of the event.

21. Unexpected operator presence can reduce the consequence of operator injury in case of any small flammable or toxic leak due to piping/equipment rupture.

22. The presence of ignition points can increase the probability of fire and/or explosion, using the Cox, Lees and Ang table. The proper classification study of the area will safeguard against this problem in HAZOP.

23. Detailed and specific operating procedures can be used as a safeguard to reduce Risk from a tolerable to an acceptable level.

24. Only credible causes or initiators should be analysed in HAZOP. For example, the failure of two independent control loops is not necessary to study in HAZOP due to their low probability of occurrence.

25. Only alarms and shutdown functions completely independent of the control systems are considered safeguards. In some cases where the consequences highlighted are only associated with operational problems, the presence of indicators (for DCS or in the field) can also be considered as potential safeguards.

26. The phrase: "Failed to open (or failed to close) the PIC, TIC, LIC, FIC, etc. implies the failure of any element of the control circuit (sensor/transmitter, controller, transducer, control valve), which leads to a valve position that is different from the position required by the design intention.

27. In the case of hazardous materials, the loss of containment is not considered a possible cause for lower flow/pressure deviation since the mentioned scenario is not strictly process-related and must be investigated using different tools (for example, QRA).

28. Internal leakage (valve passage) is not considered for valves specified as TSO.

29. In the case of blind joints, the deviation “undue flow” is not analysed, even in case of malfunction and valve passage (internal leakage).

4.6 Recording process and Report

During the meeting, it is necessary to fill the necessary HAZOP tables. The safety analysis results will be recorded and organized into headings identified by the various guidewords to demonstrate process deviations, possible causes, consequences, safeguards, necessary actions, and other factors determining the result - see Figure 4.9.

The registration sheets of the actions developed within the scope of the HAZOP study are sheets that will be used by the Engineer responsible for following up on the HAZOP and making any corrections that may be necessary.

All documents used in the preparation of the study, minutes of meetings, list of actions and other documents produced by the team must be kept by the Team Leader of the HAZOP Study.

Worksheet

Company: GALP
Facility: Matosinhos Refinery

Page: 17 de 121

Session: (1) 11/11/2019
Node: (1) ACID GAS K.O. DRUMS D-10801 AND D-10802
Drawings: RP-07-A1-108-00020-XXXXXXX-2001 Rev. 3
RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3
RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A

Notes:

Guideword	Deviation	Causes	Consequences	Safeguard	S	L	R	REF#	Recommendation
Less / No	1.1. Less / No Flow	1.1.1. No acid gas flow from U-1500 (T-1502)	1.1.1.1. Low level in D-10801, possible pump P-10801 (or P-10802B) cavitation. Equipment damage and loss of containment. Risk of fire. Personnel injuries.	1.1.1.1.1. LAL-002 activates interlock UX-016 stopping the pump P-10801 (or P-10802B) 1.1.1.1.2. LALL-003 (2oo3) activates interlock UX-016 stopping the pump P-10801 (or P-10802B) 1.1.1.1.3. Pump Double seals	D	2	II		
			1.1.1.2. No feed to the reactor H-10801 See less/ no flow in node 2						
			1.1.1.3. No liquid to SWS (U-10775) process upset						
		1.1.2. Human error closing the manual valve upstream P-10801 when required to be open	1.1.2.1. High level in D-10801, possible pump P-10801 (or P-10802B) cavitation. Equipment damage and loss of containment. Risk of fire. Personnel injuries.	1.1.2.1.1. LAH-002 interlock UX-016 starting the pump P-10801 (or P-10802B) 1.1.2.1.2. LAHH-003 (2oo3) activates interlock UX-011 tripping the unit and UX-016 starting the pump P-10801 (or P-10802B) 1.1.2.1.3. Pump Double seals	D	2	II		
			1.1.2.2. High level in the D-10801 may lead to liquid carry over to thermal reactor H-10801 (or E-10807). See other composition in node 2.						
			1.1.2.3. No liquid to SWS (U-10775). Process upset						

Figure 4.9 HAZOP worksheet (Galp Acid Gas K.O. drums D-10801/2).

The HAZOP Report must contain the following sections:

1 – Summary;

2 - Introduction (a brief description of the process under study);

3 - Study Objective (Scope of Study);

4 - Methodology (Combinations of keywords, causes, safeguards and actions to reduce hazards and respective culprits);

5 - Execution (review dates, participants, documents used);

6 - Results and conclusions.

Attachments:

Attachment A - Minutes of the meeting in the form of worksheets

Attachment B - List of all Recommendations

Attachment C - P&ID’s used in HAZOP with tagged nodes

The HAZOP recording method is very significant. Although it is hard to physically record everything said, all thoughts must be recorded. The HAZOP report should be distributed as a first draft to all team members, with a deadline for any comments.

It should include all completed worksheets and information about the study's methodology, who participated (with necessary attendance signatures), assumptions, a summary of outcomes and copies of reference materials.

It is very useful for team members to see the final report before gathering for a report review meeting. When major discoveries are reviewed, they are often fine-tuned, and new ones are discovered. A strong recording scheme is required for this process to be successful.

At least the team leader and the responsible manager will sign the final report, which will then be forwarded to those in charge of tracking the action items. As a result, management's approval of the final report version signifies their commitment to implementing all action items.

Each facility must maintain a register that details all relevant information associated with major accident risks (including normal and temporary activities) from the assessment process. The information corresponds to the team's risk analysis result and constitutes information for future reviews.

Registration is also a tool that aims to monitor the actions defined for implementation. The Risk Register must demonstrate that:

- All hazards, effects and threats have been identified;
- The probability and impact of each hazardous event have been assessed;
- Safety barriers to eliminate possible causes or mitigate consequences have been identified and are in place.

The Risk Register is a dynamic document and must be updated periodically, or if there are open actions, or whenever there is a change in a process/project with new risks formally analysed.

4.7 Strengths, Weaknesses, Advantages and Disadvantages

The success of the HAZOP depends on several factors:

- Clear definition of the purpose, objectives and scope of the study;
- Team Leader expertise and training;
- The technical skills (according to the scope) and insights of the team;
- The completeness and accuracy of drawings and other data used as a basis for the study;
- Preparation of the study in advance;
- The ability of the team to use the approach as an aid to their imagination in visualizing deviations, causes, and consequences;
- The ability of the team to concentrate on the more serious hazards which are identified;
- Ensure that Record Sheets are completed and actions distributed for follow-up.

The common mistakes that can be found during the meetings are:

- Consequences of events not held to completion;
- Take incorrect credit from safeguards;
- The absence of specific recommendations;
- Poor record-keeping of HAZOPs;

- Lack of start-up and shut-down procedures;
- Not updated or poorly constructed P&ID’s;
- “Unsafe environment” for team members;

HAZOP strengths, can be describe as:

- In addition to detecting dangers, the technique can also detect operational concerns;
- An approach with a lot of organization and formality;
- A wide range of dangers can be assessed (e.g., chemical, mechanical, control);
- New, novel and current processes can all be analysed;
- The team gains a comprehensive understanding of the process's likely behaviour;
- Much better operating procedures can be written as a result of the study;
- Using a systematic approach, apply guide words and parameters to all process equipment;
- It explores the consequences of the failure, allowing for formulating recommendations for methods to decrease or eliminate the hazard.

and the HAZOP limitations are:

- The approach is time-consuming and costly, especially in continuous chemical processes with a large number of equipment (e.g., petroleum refining processes);
- The process must be built to the point where P&ID’s are available to finish the study;
- Unusual hazards need the use of extra guidewords;
- The study relies on the leader's judgment and the team's skills to discover all the causes and consequences of the deviations;
- HAZOP paperwork is not frequently written to make it easy to read for outsiders and the analyst's prejudice, experience, knowledge and ingenuity influence the outcome.

4.8 Case Study #1 Diesel Unit First HAZOP Revalidation

This unit was designed in 1969 to treat 9850 barrels per day of a mixture of petroleum plus diesel derived from crude oil from Kuwait, Es Sider and Arabian. Its initial objective was to reduce its sulphur content by 1.42% weight (max) to 0.2% weight (max).

As part of the revamping of the fuel plant at the Matosinhos Refinery, carried out in 2010, the unit's capacity was increased to 1600 tons/day, around 25% in relation to the original project to obtain a final product containing a maximum of 8 ppm of sulphur.

The composition of the feed was also changed to a mixture of 400 ton/day of diesel from Arabian Light, 800 ton/day of kerosene from the mixture of 65% Bonny Light 65% and 35% Marlin Light, 300 ton/day of kerosene from Arabian Light and 100 ton/day of Naphtha from the Visbreaker unit.

As the process changes to the unit, there are the adaptation of a larger reactor and the introduction of a set of small modifications resulting from the new feed charge composition.

The HAZOP Revalidation process was carried out in 2014, after the remodelling of the unit in 2010, by a team of technicians from GALP, having been given the responsibility, as Team Leader, to prepare, coordinate and present the respective final report.

During this process, the unit was analysed from scratch, unlike in 2010, where only the circuits corresponding to the changes introduced were analysed. The definition of the nodes followed the previous criteria, defined in all HAZOPs of the refinery revamping, that is, standard way, small in size, individualizing all the process changes introduced.

This approach constituted a real test-run of the entire process of carrying out a HAZOP risk analysis through its traditional methodology approach. It followed three sequential steps:

- Meeting preparation (before and at the beginning of the meeting) - see Figures 4.10 and 4.11 (adapted from [75]);

- Execution of meetings;

- Post-meeting report - see Figure 4.20 (adapted from [75]).

4.8.1 Preparation of Meetings

All unit operation information was collected. A systematic and comprehensive review of the process design was carried out in terms of health, safety, environment, and operability within the scope of Galp's MOC procedure.

A complete and clear list of hazardous events has been made, to be discussed with staff before the start of meetings, based on equipment and process circuits that can potentially affect the facility's safety and its operating personnel (including third parties and the environment).

Operating and maintenance manuals and all follow-up activities have been verified as satisfactorily completed and all identified hazards and operability problems have been either eliminated or can be managed as far as is reasonably practicable.

Some P&ID´s and the cause-effect diagrams were updated, and it was identified the need for an instrumentation nomenclature standardization, however, without impacting the HAZOP execution.

The information considered relevant for the application of the methodology was collected and shared with the team, namely:

- Operation Manual; Process Flow Diagram;
- Piping & Instruments Diagram;
- Plot Plan Diagram;
- Cause/Effect Diagram;
- List of Instruments and respective alarm settings;
- Datasheets of the various equipment.

The previous PHA sheets were previously reviewed to flag deviations and/or appropriate questions that needed a review based on a preliminary assessment of each modification. This preparatory work aimed to accelerate the pace of PHA Revalidation meetings and guide their execution based on existing keywords.

Figures 4.10 and 4.11 presents the flowcharts that were used in the preliminary work carried out a few days before and at the beginning of the HAZOP execution meeting.

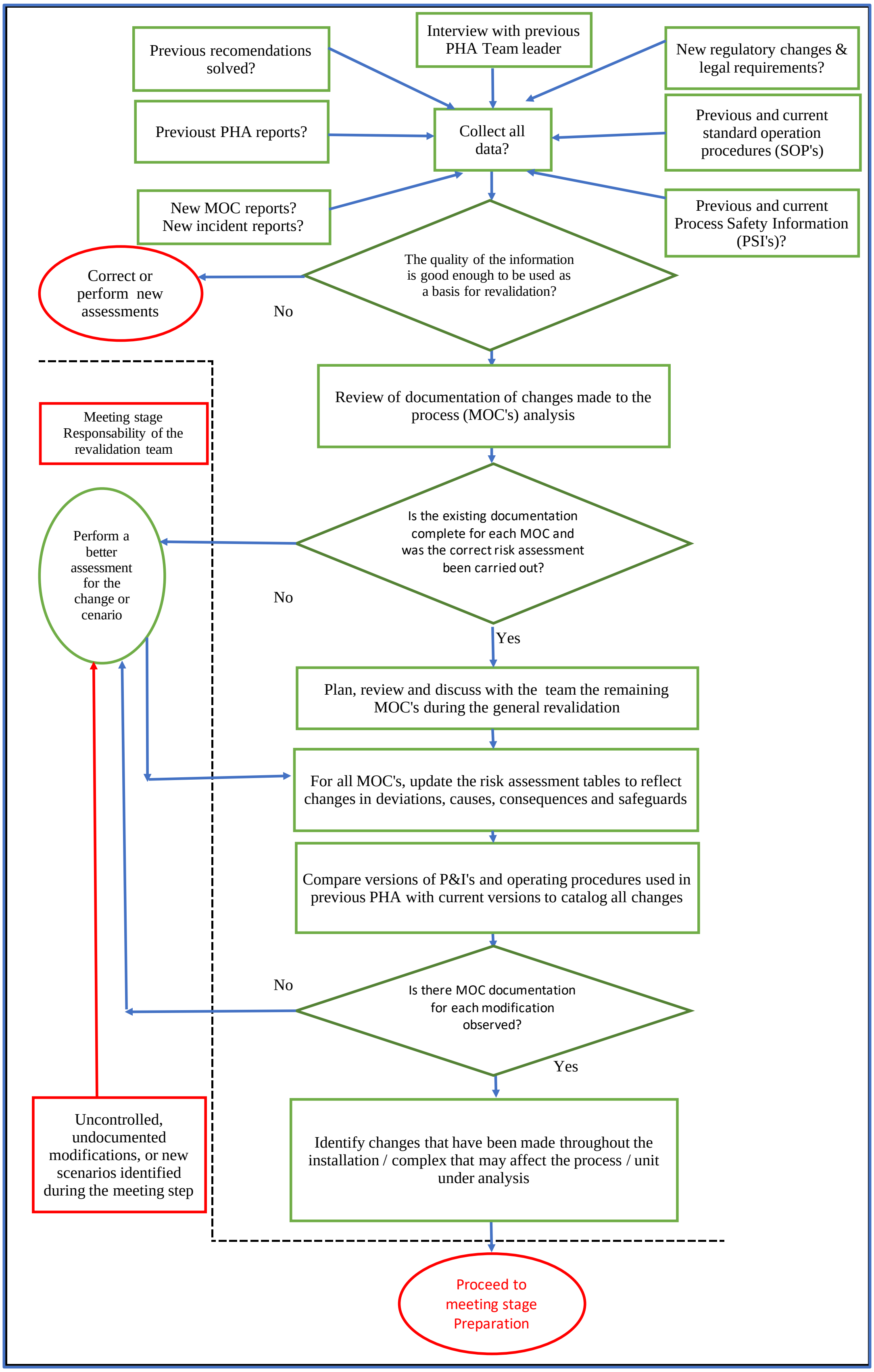

Figure 4.10 PHA preparation steps before the meeting.

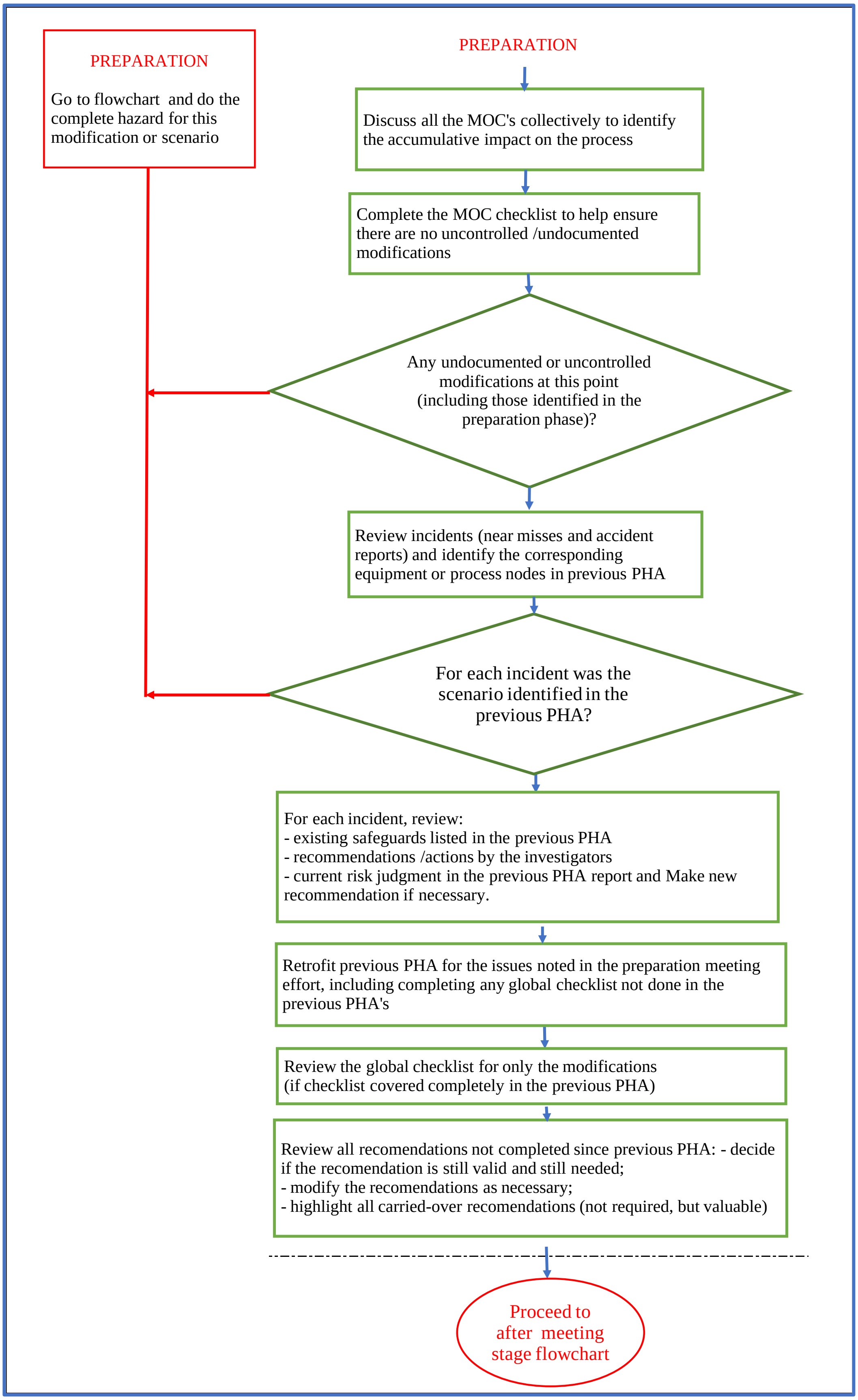

Figure 4.11 PHA preparation steps during the meeting.

The success of the risk analysis was largely due to the team formed, as it was possible to obtain the participation of the most appropriate and knowledgeable specialists in the unit under study. This fact is relevant as it is impossible to displace these professionals from their routine operational activities.

The HAZOP Team, whose names are confidential matters not mentioned in table 4.4, was composed of areas directly related to the fuel plant and particularly to the Diesel Hydrotreatment unit, namely:

Table 4.4 Galp HAZOP Team.

Name	Department
Manuel Leão Tavares	Team Leader
Galp Reserved Name	Subscriber
Galp Reserved Name	Process Engineer of the unit
Galp Reserved Name	Shift Supervisor of the unit
Galp Reserved Name	HSE Engineer of the plant
Galp Reserved Name	Maintenance Engineer of the plant
Galp Reserved Name	Inspection Supervisor of the plant

In some sessions, only a few experts participated, considering their specific knowledge, interest, and motivation. In this way, human resources were optimized throughout the various risk analysis sessions.

All HAZOP sessions were organized to be held in the fuel plant control room and their final stage in the administrative building.

As already mentioned in the previous HAZOP, only the impact of some modified equipment was studied, and global risk analysis was not performed. After the question was raised at the beginning of the sessions, the team unanimously decided to carry out a comprehensive risk analysis of the entire unit to identify all the necessary safeguards for the safety of the installation.

The same 208 hours of the previous risk analysis were considered to estimate the time to perform the HAZOP. An estimate based on the knowledge acquired with several years of operation of the unit, on the one hand and the significant increase in the number of circuits and equipment involved, on the other.

4.8.2 Meeting Execution

Following a usual procedure in Galp company, according to the EN 61882:2016 – Hazard and Operability Studies - Application Guide", a brief description of the methodology was presented since not all team members were familiar with the cause/consequence/protection logic of the process. The objectives of the Revalidation, e.g., what is to intend to achieve and what is the legal framework.

Although most team members have some basic familiarity with the process and the equipment, the process engineer was asked to describe the unit and clarify any doubts regarding its integration into the refinery. It was important for the entire team to have an overview of the process to help and accept the final definition of nodes proposed by the Team Leader.

4.8.3 Process Description

The Galp Diesel Hydrotreatment unit includes the following process main sections (see Figure 4.13):

- **Reaction Section:**

The feed coming from the Atmospheric Distillation units and/or storage units is pumped by the feed pump P-1401. At the inlet of the reactor load/bottom exchanger, gas-rich in H_2 is added and the gas-oil mixture is thus preheated by the reactor effluent and then brought to the reaction temperature in the H-1401 furnace. The reactor effluent is cooled and partially condensed in the E-1401 cooler. The effluent then enters the high-pressure separator D-1401, where the H2-rich gas and the gas oil are separated. The diesel goes, under level control, to the low-pressure separator, D-1402 and the H2-rich gas is sent to the recycle compressor separator D-1405.

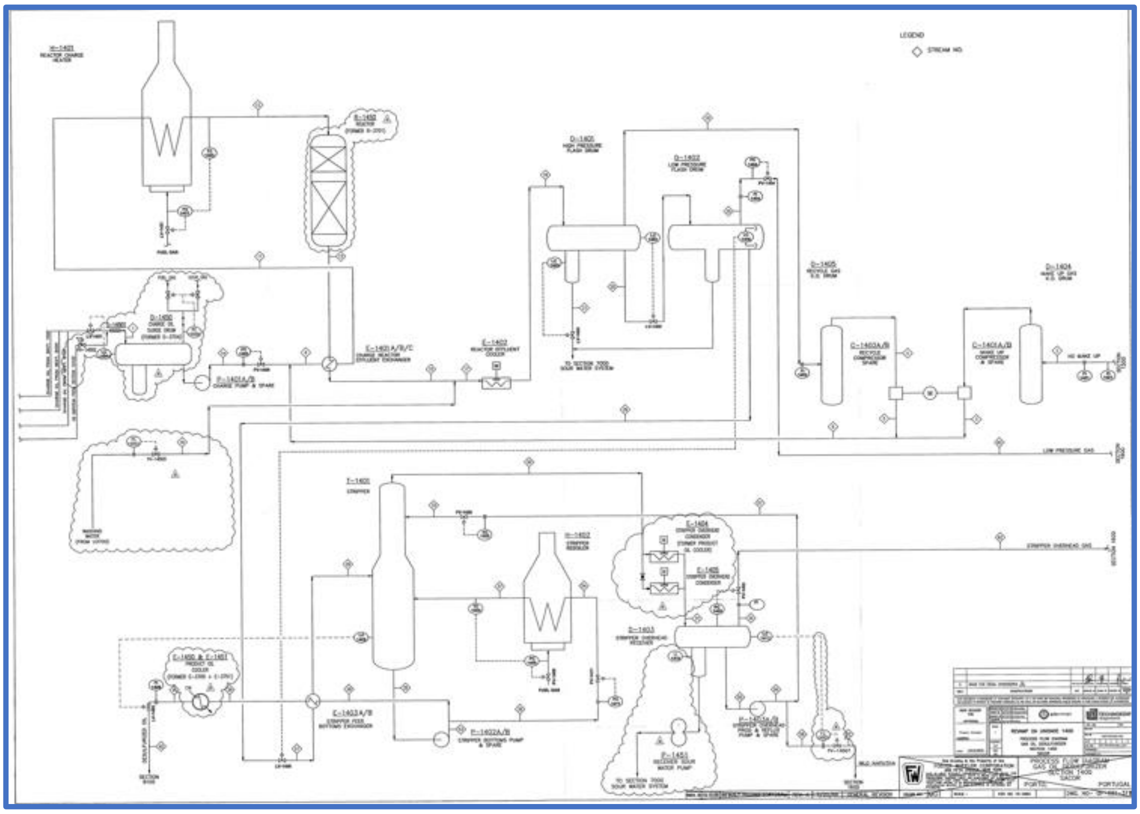

Figure 4.12 Galp Diesel hydrotreatment process flow diagram.

- **Compression Section:**

The make-up gas from the Platforming Unit enters the feed compressor separator D-1404 to remove any condensed liquid. From there, the gas is then circulated to the C-1404 feed compressor. This feed gas is added to the recycle gas from the respective compressor, C-1402, and the total hydrogen stream is added to the feed load before entering the E-1401. Part of the liquid from the low-pressure separator, D-1402, is recycled as wash oil and added to the reactor effluent. This scrubbing circuit aims to maintain the hydrogen concentration in the recycle gas. When necessary, a small amount of water is introduced by the water injection pump, P-1405, into the reactor effluent at the exit of the E-1401 exchanger to clean the system of ammonium and sulphur salts.

- **Rectification Section:**

The liquid from the low-pressure separator, D-1402, leaves under level control, is heated in the exchanger E-1403 (load/bottom of the rectifier) and enters the splitter T-1401. The P-1402 pump sends the hot bottom product through 2 circuits: a) Part of the product circulates through the furnace (revaporizer) H-1402, where it receives the heat necessary to release the H_2S from the diesel, returning to the T-1401 rectifier; b) The remaining diesel is cooled in the E-1403 exchanger (rectifier load/bottom) and the diesel cooler, E-1404, before being sent to storage. The rectifier vapours are cooled and condensed in the overhead condenser, D-1403, and sent to the Gas Recovery Unit. The condensate from the accumulator is divided into two streams - one is sent to the rectifier as reflux under flow control and the other is sent to the separation unit under accumulator level control as unstabilized gasoline.

The process engineers also explained the control systems and associated safety instrumentation, using both the P&ID's and the cause-effect diagram. The emergency equipment related to this unit, information also considered necessary for defining the safeguards used in HAZOP, was presented in detail by the HSE representative.

4.8.4 Nodes Identification

As discussed earlier, the approach will follow the steps:

- Identification of the main sections according to the unit process description;
- Highlighting the main sections in the PFD's;
- Moving these nodes from PFDs to P&ID's.

After these preliminary activities, the Team Leader started the meeting, presented the unit diagrams opportunely posted on the Fuel Plant control room wall and proposed the nodes to the rest of the team. The PFD (see Table 4.5 and Figure 4.13) and all P&IDs (see Table 4.5 and 4.6 and Figures 4.14 to 4.19) were used for this purpose.

Utility and compressor P&ID's were analysed for the first time for HAZOP purposes, corresponding to one node for each, following the same node approach for each package. In general, HAZOP considers gear in motion. Therefore, text in worksheets often uses tag numbers for operating equipment and does not always specify which list tag numbers for standby equipment or instrumentation. The most obvious example of this case is the compressor, where the HAZOP team did not specifically review compressor B in standby (although switching between compressors was considered).

Table 4.5 Galp Diesel Hydrotreatment Unit Hazop Diagrams.

Information
PFD´s
1927-PFD-0010-001_A
P&ID's
1927-PID-0021-002a. rev 3 – Feed Section
1927-PID-0021-002b. rev 3 – Reactor Section
1927-PID-0021-003. rev 3 – Stripper Section
1927-PID-0021-004. rev 2 - Utilities Flow Diagram (Fuel Gas Supply Section)
1927-PID-0021-005. rev 3 – Utilities Flow Diagram (Compressor Section)
1927-PID-0021-001-2. rev2 – Compressor Section

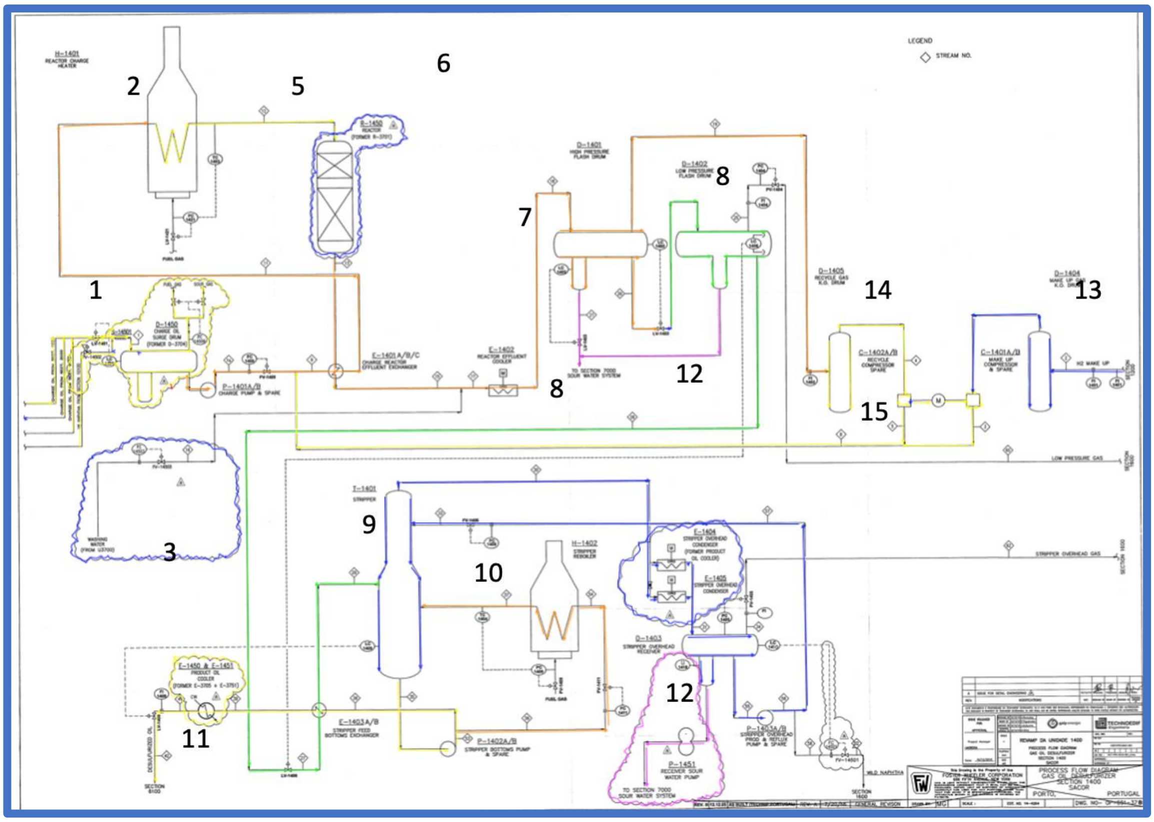

Figure 4.13 Nodes identified in 1927-PFD-0010-001_A - Feed Section).

Table 4.6 Proposed Nodes.

Node	Description
1	Feed to D-1450 /D-1450 / FG Input and Flare Output
2	Output from the D-1450 to the inlet to the H-1401 Furnace
3	Wash water circuit (P-1405)
4	Wash water circuit (BL to E-1402)
5	H-1401 up to R-1450 reactor inlet, FG circuit for burners and pilots
5.1	Feed to D-1405 and output to the furnaces
6	Reactor R-1450
7	R-1450 output; E-1401A/B/C; E-1402; D-1401
8	Low pressure accumulator (D-1402), E-1403A/B
9	Column (T-1401); Top (E-1404/5; D-1403; P-1403A/B)
10	T-1401 Reboiler Circuit (H-1402; FG circuit for burners and pilots)
11	Bottom T-1401, P-1402A/B, E-1403A/B, E-1450/1, P-1407
12	Acid waters D-1401; D-1402; D-1403 (boot accumulators); P-1451
13	Hydrogen Circuit and Pressurization Current
14	Recycle gas supply to compressor C-1402A/B (via D-1405)
15	C-1401A/B and C-1402A/B compressors and their auxiliary circuits
16	D-1404, D-1405 purge, inlet and compression drums of the C-1401A/B and C-1402A/B Purge circuit of the D-1404, D-1405 and inlet and compression drums of the compressors (C -1401A/B and C-1402A/B)
17	Vacuum production circuit on the UN-1400 (J-1401)

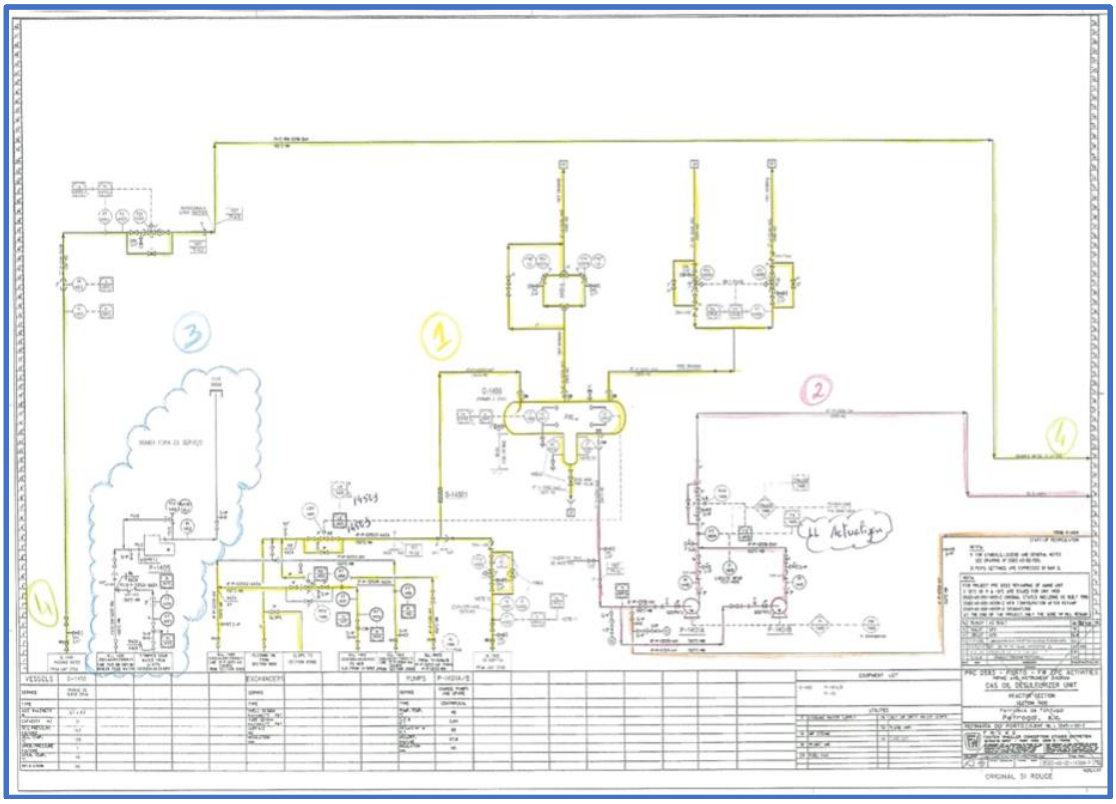

Figure 4.14 Nodes identified in 1927-PID-0021-002a.rev3 - Feed Section).

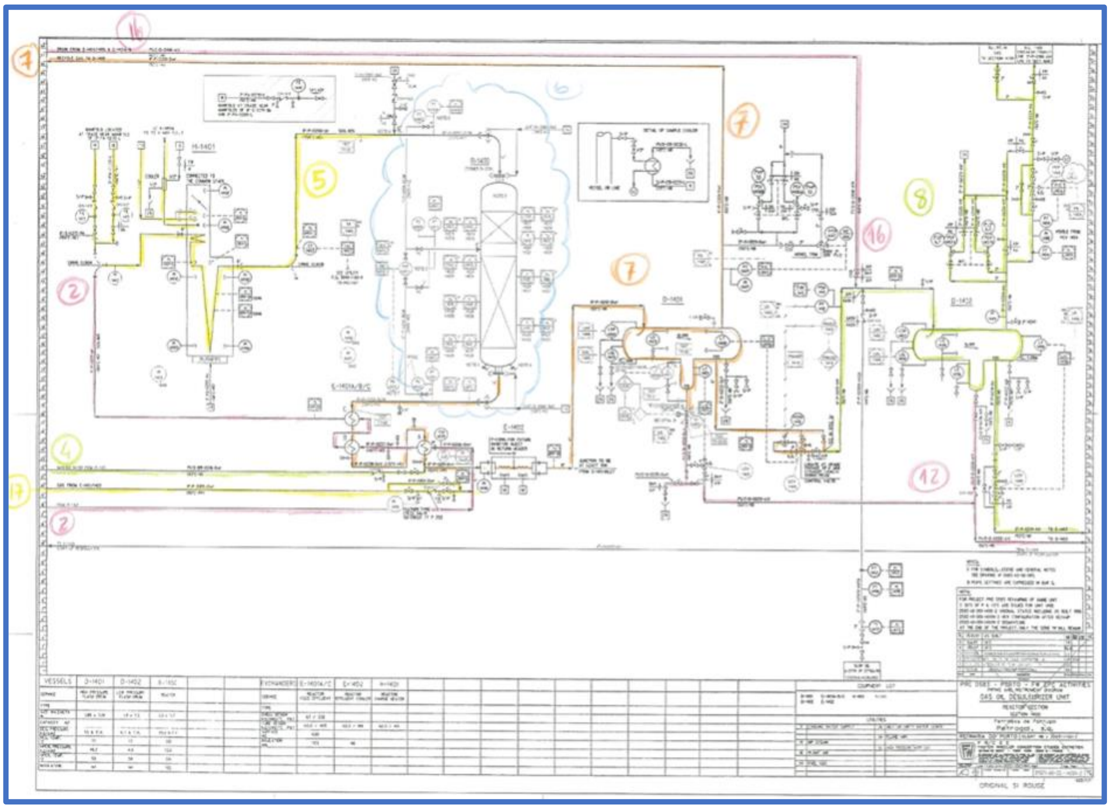

Figure 4.15 Nodes identified in 1297-0021b.rev3 - Reaction Section.

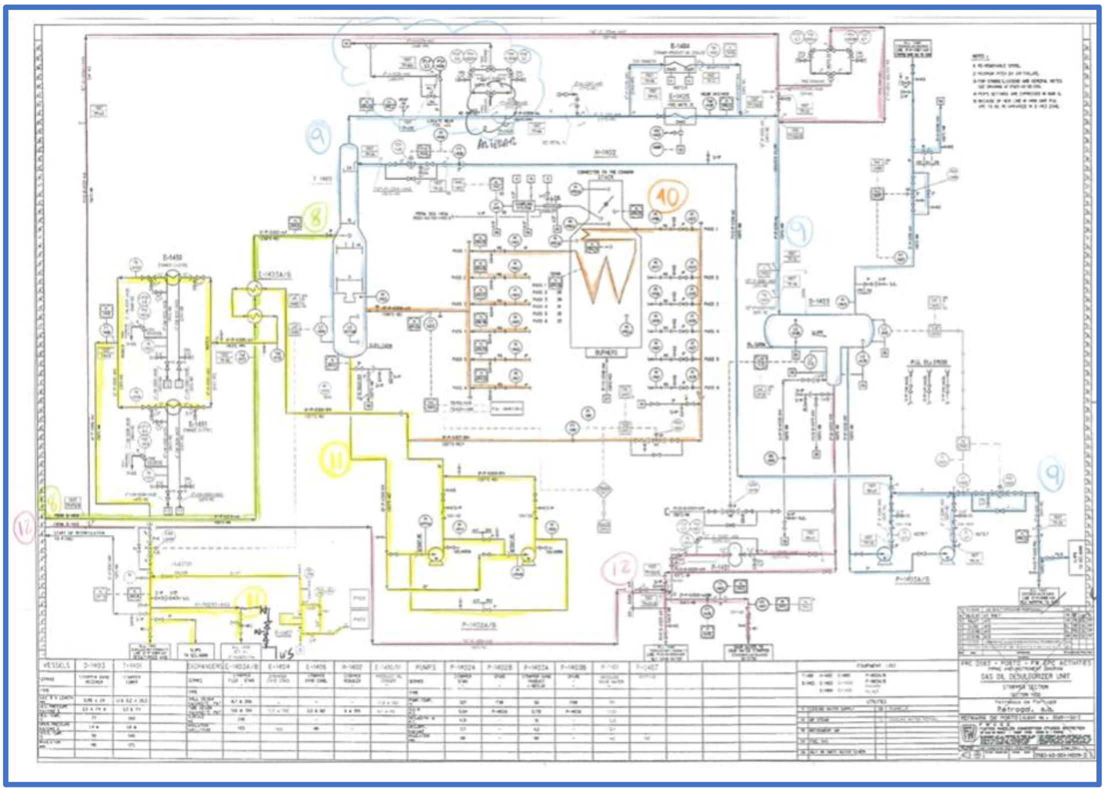

Figure 4.16 Nodes identified in 1927-PID-0021-003 - Stripper Section.

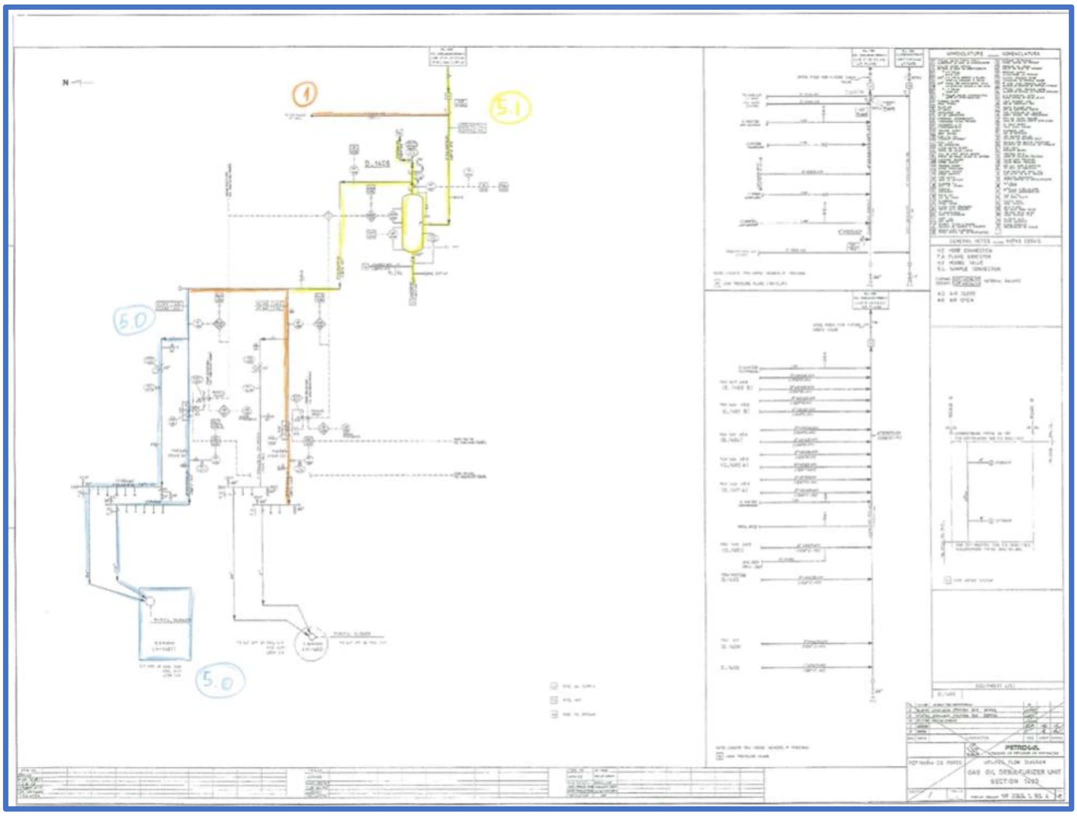

Figure 4.17 1927-PID-0021-004.rev 2-Utilities Flow Diagram (Fuel Gas Supply).

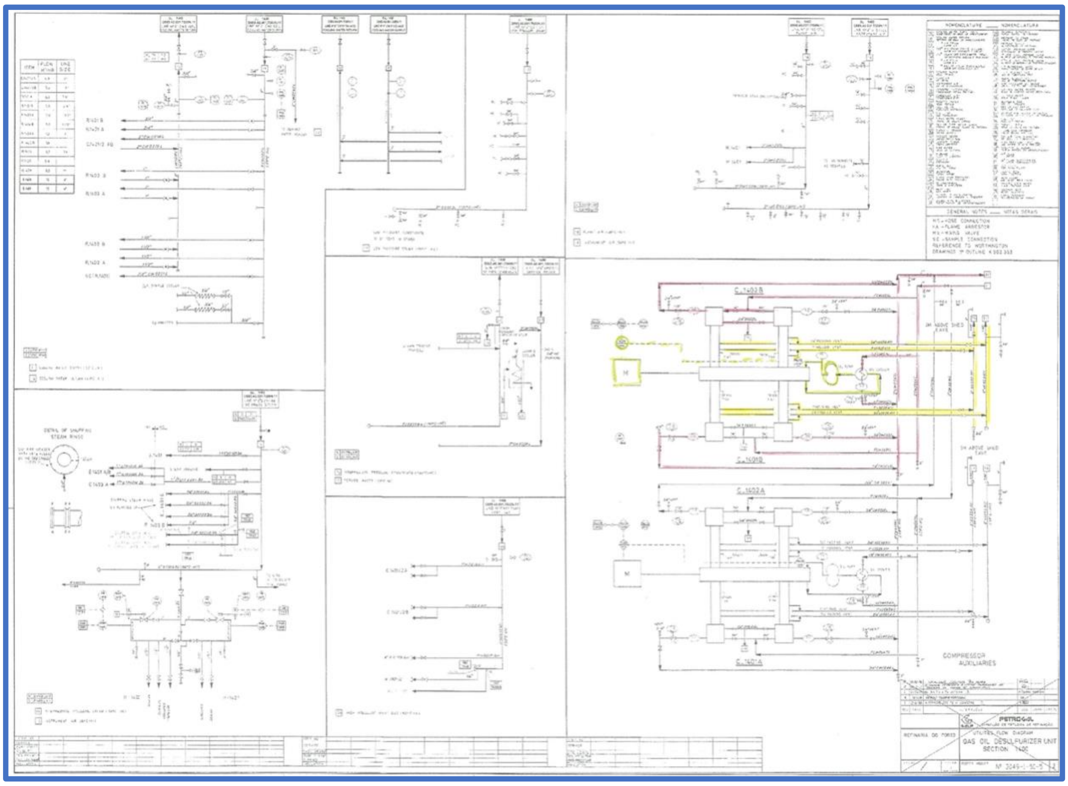

Figure 4.18 1927-PID-0021-005.rev 3-Utilities Flow Diagram (Compressor).

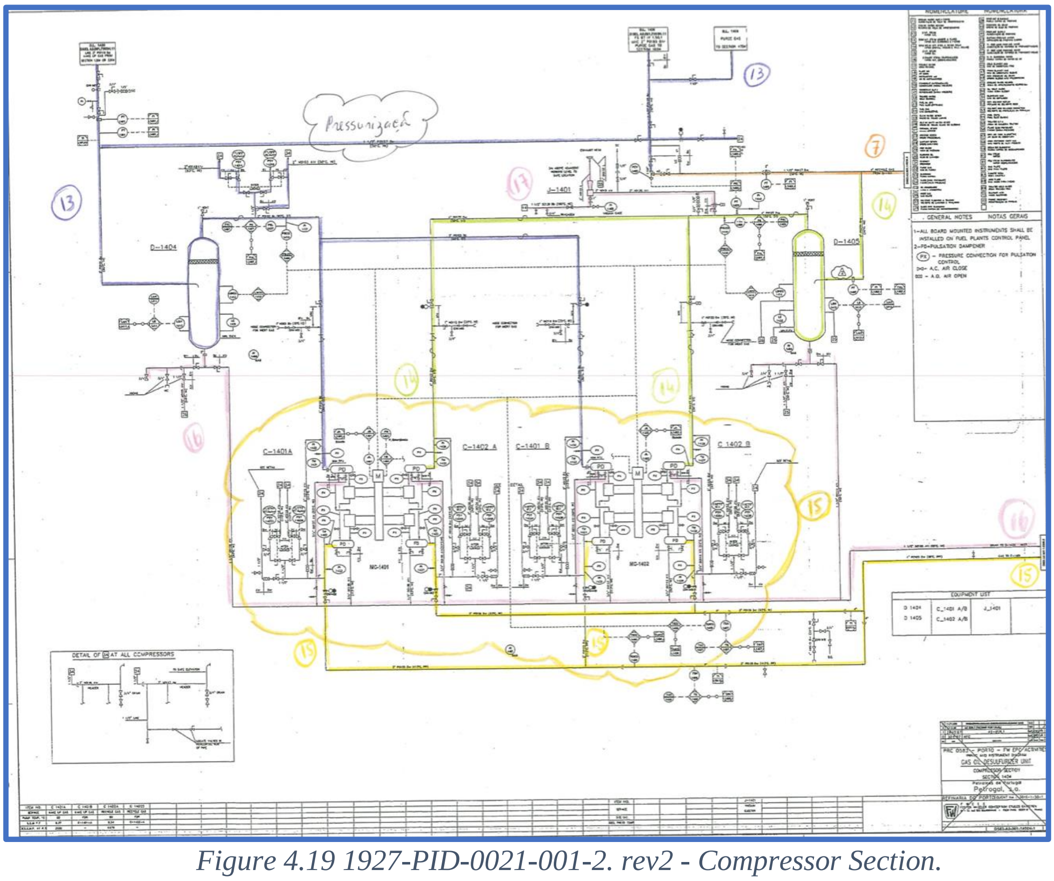

Figure 4.19 1927-PID-0021-001-2. rev2 - Compressor Section.

4.8.5 Meeting sessions

A multidisciplinary team made the study, composed only by Galp specialists, following the company's current regulations, namely "NT-P-028 - Gestão de Risco de Acidentes Graves" and " NT-P-011- Gestão de Modificações" [76].

In addition to the information collected in the previous HAZOP, the presence of those directly responsible for the unit's operation made it possible to obtain new data related to the process behaviour of the equipment involved. This allowed a more detailed global analysis of the installation, given the changes introduced in the unit's equipment and raw material.

The meetings took place without any objective of accelerating the discussions involving the cause-consequence analyses that led to the necessary recommendations. The scribe has recorded all relevant information in a dedicated HAZOP software. For example, in Annex C, the information collected around the Splitter T-1401 column can be observed during the analysis of the node 11.

There were some important differences between the current HAZOP study and the other made in the 2010 (during the revamping), which can be highlighted:

Only the nodes corresponding to the process changes introduced in the revamping project were considered in the first HAZOP study. On the contrary, in the present study, a complete analysis was performed, starting from scratch, keeping the nodes identified in the first study as unchanged.

During the HAZOP made during the revamping of the desulfurization unit, 3 P&ID's were analysed, with 7 nodes, corresponding to circuits with process changes, having identified 24 recommendations and spent 208 hours. In the HAZOP Revalidation carried out for the entire unit, 6 P&ID's were analysed, with 17 nodes, and 37 new recommendations were identified during 280 hours of study.

The total time spent was slightly higher than the initial expectations and it became clear to the entire team that since the scope of this HAZOP was substantially bigger than what was done in the revamping, there was still room to improve the overall time of the study with a different node approach identification.

The importance of constituting the team, concerning knowledge of the risk analysis methodology, the process in question and the unit's behaviour, was well demonstrated in terms of its impact on approaching the process and on the analysis of the time needed to study each node.

4.8.6 Recommendations

The high number of recommendations was representative of the fact that it was the first risk analysis carried out from scratch at the unit. The recorded recommendations, revised during the work sessions, are presented in Table 4.7.

Many of the recommendations resulted from the need to introduce alarms in the readings of the control variables due to the practical knowledge of the unit's operation.

Recommendations were also identified that resulted from comparing this older desulfurization unit with a similar one with a more modern design (HDS U-3700) with more effective safety safeguards.

No common recommendations were identified in the two risk analyses. This is an important point because it represents that the 24 recommendations found for the project were already implemented, as verified in the preparation phase of the meeting.

Table 4.7 Diesel Hydrotreatment Hazop Recommendations.

Node	Recommendation
1	Review configuration of alarms and Tag number configured in the DCS (LT14503, LIC1401, LT14505, LALL14505, LALL1401, LALL14503)
2	Review configuration of alarms and Tag number configured in the DCS (LT14503, LIC1401, LT14505, LAH14505, LAH1401, LAH14503)
3	Check for check valves upstream of the node
4	Evaluate the need to create a shutdown of the P1401A/B pumps by low level indication
5	See Flow More bypass action
6	Confirm the existence of a very low flow alarm FALL1409
7	Check the design pressure of the E-1401A/B/C exchangers against the pressure increase resulting from the revamping design (D-1450)
8	Assess the need for the low flow alarm FAL14503.

Node	Recommendation
9	Check the existence/assess the need for the FALCO 1421 cut.
10	Assess the need to place a safety associated with recycle gas failure. Evaluate the need to install flame detectors in pilots. Review the study/cause-effect diagram of the project to place fast-cut valves in furnaces (pilot safety philosophy)
11	Correct the P&ID regarding the furnace damper control. Add a high-pressure alarm to the PIC-1495. Add a furnace cut-out for high pressure in the combustion chamber, high pressure in the burners and high pressure in the pilots. Check H-1401 tubular design values.
12	Assess the need to place high temperature alarms/cuts in the combustion chamber (TI1401-4 and TI1401-5). Assess the need to place high temperature alarms on the furnace coils (TI1401-51 and TI1401-52 skin temperatures).
13	Implement a system of XV's (automatic double block and bleed - Galp standard) in the FG circuits for the pilots and burners.
14	Update P&ID (Missing PALL1415)
15	Assess the need to place a dead man valve on the accumulator purge.
16	Assess the need for tracing and insulation placement in FG circuits (see PE37/12 on technology)
17	Confirm reactor design pressure (P&ID vs Hazop report 5/14/2010)
18	Check the design pressures of the E-1401 A/B/C exchangers in case the E-1402 is completely clogged (due to the triggering pressure of the PSVs
19	Assess the need to place a high temperature alarm on the TI-1401-10 (E-1402)
20	Analyse the possibility of including a very low alarm from the D-1401 in the safety philosophy of the LCV-1402 (similar to the safety philosophy of the U-3700) and/or the possibility of including a quick shut-off valve
21	Analyse the need for the LAHH-1402 to be included as a cut-off signal to the compressor
22	See project for rapid depressurization of units
23	Evaluate the need to place the PAHCO-1412 on the safety PLC
24	Assess the need to install a high temperature alarm on the TI1401-20

Node	Recommendation
25	Check the existence/assess the need for the FALCO 1420 cut.
26	Correct the P&ID regarding the furnace damper control. Add a high-pressure alarm to the PIC-1496. Add a furnace cut-out for high pressure in the combustion chamber, high pressure in the burners and high pressure in the pilots. Confirm the existence of a low O2 alarm.
27	Assess the need to place high temperature alarms/cuts in the combustion chamber (TI1401-24 and TI1401-25). Assess the need to place high temperature alarms on the TIC1404. Assess the need to place high temperature alarms on the furnace coils (skin temperatures TI1401-28 to and TI1401-33).
28	Implement a system of XV's (automatic double block and bleed - Galp standard) in the FG circuits for the pilots and burners.
29	Update P&ID with the new XV-1401. Assess the need to set an additional alarm in case the LT-1409 fails
30	Include the PSV trigger pressure and the line tag number in the P&ID.
31	Configure high temperature alarm TAH-1401.19 (existing P&ID)
32	Assess the need to include an automated system in the recirculation line and storage outlet (similar to U-3700)
33	D-1401/2 Assess the need to place a dead man valve in the purge circuit for drain 26 with visible LG D-1403. Clarify accumulator boot level control philosophy and update P&ID (LCV-1418 and P- 1451)
34	Evaluate the need to place an interlocking system on the manual valve in the pressurization circuit.
35	Place level indication in the control room. Confirm the existence of a trace.
36	Place level indication in the control room. Confirm the existence of a trace.
37	Implement low-flow recycle gas compressor shutdown
38	Evaluate the need for continuous vibration measurement in compressors
39	Assess the possibility of flare purge and placement of dead man type valves.

Based on the recommendations identified, the respective Action and Response Sheets were prepared; see Tables 4.8 and 4.9 as examples, allowing collecting the information discussed during the HAZOP and assigning responsibility for implementing the corrective actions. These sheets are the way to follow the actions until they are closed. They are often used during incident and accident analysis to guarantee that actions to ensure the unit's safety have been implemented promptly.

Table 4.8 HAZOP study actions nº1 and response sheet.

HAZOP STUDY ACTION AND RESPONSE SHEET

ACTION ON: FCO - Renato Fernandes		RESPOND BY: A.S.A.P
ACTION NO: 1	MEETING DATES: 27/11/2013	
DRAWINGS AND DOCUMENTS: 1927-PID-0021-002a		
ITEM: (Hazop Node 1.0) Carga ao D-1450/ D-1450/ Entrada FG e Saída flare		
CAUSE: (Flow Less) Lado da nafta 1. Válvula manual inadvertidamente fechada 2. PCV-14502 falha fechada Outras: 3. Válvula manual inadvertidamente fechada 4. FCV- 1450 falha fechada 5. LIC-1401 falha na posição fechada 6. Obstrução do S-14501 7. Válvula slops inadvertidamente aberta		
CONSEQUENCE: 1.1, 2.1 Sem consequências no nó 1.2, 2.2 Subida de nível no acumulador de nafta VB 3.1, 4.1, 5.1, 6.1, 7.1 Nível baixo no acumulador D-1450		
SAFEGUARDS: 1.2.1, 2.2.1 Seguranças de nível no VB 3.1.1, 4.1.1, 6.1.1, 7.1.1 Alarme de nível baixo LAL1401 e LALL1401 (LT14503)		
ACTION: Rever a configuração dos alarmes e Tag number configurados no DCS (LT14503, LIC1401, LT14505, LALL14505, LALL1401, LALL14503) (ex: LALL14503 existente no DCS, em falta no P&ID)		
RESPONSE: DATED: SIGNED:		
ENTER YOUR RESPONSE IN THE BOX ABOVE, THEN SIGN AND RETURN TO: Equipa Hazop		
NOTES (for use of Hazop Secretary only)		

Table 4.9 HAZOP study actions nº2 and response sheet.

HAZOP STUDY ACTION AND RESPONSE SHEET

ACTION ON: FCO - Renato Fernandes		RESPOND BY: A.S.A.P
ACTION NO: 2	MEETING DATES: 27/11/2013	
DRAWINGS AND DOCUMENTS: 1927-PID-0021-002a		
ITEM: (Hazop Node 1.0) Carga ao D-1450/ D-1450/ Entrada FG e Saída flare		
CAUSE: (Flow More) Lado da nafta 1. PCV- 14502 falha aberta ou bypass aberto Outras alimentações 2. LIC-1401 falha na posição aberta e bypass aberto		
CONSEQUENCE: 1.1, 2.1. Subida de nível no D-1450 1.2 Subida de pressão no D-1450 (ver desvio pressure more)		
SAFEGUARDS: 1.1.1 Alarme de nível alto LAH1401 (LT14503)		
ACTION: Rever a configuração dos alarmes e Tag number configurados no DCS (LT14503, LIC1401, LT14505, LAH14505, LAH1401, LAH14503) (ex: LAH14503 existente no DCS, em falta no P&ID)		
RESPONSE: DATED: SIGNED:		
ENTER YOUR RESPONSE IN THE BOX ABOVE, THEN SIGN AND RETURN TO: Equipa Hazop		
NOTES (for use of Hazop Secretary only)		

4.8.1 Meeting Report

The conclusion report of the HAZOP meeting verified that actions were found with a significant impact on the unit's project, most of which are already in the implementation process. The most important actions concern:

(1) Add a high-pressure cut in the H-1401 furnace combustion chamber, high pressure in the burners and high pressure in the pilots (action 21) and H-1402 (action 27);

(2) Place high-temperature alarms/cuts in the combustion chamber and high skin temperatures in the H-1401 (Action 22) and H-1402 (Action 24) furnace coils;

(3) Implement a system of XV's (double block and bleed automatic – Galp standard) in the fuel gas circuits for the pilots and burners of the H-1401 (action 23) and H-1402 (action 25) furnaces;

(4) Examine the possibility of including a very low alarm on the LCV-1402 of the D-1401 accumulator (similar to the safety philosophy of the U-3700) and/or a shutoff valve;

(5) Analyse the need for the LAH-1402 to be included as a cut-off signal to the C-1402 A/B compressor and implement low-flow a recycle gas cut-off (Action 38).

The HAZOP Study Report is a fundamental part of the whole process. It must be a reliable record of the study with all statements issued. It must be easy to read and understand to provide a precise memory of the meeting for possible later consultation by any entity that deems it necessary to analyse.

The major responsibility rests with the HAZOP Team Leader or whoever has the responsibility to review the P&ID’s with the proposed changes. Suppose anything more than trivial changes is proposed. In that case, it is advisable to meet again with the HAZOP Study Team to verify that the proposed changes, as a result of individual investigations, do not jeopardize the safeguards that were assumed to be present when the rest of the study was done.

By Galp's rules and following its MOC procedure requirements, process studies were often carried out to consolidate the decisions agreed upon in the HAZOP meeting.

The updating of all documentation, confirmed by the close-out signatures of the respective responsible, was the final step from which new versions of P&ID’s, operation or maintenance manuals, cause-effect diagrams, etc., emerged.

The procedures developed for monitoring, closing the recommendations and updating the documentation of the Diesel Hydrotreatment unit can be analysed in Figure 4.20.

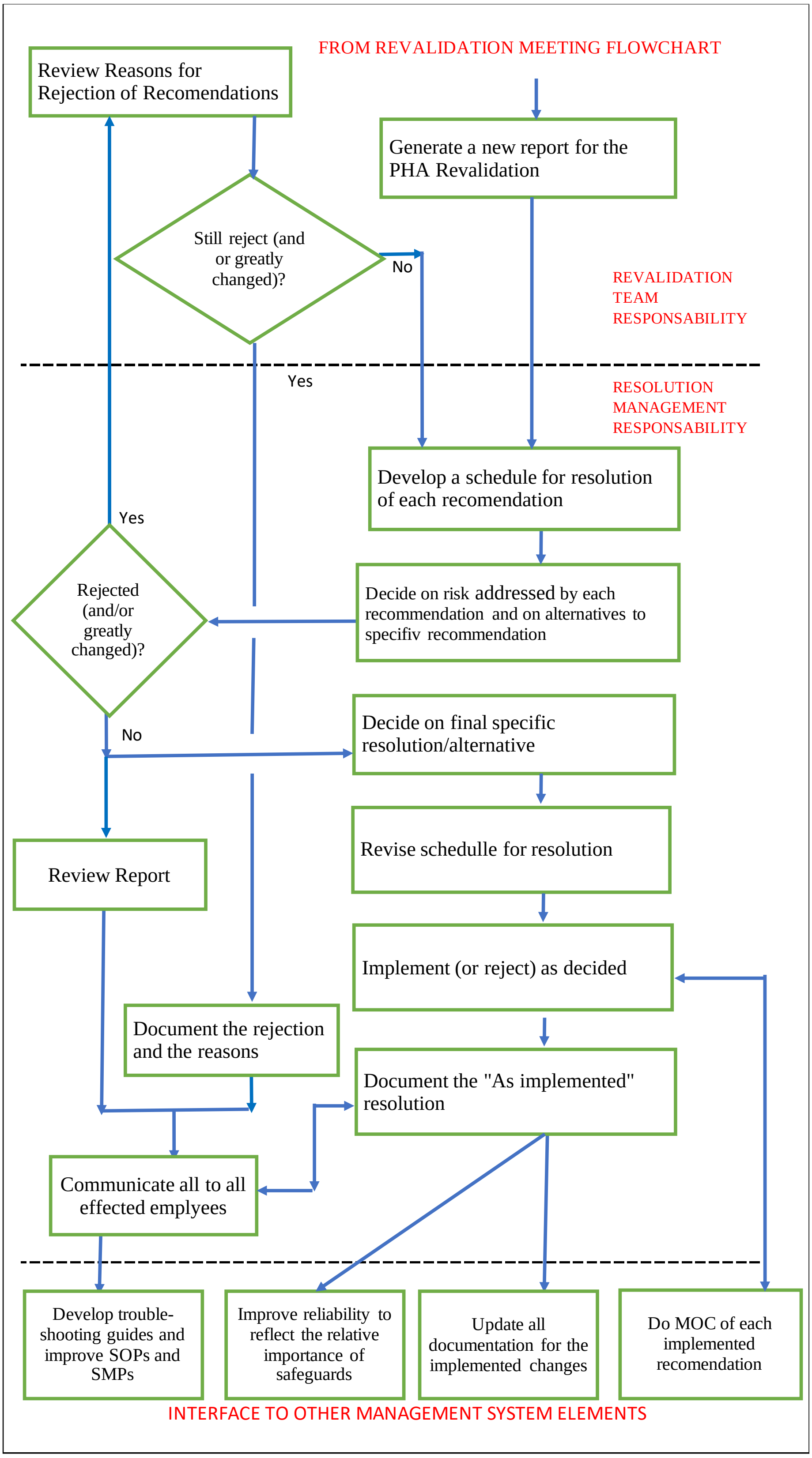

Figure 4.20 Pos Revalidation meeting step.

4.8.2 Using PHA Software

Software should be utilized to ensure that all past HAZOPs have been taken into account and a change management mechanism to ensure that all process modifications are appropriately assessed and that drawings and manuals are maintained up to date.

The main benefits of using PHA software are:

- To build on past studies to avoid wasting time and resources;
- To customize templates to the company's specific guidelines and organizational needs and assure consistency of the studies to the corporate standards;
- To provide data connecting features, decreasing the amount of time and effort required to complete a study;
- To filter reports according to stated parameters;
- To allow sharing of information in several formats for easy and controlled access.

According to the Revalidation team, one of the biggest problems with recording the PHA report occurs when the software used to document risk analysis is changed. Due to a lack of "backwards compatibility," preceding PHA worksheets were frequently retyped for the Revalidation effort. This can considerably impact the time it takes to prepare for or finish the Revalidation documentation.

5 A New Approach to HAZOP Revalidation Process

Chemical companies and design units use the HAZOP method worldwide to assess the risk of a process. However, many countries' Standard Specifications demand that the company must repeat the process hazard analysis (revalidating) several years later. Periodic Revalidation aims to discover cumulative risk changes over time. The main goal is to stay away from accidents. However, there is currently no systematic approach to lead HAZOP Revalidation, and it will be time-consuming to repeat HAZOP blindly (by doing a new HAZOP that is comparable to the original).

This chapter introduces the notion of HAZOP Revalidation, which follows the first HAZOP and examines unaddressed, remerging, or newly discovered concerns. It highlights many problems that must be addressed for Revalidation, including change management, accident analysis, and HAZOP report quality. At the same time, a new HAZOP Revalidation technique and approach are proposed and applied. The Revalidation strategy is determined using an expert panel assessment, and then a decision is made to redo or update the initial study.

At Galp, HAZOP Revalidation is carried out periodically, every five years, mainly to comply with legal requirements and internal regulations and review possible new hazards. It is a strategy aiming to continually improve its safety performance - see Figure 5.1.

Figure 5.1 PHA Revalidation Process.

In the new plants, after the design phase, HAZOP Revalidation is carried out, during construction, later in operation according to Galp's Change Management procedure, until closing in the decommissioning phase - see Figure 5.2.

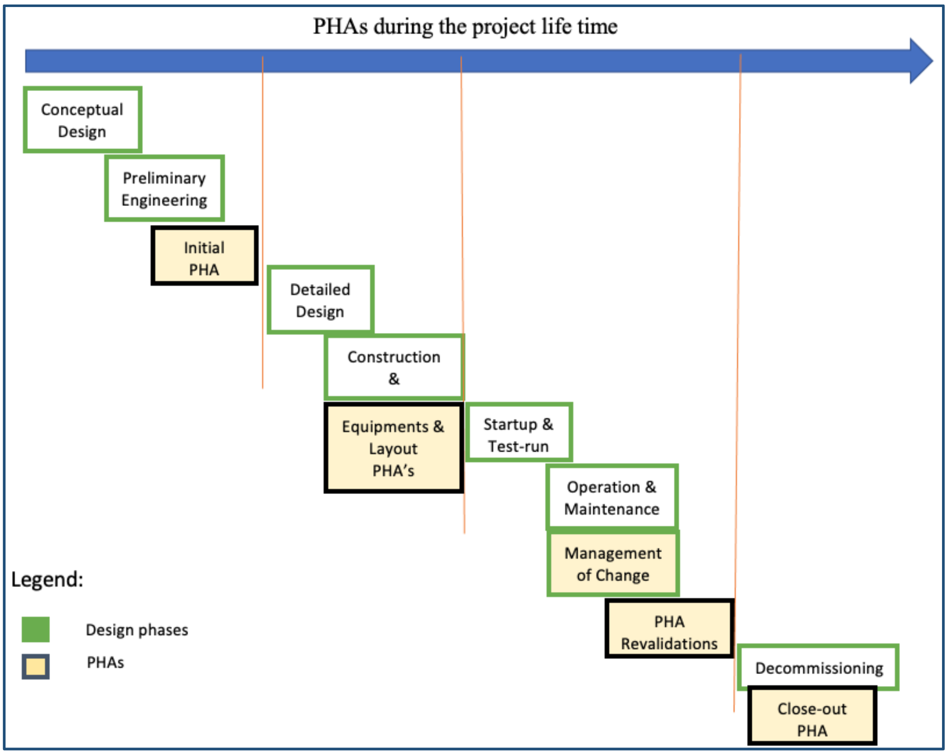

Figure 5.2 PHAs during the project life time.

5.1 The Main Reasons to Revalidate

The process's operating history can help identify scenarios not addressed in previous HAZOP or identify controls and safeguards.

The main reasons to revalidate are:

- **Process modifications**

Process modifications are changes in the operation, materials, methods, facilities, and equipment. The MOC procedure is used to assess the risks associated with changes and to document them to make it easier to update all safety issues needed to keep protections in place. Even with the MOC in place, changes must be evaluated individually and collectively to determine the quality of the hazard analysis undertaken while changing the process in question.

Some improvements in the process might be performed without using a MOC procedure. These unrecorded changes can invalidate the primary process design document and cause uncontrollable hazards and dangers. Since the previous PHA, the accumulation of process changes can bring hazards that were not discovered or believable during a single process modification evaluation.

- **Quality of previous HAZOP**

There are usually internal company rules and legal regulations that define HAZOP requirements. The methodology may have been incorrectly executed in the past or not give credit to relevant causes, consequences, and safeguards. This could have happened because they were performed by an inexperienced HAZOP team or with little knowledge about the process. They used the wrong methodology for a complex process, like "What-if" analysis.

- **Operational history**

Since the previous HAZOP, it is expected that new data and new information emerge through the experience of the operation and investigations/developments that have taken place, motivated by incidents/accidents/near misses/process improvement initiatives. Assumptions regarding causes, effects, and protections associated with process deviations may alter due to this information. The Revalidation method allows new findings to be applied to prior HAZOP results.

- **Recommendations from previous HAZOPs**

The recommendations from the previous HAZOPs should be discussed and studied by the Revalidation team. On the other hand, the Revalidation meeting should not be used to resolve these issues. The HAZOP Revalidation team members may not have the authority to decide on the suggestions made. The team can (and should) examine why a recommendation has not yet been adopted.

During the Revalidation process, the team can verify that the same recommendation(s) arise, reconfirming the need for that (these) recommendation(s). It should be noted that no recommendation identified in a previous HAZOP should have been left ignored or unaddressed.

The review of suggestions can also be used as an audit tool because the executed recommendations are checked. Because all recommendations are considered process adjustments, the MOC procedure should be used to identify potential dangers and update process information. If no MOC documentation exists, the implemented recommendations should be deemed uncontrolled alterations and thoroughly evaluated during HAZOP Revalidation.

Finally, an earlier recommendations implementation review is required to ensure that past HAZOP tables reflect the new and enhanced safeguards resulting from those recommendations. Earlier guidelines can also achieve the elimination of accident scenarios.

- **Internal Rules and Legal Requirements**

The need for Revalidation, the frequency of Revalidation, and the extent of Revalidation are all determined by legal requirements and internal company regulations. HAZOP Revalidations may be needed by changes in legal requirements and internal policies.

- **Decommissioning of process equipment**

Decommissioning process equipment (e.g., decontamination or disassembly) introduces new dangers that are unlikely to occur during ordinary process operations. Different procedures for leaking and cleaning the devices may also exist. By Revalidation protocols, the scale and complexity of the equipment to be decommissioned will need the use of a new HAZOP.

5.2 How to Revalidate

As stated before, HAZOP Revalidation is performed in the process industry as a matter of compliance to review facility hazards and improve process safety performance. The decision on how to take the most appropriate Revalidation approach depends on several factors:

- What was the quality and level of previous HAZOP recommendations?
- How extensive were the process changes or environmental impacts?
- How effective was the MOC procedure implemented?
- Current Process Safety Information (PSI) is up to date?
- Are there new company standards and/or protocols?
- Did the previous PHA apply the correct methodology?

The answers to these questions will dictate whether you need to **“Redo”, “Retrofit”** or **“Update”** the installation's HAZOP. Figure 5.3 (Adapted from [75)] demonstrates the decision process in choosing the approach to use:

"REDO" (start from scratch)

This approach should be a last resort. In practice, it corresponds to the completion of the initial PHA. It is required that the PHA methodology has been incorrectly applied and cannot be corrected. It can only be carried out with drawings, procedures, and operational conditions that reflect up-to-date information available at the beginning of the sessions. “Redo” a PHA can occur in the following situations:

- To meet the requirements of the Major Accident Risk Directive (Europe), or 29 CFR 1910.119 (e) [5] and 40 CFR 68.67 (USA) [77];
- When there is an update of the organization's safety standards or new applicable legal requirements;
- When a large number of improvements have been implemented;
- The new information is not reflected in the existing study or has not been controlled;
- When it is found that the PHA methodology has been applied incorrectly and its correction is impossible or takes longer than a new start. This can happen due to

an incorrectly composed team or the application of an overly simplistic approach to a very complex process.

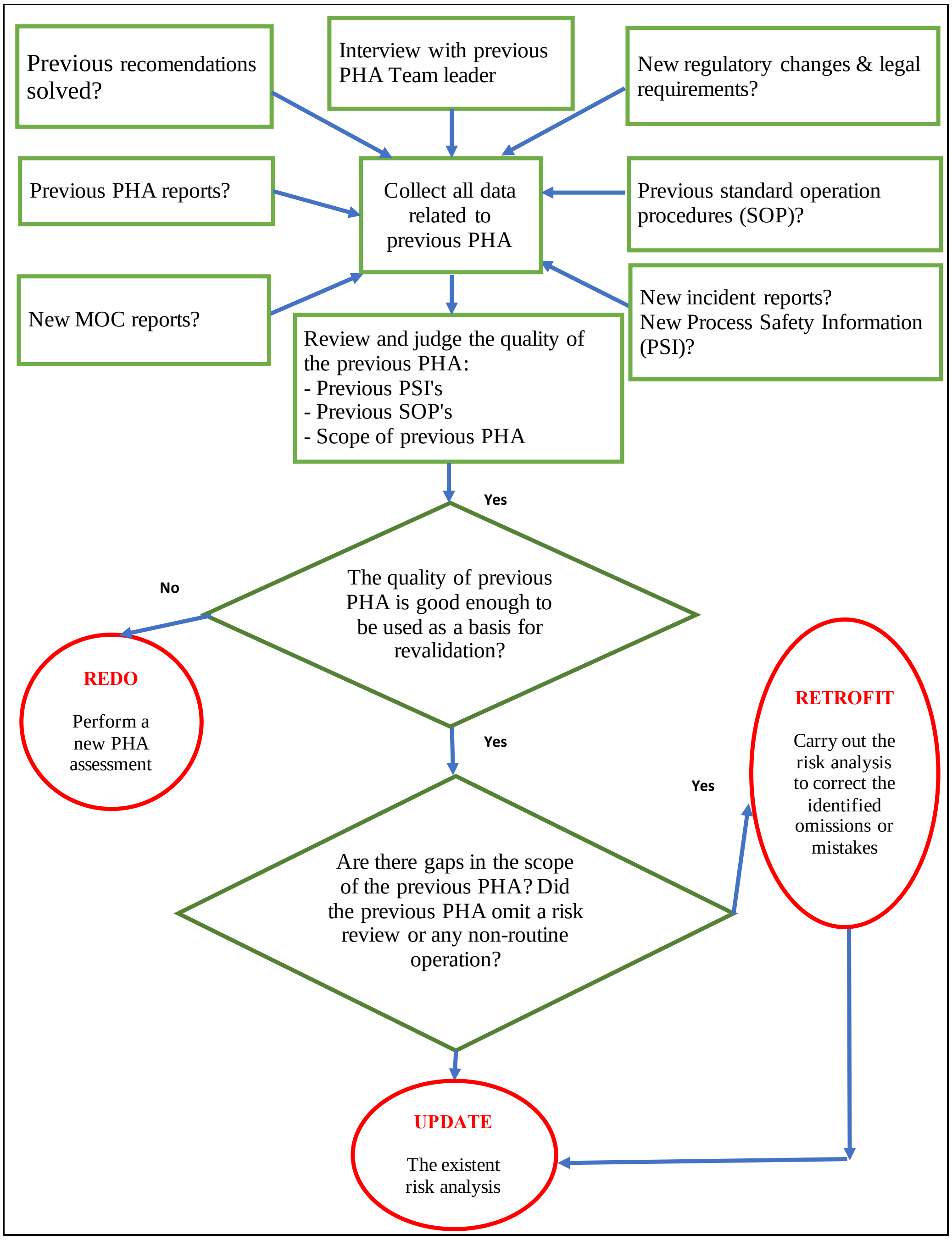

Figure 5.3 Diagrams of the decision-making process to a PHA Revalidation

To answer the question "Is the quality of the previous PHA good enough to serve as a basis for Revalidation?" a checklist such as Table 5.1 (adapted from [78]) can be used. The Revalidation Team Leader must evaluate the answers presented as "no" and propose the best approach to apply to the team. Confirmation of this decision is decisive.

Table 5.1 PHA is good enough to serve as a basis for Revalidation?

Criteria for Revalidation	Yes / No
About the Team: • Did the composition of the entire PHA team meet all the requirements? • Do members of operations have sufficient knowledge of the process and equipment? (Including recent hands-on experience?) • Are there engineers with experience and specific knowledge, design and operation of the process? • The replacement of team members, in their temporary impossibilities, is carried out by others with the same qualifications?	
About the methodology: • Is the methodology applied, included in the list below, the most adequate to the needs of the study? ✓ What-If ✓ Checklist ✓ What-If/Checklist ✓ HAZOP (Hazard and Operability Study) ✓ FMEA (Failure Mode and Effects Analysis) • Is the PHA methodology rigorous enough for the complexity of the process under review? Did this methodology correctly address all hazards/risks of the process?	
About the documentation: The information that resulted from the previous PHA is sufficient to: • Check the drawings and operational procedures qualities? • Check the qualifications of the team; • Verify the findings of the PHA team, including spreadsheets used, safeguards implemented, consequences in case of control failure and their causes; Do these findings make sense and are they complete, or do they appear to fail in several critical scenarios? • Verify that a qualitative assessment of possible risks to human health and safety has been conducted;	

RETROFIT

This approach is used when the PHA methodology was applied with gaps or faults, or some specific requirements were not addressed. In this case, the team must review each part of the previous PHA and correct any defects found.

To fix gaps or faults in a PHA, there are two basic approaches:

- A section-by-section review of past PHA documentation to improve the treatment of the specific issue(s) linked with the gaps or weaknesses; or
- Supplementary documentation, such as a standard checklist.

During the Retrofit review, the team should assess whether new safeguards or other steps are needed to control process hazards and provide suggestions accordingly.

For example, if human factors were not previously considered to be causes of danger, the PHA team should review all sections and apply that factor to causes of risk.

This method is also required if the previous PHA contains omissions. The omission can be corrected in this circumstance. Examples of omissions are not reviewing one or more modes of operation or not tracking a risk review for specific equipment.

Theoretically, such omissions could only exist in particular sections of the PHA report, and only those sections would require a Retrofit. The option to Retrofit or Redo the PHA would be influenced by how widespread the gaps or omissions were throughout the report. For example, assume that the HCl dangers in a process were not addressed in the previous PHA. If the HCl was only present in a few vessels, a Retrofit might be possible, but a Redo might be required if the HCl was present throughout the process.

Regardless of the method utilized to retrofit the PHA, the purpose is to offer the additional information that should have been included in the previous PHA report when it was issued (i.e., to fill the gaps, omissions or deficiencies).

Retrofitting could also include conducting a facility site study, which was not included in prior PHAs.

UPDATE

Updating the PHA to reflect any process changes or incidents after the last PHA. If the facility where the process is performed results from an effective MOC procedure, with a well-documented and complete PHA performed by the correct team, then Revalidation will be easier. If there are uncontrolled and poorly documented changes, or if the risk analysis is of poor quality, a more extensive examination of this deviations section of the PHA will be required.

Process changes are discussed by referring to the associated "node" or section and examining the impact on process deviation. The report must be updated afterward to reflect process changes.

For incidents, discuss whether the incident scenario was captured in the previous PHA. If this is the case, examine whether documented precautions failed or were adequate. When a new hazard is discovered during an incident, the team applies the PHA methodology to the incident scenario and updates the PHA in the appropriate section.

This assessment can provide additional information to plant managers, operators, engineering, and safety professionals to validate effectively due to process or equipment changes.

Each new Revalidation allows the reconsideration of previous decisions based on current information, namely:

- recommendations that were not solved;
- new regulatory requirements;
- new process safety information or operating procedures;
- from previous HAZOP recommendations;
- lessons learned from past incidents;
- new quality requirements or even the latest legal requirements.

Those responsible for the HAZOP study must guarantee that the operation incorporates the results and that all approved corrective actions are done as agreed after the research.

5.3 Node definition

Processes must be split down into sections for more detailed analyses. The division of a P&ID corresponds to one of the most fundamental pieces of the methodology of the HAZOP study and constitutes one of the critical points of this work. Different approaches and their implications for the time and cost of carrying out the study will be discussed.

Before the meetings, the team leader must establish the nodes, in sections, with the help of the project, process engineer, or even the person responsible for the plant. The node's size can be determined by several factors, depending on the experience, knowledge, understanding and complexity of the process manifested by the elements belonging to the HAZOP team, particularly its leader.

During the meeting, brainstorming carried out by the team, based on the information contained in the P&ID´s. All potentially dangerous scenarios are included and discussed, regardless of how the process is divided into nodes. It is a complex exercise in very elaborate industrial processes. Still, a leader with experience in the methodology and knowledge of the technology can quickly help find the best solutions.

Part of the subdivision into nodes, or manageable sections, is considered an art, depending on the leader's judgment and the team's acceptance. Each node definition and node intention need to be described by defining the following: Process Unit, Process Description, Design Conditions - Parameters (T, P, Flow, etc.), Pipe and Instrument Diagrams (P&ID's), Process Equipment items, Operation Status and maintenance or operator interventions.

Nodes can be graphically designated during the HAZOP run, marking P&ID’s, and highlighting which equipment and instrumentation are within the node boundary to investigate.

While the research nodes should be selected before the meetings, some changes will likely be made as the study progresses due to the learning process. In all cases, the team must remember that the causes remain within the node and search for the consequences elsewhere. This is important for documentation since deviations will be easy to spot when the process is changed, and the HAZOP needs to be updated or revalidated as a result.

One of the key decisions in the HAZOP study is breaking the P&ID into sections to ensure that the hazard identification has the appropriate level of detail in the intended hazard identification. For this purpose, the definition of nodes should essentially focus on identifying the section intention and, simultaneously, on the overall intention of the process.

As a result, all parts of the section must have the same design goals and all sections must be reasonably sized. If the chosen node has incompatible goals, the expert team will be confused, making it very difficult to detect challenging hazards. Suppose very small nodes are chosen, in addition to being a repetitive task. In that case, the general objective of the analysis will be more challenging to understand, and the study will take too long.

- **Separate the process into small nodes.**

It is a method to designate each main piece of equipment (heat exchangers, reactors, tanks, columns, and so on) as a node and then designate the connecting pipes and related instrumentation between each main piece of equipment as a node. If piping from one of the main pieces of equipment feeds other downstream equipment, each stream should be treated as a separate node. Figure 5.4 (adapted from [78]) shows how to use this strategy to node a P&ID. Each colour is associated with a node.

Pros: Smaller nodes may make the Team Leader feel more confident, ensuring that all causes of deviations are explored, and nothing is overlooked.

Cons: Continuous chemical processes in refining and petrochemical are complex and varied. They involve many equipments, instrumentation, utilities, etc., which are interconnected by specific process variables, making it not easy to identify, in many cases, the real design intentions. The team may not examine how variations affect upstream and/or downstream nodes. The number of nodes in a meeting reduces its efficiency and allows repeat process scenarios with different critical analyses.

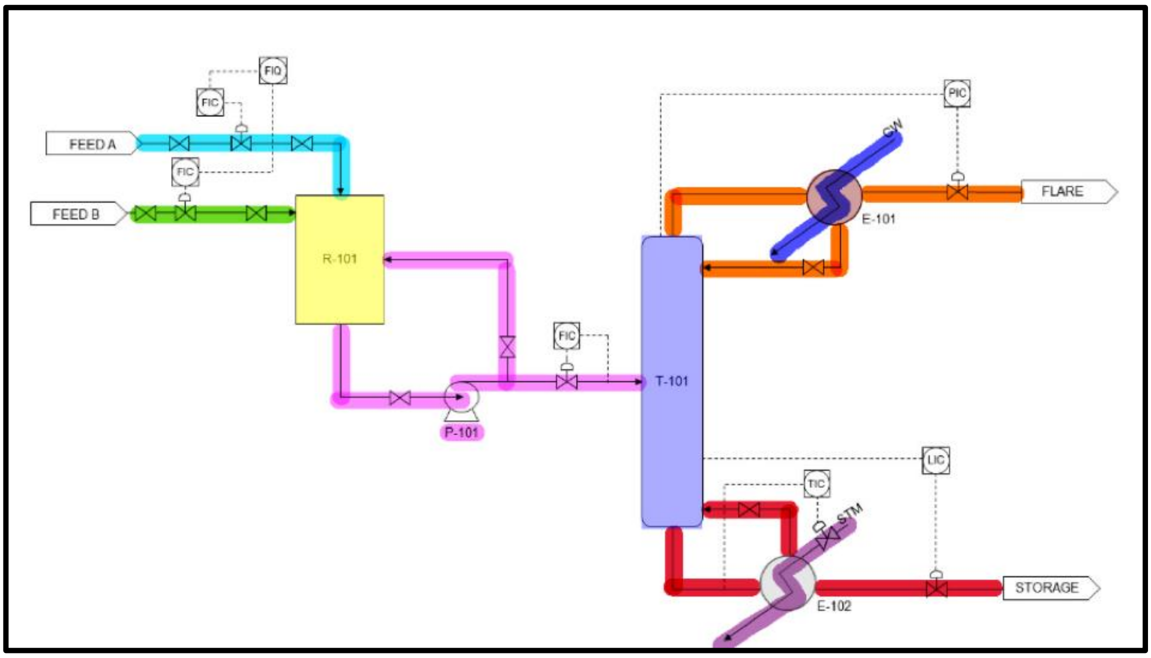

Figure 5.4 Separating s process using small nodes.

- **A large node with multiple unit operations**

In contrast to the previous strategy, another procedure focused on non-essential components of the process. This strategy enables examples such as a reactor and a distillation column in the same node for integrated analysis. It demands a detailed understanding of all variables and how they interact. Figure 5.5 (adapted from [78]) depicts an exceptionally huge node.

Pros: This method can accelerate the entire HAZOP process.

Cons: The team may fail to meet the node's goal, and deviations may not be investigated. This method gives you a bigger picture of a process, but it complicates the analysis and might overlook some possibilities. The team may have trouble identifying deviations if nodes with distinct purposes are integrated into a single node. Multiple cases of the same deviation are possible; for example, if different operating temperatures or process materials are used in other parts of the node, there will be numerous cases of the same deviation. For HAZOP teams, this is confusing, making it harder to find situations, increasing the likelihood of missed scenarios, and driving the team to become troubled in analysis.

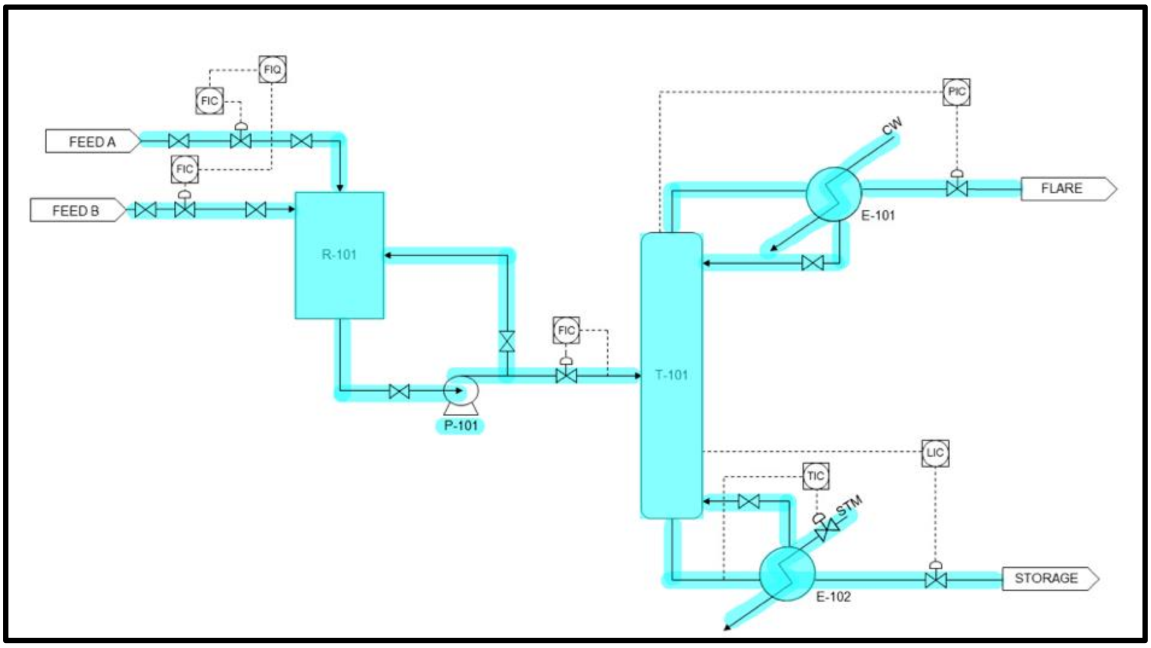

Figure 5.5 Node with multiple unit operations.

- **Nodes based on significant changes (“super-nodes”)**

Several node intentions are linked in the creation of the whole process. The initial step in the node selection process is to identify key parts (unit processes) that are simple to "disconnect" from one another (e.g., feeds section, reaction section, absorber section, distillation, etc.). Main sections are treated as many pieces of equipment involved in achieving a sub-goal: contributing to the process's overall design intention. For dividing the process into nodes, this is the first target size. This is the example when a column and its related equipment serve as one node, while a reactor and its related equipment serve as another node. This option shown in Figure 5.6 (adapted from [78]).

The goal is to see if the HAZOP team keeps the original safety and operability goals in this new strategic approach, namely, whether it can identify the causes and implications of deviations faster and more efficiently.

Studies get repetitive when several nodes have similar design intentions. As a result, lines or vessels with identical design purposes, such as parallel lines or multiple heat exchangers, can be represented by a single node to avoid repeating hazard scenarios.

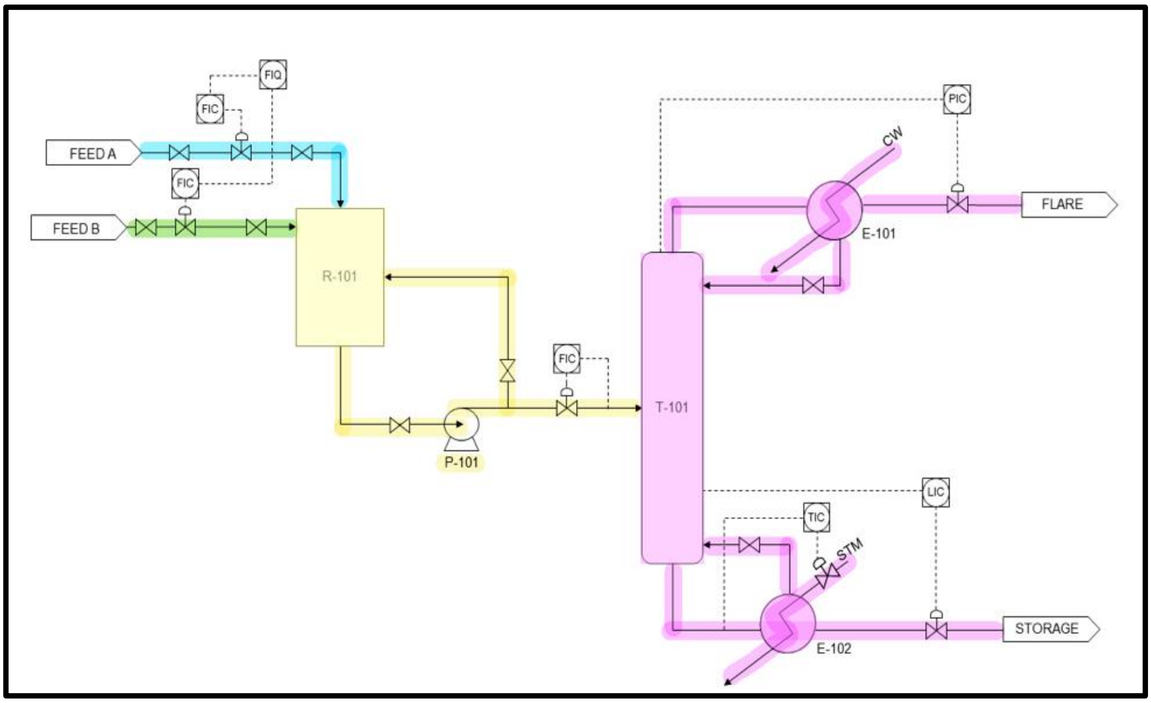

Figure 5.6 Nodes based on significant changes within the process.

Pros: This approach provides a broader view of a process. The purpose of nodding a process for HAZOP research is to select the best number of nodes so that scenarios can be detected as thoroughly as feasible, the study can be completed in a fair amount of time and the team's work is as straightforward as possible.

Cons: The analysis can be more complex, and scenarios may be missed if a team does the investigation without technical experience or knowledge of the process.

5.4 HAZOP Revalidation “super-nodes”

This approach is intended only to study risk analysis during the Revalidation processes. Its application in the design phase of the process units is not advisable, where the detailed engineering data of equipment, its relationship and behaviours are often unknown.

Furthermore, a study of the process supported by “super-nodes" requires a multidisciplinary team with deep knowledge of the system under investigation in all its aspects.

The following approach was considered to improve the HAZOP Revalidation process, supported by many previous studies, which will be discussed later in this work:

- The development of a structural hierarchy of a set of deviations ensures that the main hazardous scenarios are identified, and the order in which they are applied is defined, avoiding repetitive analyses and strengthening the HAZOP framework itself. These characteristics will help team leaders make decisions and promote standardization;
- “super-nodes” for guiding team leaders through process documentation – Process Description, PFDs, P&ID’s, and Plot Plan – detecting and defining specific project intentions;
- Rules for completing a HAZOP worksheet include defining what information should be entered in each column and how to report this information to ensure complete understanding for HAZOP members and external parties;
- Improvements to HAZOP time estimation models reduce the complexity of current models.

As a first step, process descriptions and PFD must be examined for defining and selecting all principal sections. Process descriptions describe equipment, control loops, chemicals, process conditions, utilities, and section boundaries. Team leaders will understand which different design intentions are contained within each section by carefully reading process descriptions. Preliminary "super-nodes" can be defined at this point.

On the other hand, PFD will graphically show how the sections are connected, which essential equipment is included, condition changes, and the limits, highlighting all circuits for the entire team to know. They are necessary for visualizing the complete fluid system's path through the process and crucial moments for beginning and ending nodes. As a result, team leaders will determine whether critical equipment, lines, pumps, and control valves are included in the same node.

As a second step, Team leaders should transfer all preliminary nodes from PFD to the P&ID, thoroughly detecting all existing equipment that results from the detail drawing, confirming that the "super-nodes" maintain the same reason to be studied.

The principal sections are to be identified in the P&ID, and smaller sections with the same design intention can be found more easily. In these drawings, additional equipment and process control will be involved in selecting detailed nodes, and the sizing may differ from preliminary nodes.

Additional equipment may become visible in some cases. The team leader must decide whether it should be included within the current node, incorporated into an adjacent node, or deemed a new node.

In the end, the application of the HAZOP methodology will be applied after:

- Selecting main sections according to the process description;
- Selecting preliminary "super-nodes" in the PFDs and
- Transferring and confirming these nodes from the PFDs to P&ID.

The result of this work, usually carried out by the Team Leader in the preparation phase of the sessions, must be later validated by the entire team, even before the beginning of the study.

5.5 Time consumption

The HAZOP process schedule and the sessions' planning are important factors in a company, considering both the resources that must be made available and the compliance with the regulatory deadlines usually required.

Comparing the initial PHA with the Revalidation(s) requires more work for the team leader (and secretary, if present) in the preparation steps. However, the steps of gathering and writing/preparing the documentation should be more expeditious when compared to the initial PHA. The better the quality of the initial PHA (and the quality information available for Revalidation), the less time needed for the assembly and documentation steps.

PHA Revalidation studies are expected to require less time than the initial PHA unless the Revalidation entails a “Redo” approach. That is the case where the number of changes is so high, or the quality of the initial information is so poor, that the best procedure is to carry out a completely new risk analysis.

For those situations where the Update option or the Retrofit option are feasible, the time required for the Revalidation sessions can range from 10% to 50% of the time needed for an initial PHA. Including the data gathering and preparation time, the total person-hours required for the Revalidation can range from 35% to 75% of the required initial PHA [75].

Figure 5.7 (adapted from [75]) is an example that compares the time requirements for initial PHA and PHA Revalidation.

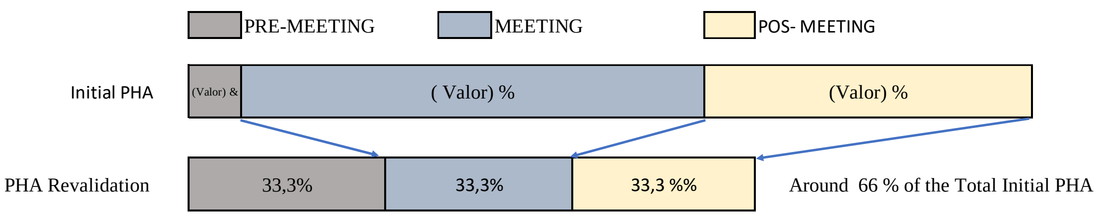

Figure 5.7 Time comparison between initial and Revalidation PHAs.

Another method for calculating meeting duration is considering the amount and complexity of modifications that will be examined during Revalidations. Consider the following four categories for estimating evaluation time: small (5 minutes or less), medium (15 minutes), large (30 to 60 minutes), and very large (greater than 60 minutes).

When classifying changes, it is good to go over any that take more than 60 minutes in greater detail to get a more accurate time estimate. These time estimates presume that the PHA Revalidation leader or other experienced staff have examined all process adjustments (and any associated documentation) before Revalidation meetings. This guarantees that employees with extensive knowledge of the modifications can explain the rationale for each change to the entire Revalidation team.

Table 5.2 (adapted from [79]) illustrates typical changes that fit under each category.

Table 5.2 Categories for estimating PHA Revalidation meeting time.

Category	Modification
Small (5 minutes or less)	• Replace a carbon steel coupling with a stainless steel coupling • Change the sampling frequency on a product tank from once per shift to once per day • Install an additional block valve on the drain line from a heat exchanger
Medium (15 minutes)	• Replace an existing gas-fired reboiler with a shell/tube heat exchanger • Install a new fixed firewater nozzle on the west side of the process • Replace a rupture disk with a relief valve on a vessel • Install a 2-inch temporary hydrogen line from the hydrogen header to a reactor
Large (30 to 60 minutes)	• Install a new storage tank in the tank farm • Tie-in an atmospheric vent line from a reactor to an existing line to a thermal oxidizer • Remove a nitrogen regulator from a unit's nitrogen supply header • Install a new bypass line around the dehydration and scrubbing system from a reactor
Very Large (> 60 minutes)	• Install an additional process train that includes a line with a pump and two columns • Add a new scrubber tower and associated caustic circulation system

5.6 Case Study #2: Diesel Unit Second HAZOP Revalidation

A second HAZOP Revalidation to the Diesel Hydrotreatment unit was carried out based on the “super-nodes” basis from September the 14th to the 15th, 2017.

With these nodes’ subdivisions, the study of a distillation column, a compressor, or a furnace can be analysed as a starting point, with the same causes and possibly the same consequences, allowing to verify if the safety safeguards are necessary or not. If not, and by comparison with safer schemes, the protections in the case under study can be more easily found - a procedure has produced positive effects on other HAZOP Revalidation processes.

The methodology followed during the HAZOP study consisted of dividing the unit into "super-nodes", where the possible deviations of the main variables (pressure, temperature, flow, etc.) was analysed. It is the objective to use all the inter-related information, variables of the process, and connected instrumentation as "joint data" for the analysis of the study.

This way, the guidewords can be applied to each process variable of interest to identify the cause and the consequences of the deviation on the system and verify the sufficient means of detecting and correcting the deviation. For each deviation, the following information has been analysed jointly:

- The list of the possible causes that lead to them;
- The list of the feasible consequences, which can be found about each existing cause;
- The response of the system in front of the studied deviation: system elements permitting the detection of the phenomenon or resisting its effects; instrumentation, detectors, alarms, etc.;
- Actions/recommendations that could be taken to avoid the causes or to limit their consequences;
- Comments: Any annotation that can help complete or clarify the points shown previously.

5.6.1 Nodes Identification

The HAZOP study was a systematic review of the process, and engineering design carried out by a team of specialists from Galp and an external company that provided the Team Leader and the scriber. The Diesel Hydrotreatment unit was divided into the follow's "super-nodes":

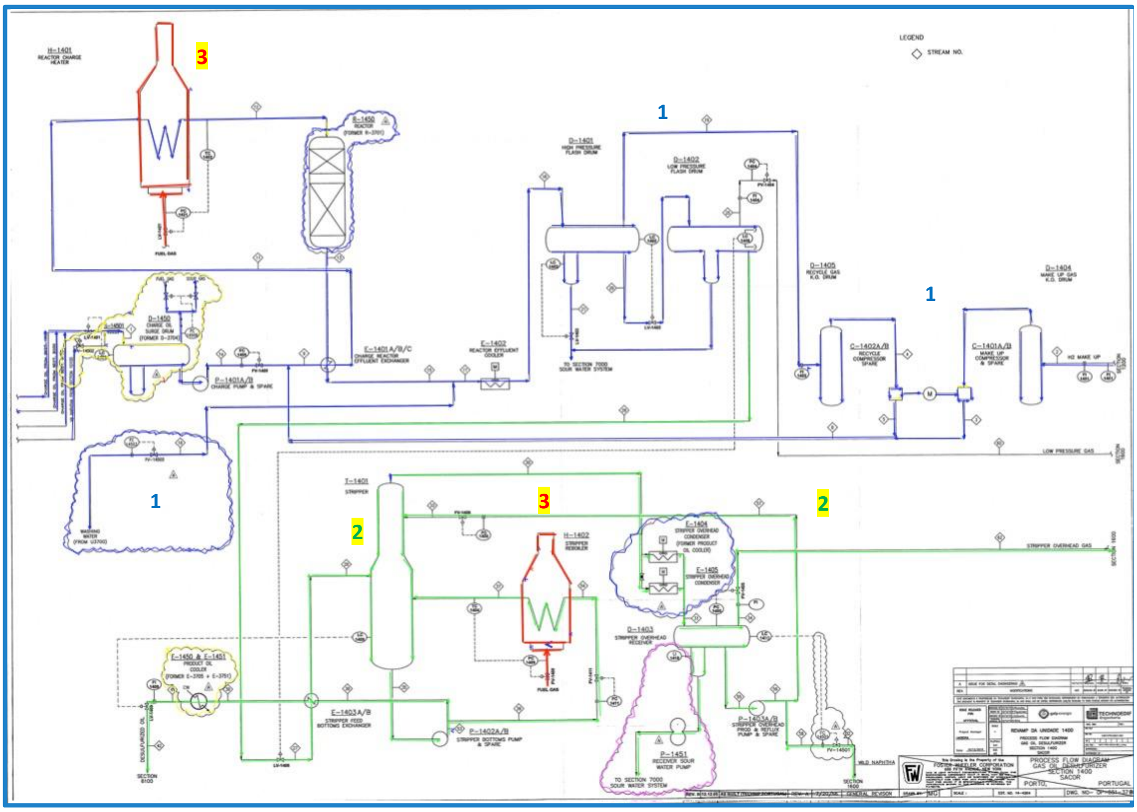

Figure 5.8 "Super-nodes" identified in 1927-PFD-0010-001_A - Feed Section).

Table 5.3 Diesel Hydrotreatment unit node identification.

Diesel Dessulfurization Unit		
Node	**Description**	**P&ID**
1	Feed, Compressor and Reactor Section: D-1450, H-1401, R-1450, D-1401, D-1402 and their equipment associated,	1927-PID-0021-002a - Rer. 3 1927-PID-0021-002b - Rer. 3 1927-PID-0021-001_2 - Rer. 3 1927-PID-0021-005 - Rer. 3
2	Stripper Section: T-1401, H-1402, D-1403 and their equipment associated	D583-A0-001-1400N-3 Rer.11
3	Fuel Gas Section Furnaces H-1401 and H-1402	3049-1-50-4_Rev. R

As a “super-node” example, the distillation column was considered a single node, number two, contrary to the previous test, which was deemed to be successive nodes for the column and each flow (feed, top circuit, and bottom circuits).

This approach was carried out to analyse causes, consequences, and recommendations to be "exported" to other similar risk analyses regarding equipment and process conditions.

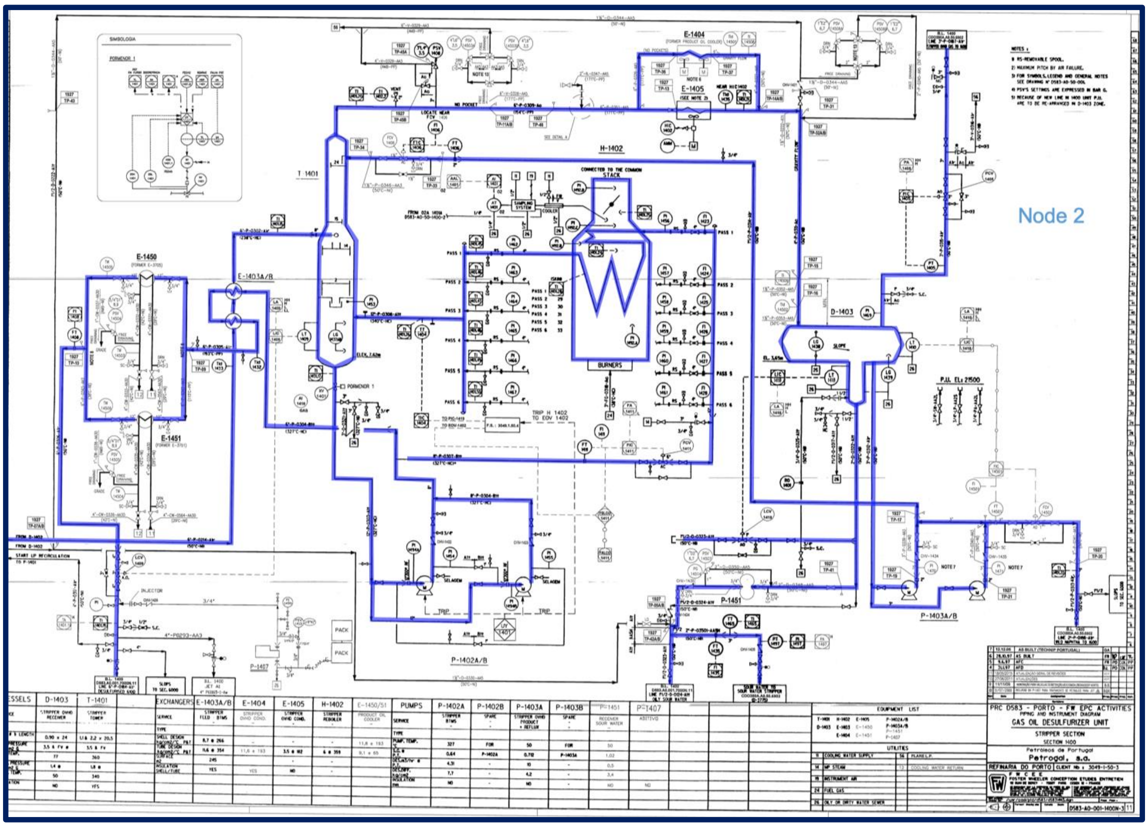

Figure 5.9 Stripper Section (node 2).

5.6.1 Meeting Sessions

In each session, the study team recorded the scenarios in spreadsheets using proprietary software, which assisted in conducting and reporting the meeting's discussions and identifying actions, recommendations and responsibilities. All this information was saved for future Revalidation studies.

The execution time of the HAZOP, in which four people participated, was 64 hours (two sessions of four hours), corresponding to about 23% of the time required to carry out the first HAZOP Revalidation, according to the conventional approach of nodes (280 hours). The HAZOP findings have been recorded on HAZOP worksheets – see Annex D.

5.6.2 Recommendations

The actions whose implementation was suggested are listed as "Recommendations" in Table 5.4. None of the recommendations was repeated since the first Revalidation study. This means that with this new "super-node" approach, it was possible to find new situations that required the implementation of new safeguards. Risk analysis is a never-ending exercise where expert knowledge should help identify unknown risks and new safeguards.

Table 5.4 Diesel Hydrotreatment Unit Second HAZOP Recommendations

REF#	Recommendations
R.2.1	Confirm that seal implemented in P-1402A/B is according to API standards.
R.2.2	Implement FAL in FT-1406.
R.2.3	Update control loop LIC-1418 / P-1451 configuration in P&ID D583-A0-001-1400N-3 Rev.11.
R.2.4	Implement independent FT in FI-1411 to implement the interlock FALCO-1411 in case of control loop FIC-1411 failure.
R.2.5	Implement redundant LT in T-1401 and configure LAH/LAHH.
R.2.6	Implement TAL in TI-1401-20.
R.2.7	Confirm double seal in pump P-1403A/B.
R.2.8	Implement LSL in D-1403 to trip pump P-1403A/B in case of low level.
R.2.9	Implement redundant LT in T-1401, configure LAL/LALL and implement the P-1402A/B trip in case of low level in T-1401.
R.2.10	Implement TAH in TI-14509.
R.2.11	Implement TAH in TI-1401-26.

5.7 Case Study #3: Gas Treatment HAZOP Revalidation

The methodology followed during the LPG treatment unit Revalidation HAZOP study consisted of dividing the unit into two subsystems or “super-nodes”. It analysed the possible deviations of the main variables (pressure, temperature, flow, etc.).

The team consensus was that using an approach with larger nodes would better understand the technical changes that occurred in each node in terms of its process conditions and associated equipment.

It was also clear that, with the help of appropriate software, the time required could be substantially reduced, allowing even periods to dispense with some specialists due to the similarity of some situations that could occur in the development of the study.

This approach, based on knowledge gained from different risk analyses, would allow a multidisciplinary team of experts to recognize and explore several important features of HAZOP analysis:

- Each study is unique and has characteristics that must be identified as soon as possible;
- In many aspects of the analysis process and the cause-effect diagrams are similar, although they are framed in different processes;
- The final global safety assessment must be verified, for each node, even if there is a lot of similarity between them.

5.7.1 Process Description

Hydrogen sulphide is removed from the gas streams destined for fuel gas in the LPG Treatment unit. The unit separates the incondensable gases in the LPG streams from different refinery units. The products resulting from these operations are the following: hydrogen sulphide gas sent to the Sulphur Recovery Unit, petroleum non-condensable (fuel gas) and LPG, which, after being subjected to the Merox treatment, are separated into commercial propane and butane. The process circuit of the LPG Treatment Unit is presented in Figure 5.9: PFD’s A560-P3601-1 Rev. 4.

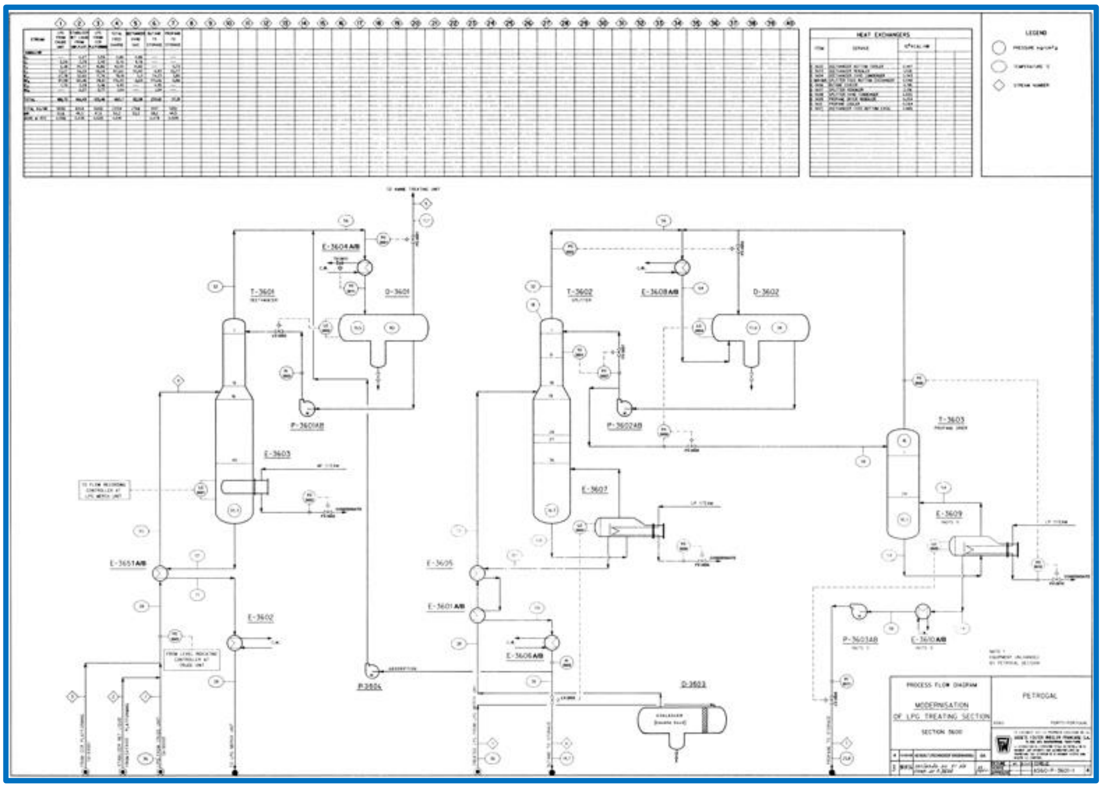

Figure 5.10 LPG treatment PFD.

5.7.1 Nodes Identification

The Unit consists of the following main sections, which can be considered simultaneously as the three "super-nodes":

Table 5.5 LPG Treatment "super-nodes".

GAS RECOVERY UNIT		
Node	**Description**	**P&ID**
1	DEETHANIZER T-3601 SYSTEM	B962-A0-50-36-10 Rev.6 5758-J-34A-00-301 Rev.7
2	SPLITTER T-3602 SYSTEM	B962-A0-50-36-10 Rev.6 B962-A0-50-36-11 Rev.5 5758-J-34A-00-301 Rev.7
3	CHLORINE SYSTEM	1667-PID-0021-01 Rev.6

As shown in Figure 5.10, "super-node" 1 represents the deethanizer column, all input streams, the top and bottom circuits, and all the equipment involved.

It is a distillation column similar to many others in operation and equipment. It can be considered and analysed in terms of hazard and operability in a single node. This approximation is relevant because it can also be analysed using existing models with available simulation software.

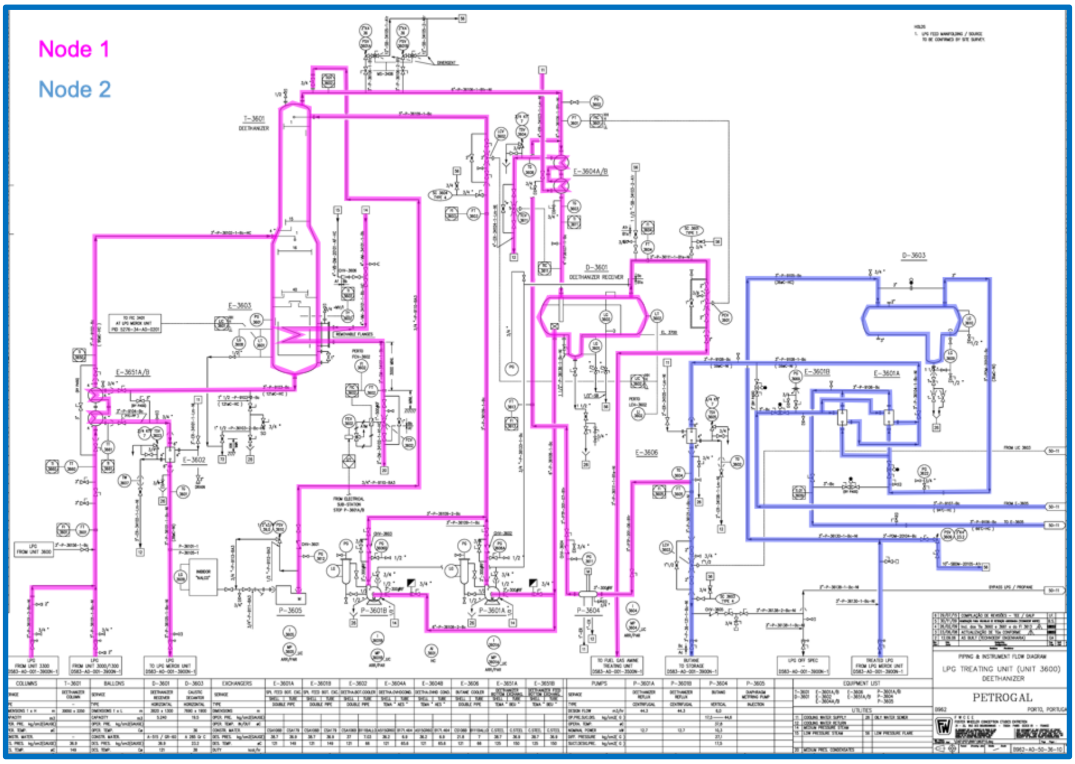

Figure 5.11 LPG treatment node definition (Deethanizer P&ID)).

A similar approach can be made for the “super-node” 2, see Figure 5.11, a similar distillation column, and the Chlorine section, “super-node 3”, since it can be used in other processes units.

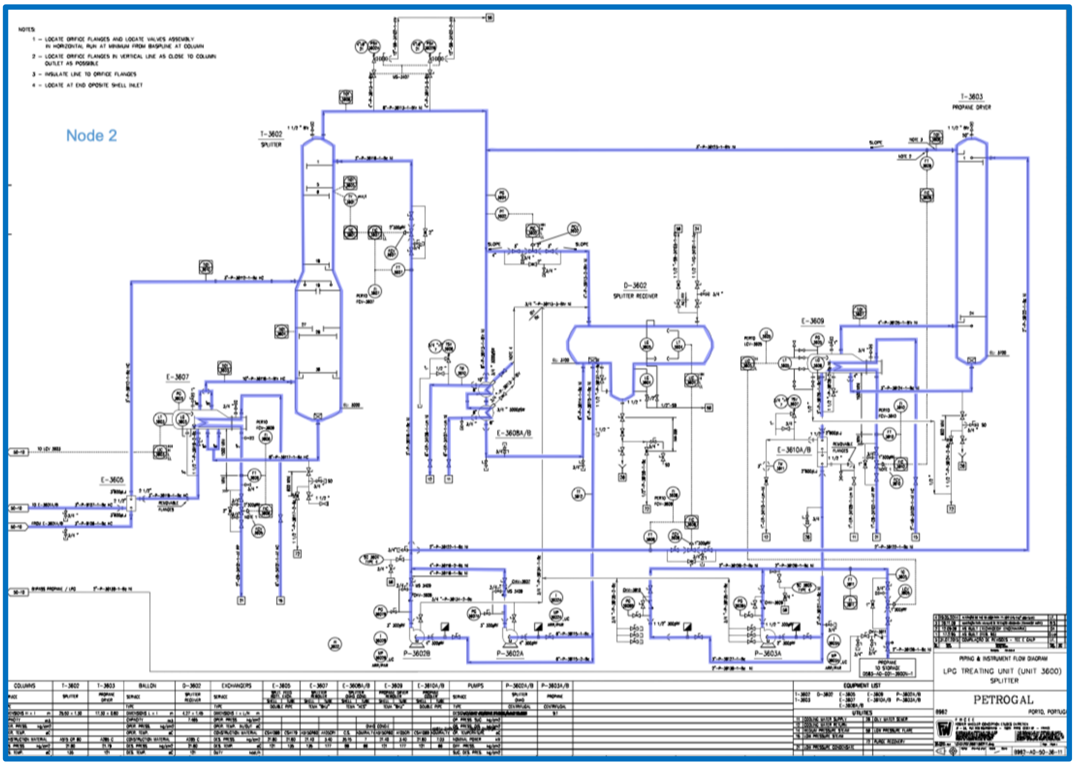

Figure 5.12 LPG treatment plant (C3/C4 Splitter P&ID)

5.7.2 Meeting sessions

This HAZOP Study was carried out at the Matosinhos Refinery offices in Matosinhos from the 26th to the 27th of September 2017 for 40 hours. The study was facilitated by an external company, through the presence of the Team Leader and the Subscriber, with the presence of 3 Galp specialists.

The worksheets that report the meeting sessions can be analysed in Annex E and justify that there is always room to increase the intrinsic safety of a plant.

It was clear that using the distillation column "super-node" during the Revalidation process can be applied with gains in speed and costs through a comparative analysis with another similar model, safeguarding the similarities and differences. Similar examples can be obtained for equipment packages supplied by companies within the scope of engineering projects.

5.7.3 Recommendations

From the study, 18 recommendations were identified:

(1) DEETHANIZER T-3601 SYSTEM
(B962-A0-50-36-10 Rev.6 and 5758-J-34A-00-301 Rev.7)

Table 5.6 Deethanizer T-3601 recommendations.

REF#	Recommendations
R.1.1	Implement FAL in FT-3601.
R.1.2	Evaluate trip P-3601A/B in case of low low level in D-3601.
R.1.3	Evaluate to implement redundant LT in T-3601 and keep alarm configured.
R.1.4	Implement FAL in FT-3621.
R.1.5	Implement redundant LT in LT-3602 and keep the alarm configured.
R.1.6	Implement double check valve in P-3605 discharge.
R.1.7	Study if PSV-3608 is designed for the case of E-3603 rupture and LPG depressurized from D-3653. If not, implement a PSV to the scenario and guarantee the safe location of downstream lines in case of LPG release.

REF#	Recommendations
R.1.8	Implement PAH in PT-3603.
R.1.9	Implement redundant PT on top of T-3601 and keep alarm of PT-3601.
R.1.10	Implement FAH in FT-3604.
R.1.11	Implement TT in the inlet line of T-3401 and configure TAH/TAHH.

(2) SPLITTER T-3602 SYSTEM
(B962-A0-50-36-10 Rev.6, B962-A0-50-36-11 Rev.5 and 5758-J-34A-00-301 Rev.7)

Table 5.7 Splitter T-3602 recommendations

REF#	Recommendations
R.2.1	Evaluate trip P-3602A/B in case of low low level in D-3602.
R.2.2	Evaluate to implement redundant LT in E-3607 and keep the alarm configured.
R.2.3	Implement redundant LT in D-3602 and keep the alarm configured.
R.2.4	Implement redundant PT in D-3602 and configure the alarm of PT-3602.

5.8 Case Study #4: Claus Unit HAZOP Design vs Revalidation

Common objectives were established for the Design and first Revalidation Claus Unit HAZOP's. The reviews should ensure compliance with good engineering practices, meet regulatory requirements, meet internal safety audit recommendations, and determine safety management recommendations.

A complete list of hazardous events that could compromise the safety of the process and potentially affect the safety of the facility and its personnel (including third parties and the surrounding environment) has been made. The specific types of hazards that have been considered can be grouped into:

- Personnel safety;
- Public safety;

- Release of Flammable or Toxic Fluids or Gases to the atmosphere, which can affect both personnel health and/or environment;
- Damage to facilities and facilities in the local vicinity of the Construction Site;
- Loss of production, including utilities;
- Eliminate operability problems.

5.8.1 Process Description

The Sulphur Recovery Unit (U10800) aims to process the acid gas from the amine regeneration column and the off-gas from the sour water stripper units into elemental, degassed sulphur and to produce a waste gas effluent to the atmosphere with very low H2S content. The following block flow diagram, Figure 5.12, shows the main process flows integration of the unit.

The Sulphur Recovery Unit (SRU) process design is based on the Claus and RAR (Reduction, Absorption, Recycle) technology to recover elementary sulphur from H_2S contained in the feedstocks - the acid gases produced in the Amine Regeneration and the Sour Water Stripper Units.

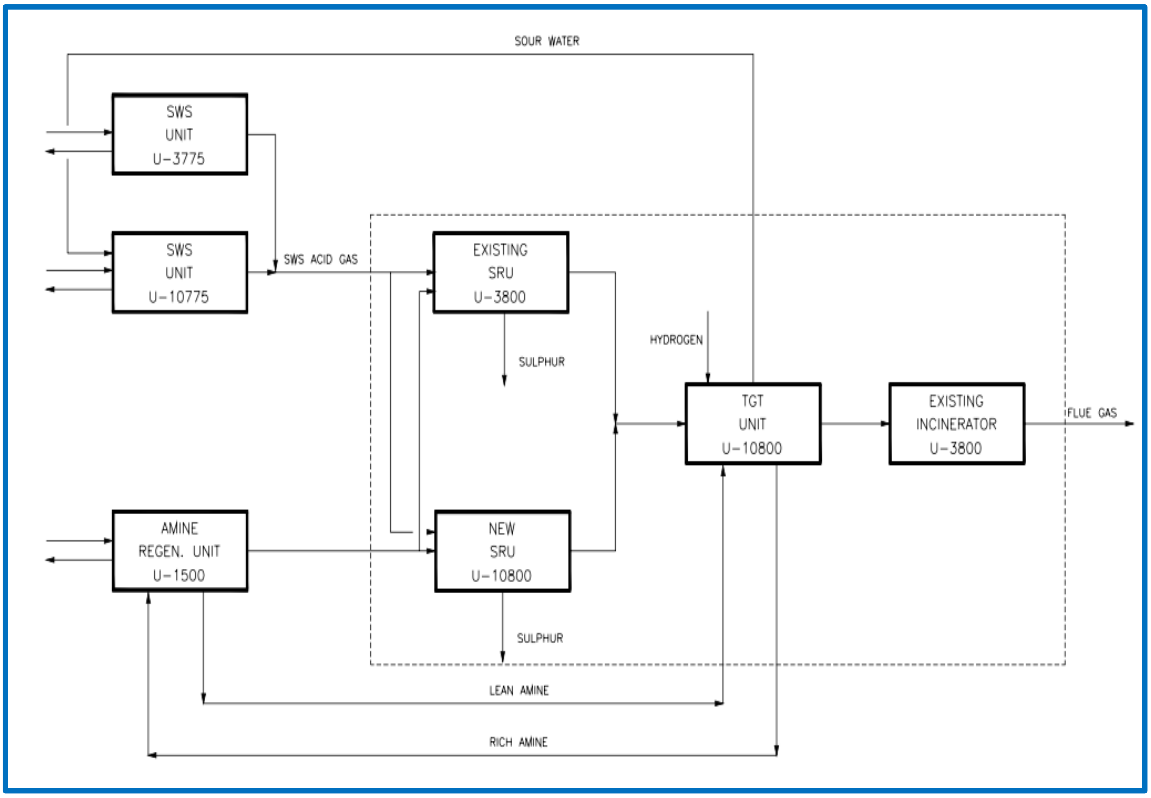

Figure 5.13 Claus Unit Block Flow Diagram Integration.

The Claus section consists of a thermal stage, in which H2S is partially burnt with air, followed by two conventional Catalytic Reactors. The tail gas coming from the Claus section is sent to the RAR section, where it is catalytically reduced with hydrogen to convert into H2S all the sulphur compounds contained (Tail Gas Treatment, called TGT Section).

Then the gas is cooled in a Quench Tower to about 38 °C and sent to an Amine Absorber to remove the most H_2S contained. The H_2S absorption is accomplished using a Lean MDEA solution at 40%wt concentration from the battery limit (Amine Regeneration Unit).

The unit is concluded with an Incineration section to convert the residual sulphur compounds into SO_2. The flue gas produced in the Incineration section is discharged into the atmosphere via a common stack.

5.8.2 Design and Revalidation Nodes Identification

The methodology followed during the design phase of the unit followed the standard form of the general project, that is, small nodes, contrary to what was done in the HAZOP Revalidation study, which consisted of dividing the unit into subsystems (“super-nodes").

With the experience of the Team Leader and the people in the process who participated in the meeting, the nodes were significantly reduced - see Tables 5.8 and 5.9 for comparison.

In both analyses, the procedure was similar; this means the guidewords were applied to each process variable of interest to identify the cause and the consequences of the deviation on the system and verify the presence of sufficient means of detection and correction of the deviation. For each deviation, the following information has been analysed jointly:

- The list of the possible causes that lead to hazard and operability problems
- A list of the possible consequences can be found for each existing cause.
- The system's response before the studied deviation: system elements permit the detection of the phenomenon or resisting its effects; instrumentation, detectors, alarms, etc.
- The risk evaluation is by Risk Matrix Management -see Annex A.

- Actions/recommendations could be taken to avoid the causes or limit their consequences.
- Comments: Any annotation that can help complete or clarify the points shown previously.

Table 5.8 Project Nodes Description.

NODE NUMBER	DESCRIPTION
1	Amine Acid gas to X-10801 including D-10801 (Amine Acid Gas flow to E-10807 and to H-10801, both included)
2	SWS Acid gas to X-10801 including D-10802
3	Condensate from D-10801 and D-10802 to B.L. including P-10801 and P-10802 A/B
4	Combustion Air from B-10801 A/B to X-10801 and H-10801 including E-10805
5	Thermal Reactor Burner X-10801, Thermal Reactor H-10801 and E-10801 (tube side) including Process Gas from the Waste Heat Boiler E-10801 to the First Sulphur Condenser E-10802 A
6	Waste Heat Boiler E-10801 (medium pressure steam side)
7	First Catalytic Reactor R-10801 including the sulphur condenser E-10802 A and First Reactor Preheater E-10803
8	Process Gas from the sulphur condenser E-10802 B (including the steam side) to the Second Catalytic Reactor R-10802 including Second Reactor Preheater E-10804
9	Process Gas from the Sulphur Condenser E-10802 C to the Static Mixer X-10807 including Tail Gas Heater E-10807
10	Process Gas from the Static Mixer X-10807 to the Quench Tower including the Hydrogenation Reactor R-10803 and the Hydrogen injection to the Static Mixer X-10807
11	Quench Tower T-10801 and Tail Gas Flow to the Absorber T-10802 including Recycle Gas to B-10802
12	Quench Water Recycle to T-10801, including P-10805 A/B, Sour Water Filter (F-10801) and Quench Water Cooler (E-10808
13	Lean Amine Supply, Absorber T-10802 and Rich Amine to Battery Limit
14	Recycle Gas from T-10801/T-10802 including Recycle Gas Preheater E-10810 and Recycle Gas Blower B-10802
15	Liquid Sulphur from the Waste Heat Boiler E-10801 and from the Sulphur Condenser E-10802 A/B/C to Sulphur Pit TK-10801 (Degassing Compartment) including the Sulphur Traps (X-10802 to10805)
16	Liquid Sulphur from P-10803 A/B to the second pit compartment including the Degassing Column T-10803, the degassed air outlet and the hydraulic seal X-10806.
17	Degassing Air Supply from Preheater E-10811
18	Second Compartment Sulphur Pit TK-10801 and Liquid Sulphur Product to B.L. and recycled to the first pit
19	Steam ejectors system J-10801 A/B
20	Blow down from E-10801/E-10802 to Blow Down Cooler E-10806
21	Fuel Gas System
22	MP Steam Desuperheater
23	Instrument Air, Plant Air and Nitrogen Distribution
24	Potable, Service, Demineralized and Boiler Feed Water Distribution
25	Cooling Water Distribution
26	ILPS / Condensate Distribution
27	Amine Drain Header

Table 5.9 Revalidation node description.

HAZOP U18000 – MATOSINHOS REFINERY		
Node	**Description**	**P&ID**
1	ACID GAS K.O. DRUMS D-10801 AND D-10802	RP-07-A1-108-00020-XXXXXXX-2001 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A
2	THERMAL REACTOR H-10801	RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2005 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3
3	COMBUSTION AIR BLOWERS B-10801 A/B	RP-07-A1-108-00020-XXXXXXX-2002 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3
4	WASTE HEAT BOILER E-10801	RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2044 Rev. 3
5	SULPHUR CONDENSER AND CATALYTIC REACTORS	RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2008 Rev. 3A
HAZOP U18000 – MATOSINHOS REFINERY		
Node	**Description**	**P&ID**
6	SULPHUR PIT TK-10801, DEGASING COLUMN T-10803 AND TRANSFER PUMPS P-10804 A/B	RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2009 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2010 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2011 Rev. 3
7	HYDROGENATION REACTOR R-10803	RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2014 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3
8	QUENCH TOWER T-10801	RP-07-A1-108-00020-XXXXXXX-2015 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2016 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2044 Rev. 3
9	AMINE ABSORBER T-10802 AND RECYCLE GAS	RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 DCM407209 Rev. 1 RP-07-A1-108-00020-XXXXXXX-2018 Rev. 3 061745-1 a00 RP-07-A1-108-00030-XXXXXXX-2045 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2047 Rev. 3
10	FLARE AND FUEL GAS SYSTEM	RP-07-A1-108-00030-XXXXXXX-2041 Rev. 3A
11	MP STEAM SYSTEM AND KPS DISTRIBUTION	RP-07-A1-108-00030-XXXXXXX-2042 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2046 Rev. 3
12	IA AND N2 DISTRIBUTION	RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3

5.8.3 Meeting Sessions

Galp (myself included), Licensor, and Front-End Engineering Design representatives were present during the Project HAZOP sessions, having analysed all 27 Process and Utilities P&ID’s issued for the project in 584 hours.

In this safety review, 27 nodes were identified, and 64 recommendations were recorded, of which 32 are for FEED company, eight are for Licensor, 17 are for both, two are for GALP and FEED company, and five are for GALP only.

The HAZOP Revalidation study was carried out by a Galp team at the Matosinhos Refinery offices, facilitated by an external company, and lasted 216 hours. 32 P&ID’s were analysed, 12 nodes and 35 different recommendations were identified.

Even considering a higher number of P&ID’s than those studied in the project, the number of nodes was substantially reduced, from 27 to 12, due to the new approach to node marking - see Figures 5.13 and 5.14 as an example.

Both HAZOP studies were recorded on HAZOP worksheets. A more detailed comparison between the two studies, including the P&ID’s and nodes analysed and the recommendations achieved, can be seen in the Annex F – Claus Unit HAZOP.

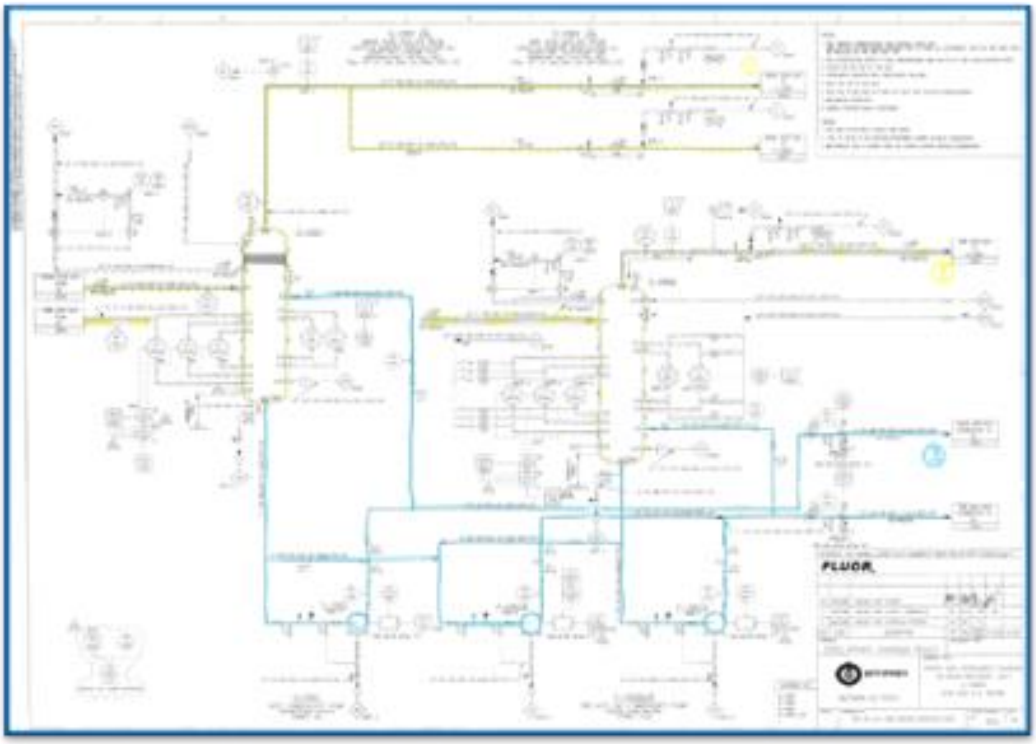

Figure 5.14 Node 1 identification (Acid Gas KO Drums) Design.

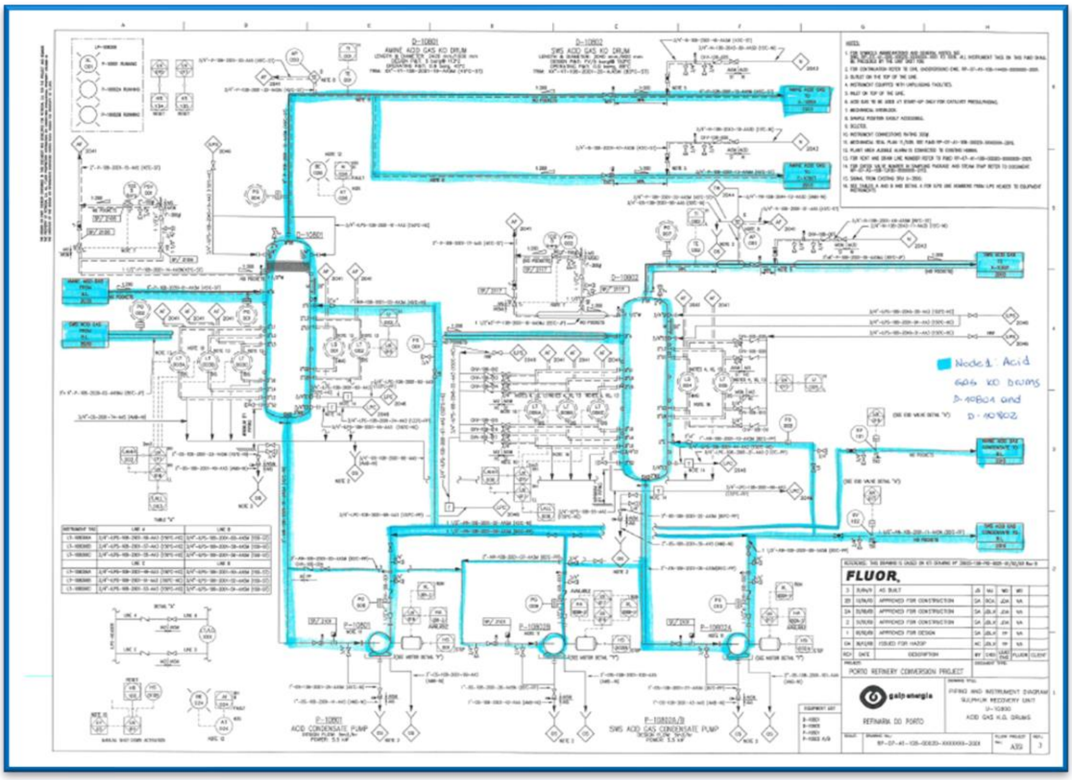

Figure 5.15 Node 1 identification (Acid Gas KO Drums) Revalidation.

5.8.4 Absorber (T-10802) HAZOP Project and Revalidation

To better understand the different approaches to HAZOPs in the two periods, we now consider the HAZOP studies carried out, in the Claus unit, to the absorber column T-10802.

For the project, the nodes can be seen in Figure 5.15, where the feed was node 11, the top section was node 14, and the remaining column and circuits were node 13.

During the Claus Revalidation process, which took place at the end of December 2019, the same absorber was analysed, having been included in only a single node, "super-node", according to the graphical representation of Figure 5.16.

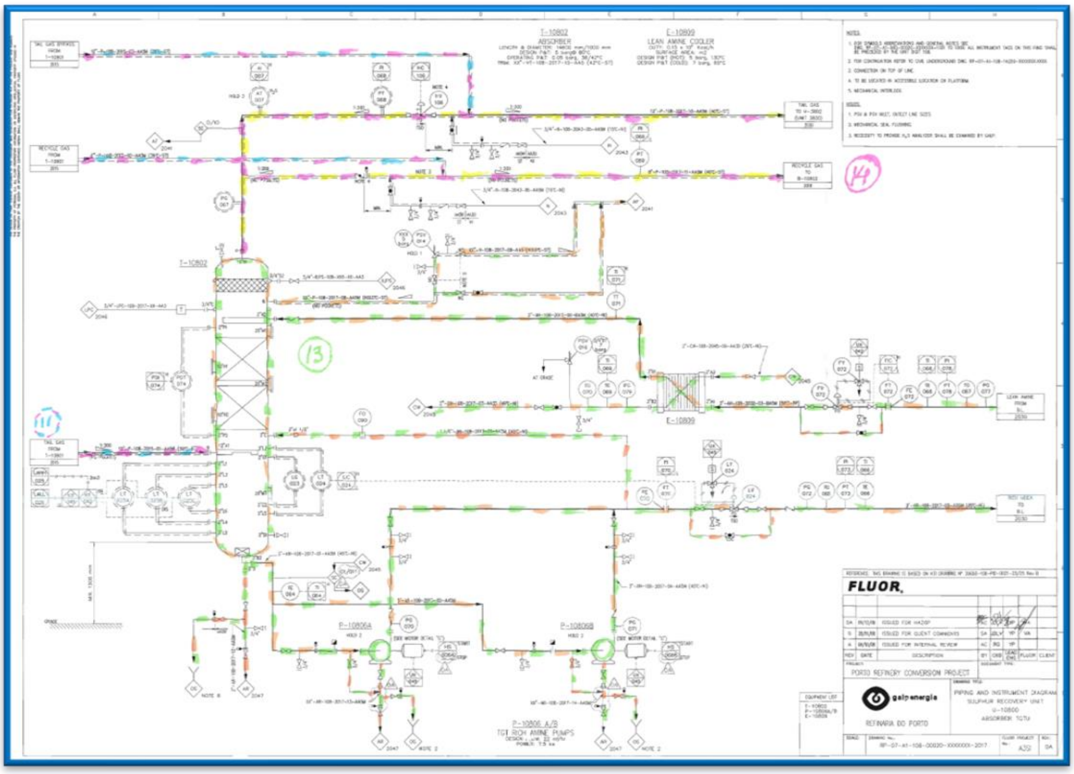

Figure 5.16 Absorber T-10802 (Project - nodes 11, 13 and 14).

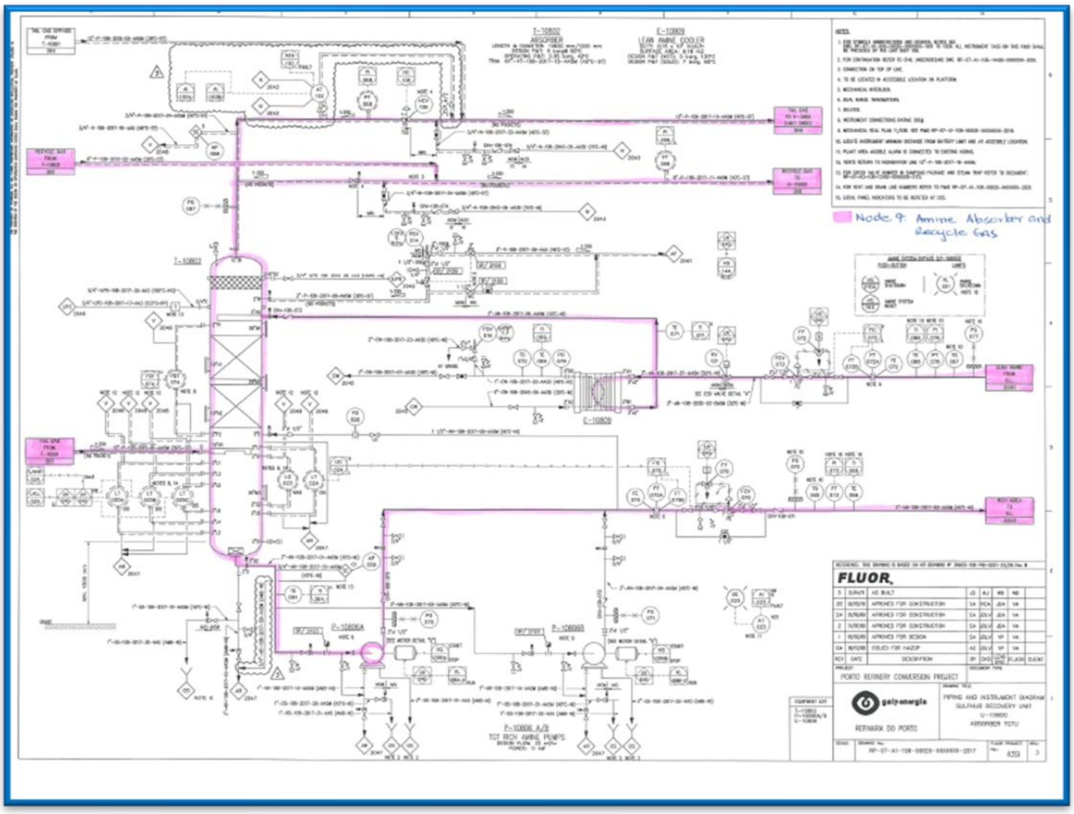

Figure 5.17 Absorber T-10802 (Revalidation - node 9).

As a result of the Project HAZOP study, five recommendations were identified to be implemented during the project phase - see Table 5.10.

Table 5.10 HAZOP Claus Project - T-10802 - node 11, 13, 14.

Node	Deviation	Causes	Consequences	Safeguard	Recommendations
11					No Recommendations
13	No Flow of Lean Amine	228, Loop FIC-072 failure	228,1 Loss of recovery Sulphur efficiency	AIH-007 (H2S analyser) hold 3 in P&ID 2017 Stack analyser (SO2 and H2S)	228. 1.1 AT-007 installation will depend on if it serves to measure the unit U-10800 efficiency. The Licensor will provide the efficiency method required.
		230, Loop LIC-024 failure	230.1 Increase in absorber level.	LAHH-025 A/B/C (2oo3) activating UX-042	230.1,1 Modify the LIC-024 putting it in cascade with FIC-070
14	Higher Pressure	256, Tube rupture in E-10810	256,1, Potential mechanical damage to the system	PSV-010	256.1,1 Licensor will check the necessity and purpose of PSV-010 and check the valve at the inlet of the blower
	Less Pressure	258, Blower B-10802 stopped during start-up or shutdown	258,1, No recycle gas flow with the potential reverse flow towards blower (mechanical damage)	Check valve	258.1,1 When blower details are known, a Hazop must be made.
	Less Temperatu re	261, Steam traps malfunctioning	261,1, Cold recycle gas causing Sulphur condensation when mixed with gas from Claus unit	No safeguard identified	261.1,1, Add a TAL to TE-045

As expected, only one recommendation was pointed out, not identified before, during the HAZOP Revalidation process, as shown in Table 5.11.

Table 5.11 HAZOP Claus - Revalidation - T-10802 - node 9.

Node	Deviation	Causes	Consequences	Safeguard	Recommendations
9	9.1 Less Lean Amine Flow	9.1.2 Human error closing manual valve upstream pimp P-10806 A/B when required to be open.	9.1.2.3 No H2S absorption. Untreated tail gas to the incinerator. Environmental impact.	9.1.2.3.1 AI-102 A/B (no full IPL)	Indicate in PID RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 that AI-102 A/B measures H2S and COS

As this column is typical in several absorption Revalidation processes, this analysis can be used as a basis for other HAZOP studies, considering specific similarities and differences that must also be subjected to safety analysis.

5.9 “Super-nodes” HAZOP Revalidation Summary

The HAZOP revalidation of the Diesel Hydrotreatment, Gas Treatment and Claus units was a good test for the new approach of identifying circuits in “super-nodes”.

By dividing and analysing the P&ID’s in this way, keeping the same design intent of the circuits, the new approach reduces the team's overall effort in revalidating the HAZOP of a plant. It is a relevant fact because the use of specialized technicians is generally limited in time and must be very well managed.

This structural change in the approach of a complex process, allows a “waterfall” analysis (part by part) to something more agile, fast, and secure (end-to-end packet analysis), which can later be replicated in new risk analyses of HAZOP Revalidation.

However, the high potential for creating models that allow greater process automation still requires further investigation to build truly effective tools capable of supporting and improving all the safety requirements of risk analysis of industrial facilities.

Revalidation of HAZOP through “super-nodes” mixed with specialized software, such as Aspen, which uses an extensive database for process simulation, may be a way to explore. The possibilities and limitations of the model-based HAZOP study using Aspen HYSYS, was discussed by Ján Janošovský et al. [80]. In this article, the possibilities and restrictions of a model-based HAZOP analysis using Aspen HYSYS were presented. Numerical simulation results were collected and converted directly into conventional HAZOP tables.

However, this type of safety studies that obtain information on individual unit processes, their characteristics, and particularities relies on the use of specialized human resources to speed up and guarantee the final quality of the HAZOP studies. It is, therefore, necessary to find the right combination between software, “super-nodes" and the experienced team that will speed up the HAZOP Revalidation and offer the necessary guarantee in terms of the quality and safety of the study.

Given the current knowledge of this risk analysis and engineering used to conduct the hazard identification studies, further research is needed to obtain solutions for the following aspects:

- Human-driven HAZOP is error-prone and requires technical experts' experience, knowledge, and inventiveness. It is critical to continue to seek the expertise and experience of new entities to standardize the HAZOP framework on processes with equivalent technology (as in the case of unit processes used in the petroleum and petrochemical industries);
- When hazard identification is focused on assessing deviations from standard processes and initiating events caused by human errors, it often becomes difficult to determine all of their impacts. These occurrences have a frequency, in many cases, greater than others (eg, control failures). The attempt to discover these types of causes and their incorporation into the HAZOP structure is a task that requires the intervention of specialists, where an integrated use of "super-nodes" allows the development of models where analysis and detection will be easier.

An intelligent system that allows automating the models used in risk analysis can reduce the time and effort involved, make the analysis completer and more detailed, and minimize or eliminate possible human errors.

To this end, the case studies above can help build a model-based framework in which the knowledge needed to perform the HAZOP analysis is divided into specific components and general components of the process.

The specific knowledge of the process can be constituted by the properties of the equipment and the P&ID's of the units. The general knowledge of the process consists of typified models, based on everyday situations studied, explicitly developed for hazard identification. These models can be set independently of context so that they can be used in various processes.

The knowledge of an experienced HAZOP team can help establish the necessary fit between the components and the process under study, to identify specific abnormal causes.

6 Refinery Global HAZOPs Indicators

A source of relevant information on the procedures and times verified during the execution of the HAZOPs can be given by the comparative analysis of the risk analyses carried out during the Matosinhos Refinery Revamping Project, which took place in 2010, and the Revalidation process of the same units verified a few years later.

The data presented here from the project phase were verified and contributed by me, as a participant in the HAZOP teams of the various units, new and revamped, and the individual packages of some equipment. This information allowed me to gain experience with the methodology application and its advantages and disadvantages.

I had the opportunity to verify that in different circumstances, some equipment's risk analysis results were used in the study of units with different process objectives. Examples are the HAZOPs carried out in centrifugal compressors, furnaces and even some conventional distillation columns. In some cases, the worksheets used for one piece of equipment were even adapted to another, from another unit, with similar characteristics and residual changes. It was also possible to observe that the preparation of the meetings and their leadership is a decisive factor for the smooth running of the studies. One of the most important factors is the detailed engineering knowledge of the project teams and the operational knowledge and experience expressed by some team members.

In this context, this work arises with the application of “super-nodes" in the identification of P&I circuits used in the HAZOP methodology. Based on this information and experience, the idea of testing models and verifying their impacts arose in the revalidation processes of the units carried out between 2017 and 2019.

In these Revalidation processes, the due quality of the approach is a mandatory requirement since they are part of the information presented by the Refinery in compliance with the Seveso Directive and are a critical document for the premiums applied by the reinsurance companies.

6.1 Project Safety Reviews (2010)

The Project aimed to increase capacity and conversion and reduce the overall energy consumption of the refinery. The production of Vacuum Diesel (VGO) was also an important objective of the Matosinhos Refinery Revamping Project carried out in 2010. With this expansion, it was possible to transfer the VGO to the Hydrocracker of the Sines Refinery, avoiding imports and thus increasing production of the Company's diesel.

Figure 6.1 shows a block diagram that lists the units involved in the project, indicating the new process units (green) and those that underwent refurbishment (orange). At the same time, other existing and auxiliary units, utility production systems, storage tanks, and other off-sites were also modified following the best available engineering technologies.

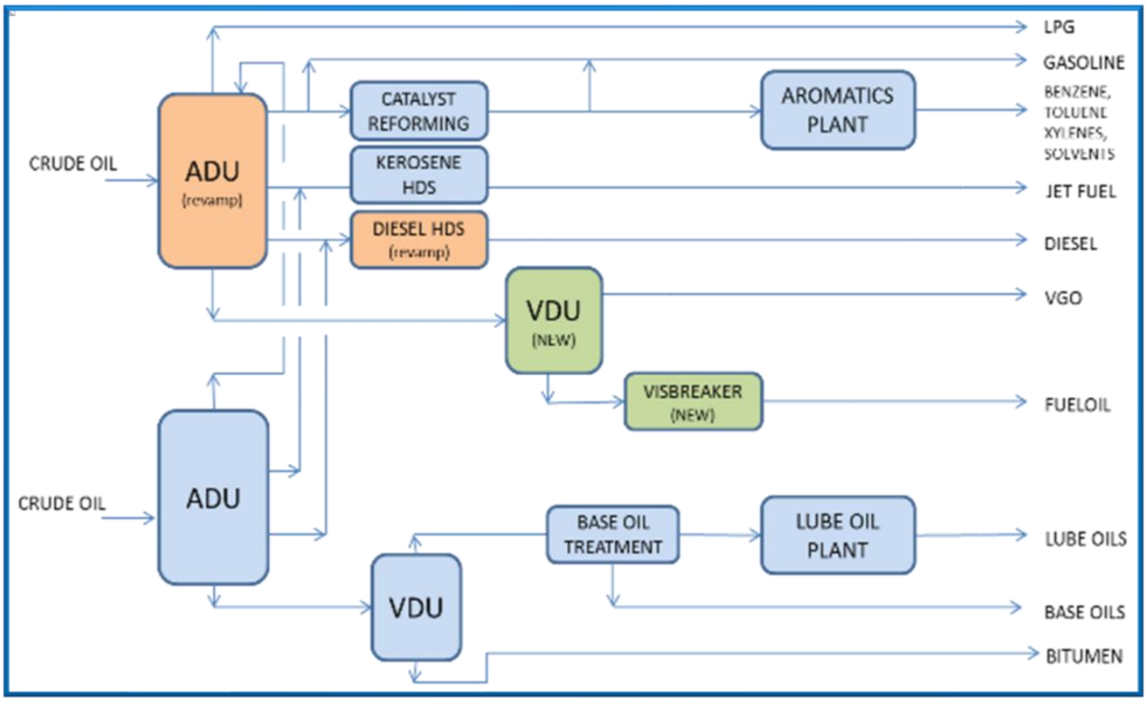

Figure 6.1 Matosinhos Refinery Flowsheet

Several HAZOP studies were performed to identify design weaknesses that could lead to dangerous operations. A lack of risk control could impact lives and damage property or the environment.

Operational problems that could prevent the process variables from operating within their project margins were also identified, that is, deviations from a normal operation that enable risks or severe anomalies to the process. Critical data was analysed in the preliminary “roller board” meetings for this general objective, which implied consecutive studies of P&ID’s, process safety data, operation and equipment manuals, and other relevant information. These studies were done by several experienced multidisciplinary teams on all the new, revamped, and modified processes units to assess the safety of the systems with significant hazard potential.

Before the HAZOP sessions, relevant information from the design was collected according to the following list:

- Process/Instrumentation: Basis of Design, Heat and material balances, Process flow diagrams (PFDs), Piping and instrument diagrams (P&ID’s), Utility Summary listings, Material selection diagrams, Process and utility equipment data sheets, Control and safeguarding narratives, Cause and Effect Diagrams, Emergency Shutdown (ESD) systems, Flare Relief load analysis, Instrument specifications, Distributed Control System (DCS) criteria and specifications, Safety reports, and Recommendations (where applicable);
- Mechanical: Critical and long lead equipment specifications, Thermal rating of heat exchangers, Sized Equipment list;
- Civil/Structural: Steel structures and foundation philosophy, Foundation and structure sketches, Outline sketches for buildings;
- Piping: Plot plan, Critical piping and equipment layouts, Piping line list, Tie-in list and Battery limit list.

With this information, it was possible to understand and describe the process, mark the nodes in the P&ID’s to be analysed and set the words and deviations to be applied. In most cases, it was considered a node, one individual piece of equipment (distillation column, reactor, drum, tank, etc.) or a line from one piece of equipment to another. In some cases, nodes could include bigger parts of the P&I (line, pump, valves, heat-exchangers) when it makes sense to analyse the system together for the same deviations.

With this procedure, HAZOP teams checked the safety of the overall project, process, and utilities P&ID’s for all the units, operation and safety procedures, location for safety equipment, vendor packages and the final layout of the major equipment (see Figures 6.2 3D model and actual Vacuum/Visbreaker equipment examples) [81].

Figure 6.2 Vacuum- Visbreaker (3D Model and May 2011 photo).

During the Front-End Engineering Design (FEED), nineteen HAZOP studies were carried out between 2008 and 2010, involving both new and modified units, as a result of identifying weaknesses in the project - see Table 6.1- Masterplan Safety Review List.

Table 6.1 Masterplan Safety Review List (19 HAZOPs).

Unit	Title	Number P&I's	Nodes (number)	Recommendations (number)	Time (days)	People (number)	Hours (number)
Amine Unit	Amine Regeneration Unit Lean Amine Filter Package F-1652	2 2	6 3	15 14	1 1	15 9	120 72
Topping / Unifining	Atmospheric Distillation and Unifining Atmospheric Distillation and Unifining (2ª session)	13 4	17 6	51 10	4 1 1	14 16	440 168
Diesel HDS I	**Reactor R-3701 transfer to HDS I**	**3**	**7**	**24**	**2**	**13**	**208**
Diesel HDS II	HDS-2 Unit Revamp HDS-2 Unit Revamp (Second Session) Cooling Water Skid-Makeup Compress	23 6 6	22 6 2	32 8 11	3 1 1	21 11 9	408 88 72
Exist.Sour Water Stripp	Existing Sour Water Stripper	2	4	6	1	14	112
Existing Claus Unit	Existing Sulphur Recovery Unit	9	10	9	1	14	112
New Sour Water Strippe	New Sour Water Stripper	3	7	40	3	16	336
New Claus Unit	**New Sulphur Recovery Unit**	**27**	**27**	**64**	**5**	**17**	**584**
Vácuo /Visbreaker	VUVB Unit Utility Report VUVB Heaters Sour Gas Compressors Vacuum Ejector Pump Seal Plans MP/LP Steam Letdown	47 22 14 14 1 2 1	57 13 10 10 3 2 2	191 84 43 11 21 16 5	13 3 2 2 2 1 1	20 10 14 15 15 15 8	2080 240 224 240 240 120 64
Total		**201**	**214**	**655**	**49**	**266**	**5928**

HAZOP Close-out Reports were done to the modified systems with all actions implemented and data collected. Some equipment specifications were changed and several modifications to the P&ID's were implemented to allow the engineering progress.

HAZOP recorded information was also critical for a Safety Integrity Level (SIL) classification executed for all Emergency Shut down Valves (ESD) functions shown on the P&ID's and the Cause & Effect diagrams. The objective of this SIL classification was to establish the required level of reliability for the instrumented safety functions (part of the ESD trip loops as defined by the ESD interlock description in the Cause & Effects).

6.2 Revalidation Safety Review (2019)

As discussed before, taking the most appropriate Revalidation approach depends on several factors: What was the quality and level of recommendations from previous PHA? How extensive were the process changes or environmental impacts? How effective was the MOC procedure implemented?

In the process of Revalidation of GALP's risk analyses, it was decided to carry out all the HAZOP studies from scratch ("Redo"), based on the changes made and included in the refinery's MOC procedure, in the operational and incident investigation history, in the recommendations and finally, in the new regulatory and company requirements. The first Revalidation process was carried out after the start-up of new units and those that underwent revamping.

All issues previously addressed were again collectively discussed by a new Galp team to identify the cumulative impact on the process. Checklists were used to ensure that uncontrolled or undocumented changes were not forgotten. New consolidated data was introduced, allowing verification of new causes and new safety requirements on the process.

The specialists present at the meetings were selected according to the complexity of the industrial process and the technical and process areas involved. In some cases, external contributions from a "Team Leader" and a "Scriber" were also requested to lead, document, and manage the conduct of the HAZOP workshops.

Process operators were fundamental in describing and identifying changes to the project. At the same time, maintenance personnel actively collaborated on all useful information with instrumentation and electricity and their predictive and preventive maintenance procedures.

The review process of the units' risk analyses corresponding to the Matosinhos Refinery revamping, which took place between 2009 and 2011, started in 2013 and continued until 2019.

Ten HAZOP sessions were carried out during 1960 hours, in which 190 P&ID's were analysed, resulting in a total of 335 recommendations - see Table 6.2.

Table 6.2 PHA Revalidation Safety Review List (10 HAZOPs).

Unit	Number P&I's	Nodes (number)	Recom. (number)	Time (days)	People (number)	Hours (number)
Amine Unit	3	6	17	2	4	72
Topping/Unifinning	8 13	14 10	26 46	3 3	11 5	224 168
Diesel HDS I- 1º Revalid. Diesel HDS I- 2º Revalid.	6 6	17 3	37 30	5 2	7 4	280 64
Diesel HDS II Exist.Sour Water Strip.	25	14	48	7	5	224
Existing Claus	14	7	16	2	3	48
New Sour Water Strip.	8	9	25	4	9	232
New Sulphur Recovery Unit	32	12	35	5	7	216
Vácuo /Visbreaker	75	30	55	12	6	432
Total	**190**	**122**	**335**	**45**	**61**	**1960**

6.3 Project vs Revalidation HAZOP Studies

The risk analyses carried out in the two periods, Project and Revalidation, can hardly be compared due to a significantly different HAZOP approach taken during the two stages.

Contrary to what happened in the Project, in the Revalidation process, the analyses of the P&ID´s referring to the equipment packages such as compressors, furnaces, etc., were not integrated and analysed in the global set of the respective units.

In addition, the difference in the number of P&ID’s analysed was also due to a process of updating the diagrams carried out after the construction and operation startup of the units. This resulted in a different number of P&ID’s, studied in the two periods, with 201 P&ID’s considered during the execution of the FEED and 190 during the Revalidation process.

The number of nodes considered was also significantly different, 214 for the first case and 122 for the second, as a result not only of the drawing mentioned above updates but also due to a different identification of the start and endpoints of the circuits corresponding to a different dimension of the analysed nodes, in particular the use of “super-nodes” in most of the units.

From Tables 6.1 and 6.2, as a result of the analysis of deviations and causes carried out in the two HAZOPs, many safety recommendations and “safeguards” for the units were identified, with 655 during FEED, 335 found during the Revalidation process. From the analysis of them, it was checked that there were no repeated proposals between the two studies, so it was concluded that the recommendations identified in the FEED were implemented before the HAZOP Revalidation was carried out.

In any case, given the number of recommendations found, the Revalidation process confirmed the need and the relevance of repeated periodic hazard and operational analyses to guarantee the conformity of the process with its real and current characteristics and that the risk assessment is up to date and is representative of a safer process.

In all the Revalidation procedures, except from the project to first Revalidation of the Diesel Hydrotreatment unit, for the reasons explained in Chapter 4, the total number of hours used by all the participants in the HAZOP team was substantially reduced. In some cases, about a third of the time used in the project corresponds to the values presented in Figure 5.7 in Chapter 5.

This fact proves the success of the strategy followed in the HAZOP Revalidation of the Diesel Hydrotreatment unit when going from Case #1(280 hours), with identification of standard small nodes, to Case #2, using “super-nodes” (64 hours), with a greater number of circuits and equipment.

It is also proven that in any Revalidation process, new recommendations always arise, even for units in which no process changes have been made, or regulatory norms have been changed. These recommendations arise, in most cases, from different leadership and degree of knowledge of the HAZOP team members.

Normally, changes that occur in units result from changes in process variables (such as flow rates, temperatures, pressures, etc.) while changes in circuits and equipment remain unchanged. Thus, the definition of “super-nodes" also remains unchanged, significantly reducing the use of human resources and the costs involved in carrying out risk analyses.

Table 6.3 Project vs Revalidation HAZOP execution time.

Unit	Project			Revalidation			Time Reduction
	Number P&I's	Nodes (number)	Hours (number)	Number P&I's	Nodes (number)	Hours (number)	DELTA %
Amine Unit	4	9	192	3	6	72	37,5
Topping / Unifining	17	23	608	21	24	392	64,5
Diesel HDS I - R-3701 Transfer	3	7	208				
Diesel HDS I - First Revalidation				6	17	280	22,9
Diesel HDS I - Second Revalidation				6	3	64	
Diesel HDS II /Exist.Sour Water Strip.	37	34	680	25	14	224	32,9
Existing Claus Unit	9	10	112	14	7	48	42,9
New Sour Water Stripper	3	7	336	8	9	232	69,0
New Sulphur Recovery Unit	**27**	**27**	**584**	**32**	**12**	**216**	**37,0**
Vácuo /Visbreaker	69	70	2080	75	30	432	20,8
Total	**169**	**187**	**4800**	**190**	**122**	**1960**	**40,8**

7 Conclusions and Future Perspectives

Process safety is at the heart of accident prevention and results from applying good design and engineering principles and robust operation and maintenance practices.

Countries, local governments, the public, and commercial sector and non-governmental organizations must include safety, health, and the environment in their current objectives and agendas.

These companies must manage safety efficiently and transparently to be sustainable and competitive, carrying out their activities only when all the necessary conditions are duly safeguarded. Unsafe operations do not survive in today's cultures because of the tremendous danger they pose to organizations regarding high-impact personal, material, environmental and reputational issues. It is a continuous improvement resulting from changes in process, equipment, or procedures, creating new safety, health, and environmental concerns, new market opportunities, or even specific process requirements.

In this context, companies implement a Process Safety Management system, which incorporates various risk analysis approaches to achieve the safe operation of facilities.

The most used PHA option, the HAZOP approach, involves a detailed description of the process and a methodical examination of each component to determine how deviations from the design or its operation may occur. This periodic safety assessment is necessary to verify that all hazards are identified and managed following the best practices and standards existing in the companies, namely those that require periodic Revalidation of risk assessments for all industrial facilities, normally every five years.

The assessment of deviations and their repercussions, if found, may have the potential to negatively impact industrial units' safe and efficient operation, requiring recommendations/actions to mitigate or even eliminate any critical scenarios. HAZOP results can also convey safety information to operational and maintenance workers to improve overall process safety management. Operational processes, emergency plans, and preparations for internal and external audits are all things that should be verified.

As part of the Revalidation of risk studies required by the European Seveso Standard and OSHA PSM Standards, a HAZOP was performed on the Diesel Hydrotreatment unit, which served as a test for the standard approach identifying small nodes in the unit's P&ID´s circuits. A second Revalidation was also carried out for the same unit, allowing the development of a new node selection strategy, called “super-nodes", to collect the knowledge of the process necessary to carry out faster HAZOP studies while maintaining the mandatory safety requirements. By splitting the installation along "super-nodes" and examining them with the same function just once, the approach decreases the effort involved in studying a unit.

The experience and knowledge of the HAZOP team, the technical experts, the quality of the new information provided, and the knowledge of the equipment can significantly contribute to the success of this new approach that preserves the rigor and traceability of previous reports, guaranteeing the high standards of quality required for submission to the Portuguese authorities.

This methodological approach was also carried out at the Gas Treatment and Sulphur Recovery (Claus) units. Given the success of the results, the HAZOPs of the Revamping of the Matosinhos Refinery were also comparatively analysed with the Revalidation processes of the same scope The main objective was to assess the time savings that occurred in the risk analysis sessions and what their impacts were on the recommendations to control possible new hazards in the installation.

The data was treated in a comprehensive, integrated, and consistent way by identifying “super-nodes” for specific components of the unit, to allow reuse while maintaining the respective safety criteria. Thus, the HAZOP analysis can be "partially automated" by using "generic models" that allow an implementation-oriented study and analysis of objects. Decomposition of P&ID’s is based on the specific knowledge of the unit and general understanding of the processes and the development of "generic models" of cause and effect of various processes and process equipment. A functional analysis that allows locating causes far from the node in question but requires a more thorough investigation of the workflow involved in the studies to create practical tools to support the most complex HAZOP studies.

For future work, developing heuristic models, supporting the identification of “super-nodes", can help in time-consuming and repetitive operations, streamlining the entire process without sacrificing efficiency, regardless of the information consulted or the risk analysis performed. These templates can be especially useful during "Retrofit" and "Update" Revalidation when only part of the unit is to be examined.

The construction of heuristic models, their integration with computer-aided HAZOP systems and CAD software, or even process simulators may be a way to streamline the entire process risk analysis process. Engineers involved in the design, commissioning or operation of similar installations will be able to make a solid contribution to the construction of these applications.

In this work, it was chosen to use all available data, which, admittedly and in a practical way, allows for the optimization of resources and the use of technologies and previous data from comparable equipment and units. These are the combined knowledge and experience of individual professionals and the industry.

However, the safety and reliability design of a unit is based on a large amount of data and the application of numerous norms of practice or design rules and standards. As a result, this information can be prepared in advance, in terms of software, to be used in a proactive and inventive response to deviations that may arise as a result of, for example, equipment breakdown or operator error.

When combined with computerized data, heuristic models can help operational, and safety professionals diagnose problems, assess critical circumstances, and manage other functions typically part of process unit risk assessment.

Modern chemical facilities are highly complex, making them difficult to analyse and evaluate from a HAZOP perspective, creating significant occupational safety concerns. Recent catastrophes at chemical plants illustrate that they are also more prone to equipment failure due to their complexity. A knowledge-based system architecture to automate process plant HAZOP analysis can be built using data from different process projects and operations. These automated technologies have the potential to improve chemical plant worker safety significantly.

HAZOP analysis is often performed by a group of experts who spend weeks or months examining process flowcharts. As a result, HAZOP analysis is changing, time-consuming and labour intensive. Two essential elements of the HAZOP study can be used for future work in a knowledge-based framework:

- While each HAZOP analysis is unique to a process, they are all systematic and rational and
- For different process flowcharts, many analysis components are the same.

As a result, HAZOP analysis can be automated using a knowledge-based system that employs several unique methodologies in a model-based framework to solve the problem. These are:

- Split the knowledge base ("super-nodes") into process-specific knowledge and process-wide knowledge
- Create general cause and effect models for a variety of processes and process equipment and
- A framework for object-oriented implementation.

Expert Systems tend to advance HAZOP and fields such as process engineering and artificial intelligence, where the need to design inter-relational models allows them to be used in various technologies with similar, if not identical, equipment.

Knowledge bases, diverse databases, and other ideas can help improve hazard identification in process industries. Much effort has been made in this complex sector, but more study and application/verification of expert systems is still needed to use them effectively in hazard detection and loss prevention;

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Glossary

(Adapted from Primatech: https://www.primatech.com/technical/glossary-of-pha-terms)

Abnormal Condition	Any deviation in the operation of a facility from that prescribed in the standard operating procedure for normal operating ranges, if not correct, could result in an accident.
Acceptable Risk	The average rate of risk is considered tolerable for a given activity.
Accident	A specific combination of events or circumstances leads to an undesirable consequence.
Acute	Immediate, short-term. Relating to exposure: conditions which develop rapidly and may cause harm within a short time. Relating to effects: effects which appear promptly after exposure.
As Low As Reasonably Possible ALARP)	The notion that the risk to individuals, society and the environment should be "As Low as Reasonably Possible" is captured by this principle related to the design and development of safety systems.
Catastrophic release	Major uncontrolled emissions, fires or explosions involving one or more highly hazardous chemicals present a serious danger to employees in the workplace.

Basic Event	A simple initiating defect that doesn't need to be developed further (term used in FTA).
Causes	These are the possible causes of deviations. Once a credible explanation for a deviation has been established, it can be treated as a relevant deviation. Hardware failures, human errors, unexpected process states (e.g., composition change) and external disruptions (e.g., power outage) are examples of these causes.
Cause-Consequence	A procedure uses diagrams to illustrate a particular scenario's causes and consequences. Experienced risk analysts employ this technique.
Consequences	These are the outcomes of the expected deviations (e.g., the release of toxic materials). In terms of the study's goal, inconsequential outcomes are eliminated.
Checklists	Simple means of applying experience to designs or situations to ensure that the features appearing in the list are not overlooked. Tend to be general and may not be appropriate to a specific situation. They may not handle adequately the novel designs or unusual processes.
Consequence	The direct, undesirable result of an accident is usually measured in health and safety effects, loss of property, or business costs or a measure of the expected impact of an accident outcome case.
Demand	Process scenario or equipment condition or event which requires a Safeguarding Function/Instrumented Protective Function to take action to prevent a hazardous situation.

Design Intention	Set of required or desired process behaviours, as intended by the process designers. The different aspects of a node are represented by parameters such as flow and pressure.
Deviation	This is the departure from the intention discovered by systematically applying the guidewords (e.g., "more pressure").
Domino effect	An incident starts in one piece of equipment and affects other nearby items, such as vessels containing hazardous materials by thermal blast or fragment impact. These can lead to an escalation of consequences or frequency of occurrence. This is also known as a Knock-on-Effect.
Event	An occurrence involving equipment performance or human action or an occurrence external to the system that causes system upset. An event is associated with an incident, either as a cause or a contributing cause of the incident or as a response to an initiating event.
Facility	The buildings, containers and equipment that could reasonably participate in a catastrophic release due to being physically interconnected or their proximity and in which dangerous substances are used, stored, manufactured, handled or moved.
Failure Mode and effect analysis (FMEA)	A hazard identification technique in which all known failure modes of components or features of a system are considered in turn and undesired outcomes are noted. It is usually used in combination with fault tree analysis. It is a complicated procedure usually carried out by experienced risk analysts. This methodology tabulates the source's equipment, failure modes (how equipment fails), each failure mode's effect on the source and the ranking of each failure mode.

Fire and Explosion Index	The F&EI is used to rate the potential hazard of fires and explosions.
FTA – Fault Tree Analysis	A graphic model that displays the various combinations of equipment faults and failures that can result in a release.
Guidewords	These are simple words used to qualify or quantify the intention to guide and stimulate the brainstorming process and discover deviations.; some organizations have made this list specific to their operations to guide the team more quickly to the areas where they have previously been found problems. Each guide word is applied to the process variables at the point in the plant (study node) which is being examined.
Frequency	Number of occurrences of an event per unit of time
Hazard	Any operation that could cause a release of toxic, flammable or explosive chemicals or any action that could result in injury to personnel or harm to the environment.
Highly Hazardous	Substances possessing toxic, reactive, flammable or explosive properties
Hazard and Operability Studies (HAZOP)	This is a set of formal hazard identification and elimination procedures designed to identify hazards to people, process plants and the environment. Studies are to be conducted by teams that brainstorm to systematically identify hazards or operability problems throughout a source through the use of certain guidewords such as "no flow" and "no cooling". The consequences of the deviation associated with the guidewords are assessed and credible deviations are identified and addressed.
Human Error	the major cause of almost all of the catastrophic accidents that have occurred in the chemical process industries

Incident	The loss of containment of energy material; for example, a leak of flammable and toxic gas.
Initiating event	A system is inherently safe if it remains in a non-hazardous situation after the occurrence of non-acceptable deviations from normal operating conditions
Intention	Defines how the plant is expected to operate without deviations at the study nodes. This can take several forms and can either be descriptive or diagrammatic, e.g., flowsheets, line diagrams and P&ID’s.
Likelihood	How often an accident can happen, either probability or frequency.
Loss prevention	the prevention of accidents through the use of appropriate technologies to identify the hazards of a chemical plant and eliminate them before an accident occurs
Major Hazard	An imprecise term for a large-scale chemical hazard, especially one which may be realized through an acute event.
Major Incident	An incident whose effect zone, while significant, is still limited to site boundaries.
Material Safety Data Sheets	A document which describes the chemical and physical properties and the physical and health hazards of a substance.
Mitigation System	Equipment and/or procedures designed to respond to an accident event sequence by interfering with accident propagation and/or reducing the accident consequences.

Near Miss	an occurrence in which an accident (that is, property damage, material loss, environmental impact, or human loss) or an operational interruption could have plausibly resulted if circumstances had been slightly different
Nodes	Locations (on piping and instrumentation drawings and procedures) at which the process parameters are investigated for deviations.
Node Intention	defines how the process is expected to be operated, only considering node equipment
Operability	any operation inside the design envelope that would cause a shutdown that could lead to a violation of environmental, health or safety regulations or negatively impact profitability
Piping and Instrument Diagram (P&ID)	One or more detailed diagrams including legends and citations of referenced documents showing: every item of equipment including its identification number; every pipe including size, flow direction, identification number and an indication of ANSI piping specification and break between piping identification, etc.
Probability	The likelihood of an occurrence of events or a measure of the degree of belief, the values of which range from 0 to 1.
Probability Analysis	Evaluates the likelihood of an event occurring. The frequency (events/year) can be quantified using failure rate data for equipment, piping, instruments and fault tree techniques; the frequency (events/year) can be quantified.
Process	Activity involving a highly hazardous chemical, including any use, storage, manufacturing, handling or the on-site movement of such chemicals.

Process Flow Diagram	Diagram including a legend of any facility which depicts the use, generation, storage or handling equipment, flow or material from item to item, simplified basic control loops or major control schemes, etc.
Process hazard analysis (PHA)	Application of one or more analytical techniques that aid in identifying and evaluating process hazards.
Process Safety	Operation of facilities that handle use, process or store hazardous materials in a manner free from episodic or catastrophic incidents. It is a blending of engineering and management skills focused on preventing catastrophic accidents and near hits – particularly explosions, fires and damaging releases associated with the loss of containment of energy or dangerous substances such as chemicals and petroleum products
Process Safety Management (PSM)	Application of management systems to identify, understand and control process hazards to prevent process-related injuries and incidents. Is the application of management systems to identify, understand and control process hazards, thus preventing process-related injuries and incidents? The goal is to minimize process incidents by evaluating the whole process. PSM came into widespread use after adopting OSHA Standard 20 CFR 1910.119 Process Safety Management of Highly Hazardous Chemicals in 1992.
Release	The discharge of energy or a hazardous substance from its containment system.
Recommendation	Suggested action to prevent, detect, control, or mitigate the scenario identified

Reliability	The probability that an item can perform a required function under stated conditions for a stated period or a stated demand.
Risk	It is a measure of economic loss or injury in terms of both the incident likelihood and magnitude of loss or injury. It implies a probability of something occurring. Risk is equal to Severity multiplied by Likelihood.
Risk Analysis	The development of a quantitative estimate of risk based on engineering evaluation and mathematical techniques for combining estimates of incident consequences and frequencies.
Risk Assessment	The process by which results of risk analysis are used to make decisions, either through a relative ranking of risk reduction strategies or through comparison with risk targets. The terms risk analysis and risk assessments are often used interchangeably in the literature.
Risk Management	The systematic application of management policies, procedures and practices to the tasks of analysing, assessing and controlling risk to protect employees, the general public and the environment, as well as company assets, while avoiding business interruptions
Safeguard	physical- or process-measure that will eliminate or reduce the likelihood of a hazard
Safety Audit	A critical examination of all, or part, of a total operating system relevant to safety.
Safety Procedures	Rules of conduct to safeguard personnel at a site from injury to health.

Safety System	Equipment and/or procedures designed to respond to an accident event sequence by preventing accident propagation and thereby prevent the accident and its consequences.
Severity	The accident's impact in terms of the effect on people, property or the environment.
Serious Accident	An event, namely an emission, fire or explosion, of serious proportions, resulting from uncontrolled developments during the operation of an establishment and which causes a serious, immediate danger or delay, for human health, inside or outside the establishment, or for the environment and involving one or more hazardous substances;
SIF	Set of equipment intended to reduce the risk due to a specific hazard (a safety loop). Its purpose is to 1. Automatically taking an industrial process to a safe state when specified conditions are violated; 2. Permit a process to move forward safely when specified conditions allow (permissive functions); or 3. Taking action to mitigate the consequences of an industrial hazard. It includes elements that detect an imminent accident, decide to take action and then carry out the necessary action to bring the process to a safe state. Its ability to detect, decide and act is designated by the safety integrity level (SIL) of the function
Safety Integrity Level	It is defined as a relative level of risk reduction provided by a safety function or to specify a target level of risk reduction. In simple terms, SIL is a measurement of performance required for a safety instrumented function (SIF). The requirements for a given SIL are not consistent among all functional safety standards. In the functional safety standards based on the IEC 61508 standard, four SILs are defined, with SIL 4 the most dependable and SIL 1 the least. The applicable SIL is determined based on a number of

	quantitative factors in combination with qualitative factors such as development process and safety life cycle management.
Site	The entire plot of contiguous land upon which the registrant operates or locates one or more facilities.
Top event	The undesired event or incident at the “top” of a Fault Tree
What If	Analysis which considers the consequences associated with events that occur as a result of failures involving equipment, design, or procedures. All possible system failures may be collected in a checklist form and evaluated. Compiling a list of failures requires a basic understanding of what is intended and the ability to combine or synthesize possible deviations and reject incredible situations. This technique relies on the experience level of the team leader.

Annex A - HAZOP Risk Matrix

The risk matrix in Figure 7.1 is used to classify the level of risk associated with a given hazardous event. It can be used for qualitative and semi-quantitative approaches.

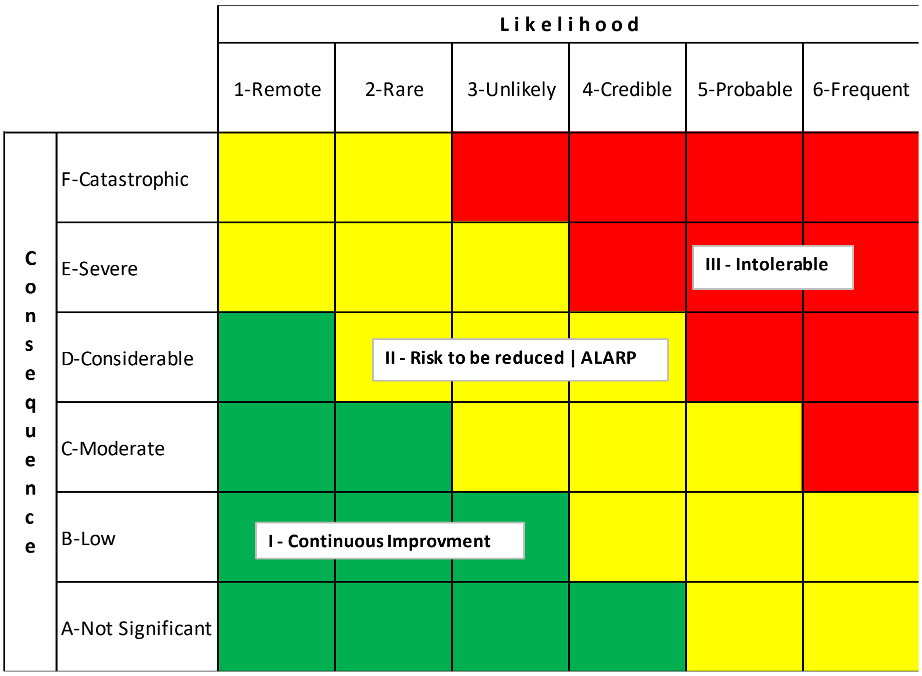


Figure 7.1 Risk Matrix

Impact and probability are used together to assign a final risk rating. The matrix defines three types of risk:

- **Risks to People:** Risks associated with dangerous activities that can result in serious accidents, causing injuries, fatalities or illnesses, both for workers and service providers and people in the community in general;

- **Environmental Risks:** Risks associated with hazardous activities that can result in serious accidents, causing damage to the environment with a direct impact on air, water or soil (inside or outside the facility) and biodiversity;
- **Asset Risk:** Risk of damage to the company's physical assets, impacts on production/operation in terms of failure to meet production objectives and the costs of replacing structures and equipment damaged due to incidents.

1. Assessment of Consequences

The team assigns a consequence level for each dangerous event scenario, defined in the risk matrix as 'Consequence'. This is classified into 6 levels (**A - Not significant; B - Low; C Moderate; D - Considerable; E - Severe; F - Catastrophic**)

Consequences should be assessed as if there were no preventative safeguards or post-event mitigations and the dangerous event could escalate to the final consequence.

The team can base its assessment of consequences on a qualitative discussion or interpretation of quantitative data for the scenario in question.

2. Determination of Likelihood

Given the dangerous event scenario, the team estimates the frequency with which the critical event could occur. This is determined using the risk matrix in the 'Likelihood column. The probability or frequency is also classified into 6 levels **(1 - Remote; 2 - Rare; 3 - Unlikely; 4 - Credible; 5 - Probable; 6 - Frequent**).

When determining the likelihood, the team considers the barriers and safeguards that are in place that are intended to prevent the event from starting or progressing to final consequences.

Whenever there are quantitative data regarding the frequency of the event, these must be used first; otherwise, the matrix defines qualitative criteria that must be used based on the team members' experience.

3. Risk Assessment

3.1 Tolerability criteria

Risk classification places hazardous events into three Levels:

- **Intolerable** - Any risk identified as intolerable must be reduced to a tolerable level. It is necessary to implement mitigation measures to ensure that the provisions control these risks;
- **Risk to be reduced | ALARP** - The risk level can only be tolerated when a structured review of risk reduction measures has been carried out. This means that all identified improvements must be implemented unless it can be demonstrated that there is a large disproportion between costs and benefits, by ALARP 6 principle (see 6
- **Continuous Improvement** - The level of risk is acceptable and only generic control measures to prevent the deterioration of existing controls or promote their improvement are necessary.

3.2 Determination of the risk level

Determining the risk level of a hazardous event starts with selecting the impact using the matrix's qualitative criteria, referring to physical damage to people, environment and assets. Likelihood determination follows. The risk level is the resulting intercept.

In cases where the level of risk found is in the “Intolerable zone” and whenever the scenario is a Serious Accident, within the scope of the Seveso directive:

- For the component of risks for people, modelling and analysis of risks must be carried out by the Seveso criteria;
- A quantitative assessment of environmental damage must be carried out for the component of threats to the environment.

Whenever there is a risk calculated as intolerable, regardless of the Seveso criteria, risk mitigation measures are always required to reduce it to a tolerable level.

4. Risk Treatment

Risks classified as intolerable are not acceptable and risks classified as ‘Risk to reduce|ALARP” must be reduced as much as possible to operate safely. The team is therefore required to make recommendations to address these risks.

4.1 Definition of safety barriers

The team must identify and specify safety barriers, in addition to those previously existing that it believes will be able to reduce the level of risk. The main lines of defence to consider are:

- Design barriers
- Hardware barriers, with particular attention to safety locks
- Human Safeguards
- Management System Elements.

The Operating Procedure regarding the identification and analysis of safety barriers guides helps the team manage the lines of defence for the Risk Analysis.

4.2 Calculation of Mitigated Risk

After defining mitigation measures, the team returns to the risk matrix and repeats the risk calculation. The process ends when efforts to introduce new mitigation measures become excessively disproportionate to the additional risk reduction achieved.

4.3 ALARP and Cost-Benefit Analysis

After defining the safety barriers, there may be risks that are still in the “Risk to reduce|ALARP” zone of the matrix. For those risks, the team has to provide sufficient evidence that all practicable measures have been identified and that only measures where the costs are manifestly disproportionate to the safety benefit provided have been rejected.

The cost-benefit analysis aids in the decision-making process by estimating values for the costs and benefits of implementing additional safety barriers.

For each risk that falls in the 'Risk to reduce|ALARP' zone, the team must do the following:

First step - approximate calculation of the feasibility of the barrier:

1) Discuss potential barriers and calculate the monetary value of risk loss

2) Calculate the approximate cost of implementing barriers;

3) If 2) exceeds 1), discard the measure;

4) For feasible measures, proceed to the second step.

Second step - detailed selection of viable barriers:

1) Determine the precise costs of the barrier (cost of installation, operation, formation, maintenance, loss of production, etc.);

2) Determine the precise benefits of the barrier (risk reduction for workers, members of the public and community, non-implementation of emergency services, etc.) translated into monetary values;

3) Decide whether or not to implement each barrier by comparing 1) and 2);

4) Reassess the risk considering the barriers selected to implement.

The process has achieved the objective if the reassessed risk is within the '**Continuous Improvement'** region. If it remains within the **'Risk to be reduced'** zone, the risk becomes ALARP and the process ends.

When applying a cost-benefit analysis, the team should take into account that:

- It cannot be used to argue against the implementation of relevant good practices or statutory duties;
- The depth of analysis must be adequate;
- It cannot justify intolerable risks.

Annex B – Typical MOC Changes

While some changes may be small and unlikely to compromise process safety, all changes have the potential for disruption. This annex presents non-exhaustive examples of modifications according to the Galp procedure "NT-P-028 - Serious Accident Risk Management" [76], which must be justified through a Management of Change procedure.

TECHNOLOGY OR PROCESS MODIFICATIONS

- Changes in process charges
- Changes in process variables
- Changes to product or component specifications
- Change in product quality control
- Changes in products or components stored, received or shipped, including waste
- Change of project inventories
- Change in the logistics circuit
- Change of additives
- Catalyst change
- Modification of operating procedures
- Modifications to operating conditions, including pressures, temperatures, flows, or process conditions that exceed the original design limits
- Modifications to the process or equipment imply operating above the design capability. This may include increasing rated capacity, operating at higher temperatures and pressures, modifying equipment sizing, or adding equipment that can contribute to higher depressurization needs.

INSTALLATION / EQUIPMENT MODIFICATIONS

- Design of new facilities that involve tie-ins or modifications to existing equipment or units
- Modifications to existing facilities, including the construction/assembly of new equipment
- Projects to increase the rated capacity of units or accommodate new power loads or products
- The modification that may change the classification of the installation by the provisions of DL 150/2015 or that requires the updating of the existing authorization or licenses
- The modification that changes existing licensing conditions or requires new licensing
- Bypass interconnections to equipment normally in service
- Modifications of operations and related procedures, including start-up, normal stop and emergency stop operations
- Introduction of new process additives
- Changes to the product contained in tanks and/or pipes
- Replacement of equipment/ machinery for another with different characteristics
- Alternative supply of process material, catalysts or reagents through temporary accumulators or tanks located inside the facility;
- Total or partial dismantling or deactivation of process units and equipment/facilities;
- Structural modification of equipment or its support
- New chemicals
- New discharge point for liquid or gaseous emissions
- Replacement or change of location of monitoring systems for gaseous or liquid emissions;
- Modifications of drainage networks
- The modification that alters the production of waste, effluents or emissions in terms of quality or quantity
- Modification of the layout of the facility or equipment
- Modification of stored, received or shipped products

- Addition, removal or modification of piping and valves
- Modifications of safety systems set points (e.g. in the control, setpoint, safety/relief/overfill valve fixed)
- Modification of safety trip process valves (ESDs, Trips, etc.)
- Modification of equipment outside the current specifications (i.e. motor size, rotor size, coatings, etc.)
- Modifications to the control system, strategies, loop diagrams and information flow; Modifications to UPS or emergency power supply equipment
- Modifications in the settings of electrical protections
- Modification of the scale of measuring instruments
- Modification, alteration and inhibition of alarms
- Introduction of new products or components
- Modification of material specification
- Use of spare parts not following the original specification
- Modification of engineering specification
- Modification of the type of interior or exterior coating (including painting and thermal or other insulation)
- Modifications to fire or spill fighting equipment (including location layout).

ENVIRONMENT MODIFICATIONS

- Changes in the ordering of circulation or parking on roads adjacent to the installation
- Modifications to the Municipal Master Plan
- Changes in the type or intensity of use of existing public facilities adjacent to the facility (e.g. parks, playgrounds, beaches, schools, etc.)
- Started the exploration or operation of new buildings that receive the public (e.g. schools, hospitals, churches, etc.) in the surroundings of the installation
- Installation of a new industrial, process or storage unit with a potential domino effect.

HUMAN RESOURCE MODIFICATIONS

- Transfer to critical function
- Temporary replacement of a critical function
- Reduction of the larger contingent than previously defined as the minimum size of teams that perform critical functions
- Transfer with critical function modification
- Elimination of critical function.

Annex C – Case #1 Diesel HAZOP Revalidation Worksheets

In this annex, as an example of the analysis carried out in the HAZOP of the Diesel Hydrotreatment unit, the worksheets referring to nodes 9, 10, 11 and 12 that correspond to the circuits connected to the Splitter T-1401 are presented.

PETROGAL S.A., REFINARIA DE MATOSINHOS
HAZOP Study

CLIENT: Fábrica de Combustíveis (FCO)

PROJECT NO: FCO_01

PROJECT: Dessulfuração U-1400

DETAILS: Capacidade da unidade = 1600 t/d (que corresponde a um aumento de 25% relativamente ao design original da unidade), com um produto (corte 150+) contendo no máximo 8 ppm de enxofre.
Alimentação à unidade:
400 t/d de gasóleo SR ARL,
800 t/d de querosene BNL65-MRL35,
300 t/d de querosene ARL e
100 t/d de nafta do visbreaker.

MEETING DATES: Conforme folha de presenças em anexo

TEAM MEMBERS

Manuel Leão (ML) - Coordenador do Hazop (Chairman)
ɔerações MOV
- Operações MOV
Equipa Hazop
) - Segurança
- Processo (FCO)
cesso (FCO)
) - Instrumentos
Automação
Inspecção Estática

ACTION RESPONSES TO: Equipa Hazop

DOCUMENTS STUDIED

Piping &Instrument diagrams
1927-PID-0021-001
1927-PID-0021-002a
1927-PID-0021-002b
1927-PID-0021-003
1927-PID-0021-004
1927-PID-0021-004_2
1927-PID-0021-005
1927-PID-0021-006
1927-PID-0021-001-2

Manual de Operação da Unidade
Memória descritiva do processo

OTHER DETAILS

- O Hazop às utilidades será efectuado conjuntamente com as restantes unidades da FCO.
- Nas falhas de válvulas de controlo estão consideradas todas as falhas inerentes ao loop.
- Os sistemas de F&G não foram considerados para efeitos de safeguards.

Será necessário:
- Desencadear processo de correcção/actualização dos diagramas P&I.
- Actualizar diagrama de causa-efeito com as novas seguranças processuais.
- Uniformizar a nomenclatura de instrumentação de acordo com as normas em vigor na RM.
- Avaliar a substituição da instrumentação digital e pneumática por instrumentação analógica (4-20mA).

PRIMARY KEYWORDS

Flow	Pressure	Temperatu re	Level	Compositi on
Other	Utilities	Sample		

SECONDARY KEYWORDS

No	Less	More	Reverse	Corrosion
Sample	Isolate	Drain	Vent/Purg e	Thermal Expansion
Maintenan ce	Contamina tion	Change	Other	Fire
Start up	Different	Vibration		

FREQUENCY CODES:
[0] Once per 1000 years
[1] Once per 100 years
[2] Once per 10 years
[3] Once per year
[4] Once per month

HAZARD CATEGORY CODES:
[1] Personnel Injury
[2] Equipment Damage
[3] Production Loss
[4] Environmental Impact
[5] External Reaction

SEVERITY CODES:
[0] Minor
[1] Appreciable
[2] Major
[3] Severe
[4] Catastrophic

RISK MATRIX

F4	2R	3R	4R	1U	2U
F3	1R	2R	3R	4R	1U
F2	2C	1R	2R	3R	4R
F1	1C	2C	1R	2R	3R
F0	0	1C	2C	1R	2R
	S0	S1	S2	S3	S4

F = Frequency Code
S = Severity Code

SEVERITY / HAZARD CATEGORY MATRIX

	0 Minor	1 Appreciable	2 Major	3 Severe	4 Catastrophic
1 Personnel Injury	Minor first aid required.	Lost time accident.	Injuries or illness requiring hospitalisation	Permanent disability, perhaps one fatality.	Multiple fatalities.
2 Equipment Damage	£0 - £5000.	£5001 - £50,000	£50,001 - £500,000	£500,001 - £5,000,000	> £5,000,000
3 Production Loss	Less than one hour.	Up to half a day.	One to five days.	Many weeks, significant loss to customer base.	Over one year, business unlikely to survive.
4 Environmental Impact	Limited to site, dispersed quickly by natural means	Noticeable off site impact, but local and short term.	Widespread but short term off site impact.	Long term pollution affecting large area.	Severe, requiring national efforts to mitigate damage.
5 External Reaction	Local gossip and minor complaints.	Local unfavourable newspaper and television reports.	Negative reports on national television / media.	Public enquiry, with protracted adverse media coverage.	Worldwide publicity, criminal prosecutions.

NODE: 9.0					DATE REVIEWED: 04/12/2013
ITEM: Coluna (T-1401)+ Topo (E-1404/5 + D-1403 + P-1403A/B) T1401; D-1403; P-1403A/B; E-1404 + E-1405 a funcionar em paralelo DRAWINGS AND DOCUMENTS 1927-PID-0021-003 TEAM MEMBERS: De acordo com a folha de presenças em anexo.					
DEVIATION		CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
40	Flow No	Alimentação T-1401 1. Ver nó 8.0 desvio Flow No			
42	Flow Less	1. Obstrução dos E-1404/5 2. Válvula de globo inadvertidamente fechada	1.1, 2.1 Instabilidade de operação (dificuldade de controlo da temperatura de topo da T-1401 com implicação na qualidade do produto; aumento da pressão de topo T-1401).	1.1.1, 2.1.1 PSV's 14503A/B; PSV 1408; PSV's 14506A/B	
43	Flow More	1. Ver nó 8.0 desvio Level Less	1.1 Ver nó 8.0 desvio Level Less	1.1.1Ver nó 8.0 desvio Level Less 1.1.2 Alarmes de nível LAH/LAHH1409	
47	Pressure Less	1. Ver nó 8.0 desvio Level More 2. PCV-1405 falha aberta ou bypass aberto 3. Válvula manual para a flare inadvertidamente aberta	2.1, 3.1 Sem consequências relevantes		
46	Pressure More	1. Ver nó 8.0 desvio Level Less 2. PCV-1405 falha fechada 3. FCV-1406 falha fechada	2.1, 3.1 Instabilidade da T-1401	2.1.1, 3.1.1 PSV's 14503A/B e 1408 3.1.2 Alarmes de pressão PAH/PAHH-1405	
48	Temperature More	1. Ver desvio Pressure More			

NODE: 9.0 (continued) DATE REVIEWED: 04/12/2013
ITEM: Coluna (T-1401)+ Topo (E-1404/5 + D-1403 + P-1403A/B)

	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
45	Level Less	T-1401 1. Falha LT-1409 D-1403 2. FCV-1406 falha aberta ou bypass aberto 3. FCV-14501 falha aberta ou bypass aberto 4. Falha LT-1410	1.1 Instabilidade na T-1401 1.2 Instabilidade da H-1402 (ver nó respectivo) 2.1, 3.1, 4.1 Perda de nível no D-1403 com consequente perda de refluxo e instabilidade na coluna	1.1.1, 2.1.1, 3.1.1 Alarmes de nível LAL/LALL-1410 1.2.1 ver nó H-1402 2.1.2, 4.1.1 Alarmes de pressão PAH/PAHH-1405 2.1.3, 4.1.2 PSV's 14503A/B	Avaliar a necessidade de instalar um alarme de temperatura alta no TI1401-20
	ACTION NO: 14 ASSIGNED TO: FCO-				
44	Level More	T-1401 1. Válvulas manuais inadvertidamente fechadas a jusante da T-1401 2. Falha LT-1409 D-1403 3. Falha das P-1403A/B 4. FCV-1406 falha fechada 5. FCV-14501falha fechada 6. Falha LT-1410	1.1, 2.1 Instabilidade T-1401 3.1, 4.1, 5.1, 6.1 Eventual arrastamento de fase líquida para a U-1600	1.1.1, Alarmes de nível LAH/LAHH1409 2.1.1,3.1.1, 4.1.1, 5.1.1 Alarmes de nível LAH/LAHH1410	Verificar se, em caso de falha do LT-1410, existem seguranças na U-1600 associadas ao eventual arrastamento de fase líquida.
49	Composition Other	1. Excesso de nafta de VB na carga à unidade	1.1 Instabilidade de pressão na T-1401	ver desvio Pressure More	

NODE: 10.0 DATE REVIEWED: 13/12/2013

ITEM: Circuito Reboiler da T-1401 (H-1402; circuito de FG para os queimadores e pilotos)

DRAWINGS AND DOCUMENTS
1927-PID-0021-003
1927-PID-0021-004_2

TEAM MEMBERS: De acordo com a folha de presenças em anexo.

	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
81	Flow No	Circuito carga 1.Paragem inadvertida das P-1402A/B 2. FCV-1411 falha fechada Circuito FG para Pilotos 3. PCV-1420 falha fechada. 4. Válvulas manuais inadvertidamente fechadas Circuitos FG queimadores 5. PCV-1419 falha fechada. 6. Válvulas manuais inadvertidamente fechadas.	Ver desvio Flow Less.		Verificar a existência/ avaliar a necessidade do corte FALCO 1420.
	ACTION NO: 26 ASSIGNED TO: FCO-Renato Fernandes				
82	Flow Less	Circuito carga 1. Obstrução da FCV-1411 Circuito FG para Pilotos 2. Obstrução da PCV-1420. Circuitos FG queimadores 3. Obstrução da PCV-1419. 4. Seccionamento parcial de queimadores	1.1 Danos nos tubulares da fornalha com potencial rotura e incêndio. 2.1. Eventual apagamento dos pilotos com risco de explosão (pior cenário). 3.1, 4.1 Upsets operacionais sem consequências relevantes.	1.1.1 Paragem da fornalha H-1402 por indicação do FT-1411 e actuação da EOV-1402 (queimadores) mantendo os pilotos acesos para segurança da fornalha. 4.1.1 Corte da fornalha por pressão baixa no circuito de FG para os queimadores PALCO1419.	Avaliar a necessidade de instalação de detectores de chama nos pilotos. Rever o estudo/diagrama causa-efeito do projecto de colocação de válvulas de corte rápido em fornalhas (filosofia de segurança dos pilotos)

NODE: 10.0 (continued) DATE REVIEWED: 13/12/2013 ITEM: Circuito Reboiler da T-1401 (H-1402; circuito de FG para os queimadores e pilotos)					
	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
83	Flow More	Circuito carga 1. P-1402A/B a operar em simultâneo Circuito FG para Pilotos 2. PCV-1420 falha aberta. Circuitos FG queimadores 3. PCV-1419falha aberta ou bypass aberto.	1.1 Sem consequências relevantes 2.1 Eventual apagamento dos pilotos. com risco de explosão (pior cenário). Ver acção do desvio Flow Less 3.1 Eventuais danos mecânicos na fornalha. Ver desvio Temperature More.		
84	Pressure Less	Circuito carga 1. Obstrução da FCV-1411 Circuito FG para Pilotos 2. Obstrução da PCV-1420. Circuitos FG queimadores 3. Obstrução da PCV-1419.	Ver desvio Flow Less		
85	Pressure More	H-1402 1. Damper inadvertidamente fechado (manual) 2. Damper falha fechado (sistema de controlo) Circuito carga Não identificadas Circuito FG para Pilotos 3. PCV-1420 falha aberta. Circuitos FG queimadores 4. PCV-1419 falha aberta ou bypass aberto.	1.1, 2.1, 4.1 Danos mecânicos na fornalha e risco de explosão. 3.1 Eventual apagamento dos pilotos. com risco de explosão (pior cenário).	1.1.1, 2.1.1, 3.1.1, 4.1.1 Existência de portas de explosão.	Corrigir o P&ID relativamente ao controlo do damper da fornalha. Adicionar um alarme de pressão alta na PIC-1496. Adicionar um corte da fornalha por pressão alta na câmara de combustão, pressão alta nos queimadores e pressão alta nos pilotos Confirmar a existência de alarme baixo de O2.
	ACTION NO: 27 ASSIGNED TO: FCO-Renato Fernandes				

NODE: 10.0 (continued) DATE REVIEWED: 13/12/2013 ITEM: Circuito Reboiler da T-1401 (H-1402; circuito de FG para os queimadores e pilotos)					
	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
86	Temperature More	Circuito carga 1.Paragem inadvertida das P-1402A/B 2. FCV-1411 falha fechada Circuitos FG queimadores 3. PCV-1419 falha aberta ou bypass aberto.	1.1, 2.1, 3.1 Danos na fornalha com potencial rotura e incêndio.		Avaliar a necessidade de colocar alarmes/cortes de/por temperatura alta na câmara de combustão (TI1401-24 e TI1401-25). Avaliar a necessidade de colocar alarmes de temperatura alta na TIC1404 Avaliar a necessidade de colocar alarmes de temperatura alta nas serpentinas da fornalha(temperaturas de pele TI1401-28 a e TI1401-33).
	ACTION NO: 24 ASSIGNED TO: FCO- Renato Fernandes				
87	Other Isolate	Circuito FG para pilotos 1. Ausência de isolamento remoto (automático) do circuito. 2. Válvula manual com passagem Circuito FG para queimadores 3. Válvula manual com passagem 4. PCV-1419 com passagem	1.1, 2.1, 3.1, 4.1 Eventual passagem de FG com eventual risco de atmosfera explosiva na câmara de combustão.		Implementar sistema de XV's (double block and bleed automático - standard Galp) nos circuitos de FG para os pilotos e queimadores.
	ACTION NO: 25 ASSIGNED TO: FCO-Renato Fernandes				

NODE: 11.0 DATE REVIEWED: 05/12/2013

ITEM: Fundo T-1401, P-1402A/B, E-1403A/B, E-1450/1, P-1407

DRAWINGS AND DOCUMENTS
1927-PID-0021-003

TEAM MEMBERS: De acordo com a folha de presenças em anexo.

	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
50	Flow No	1. Falha das P-1402A/B 2. Válvulas manuais inadvertidamente fechadas 3. XV-1401 falha fechada 4. LCV-1409 falha fechada 5. Falha da P-1407	1.1, 2.1, 3.1, 4.1 Instabilidade T-1401 devido ao aumento de nível do fundo. 1.2, 3.2 Impacto na operação da H-1402(paragem) 3.3 Cavitação da P-1402A/B com risco de sobreaquecimento 5.1 Sem consequências relevantes	1.1.1, 2.1.1, 3.1.1 Alarmes de nível alto LAH/LAHH1409 4.1.1 Não identificada 1.2.1, 3.2.1 Ver nó da H-1402 3.3.1 Lógica de segurança da XV-1401 que implica a paragem das P-1402A/B	Actualizar P&ID com a nova XV-1401 Avaliar a necessidade de colocar um alarme adicional para o caso de falha do LT-1409
	ACTION NO: 15 ASSIGNED TO: FCO- Renato Fernandes				
51	Flow Less	1. Obstrução dos E-1403A/B, E-1450/1	1.1 Sem consequências relevantes		
52	Flow More	1. LCV-1409 falha aberta ou bypass aberto	1.1 Falha de nível na T-1401 com consequente instabilidade na H-1402 e possíveis danos nas P-1402A/B 1.2 Eventual má aditivação do Jet	1.1.1 Alarmes de nível LAL/LALL-1409 1.2.1 Existência de PIE (Plano de Inspecção e Ensaio)	
55	Flow Reverse	1. Válvulas manuais inadvertidamente abertas	1.1 Eventuais danos nas P-1402A/B 1.2 Eventuais danos na P-1407	1.1.1 Check valves CHV-1402A/B 1.2.1 Check valve CHV-1429	
53	Pressure Less	1. Falha das P-1402A/B	1.1 Ver desvio Flow No		

NODE: 11.0 (continued) ITEM: Fundo T-1401, P-1402A/B, E-1403A/B, E-1450/1, P-1407					DATE REVIEWED: 05/12/2013
	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
54	Pressure More	1. Válvulas manuais inadvertidamente fechadas 2. válvula manual a jusante da CHV-1429 inadvertidamente fechada	1.1. Sem consequências relevantes (pressão de design da linha e permutadores) 2.1 Eventuais danos na P-1407	2.1.1 PSV-1413	Incluir no P&ID a pressão de disparo da PSV e o tag number da linha.
	ACTION NO: 28 ASSIGNED TO: FCO-Renato Fernandes				
58	Temperature More	1. Perda de rendimento nos permutadores de arrefecimento de petroleo	1.1. Volatilização elevada de produto na armazenagem, colocando eventualmente o equipamento numa condição insegura		Configurar alarme de temperatura alta TAH-1401.19 (existente P&ID)
	ACTION NO: 29 ASSIGNED TO: FCO-Renato Fernandes				
56	Composition Contamination	1. Válvula na linha de recirculação (start up) inadvertidamente aberta ou com passagem	1.1 Contaminação do produto de saída com a carga	1.1.1 Existência de PIE	
57	Other Isolate	1. Upset na produção	1.1 Eventual contaminação do produto		Avaliar a necessidade de incluir sistema automatizado na linha de recirculação e saída para armazenagem (semelhante à U-3700)
	ACTION NO: 30 ASSIGNED TO: FCO-Renato Fernandes				

NODE: 12.0				DATE REVIEWED: 09/12/2013
ITEM: Águas ácidas D-1401; D-1402; D-1403 (bota acumuladores); P-1451 DRAWINGS AND DOCUMENTS 1927-PID-0021-002b 1927-PID-0021-003 TEAM MEMBERS: De acordo com a folha de presenças em anexo.				

	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
62	Flow No	1. Ver desvio Level No			
63	Flow More	1. Ver desvio Level More			
66	Flow Reverse	P-1451 em serviço 1. Válvulas na saída da unidade fechadas	1.1 Eventual retorno pela linha 1 1/2"-D-0330-AA5	1.1.1 Check valves CHV-1420	
65	Pressure Less	1. Válvulas manuais advertidamente abertas para dreno 26	1.1 Ver desvio Level No		
64	Pressure More	1. Ver desvio Level No P-1451 2. Válvula manual inadvertidamente fechada Saída D-1401/2 3. Válvula manual inadvertidamente fechada na linha 1 1/2"-D-0330-AA5 D1401/2/3 4. Seccionamento inadvertido na linha dos BL's	2.1, 3.1 Eventual rotura da linha 4.1 Eventual subida de nível nas botas dos acumuladores 4.2 Eventual arrastamento de gás na fase líquida	2.1.1 PSV 14507 3.1.1 PSV's 14506 A/B 4.1.1, 4.2.1 Alarme de pressão PAH-1497	

NODE: 12.0 (continued) ITEM: Águas ácidas D-1401; D-1402; D-1403 (bota acumuladores); P-1451					DATE REVIEWED: 09/12/2013
	DEVIATION	CAUSE	CONSEQUENCE	SAFEGUARDS	ACTION
59	Level No	D-1401 1. LCV-1403 falha aberta ou bypass aberto 2. Válvulas manuais inadvertidamente abertas para dreno 26 D1402 3.Válvulas manuais inadvertidamente abertas 4. Válvulas manuais inadvertidamente abertas para dreno 26 D1403 5.Válvulas manuais inadvertidamente abertas	1.1 Eventual envio de HC's na fase líquida para o circuito de águas ácidas 2.1, 4.1 Eventual envio de HC's na fase líquida para dreno 26 3.1, 5.1 Eventual envio de HC's na fase líquida para o circuito de águas ácidas sem impacto relevante.	1.1.1 Alarmes de nível LAL/LALL 14506 e XV-14501	D-1401/2 Avaliar a necessidade de colocar uma válvula de homem-morto no circuito de purga para dreno 26 com LG visível D-1403 Esclarecer a filosofia de controlo de nível da bota do acumulador e actualizar P&ID (LCV-1418 e P-1451)
	ACTION NO: 16 ASSIGNED TO: FCO- Renato Fernandes				
60	Level Less	1. Obstrução do circuito de saída ou paragem das unidades a jusante (U3775/U10775)	1.1 Eventual passagem de HC do D-1401 para o D-1402/3	1.1.1 Check valves CHV-1420/24/36	
61	Level More	D-1401 1. LCV-1403 falha fechada 2. válvulas manuais inadvertidamente fechadas D-1402 3. válvulas manuais inadvertidamente fechadas D-1403 4. válvulas manuais inadvertidamente fechadas	1.1, 2.1 Arrastamento de água com os HC 3.1, 4.1 Arrastamento de água com os HC sem impacto relevante	1.1.1, 2.1.1 Alarmes de nível LAH/LAHH1403 e LAH14506	

Annex D – Case #2 Diesel HAZOP Revalidation Worksheets

In this annex, as an example of the analysis carried out in the HAZOP of the Diesel Hydrotreatment unit, the worksheets referring to nodes that correspond to the circuits connected to the Splitter T-1401 are presented.

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Page: 8 of 16

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Flow

Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
Less / No	2.1. Less / no flow	2.1.1. No flow from D-1402.	2.1.1.1. Low level in T-1401 leading to possible pump P-1402A/B cavitation. Seal / Pump damage. Possible flammable substance leakage.	2.1.1.1.1. LIC-1409. 2.1.1.1.2. LAL/LALL-1409. 2.1.1.1.3. Double seal.	R.2.1	Confirm that seal implemented in P-1402A/B is according to API standard.		
			2.1.1.2. No liquid flow through H-1402 leading to increase temperature in furnace coil. Possible coil damage and rupture.	2.1.1.2.1. TAH in skin temperature points. 2.1.1.2.2. FAL-1411 2.1.1.2.3. Interlock FALCO-1411, trips H-1402.				
		2.1.2. Pump P-1403A/B failure.	2.1.2.1. High level in D-1403 leading to liquid carry over to compressor C-1601A/B/C. Possible compressor damage.	2.1.2.1.1. LAH/LAHH-1410. 2.1.2.1.2. Spare pump. 2.1.2.1.3. D-1610, KO Drum in compressor C-1601A/B/C. 2.1.2.1.4. LIC-1661. 2.1.2.1.5. LAH/LAHH-1661. 2.1.2.1.6. Interlock LAHH-1602, trips compressor C-1601A/B/C.				
			2.1.2.2. Loss of reflux to T-1401 leading to possible high temperature / pressure and possible tower internal damage.	2.1.2.2.1. PAH/PAHH-1405. 2.1.2.2.2. Spare pump. 2.1.2.2.3. PSV-1408. 2.1.2.2.4. PSV-14503A/B.	R.2.2	Implement FAL in FT-1406.		
		2.1.3. Control loop FIC-1406 failure, closing FCV-1406.	2.1.3.1. Loss of reflux to T-1401 leading to possible high temperature / pressure and possible tower internal damage.	2.1.3.1.1. PAH/PAHH-1405. 2.1.3.1.2. PSV-1408. 2.1.3.1.3. PSV-14503A/B.				
		2.1.4. Control loop LIC-1410 failure, closing FCV-14501 (D-1403).	2.1.4.1. High level in D-1403 leading to liquid carry over to compressor C-1601A/B/C. Possible compressor damage.	2.1.4.1.1. D-1610, KO Drum in compressor C-1601A/B/C. 2.1.4.1.2. LIC-1661. 2.1.4.1.3. LAH/LAHH-1661. 2.1.4.1.4. Interlock LAHH-1602, trips compressor C-1601A/B/C.				
		2.1.5. Control loop LIC-1418 failure, opening LCV-1418 (D-1403).	2.1.5.1. Product contamination with water leading to quality issues.	2.1.5.1.1. Sampling.	R.2.3	Update control loop LIC-1418 / P-1451 configuration in P&ID D583-A0-001-1400N-3 Rev.11.		
		2.1.6. Pump P-1451 failure.	2.1.6.1. Product contamination with water leading to quality issues.	2.1.6.1.1. Sampling. 2.1.6.1.2. LAH/LAHH-1418. 2.1.6.1.3. Manual drain system.				
		2.1.7. XV-1401 closed when required to be...	2.1.7.1. No flow through P-1402A/B...	2.1.7.1.1. Limit switch valve.				

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Page: 9 of 16

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Flow

Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
		...opened.	...leading to pump cavitation. Seal / Pump damage. Possible flammable substance leakage.	2.1.7.1.2. Interlock ZSH-1401: Closed limit switch position trips pump P-1402A/B.				
			2.1.7.2. No liquid flow through H-1402 leading to increase temperature in furnace coil. Possible coil damage and rupture.	2.1.7.2.1. Limit switch valve. 2.1.7.2.2. TAH in skin temperature points. 2.1.7.2.3. FAL-1411 2.1.7.2.4. Interlock FALCO-1411, trips H-1402. 2.1.7.2.5. Interlock ZSH-1401: Closed limit switch position trips furnace H-1402.				
		2.1.8. Pump P-1402A/B failure.	2.1.8.1. High level in T-1401 leading to possible tower internal damage.	2.1.8.1.1. LAH/LAHH-1409. 2.1.8.1.2. Spare pump.				
			2.1.8.2. No liquid flow through H-1402 leading to increase temperature in furnace coil. Possible coil damage and rupture.	2.1.8.2.1. FAL-1411. 2.1.8.2.2. TAH in skin temperature points. 2.1.8.2.3. Spare pump. 2.1.8.2.4. Interlock FALCO-1411, trips H-1402.				
		2.1.9. Control loop FIC-1411 failure, closing FCV-1411.	2.1.9.1. No liquid flow through H-1402 leading to increase temperature in furnace coil. Possible coil damage and rupture.	2.1.9.1.1. TAH in skin temperature points.	R.2.4	Implement independent FT in FI-1411 in order to implement the interlock FALCO-1411 in case of control loop FIC-1411 failure.		
		2.1.10. Control loop LIC-1409 failure, closing LCV-1409 (T-1401).	2.1.10.1. High level in T-1401 leading to possible tower internal damage.	2.1.10.1.1. Not safeguard identified.	R.2.5	Implement redundant LT in T-1401 and configure LAH/LAHH.		
More	2.2. More flow	2.2.1. Control loop FIC-1406 failure, opening FCV-1406.	2.2.1.1. Less temperature in T-1401 leading to light compounds to white naphtha. Quality issues.	2.2.1.1.1. Sampling. 2.2.1.1.2. Temperature profile in T-1401.	R.2.6	Implement TAL in TI-1401-20.		
		2.2.2. Control loop LIC-1410 failure, opening FCV-14501 (D-1403).	2.2.2.1. Low level in D-1403 leading to pump P-1403A/B cavitation. Seal / Pump damage. Possible flammable substance leakage.	2.2.2.1.1. Double seal.	R.2.7 R.2.8	Confirm double seal in pump P-1403A/B. Implement LSL in D-1403 in order to trip pump P-1403A/B in case of low level.		
			2.2.2.2. Loss of reflux to T-1401 leading to possible high temperature / pressure and possible tower internal damage.	2.2.2.2.1. PAH/PAHH-1405. 2.2.2.2.2. PSV-1408. 2.2.2.2.3. PSV-14503A/B.		:Same As R.2.2		
		2.2.3. Control loop LIC-1418 failure, closing LCV-1418 (D-1403).	2.2.3.1. Low level in water boot of D-1403 leading to possible oil carry over to sour water unit. SWS contamination. Operational issues.	2.2.3.1.1. Oil / water separator drum in sour water unit.				
		2.2.4. XV-1401 opened when required to be closed.	2.2.4.1. Not possible to isolate T-1401 in case of external fire or leakage. Safety and environmental issues.	2.2.4.1.1. Valve limit switch. 2.2.4.1.2. Valve included in ESD (SIL 2).				

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Flow

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
				2.2.4.1.3. Fire Fighting System (FFS). 2.2.4.1.4. F&G system.				
		2.2.5. Control loop FIC-1411 failure, opening FCV-1411.	2.2.5.1. More recirculation in the bottom of T-1401 leading to possible high level in T-1401 bottom. Possible not fulfill temperature profile in T-1401. Operational and quality issues.	2.2.5.1.1. LIC-1409. 2.2.5.1.2. LAH/LAHH-1409. 2.2.5.1.3. TIC-1404.				
		2.2.6. Control loop LIC-1409 failure, opening LCV-1409 (T-1401).	2.2.6.1. Low level in T-1401 bottom leading to pump P-1402A/B cavitation. Seal / Pump damage. Possible flammable substance leakage.	2.2.6.1.1. Double seal. 2.2.6.1.2. FAL-1411.	 R.2.9	:Same As R.2.1 Implement redundant LT in T-1401, configure LAL/LALL and implement the P-1402A/B trip in case of low level in T-1401.		
Reverse / Misdirected	2.3. Reverse / Misdirected Flow	2.3.1. Pump P-1403A/B in spare position.	2.3.1.1. Possible pump inverse rotation. Possible pump damage.	2.3.1.1.1. Check valve in discharge.				
		2.3.2. Pump P-1402A/B in spare position.	2.3.2.1. Possible pump inverse rotation. Possible pump damage.	2.3.2.1.1. Check valve in discharge.				
		2.3.3. Pump P-1451 shut down.	2.3.3.1. Possible pump inverse rotation. Possible pump damage.	2.3.3.1.1. Check valve in discharge.				
		2.3.4. Pump P-1407 shut down.	2.3.4.1. Possible pump inverse rotation. Possible pump damage.	2.3.4.1.1. Check valve in discharge.				
		2.3.5. Heat exchanger E-1403A/B tube rupture.	2.3.5.1. Bottom to the feed of T-1401. Possible loss of T-1401 capacity. Not relevant consequences.					
		2.3.6. Heat exchanger E-1450/51 tube rupture.	2.3.6.1. Possible hot naphtha to cooling water side of E-1450/51 leading to cooling water contamination.	2.3.6.1.1. Sampling.				

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Pressure

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
More	2.4. Higher Pressure	2.4.1. See Less / No Flow and More Flow in this node.						
		2.4.2. Control loop PIC-1405 failure, closing PCV-1405.	2.4.2.1. High pressure in T-1401 / D-1403 leading to possible tower internal damage.	2.4.2.1.1. PSV-1408. 2.4.2.1.2. PSV-14503A/B.	R.2.10	Implement TAH in TI-14509.		
		2.4.3. External fire.	2.4.3.1. Increase pressure in pipes, vessels and heat exchangers leading to damage and domino effect.	2.4.3.1.1. PSV. 2.4.3.1.2. Fire Fighting System (FFS).				
		2.4.4. Any loss of containment or any pipe or equipment rupture.	2.4.4.1. Flammable substance release leading to pool fire or flammable cloud leading to potential explosion: potential operator injuries and equipment damage.	2.4.4.1.1. Fire Fighting System (FFS). 2.4.4.1.2. Personal Protection Equipment (PPE). 2.4.4.1.3. F&G system. 2.4.4.1.4. ATEX area classification.				
Less	2.5. Lower Pressure	2.5.1. See Less / No Flow and More Flow...						

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Pressure

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
		...in this node.						
		2.5.2. Control loop PIC-1405 failure, opening PCV-1405.	2.5.2.1. Low pressure in T-1401 top leading to possible heavy compounds to white naphtha. Quality issues.	2.5.2.1.1. Sampling.				

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Temperature

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
More	2.6. Higher Temperature	2.6.1. See More Pressure in this node.						
		2.6.2. Control loop TIC-1404 failure, more combustion in furnace H-1402.	2.6.2.1. High temperature / pressure in T-1401 bottom leading to heavy compounds to overhead drum. Quality issues.	2.6.2.1.1. PIC-1405. 2.6.2.1.2. PAH/PAHH-1405.	R.2.11	Implement TAH in TI-1401-26.		
			2.6.2.2. High temperature inside the furnace H-1402. Possible tube rupture leading to combustible substance to the combustion chamber. External fire. Equipment damage.	2.6.2.2.1. TAH in each skin point temperature.				
		2.6.3. Cooling water failure in E-1450/51.	2.6.3.1. High temperature in the bottom final product to storage. Possible high temperature in storage leading to possible storage damage.	2.6.3.1.1. TAH-1401-19. 2.6.3.1.2. TAH in storage system.				
		2.6.4. Air cooler E-1404/5 failure.	2.6.4.1. Not possible to condensate overhead fractionater stream leading to high pressure in T-1401 top. Possible tower internal damage.	2.6.4.1.1. PIC-1405. 2.6.4.1.2. PAH/PAHH-1405. 2.6.4.1.3. PSV-1408. 2.6.4.1.4. PSV-14503A/B.				
Less	2.7. Lower Temperature	2.7.1. Control loop TIC-1404 failure, less combustion in furnace H-1402.	2.7.1.1. Low temperature in T-1401 bottom leading to quality issues. Impact in flash point or initial boiling point (IBP).	2.7.1.1.1. Sampling.		:Same As R.2.6		

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Level

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
More	2.8. Higher Level	2.8.1. See Less / No Flow and More Flow in this node.						
Less	2.9. Lower Level	2.9.1. See Less / No Flow and More Flow in this node.						

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (ºC) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (ºC)
Drawings: D583-A0-001-1400N-3 Rev.11
Parameter: Composition

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
Other	2.10. Other Composition	2.10.1. Pump P-1407 failure when required to be running (chemical dosing failure).	2.10.1.1. Not antioxidant protection on jet fuel leading to quality issues.	2.10.1.1.1. Operational supervision.				

ompany: GALP
Facility: Matosinhos Refinery

Session: (2) 15/09/2017
Node: (2) STRIPPER SECTION: T-1401, H-1402, D-1403 and their equipment associated
Intention: Pdes= 3.5 - FV (kg/cm2g) / Tdes= 77 to 360 (°C) // Pop= 1.4 (kg/cm2g) / Top= 50 - 340 (°C)
Drawings: D583-A0-001-1400N-3 Rev.11
arameter: Utilities

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
ailure	2.11. Failure Utilities	2.11.1. Black out / Electricity failure from grid outside.	2.11.1.1. Difficulties in U-1400 control leading to potential unit shut down.	2.11.1.1.1. UPS from two sources.				
				2.11.1.1.2. Co-generation in refinery.				
		2.11.2. Internal blackout.	2.11.2.1. Difficulties in U-1400 control leading to potential unit shut down.	2.11.2.1.1. UPS from two sources.				
			2.11.2.2. Loss of external light .	2.11.2.2.1. Some lights are connected to emergency illumination.		:Same As R.1.12		
			2.11.2.3. Pump P-1403A/B failure. See less/no flow in this node.					
			2.11.2.4. Pump P-1451 failure. See less/no flow in this node.					
			2.11.2.5. Pump P-1402A/B failure. See less/no flow in this node.					
			2.11.2.6. Air cooler E-1404/5 failure. See more temperature in this node.					
		2.11.3. Cooling water failure.	2.11.3.1. Cooling water failure in E-1450/51. See More Temperature in this node.					
		2.11.4. Instrument air failure.	2.11.4.1. Valves go to safe position in case of instrument air failure.					

Annex E – Case #3 Gas Treatment Revalidation Worksheets

In this annex, as an example of the analysis carried out in the HAZOP of the Gas Treatment unit, the worksheets referring to nodes that correspond to the circuits connected to the deethanizer T-3601 are presented.

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Page: 1 of 14

Session: (1) 26/09/2017
Node: (1) DEETHANIZER T-3601 SYSTEM.
Drawings: B962-A0-50-36-10 Rev.6
5758-J-34A-00-301 Rev.7
Parameter: Flow

Intention: Pdes= 36.9 (kg/cm2g) / Tdes= 149 (ºC) // Pop= 32 (kg/cm2g) / Top= 50 - 100 (ºC)

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
Less / No	1.1. Less / no flow	1.1.1. No LPG from source (U-3000 / 1300 / 3300).	1.1.1.1. No flow to T-3601 leading to loss of temperature profile in T-3601 and low level in D-3601. Possible pump P-3601A/B cavitation. Seal / Pump damage. Possible flammable substance leakage.	1.1.1.1.1. LAL/LALL-3602. 1.1.1.1.2. Double seal (include PAH-3601A/B and LAL-3608A/B in seal system). 1.1.1.1.3. F&G System.	R.1.1 R.1.2	Implement FAL in FT-3601. Evaluate to trip P-3601A/B in case of low low level in D-3601.		
		1.1.2. Control loop LIC-3601 failure, closing FCV-3401 (MEROX Unit).	1.1.2.1. High level in T-3601 leading to possible high pressure and tower internal damage.	1.1.2.1.1. PAH/PAHH-3611. 1.1.2.1.2. PSV-3601A/B.	R.1.3	Evaluate to implement redundant LT in T-3601 and keep alarm configured.		
		1.1.3. Control loop FIC-3602 failure, closing FCV-3602.	1.1.3.1. No steam to E-3603 leading to low temperature / pressure in T-3601. More light cuts in the bottom. Quality issues.	1.1.3.1.1. TAL-3602. 1.1.3.1.2. PAL/PALL-3601.	R.1.4	Implement FAL in FT-3621.		
		1.1.4. Pump P-3601A/B failure.	1.1.4.1. No reflux to T-3601 leading to high temperature / pressure in T-3601. Possible tower internal damage.	1.1.4.1.1. PIC-3601. 1.1.4.1.2. PAH/PAHH-3601. 1.1.4.1.3. TAH/TAHH-3602 (TI01). 1.1.4.1.4. Spare pump. 1.1.4.1.5. Interlock FEV-3602, closes FCV-3602 in case of P-3601A/B failure. 1.1.4.1.6. PSV-3601A/B.				
			1.1.4.2. High level in D-3601 leading to LPG carry over to amine unit. High pressure in amine unit, possible damage and possible flammable cloud to atmosphere.	1.1.4.2.1. LAH/LAHH-3602. 1.1.4.2.2. Spare pump. 1.1.4.2.3. PIC-1554 (T-1501). 1.1.4.2.4. PSV-1551A/B (T-1501).				
		1.1.5. Control loop LIC-3602 failure, closing LCV-3602.	1.1.5.1. No reflux to T-3601 leading to high temperature / pressure in T-3601. Possible tower internal damage.	1.1.5.1.1. PIC-3601. 1.1.5.1.2. PAH/PAHH-3601. 1.1.5.1.3. TAH/TAHH-3602 (TI01). 1.1.5.1.4. PSV-3601A/B.				
			1.1.5.2. High level in D-3601 leading to LPG carry over to amine unit. High pressure in amine unit, possible damage and possible flammable cloud to atmosphere.	1.1.5.2.1. PIC-1554 (T-1501). 1.1.5.2.2. PSV-1551A/B (T-1501).	R.1.5	Implement redundant LT in LT-3602 and keep alarm configured.		
		1.1.6. Control loop LIC-3606 failure, closing LCV-3606.	1.1.6.1. High level in D-3653 leading to condensate formation in T-3603 and low temperature in T-3601. More light cuts in the bottom. Quality issues.	1.1.6.1.1. TAL-3602. 1.1.6.1.2. PAL/PALL-3601. 1.1.6.1.3. Interlock LAHCO-3607, force to open LCV-3606.				
		1.1.7. Pump P-3604 failure.	1.1.7.1. Possible quality issues in butane. Not relevant consequences (nowadays P-3604 is not necessary for operation).	1.1.7.1.1. Sampling.				

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Page: 2 of 14

Session: (1) 26/09/2017
Node: (1) DEETHANIZER T-3601 SYSTEM.
Drawings: B962-A0-50-36-10 Rev.6
5758-J-34A-00-301 Rev.7
Parameter: Flow

Intention: Pdes= 36.9 (kg/cm2g) / Tdes= 149 (ºC) // Pop= 32 (kg/cm2g) / Top= 50 - 100 (ºC)

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
More	1.2. More flow	1.2.1. Control loop LIC-3601 failure, opening FCV-3401 (MEROX Unit).	1.2.1.1. Low level in T-3601 bottom leading to possible high temperature / pressure in T-3601. Possible tower internal damage.	1.2.1.1.1. PAH/PAHH-3601. 1.2.1.1.2. PSV-3601A/B.		:Same As R.1.3		
			1.2.1.2. Possible high pressure in MEROX Unit (U-3400) leading to possible T-3401 damage.	1.2.1.2.1. PIC-3401. 1.2.1.2.2. PAH/PAHH-3401. 1.2.1.2.3. PSV in T-3401/2/3.				
		1.2.2. Control loop FIC-3602 failure, opening FCV-3602.	1.2.2.1. High temperature in T-3601 leading to high pressure in T-3601. Possible tower internal damage.	1.2.2.1.1. TAH/TAHH-3602 (TI01). 1.2.2.1.2. PAH/PAHH-3601. 1.2.2.1.3. PSV-3601A/B.				
		1.2.3. Control loop LIC-3602 failure, opening LCV-3602.	1.2.3.1. More reflux to T-3601 leading to low level in D-3601. Possible pump P-3601A/B cavitation and seal / pump damage. Possible flammable substance leakage.	1.2.3.1.1. Double seal (include PAH-3601A/B and LAL-3608A/B in seal system). 1.2.3.1.2. F&G System.		:Same As R.1.2 :Same As R.1.5		
		1.2.4. Control loop LIC-3606 failure, opening LCV-3606.	1.2.4.1. Low level in D-3653. Not relevant consequences.					
Reverse / Misdirected	1.3. Reverse / Misdirected Flow	1.3.1. Pump P-3601A/B in spare position.	1.3.1.1. Possible pump inverse rotation. Possible pump damage.	1.3.1.1.1. Check valve in discharge.				
		1.3.2. Pump P-3604 shut down.	1.3.2.1. Possible pump inverse rotation. Possible pump damage.	1.3.2.1.1. Double check valve in discharge.				
			1.3.2.2. Possible butane storage contamination with H_2S in case of overhead of T-3601 go through the pump to butane storage.	1.3.2.2.1. Double check valve in discharge.				
		1.3.3. Pump P-3605 shut down.	1.3.3.1. Possible reverse flow to inhibitor dosing system leading to possible tank damage and rupture. Flammable cloud to atmosphere.	1.3.3.1.1. Check valve in discharge.	R.1.6	Implement double check valve in P-3605 discharge.		
		1.3.4. Heat exchanger E-3651A/B tube rupture.	1.3.4.1. Bottom of T-3601 contamination with feed. Quality issues.	1.3.4.1.1. Sampling.				
		1.3.5. Heating coil E-3603 tube rupture.	1.3.5.1. Condensate contamination with LPG. Possible D-3653 pressurization and damage. Flammable cloud to atmosphere.	1.3.5.1.1. PSV-3608.	R.1.7 R.1.8	Study if PSV-3608 is designed for the case of E-3603 rupture and LPG depressurized from D-3653. If not, implement a PSV according the scenario and guarantee the safe location of downstream lines in case of LPG release. Implement PAH in PT-3603.		
		1.3.6. Heat exchanger E-3602 tube rupture.	1.3.6.1. Cooling water contamination with LPG. Quality issues.	1.3.6.1.1. Sampling.				
		1.3.7. Heat exchanger E-3604A/B tube rupture.	1.3.7.1. Cooling water contamination with ethane leading to possible flammable cloud in cooling tower.	1.3.7.1.1. F&G system. 1.3.7.1.2. ATEX area classification.				

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Session: (1) 26/09/2017
Node: (1) DEETHANIZER T-3601 SYSTEM.
Intention: Pdes= 36.9 (kg/cm2g) / Tdes= 149 (ºC) // Pop= 32 (kg/cm2g) / Top= 50 - 100 (ºC)
Drawings: B962-A0-50-36-10 Rev.6
5758-J-34A-00-301 Rev.7
Parameter: Temperature

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
More	1.6. Higher Temperature	1.6.1. See Less / No Flow in this node.						
		1.6.2. Control loop TIC-3611 failure, closing TCV-3611.	1.6.2.1. Not possible to condensate the top of T-3601 leading to possible high pressure in T-3601. Possible tower internal damage.	1.6.2.1.1. PIC-3601. 1.6.2.1.2. PAH/PAHH-3601. 1.6.2.1.3. TAH/TAHH-3602 (TI01). 1.6.2.1.4. PSV-3601A/B.				
			1.6.2.2. Low level in D-3601 leading to pump P-3601A/B cavitation. Seal / Pump damage. Possible flammable substance leakage.	1.6.2.2.1. LAL/LALL-3602. 1.6.2.2.2. Double seal (include PAH-3601A/B and LAL-3608A/B in seal system). 1.6.2.2.3. F&G System.		:Same As R.1.2		
		1.6.3. Cooling water failure in E-3604A/B.	1.6.3.1. Not possible to condensate the top of T-3601 leading to possible high pressure in T-3601. Possible tower internal damage.	1.6.3.1.1. PIC-3601. 1.6.3.1.2. PAH/PAHH-3601. 1.6.3.1.3. TAH/TAHH-3602 (TI01). 1.6.3.1.4. PSV-3601A/B.				
			1.6.3.2. Low level in D-3601 leading to pump P-3601A/B cavitation. Seal / Pump damage. Possible flammable substance leakage.	1.6.3.2.1. LAL/LALL-3602. 1.6.3.2.2. Double seal (include PAH-3601A/B and LAL-3608A/B in seal system). 1.6.3.2.3. F&G System.		:Same As R.1.2		
		1.6.4. Cooling water failure in E-3602.	1.6.4.1. Possible high temperature of LPG to MEROX Unit. Quality issues.	1.6.4.1.1. No safeguard identified.	R.1.11	Implement TT in the inlet line of T-3401 and configure TAH/TAHH.		
Less	1.7. Lower Temperature	1.7.1. See Less / No Flow and More Flow in this node.						
		1.7.2. Control loop TIC-3611 failure, opening TCV-3611.	1.7.2.1. Not relevant consequences in this node.					
		1.7.3. Steam failure in E-3603.	1.7.3.1. No steam to E-3603 leading to low temperature / pressure in T-3601. More light cuts in the bottom. Quality issues.	1.7.3.1.1. TAL-3602. 1.7.3.1.2. PAL/PALL-3601.		:Same As R.1.4		

Session: (1) 26/09/2017
Node: (1) DEETHANIZER T-3601 SYSTEM.
Intention: Pdes= 36.9 (kg/cm2g) / Tdes= 149 (ºC) // Pop= 32 (kg/cm2g) / Top= 50 - 100 (ºC)
Drawings: B962-A0-50-36-10 Rev.6
5758-J-34A-00-301 Rev.7
Parameter: Level

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
More	1.8. Higher Level	1.8.1. See Less / No Flow and More Flow in this node.						
Less	1.9. Lower Level	1.9.1. See Less / No Flow and More Flow in this node.						

HAZOP

Company: GALP
Facility: Matosinhos Refinery

Session: (1) 26/09/2017
Node: (1) DEETHANIZER T-3601 SYSTEM.
Intention: Pdes= 36.9 (kg/cm2g) / Tdes= 149 (ºC) // Pop= 32 (kg/cm2g) / Top= 50 - 100 (ºC)
Drawings: B962-A0-50-36-10 Rev.6
5758-J-34A-00-301 Rev.7
Parameter: Composition

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
Other	1.10. Other Composition	1.10.1. Inhibitor dosing malfunction.	1.10.1.1. No lines protections in overhead of T-3601 leading to increase corrosion rate. Pipelines damage and possible flammable substance leakage.	1.10.1.1.1. CT-3601 corrosion probe. 1.10.1.1.2. Sampling. 1.10.1.1.3. Operational supervision.				

Session: (1) 26/09/2017
Node: (1) DEETHANIZER T-3601 SYSTEM.
Intention: Pdes= 36.9 (kg/cm2g) / Tdes= 149 (ºC) // Pop= 32 (kg/cm2g) / Top= 50 - 100 (ºC)
Drawings: B962-A0-50-36-10 Rev.6
5758-J-34A-00-301 Rev.7
Parameter: Utilities

Guideword	Deviation	Causes	Consequences	Safeguard	REF#	Recommendation	BY	Comments
Failure	1.11. Failure Utilities	1.11.1. Black out / Electricity failure from grid outside.	1.11.1.1. Difficulties in U-3600 control leading to potential unit shut down.	1.11.1.1.1. UPS from two sources. 1.11.1.1.2. Co-generation in refinery.				
		1.11.2. Internal blackout.	1.11.2.1. Difficulties in U-3600 control leading to potential unit shut down.	1.11.2.1.1. UPS from two sources.				
			1.11.2.2. Pump P-3601A/B failure. See Less / No Flow in this node.					
			1.11.2.3. Pump P-3604 failure. See Less / No Flow in this node.					
		1.11.3. Cooling water failure.	1.11.3.1. Cooling water failure in E-3604A/B. See More Temperature in this node.					
			1.11.3.2. Cooling water failure in E-3602. See More Temperature in this node.					
		1.11.4. Steam failure.	1.11.4.1. Steam failure in E-3603. See Less Temperature in this node.					
		1.11.5. Instrument air failure.	1.11.5.1. Valves go to safe position in case of instrument air failure.					

Annex F – Case #4 Claus Unit HAZOP Comparision

DRAWING NUMBER	DESCRIPTION
RP-07-A1-108-00020-XXXXXXX-2001	Acid Gas K.O. Drums
RP-07-A1-108-00020-XXXXXXX-2002	Combustion Air Blowers
RP-07-A1-108-00020-XXXXXXX-2003	Thermal Reactor Burner control and ESD System
RP-07-A1-108-00020-XXXXXXX-2004	Thermal Reactor Burner
RP-07-A1-108-00020-XXXXXXX-2005	Thermal Reactor
RP-07-A1-108-00020-XXXXXXX-2006	Waste Heat Boiler
RP-07-A1-108-00020-XXXXXXX-2007	1st, 2nd, 3rd Sulphur Condenser
RP-07-A1-108-00020-XXXXXXX-2008	Catalyst Reactors & Reactor Reheaters
RP-07-A1-108-00020-XXXXXXX-2009	Sulphur Pit Rundown Section
RP-07-A1-108-00020-XXXXXXX-2010	Sulphur Degassing Column
RP-07-A1-108-00020-XXXXXXX-2011	Sulphur Pit Storage Section
RP-07-A1-108-00020-XXXXXXX-2012	Combustion Air preheaters & Blow down Cooler
RP-07-A1-108-00020-XXXXXXX-2013	TGT / Incinerator Diversion System TGTU
RP-07-A1-108-00020-XXXXXXX-2014	Tail Gas Heater & Hydrogenation Reactor TGTU
RP-07-A1-108-00020-XXXXXXX-2015	Quench Water TGTU
RP-07-A1-108-00020-XXXXXXX-2016	Quench Tower Cooling System TGTU
RP-07-A1-108-00020-XXXXXXX-2017	Absorber TGTU
RP-07-A1-108-00020-XXXXXXX-2018	Recycle Gas Preheater & Blower TGTU

DRAWING NUMBER	DESCRIPTION
RP-07-A1-108-00030-XXXXXXX-2030	Process Battery Limit Interconnections
RP-07-A1-108-00030-XXXXXXX-2040	Utilities Battery Limit Interconnections
RP-07-A1-108-00030-XXXXXXX-2041	Fuel Gas and Flare System
RP-07-A1-108-00030-XXXXXXX-2042	MP Steam Desuperheater
RP-07-A1-108-00030-XXXXXXX-2043	Instrument Air, Plant Air and Nitrogen Distribution
RP-07-A1-108-00030-XXXXXXX-2044	Potable, Service, Demineralized and Boiler Feed Water Distribution
RP-07-A1-108-00030-XXXXXXX-2045	Cooling Water Distribution
RP-07-A1-108-00030-XXXXXXX-2046	ILPS / Condensate Distribution
RP-07-A1-108-00030-XXXXXXX-2047	Amine Drain Header

The following documents were used during the Hazop sessions:

- Basis of Design Sulphur Recovery Unit (U-10800). Document number: No. RP-07-A4-108-95070-XXXXXXX-2002.
- Control and Safeguarding Narrative Sulphur Recovery Unit (U-10800). Document number: RP-07-A4-108-00110-XXXXXXX-2001.
- BEDP Licensor Package.

The node numbers and its descriptions are shown in the following table:

NODE NUMBER	DESCRIPTION
1	Amine Acid gas to X-10801 including D-10801 (Amine Acid Gas flow to E-10807 and to H-10801, both included)
2	SWS Acid gas to X-10801 including D-10802
3	Condensate from D-10801 and D-10802 to B.L. including P-10801 and P-10802 A/B
4	Combustion Air from B-10801 A/B to X-10801 and H-10801 including E-10805
5	Thermal Reactor Burner X-10801, Thermal Reactor H-10801 and E-10801 (tube side) including Process Gas from the Waste Heat Boiler E-10801 to the First Sulphur Condenser E-10802 A
6	Waste Heat Boiler E-10801 (medium pressure steam side)
7	First Catalytic Reactor R-10801 including the sulphur condenser E-10802 A and First Reactor Preheater E-10803
8	Process Gas from the sulphur condenser E-10802 B (including the steam side) to the Second Catalytic Reactor R-10802 including Second Reactor Preheater E-10804
9	Process Gas from the Sulphur Condenser E-10802 C to the Static Mixer X-10807 including Tail Gas Heater E-10807
10	Process Gas from the Static Mixer X-10807 to the Quench Tower including the Hydrogenation Reactor R-10803 and the Hydrogen injection to the Static Mixer X-10807
11	Quench Tower T-10801 and Tail Gas Flow to the Absorber T-10802 including Recycle Gas to B-10802
12	Quench Water Recycle to T-10801, including P-10805 A/B, Sour Water Filter (F-10801) and Quench Water Cooler (E-10808
13	Lean Amine Supply, Absorber T-10802 and Rich Amine to Battery Limit
14	Recycle Gas from T-10801/T-10802 including Recycle Gas Preheater E-10810 and Recycle Gas Blower B-10802
15	Liquid Sulphur from the Waste Heat Boiler E-10801 and from the Sulphur Condenser E-10802 A/B/C to Sulphur Pit TK-10801 (Degassing Compartment) including the Sulphur Traps (X-10802 to10805)
16	Liquid Sulphur from P-10803 A/B to the second pit compartment including the Degassing Column T-10803, the degassed air outlet and the hydraulic seal X-10806.
17	Degassing Air Supply from Preheater E-10811
18	Second Compartment Sulphur Pit TK-10801 and Liquid Sulphur Product to B.L. and recycled to the first pit
19	Steam ejectors system J-10801 A/B
20	Blow down from E-10801/E-10802 to Blow Down Cooler E-10806
21	Fuel Gas System
22	MP Steam Desuperheater
23	Instrument Air, Plant Air and Nitrogen Distribution
24	Potable, Service, Demineralized and Boiler Feed Water Distribution
25	Cooling Water Distribution
26	ILPS / Condensate Distribution
27	Amine Drain Header

NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 1	No Flow	1. Battery limit valve inadvertently closed.	1.1. Loss of feed.	Unit shutdown FALL-016 (UX-011)	1.1.1. Check and include in operating procedure to not close the B.L valve when unit is in operation.	Galp
			1.3. Potential pressure increase in amine unit.	No safeguard identified.	1.3.1. Check the high pressure protection in the amine unit.	Galp
	More Flow	7. Loop PIC-018 failure.	7.1. Increase in the duty needed to remove from thermal reactor X-10801.	LALL A/B/C-007 (2oo3): activating UX-011	7.1.1. Add a FAH to FT-005.	KTI /Fluor
	Higher Level	19. Liquid carryover from the amine unit.	19.1. Liquid carryover to the burner X-10801.	LAHH-003 A/B/C (2oo3): activating UX-011/016 LAH-002: activating UX-016	19.1.1. Confirm if it is possible to start/stop all pumps in the unit from DCS instead of ESD. TQ-2073 has been raised from Fluor to Galp to clarify this philosophy. Cause-effect matrix will be reviewed accordingly	Fluor / Galp
	Other Than Maintenance	24. Not possible to isolate lines.	24.1. Difficulties during maintenance.	No safeguards identified.	24.1.1. See note 5 (KTI will check that isolation means in vessels are according to the Project applicable standard and Fluor will review)	KTI / Fluor
		25. Difficulty to clean and/or remove the demister in D-10801	25.1. Difficulties during maintenance.	No safeguards identified.	25.1.1. Provide a suitable procedure to clean and remove the demister in D-10801 (ultimate solution could be change to flanged head).	KTI /Fluor
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 2	Less Temperature	39. Loss of jacketing media (steam).	39.1. Plugging and corrosion of lines and equipment.	Included in the operating manual the importance of keeping the tracing operating. Lines designed with no pockets	39.1.1. Add a TAL to TI-002.	KTI / Fluor
	Other Than Maintenance	45. Not possible to isolate lines.	45.1. Difficulties during maintenance.	No safeguards identified.	45.1.1. See note 5 (KTI will check that isolation means in vessels are according to the Project applicable standard and Fluor will review)	KTI / Fluor
NODE 3	No Flow	47. Manual valves inadvertently closed.	47.2. Possible pump damage	No safeguards identified.	47.2.1. Include in operating procedure.	Galp
	More Flow	48. Two pumps running at the same time.	48.1. Potential reverse flow from one drum to the other.	No safeguards identified.	48.1.1. Add check valves to lines AW-108-2001 -04/11 8next to AW-108-2016-06).	Fluor
NODE 4	Less Flow	62. FV-009 fails close.	62.1. Loss of sulphur recovery with no hazardous consequences.	FAL-009	62.1.1. Add a AAH to AI-004A/B/C (H2S and SO2)	KTI/ Fluor
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 6	No Level	111. Loop FIC-085 failure.	111.1. Potential tube damage in E-10801.	LALL-007 A/B/C. activating UX-011	111.1.1. Add a LAL to LT-007 A/B/C (to be shown in DCS).	Fluor
	More Level	115. Loop FIC-085 failure.	115.1. Water carryover with steam.	LAHH-007 A/B/C: activating UX-018.	115.1.1. A TQ has been raised from Fluor to Galp to clarify if LAHH-007 is a cause to shut down the Claus Unit. Answer required.	Galp
NODE 7	Higher Temperature	124. Excess oxygen in combustion air.	124.1. Potential sulphur fire inside R-10801.	TAH-023 A/B/C Nitrogen connection to cool R-10801 TAH-025 TAH-099 and TAHH-099: activating UX-020	124.1.1. Increase the nitrogen connection line (N-108-2043-XX-AA3D) from 3/4" to 1".	Fluor
	Other Than Maintenance	128. Exchanger E-10803 plugged.	128.1. Pressure increase.	No safeguards identified.	128.1.1. Change PG-038 for a strahman valve.	Fluor
NODE 8	No Flow in BW/ Steam/Blow down side	134. LV-011 fails close	134.1. BW Level decrease causing an efficiency loss and an increase in sulphur side temperature.	LAL-011 TAH-018/019/020	134.1.1. Add a LAL to LT-014	Fluor

NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 8	Higher Temperature	147. Excess oxygen in combustion air.	147.1. Potential sulphur fire inside R-10802.	TAH-024 A/B/C Nitrogen connection to cool R-10802 TAH-026 TAH-101 and TAHH-101: activating UX-021	147.1.1. Increase the nitrogen connection line (N-108-2043-XX-AA3D) from 3/4" to 1".	Fluor
	Other Than Maintenance	156. Exchanger E-10804 plugged.	156.1. Pressure increase.	No safeguards identified.	156.1.1. Change PG-039 for a strahman valve.	Fluor
	Other Than Other	157. Operability improvement.			157.1.1. Convert FI-041 into FIC-041 to form a cascade control with LIC-011.	Fluor
NODE 9	No Flow	159. HV-102 fails close.	159.1. Pressure increase in U-3800.	No safeguards identified.	159.1.1. Check the existing safeguards in U-3800 against pressure increase; in case it does not exist, add an appropriate one.	Galp
	Less Pressure	168. HV-103 or HV-104 fails open.	168.1. Loss of efficiency in TGTU unit.	Stack analyzer.	168.1.1. Add a discrepancy alarm between the limit switch indication and the selected position in the manual switch (for HV-103/104).	Fluor
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 9	Less Temperature	170. Steam tracing failure.	170.1. Potential line plugging causing a pressure increase in Claus Units.	PAHH-027 A/B/C: activating UX-011 PAHH-051 A/B/C: activating UX-041 PAH-052 TAL-103 TAL-047 TALL-049 C/F/I (2oo3): activating UX-041	170.1.1. Clarify in the P&Id the representation of the thermocouples that cause the activation of trip UX-041 from R-10803 (TAHH/TALL-049 C/F/I)	Fluor
	Other Than Maintenance	172. No bypass around HV-101/102	172.1. Need to shutdown the unit when doing maintenance in HV-101/102	No safeguards identified.	172.1.1. Evaluate possible alternative arrangement in HV-101/102 to do maintenance in them without having to stop the unit	KTI
NODE 12	No Flow	213. Loop FIC-067 failure.	213.1. See Higher temperature in node 11.	LAHH-022 A/B/C (2oo3): activating UX-044 TAH-054 FALL-068: activating UX-041	213.1.1. Study the possibility of installing a minimum flow protection for P-10805 A/B.	KTI
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 12	Reverse Flow	219. Higher pressure in condensates from SWS acid gas and amine gas.	219.1. No hazardous consequences identified.	No safeguards identified.	219.1.1. Install a check valve in line 1 1/2"-AW-108-2016-05 upstream the SWS acid gas condensate connection	Fluor
NODE 13	No Flow of Lean Amine.	228. Loop FIC-072 failure.	228.1. Loss of recovery sulphur efficiency.	AIH-007 (H2S analyzer) Hold 3 in P&Id 2017 Stack analyzer (SO2 and H2S)	228.1.1. AT-007 installation will depend on if it serves to measure the unit U-10800 efficiency. KTI will provide the efficiency method required.	KTI
	No Flow of Rich Amine	230. Loop LIC-024 failure	230.1. Increase in absorber level.	LAHH-025 A/B/C (2oo3): activating UX-042	230.1.1. Modify the LIC-024 putting it in cascade with FIC-070.	Fluor
NODE 14	Higher Pressure	256. Tube rupture in E-10810	256.1. Potential mechanical damage to system.	PSV-010	256.1.1. KTI will check the necessity and purpose of PSV-010 and the check valve at the inlet of the blower.	KTI
	Less Pressure	258. Blower B-10802 stopped during start-up or shutdown.	258.1. No recycle gas flow with potential reverse flow towards blower (mechanical damage)	Check valve	258.1.1. When blower details are known a Hazop must be made.	Galp / Fluor
	Less Temperature	261. Steam traps malfunctioning.	261.1. Cold recycle gas causing sulphur condensation when mixed with gas from Claus unit.	No safeguards identified	261.1.1. Add a TAL to TE-045	KTI/ Fluor

NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 14	Less Temperature	262. Tracing failure upstream the B-10802.	262.1. Liquid carryover to the blower causing potential damage.	LAHH-028: activating UX-046	262.1.1. Design the line between the blower and the condensate pot sloped towards the pot.	Fluor
				LAH-027		
NODE 15	No Flow	267. Line plugging.	267.1. Same as 266.1.	Recirculation line from pumps P-10804 to unplug the liquid sulphur lines.	267.1.1. Check with Sultrap supplier if the liquid sulphur recirculation is suitable with the traps.	Fluor
	More Level	280. Loop LIC-016 failure.	280.1. Potential flow of undegassed sulphur to second pit compartment.	No safeguards identified.	280.1.1. Add a LAH to LT-015.	Fluor
NODE 16	No Liquid Sulphur Flow	285. Plugging of the lines.	285.2. Potential pump P-10803 A/B damage	Minimum flow line (2"x3"-LS-108-2009-11-AA5J)	285.2.1. Add a LO to the minimum flow line valve.	Fluor
	No Degassing Air Flow	288. Loop PIC-047 failure.	288.1. Increase of pressure in degassing column T-10803 causing potential air flow through the hydraulic seal increasing the content of H_2S in the 2nd compartment of the pit (recovery efficiency reduction).	PAHH-046: activating UX-015	288.1.1. Add a PAH to PT-046.	KTI / Fluor
				PAH-045		

NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 16	No Degassing Air Flow to burner X-10801	289. Valve inadvertently closed.	289.1. Same as 288.1.	No safeguards identified.	289.1.1. Add a PAH to PT-047	KTI/ Fluor
	Less Liquid Sulphur Flow	294. Check valve plugged.	294.1. Same as no flow in this node.		294.1.1. Remove check valve in line 2"x3"-LS-108-2009-09-AA5J.	Fluor
	Less Degassing Air Flow	296. XV-118 inadvertently opened	296.1. Less Degassing Air Flow to burner X-10801.	No safeguards identified.	296.1.1. Add a FAL to FT-003	KTI / Fluor
					296.1.2. Add an alarm with time delay (2 minutes) when XV-118 and XV-104 are both open.	Fluor
	Higher Temperature	307. Fire inside the degassing column (when oxygen inside the column burning the sulphur).	307.1. Potential mechanical damage to column.	TAHH-033: activating UX-014/015	307.1.1. Confirm the activation of UX-014/015 with TAHH-033	KTI
				TAH-036		
				TAH-035		
				TAH-034		
	Other Than Maintenance	314. Different criteria for instrument purging.			314.1.1. Confirm if nitrogen or air to purge is required to purge the instruments.	KTI

NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 16	Other Than Maintenance	315. Difficulties during sulphur pumps maintenance.	315.1. Difficulties during maintenance		315.1.1. The steam traps for the condensate return from the pumps discharge jacketing should be in the same manifold (s).	Fluor
NODE 17	No Flow	319. Plugging in the jacketed line.	319.1. Same as 316.1	FALL-050: activating UX-015	319.1.1. Remove the check valve in the air inlet line to the degassing column T-10803.	KTI / Fluor
				FAL-049		
				PAH-045		
				PSV-007		
		320. Valve to atmosphere for start-up inadvertently opens during normal operation.	320.1. Same as 316.1	Operating procedures	320.1.1. Add a PAL to PT-045.	KTI / Fluor
	Higher Temperature	327. No causes identified.	327.1. No consequences identified		327.1.1. Remove TAH in TT-032	Fluor

NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 17	Other Than Composition	329. Nitrogen injection during normal operation.	329.1. More inert flow to degassing column decreasing its efficiency and decreasing the temperature in it.	TAL-035	329.1.1. Add a check valve between XV-117 and FE-049/050.	Fluor
				TAL-036 TAL-034	329.1.2. Remove one of the valves in the nitrogen injection line 1"-N-108-2043-14-AA3D and a purge upstream the one that is left.	Fluor
NODE 18	No Flow	332. Line plugged.	332.2. Potential pump damage.	Minimum flow line (2"x3"-LS-108-2011-03-AA5J)	332.2.1. Add a LO to the minimum flow line valve.	Fluor
	Reverse Flow	336. Pumps P-10804 A/B stopped during recycle operation to E-10801 and E-10802 A/B/C.	336.1. Undegassed liquid sulphur to pit second compartment.	No safeguards identified.	336.1.1. Include in operating procedure to close the recycle valve immediately after pumps P-10804 A/B are stopped during this operation.	Fluor
	More Level	344. Sulphur not discharged from the pit.	344.1. Overfilling of the pit	LAH-018	344.1.1. Add a LAH to LT-019	Fluor
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 21	No Flow	373. Manual valves inadvertently closed downstream F-10802.	373.1. No fuel gas to burner X-10801 during start-up not being able to light-it on.	PDALL-022: activating UX-011	373.1.1. Add a PAL to PT-016	KTI/ Fluor
					373.1.2. Add a new FT to FE-013 with a FALL.	KTI / Fluor
					373.1.3. Evaluate the need to incorporate the new FT to FE-013 to the ESD to shutdown the fuel gas lines to the burner.	KTI
NODE 21	No Flow	379. XV-108 fails open.	379.2. Fuel gas sent to atmosphere.	No safeguards identified.	379.2.1. Reduce line size of AV-108-2003-05-AA3.	Fluor
	More Flow	381. Loop FIC-013 failure.	381.1. Not stochiometric combustion causing deposition of ashes in the reactor.	No safeguards identified.	381.1.1. Add a new FT to FE-013 with a FAH.	KTI / Fluor
	Higher Level	386. Heavier hydrocarbon carryover with fuel gas.	386.2. Level increase in separator D-10803 causing liquid carryover to the U-3800 incinerator H-3802.	No safeguards identified.	386.2.1. Study the implementation of the required protection to protect the H-3802 incinerator.	KTI
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 22	Higher Pressure	390. Loop PIC-107 failure: opening PV-107A.	390.1. Pressure and temperature increase with potential mechanical damage to ILPS system.	PSV-020 A/B	390.1.1. Add a TAH to TIC-092.	KTI / Fluor
	Less Pressure	391. Loop PIC-107 failure.	391.1. No tracing in the lines.	No safeguards identified.	391.1.1. Add a new additional PT to PT-107 with an independent PAL.	KTI / Fluor
	Higher Temperature	393. Loop TIC-092 failure	393.1. Temperature increase with potential mechanical damage to ILPS system.	No safeguards identified.	393.1.1. Add a new additional TE to TE-092 with an independent TAH and a TAL.	KTI / Fluor
NODE 23	Other Than Other	398. No measurement required.	398.1. No consequences identified		398.1.1. Remove TG-082 in IA system in P&Id 2043.	Fluor
					398.1.2. Remove TG-088 in PA system in P&Id 2043.	Fluor
		399. Nitrogen measurement not available.	399.1. Not possible measurement		399.1.1. Evaluate the need to install a new FE/FT in nitrogen supply line 2"-N-108-2040-07-AA3D	Fluor
NODE	DEVIATION	CAUSES	CONSEQUENCES	SAFEGUARDS	RECOMMENDATIONS	BY
NODE 24	Other Than Other	400. No measurement required.	400.1. No consequences identified		400.1.1. Remove TG-109 in service water supply line in P&Id 2044.	Fluor
NODE 25	Other Than Other	401. Cooling water system pumps stopped.	401.1. No alarm available.		401.1.1. Add a PAL to PT-091	Fluor

DWG NUMBER	P&ID TITLE
RP-07-A1-108-00020-XXXXXXX-2001 Rev. 3	Sulphur Recovery Unit U-10800 Acid Gas K.O. Drums
RP-07-A1-108-00020-XXXXXXX-2002 Rev. 3	Sulphur Recovery Unit U-10800 Combustion Air Blowers
RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3	Sulphur Recovery Unit U-10800 Thermal Reactor Burner Control and ESD System
RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3	Sulphur Recovery Unit U-10800 Thermal Reactor Burner
RP-07-A1-108-00020-XXXXXXX-2005 Rev. 3	Sulphur Recovery Unit U-10800 Thermal Reactor
RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A	Sulphur Recovery Unit U-10800 Waste Heat Boiler
RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A	Sulphur Recovery Unit U-10800 1st, 2nd and 3rd Sulp hur Condenser
RP-07-A1-108-00020-XXXXXXX-2008 Rev. 3A	Sulphur Recovery Unit U-10800 Catalyst Reactors and Reactor Reheaters
RP-07-A1-108-00020-XXXXXXX-2009 Rev. 3A	Sulphur Recovery Unit U-10800 Sulphur Pit Rundown Section
RP-07-A1-108-00020-XXXXXXX-2010 Rev. 3	Sulphur Recovery Unit U-10800 Sulphur Degassing Column
RP-07-A1-108-00020-XXXXXXX-2011 Rev. 3	Sulphur Recovery Unit U-10800 Sulphur Pit Storage section
RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3A	Sulphur Recovery Unit U-10800 Combustion Air Preheater and Blow Down Cooler
RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3	Sulphur Recovery Unit U-10800 TGT/ Incinerator Diversion System TGTU
RP-07-A1-108-00020-XXXXXXX-2014 Rev. 3	Sulphur Recovery Unit U-10800 Tail Gas Heater and Hydrogenation Reactor TGTU
RP-07-A1-108-00020-XXXXXXX-2015 Rev. 3	Sulphur Recovery Unit U-10800 Quench Tower TGTU
RP-07-A1-108-00020-XXXXXXX-2016 Rev. 3	Sulphur Recovery Unit U-10800 Quench Tower Cooling System TGTU
RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3	Sulphur Recovery Unit U-10800 Absorber TGTU

RP-07-A1-108-00020-XXXXXXX-2018 Rev. 3	Sulphur Recovery Unit U-10800 Recycle Gas Preheater and Blower TGTU
RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3	Sulphur Recovery Unit U-10800 Vents to Incinerator
RP-07-A1-108-00030-XXXXXXX-2047 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 Amine Drain Header
RP-07-A1-108-00030-XXXXXXX-2040 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 Utilities Battery Limit Interconnections
RP-07-A1-108-00030-XXXXXXX-2041 Rev. 3A	Utility Distribution Diagram Sulphur Recovery Unit U-10800 Fuel Gas and Flare System
RP-07-A1-108-00030-XXXXXXX-2042 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 MP Steam Desuperheater
RP-07-A1-108-00030-XXXXXXX-2046 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 ILPS/ Condensate Distribution
RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 Instrument Air, Plant Air and Nitrogen Distribution.
RP-07-A1-108-00030-XXXXXXX-2044 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 Potable, Service, Demineralized and Boiler Feed Water Distribution
RP-07-A1-108-00030-XXXXXXX-2045 Rev. 3	Utility Distribution Diagram Sulphur Recovery Unit U-10800 Cooling Water Distribution
RP-07-A1-108-00020-XXXXXXX-2030 Rev. 3	Diagram Sulphur Recovery Unit U-10800 Process Battery Limit Interconnections
RP-07-A1-108-00020-XXXXXXX-2019 Rev. 3	Pump Seal Systems Pump Type OH
RP-07-A1-108-00020-XXXXXXX-2021 Rev. 3	Level Instrumentation Vent and Drains Line Index
061745-1 Rev. a00	Nitrogen Regeneration
DCM407209 Rev. 01	1.5 HPX 9A Centrifugal Pump – API Plan 11/53B

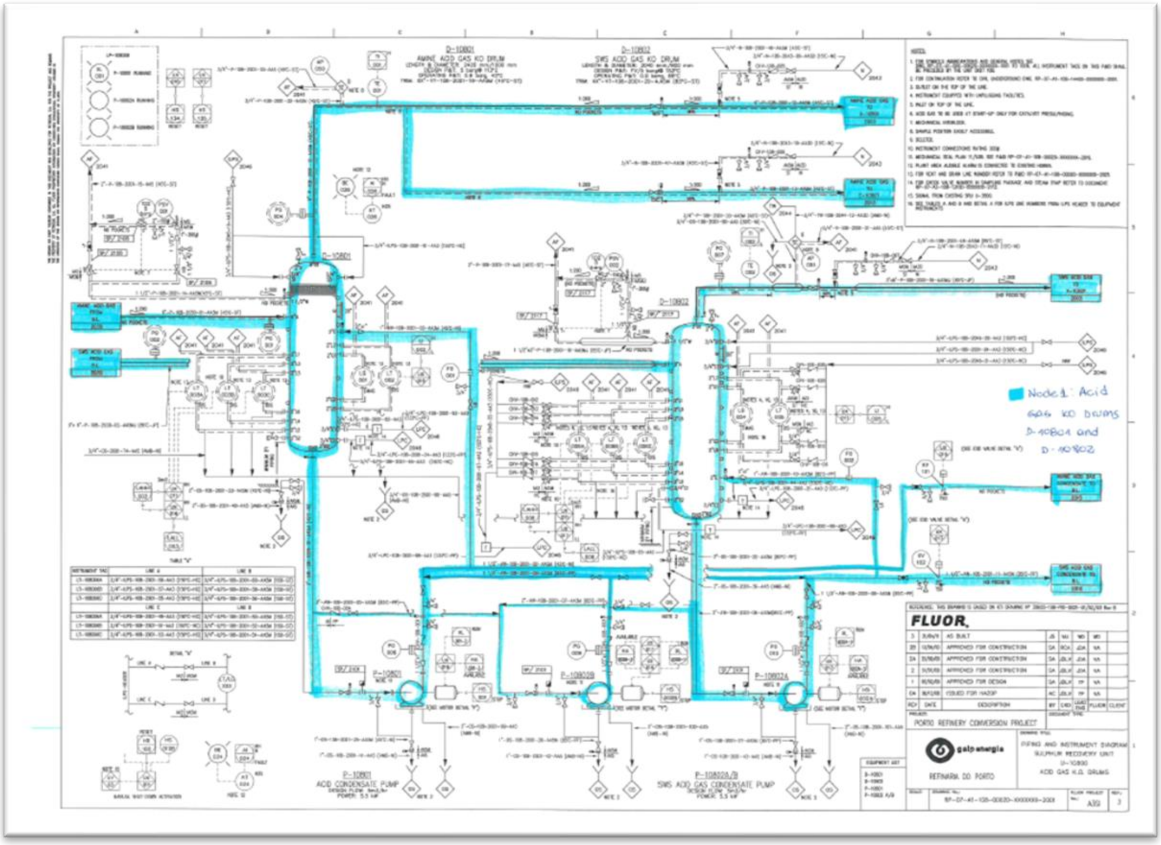
HAZOP U18000 – MATOSINHOS REFINERY		
Node	**Description**	**P&ID**
1	ACID GAS K.O. DRUMS D-10801 AND D-10802	RP-07-A1-108-00020-XXXXXXX-2001 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A
2	THERMAL REACTOR H-10801	RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2005 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3
3	COMBUSTION AIR BLOWERS B-10801 A/B	RP-07-A1-108-00020-XXXXXXX-2002 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3
4	WASTE HEAT BOILER E-10801	RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2044 Rev. 3
5	SULPHUR CONDENSER AND CATALYTIC REACTORS	RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2008 Rev. 3A

6	SULPHUR PIT TK-10801, DEGASING COLUMN T-10803 AND TRANSFER PUMPS P-10804 A/B	RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2009 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2010 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2011 Rev. 3
7	HYDROGENATION REACTOR R-10803	RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2014 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3
8	QUENCH TOWER T-10801	RP-07-A1-108-00020-XXXXXXX-2015 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2016 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2044 Rev. 3
9	AMINE ABSORBER T-10802 AND RECYCLE GAS	RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 DCM407209 Rev. 1 RP-07-A1-108-00020-XXXXXXX-2018 Rev. 3 061745-1 a00 RP-07-A1-108-00030-XXXXXXX-2045 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2047 Rev. 3
10	FLARE AND FUEL GAS SYSTEM	RP-07-A1-108-00030-XXXXXXX-2041 Rev. 3A
11	MP STEAM SYSTEM AND KPS DISTRIBUTION	RP-07-A1-108-00030-XXXXXXX-2042 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2046 Rev. 3
12	IA AND N2 DISTRIBUTION	RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3

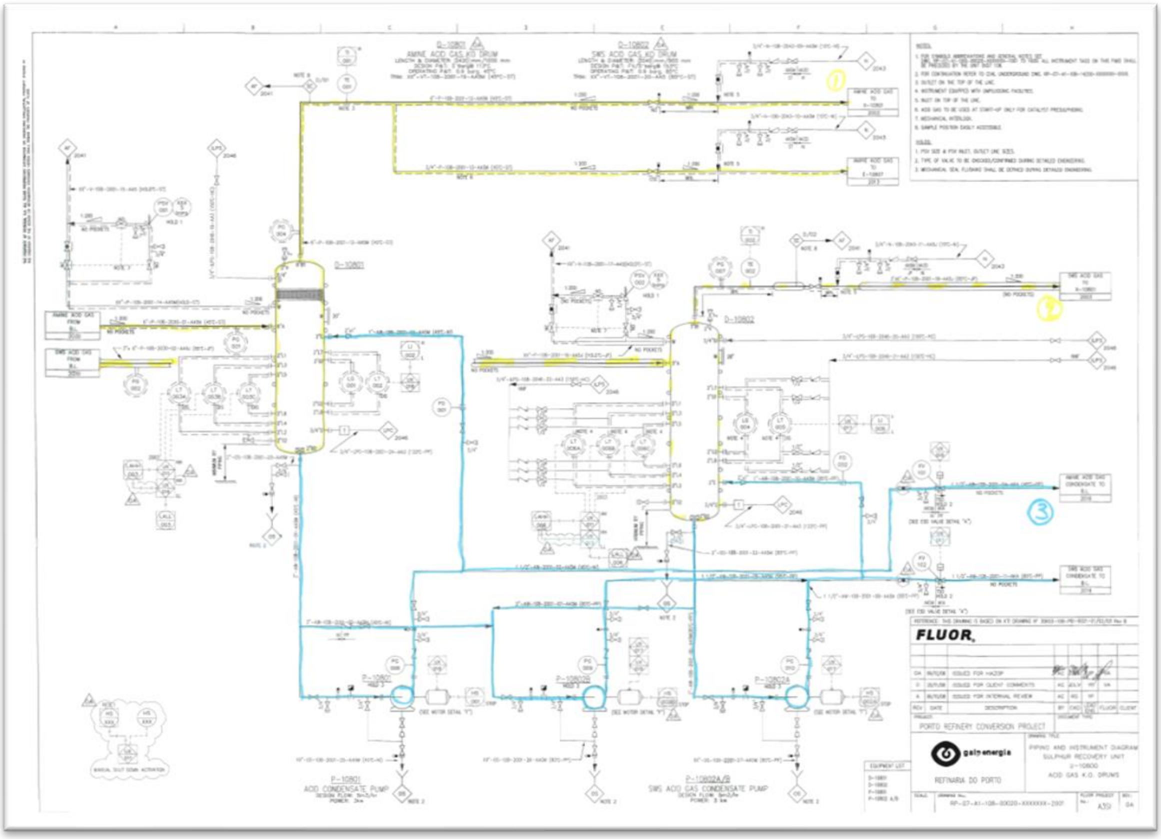
Node	Drawings	Risk Eval.	REF #	Recommendations
(1) ACID GAS K.O. DRUMS D-10801 AND D-10802	RP-07-A1-108-00020-XXXXXXX-2001 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A	II	R.1.1	Implement PAH-107001 reading in DCS visualization page S10802.
		I	R.1.2	Specify interlock number for UY activated by TAHH-1571 belonging to regeneration tower T-1502.
(2) THERMAL REACTOR H-10801	RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2005 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3	II	R.2.1	Update RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 indicating XZSO-113 / XZAO-113 on XV-113.
		II	R.2.2	Implement PAL on PI-028 and update RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3
		I	R.2.3	Update RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 indicating XZSO-107 / XZAO-107 on XV-107.
		II	R.2.4	Update RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 indicating XZSO-108 / XZAO-108 on XV-108.
		I	R.2.5	Update RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3 indicating XZSO-109 / XZAO-109 on XV-109.
		II	R.2.6	Update RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 indicating XZSO-114 / XZAO-114 on XV-114
		II	R.2.7	Implement CSO of nitrogen feed line to pyrometers of reactor H-10801 and update RP-07-A1-108-00020-XXXXXXX-2005 Rev. 3
		II	R.2.8	Confirm that FCV-007 digital maximum stop is implemented in DCS.
		II	R.2.9	Evaluate to install a mechanical maximum stop to FCV-008 to prevent excess of air to reactor H-10801
		III	R.2.10	As legal requirement a PSV shall be installed on E-10805 shell side.
		II	R.2.11	Implement FAL on FI-012 (SWS acid gas flow to burner X-10801).
(3) COMBUSTION AIR BLOWERS B-10801 A/B	RP-07-A1-108-00020-XXXXXXX-2002 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2003 Rev. 3	I	R.3.1	Remove PAL-014 from DCS and update PID RP-07-A1-108-00020-XXXXXXX-2002 Rev. 3 deleting low pressure alarm of PIC-013 and PIC-014.
(4) WASTE HEAT BOILER E-10801	RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2012 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2014 Rev. 3	II	R.4.1	Evaluate to change the blow down cooler makeup source from blow down of E-10801 to cooling water supply line.
(5) SULPHUR CONDENSER AND CATALYTIC REACTORS	RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2008 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A	II	R.5.1	Install a differential pressure gauge downstream R-10801 or a PG to be checked against PG-038.
		II	R.5.2	Install a differential pressure gauge downstream R-10802 or a PG to be checked against PG-039.
		II	R.5.3	Ensure during SIF verification that LI-014 has a proper SIL assignment.
(6) SULPHUR PIT TK-10801, DEGASING COLUMN T-10803 AND TRANSFER PUMPS P-10804 A/B	RP-07-A1-108-00020-XXXXXXX-2004 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2006 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2007 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2009 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2010 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2011 Rev. 3	III	R.6.1	Lock open pump P-10803 A/B minimum flow manual valve.
		III	R.6.2	Lock close bottom drain manual valve of T-10803.
		II	R.6.3	Correct the representation of UX-015 on LT-015 moving high and low-low alarms on LI-015.
		II	R.6.4	Review the effectiveness and reliability of the design of snuffing steam system. (corrosion issue due to CSO valves, delay in opening ILPS manual regulation valve)

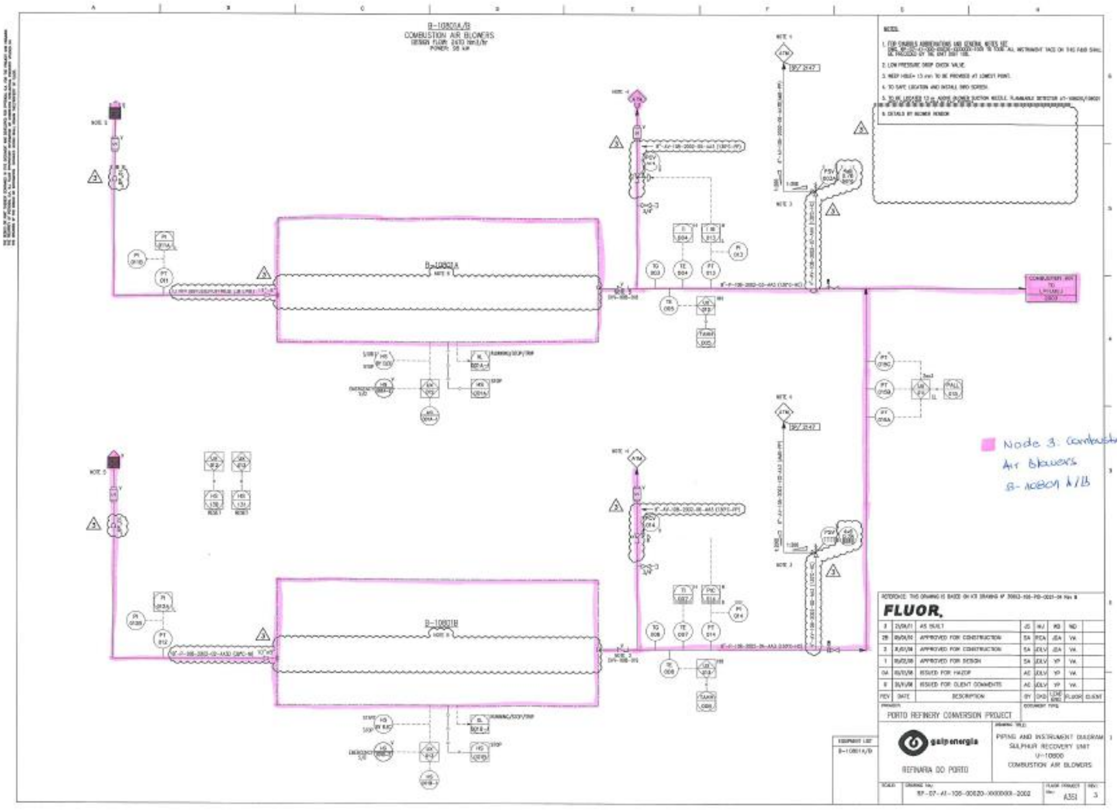
(7) HYDROGENATION REACTOR R-10803	RP-07-A1-108-00020-XXXXXXX-2013 Rev. 3A RP-07-A1-108-00020-XXXXXXX-2014 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3	II	R.7.1	Confirm that butterfly valve SP-2113 downstream HCV-101 guarantees a minimum passage area to avoid back pressure in H-10801.
		II	R.7.2	Confirm that butterfly valve SP-2113 downstream HCV-102 guarantees a minimum passage area to avoid back pressure in H-10801.
		II	R.7.3	Confirm that butterfly valve SP-2115 downstream HCV-103 guarantees a minimum passage area to avoid back pressure in H-10801.
		III	R.7.4	Consider to install a PAHH with proper SIL assignment upstream HCV-104.
		III	R.7.5	Confirm that butterfly valve SP-2115 downstream HCV-104 guarantees a minimum passage area to avoid back pressure in H-10801.
		II	R.7.6	Manual regulation valve upstream XV-119, shall be provided with minimum opening mechanical stop.
		II	R.7.7	Manual isolation valves downstream XV-119, shall be CSO.
		I	R.7.8	Review TAH-103 set point to be at least above TAH-047.
(8) QUENCH TOWER T-10801	RP-07-A1-108-00020-XXXXXXX-2015 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2016 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2044 Rev. 3	II	R.8.1	Implement an interlock that on high high pressure on PT-060 stops pumps P-10805 A / B.
(9) AMINE ABSORBER T-10802 AND RECYCLE GAS	RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2018 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2045 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2047 Rev. 3 061745-1 a00 DCM407209 Rev. 1	II	R.9.1	Indicate in PID RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 that AI-102 A/B measures H2S and COS
(10) FLARE AND FUEL GAS SYSTEM	RP-07-A1-108-00030-XXXXXXX-2041 Rev. 3A	II	R.10.1	Implement CSO on manual valve to fuel gas users represented in RP-07-A1-108-00030-XXXXXXX-2041 Rev. 3A.
		II	R.10.2	Implement CSC on bypass valve of filter F-10802 represented in RP-07-A1-108-00030-XXXXXXX-2041 Rev. 3A.
(12) IA AND N2 DISTRIBUTION	RP-07-A1-108-00030-XXXXXXX-2043 Rev. 3	III	R.12.1	Ensure during SIF verification that PCV-098 has proper SIL assignment.

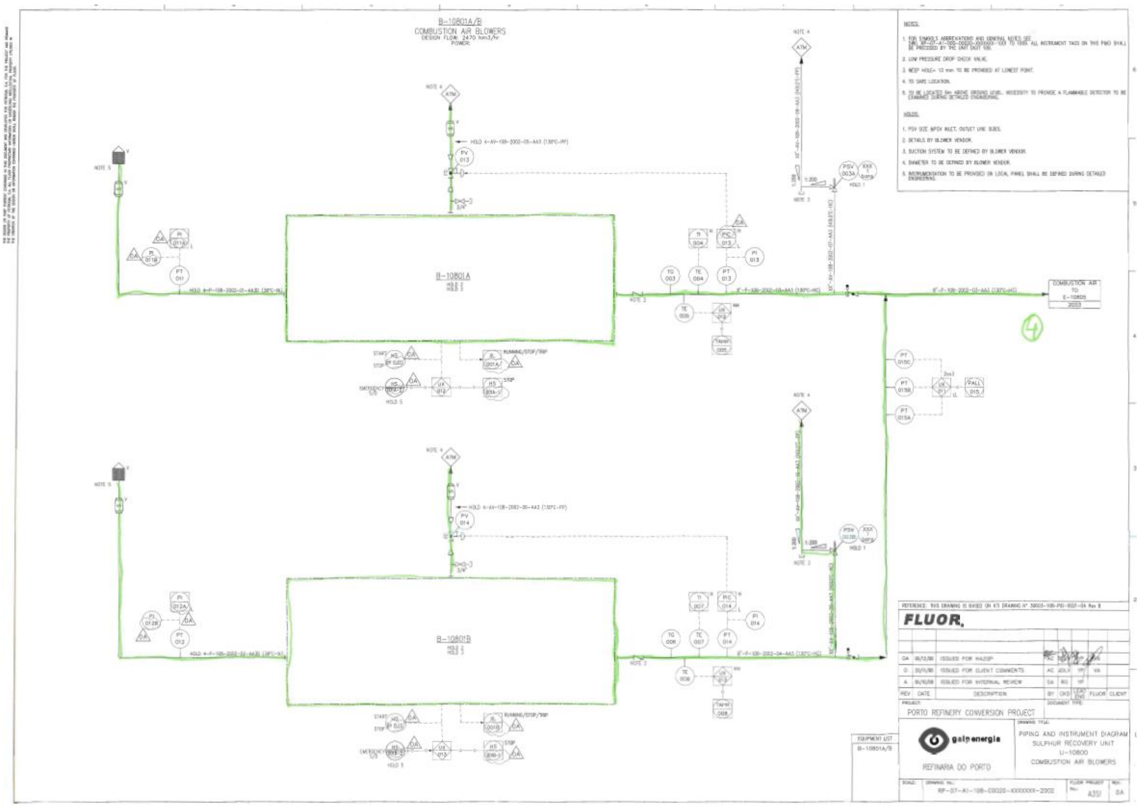
HAZOP CLAUS – Revalidation

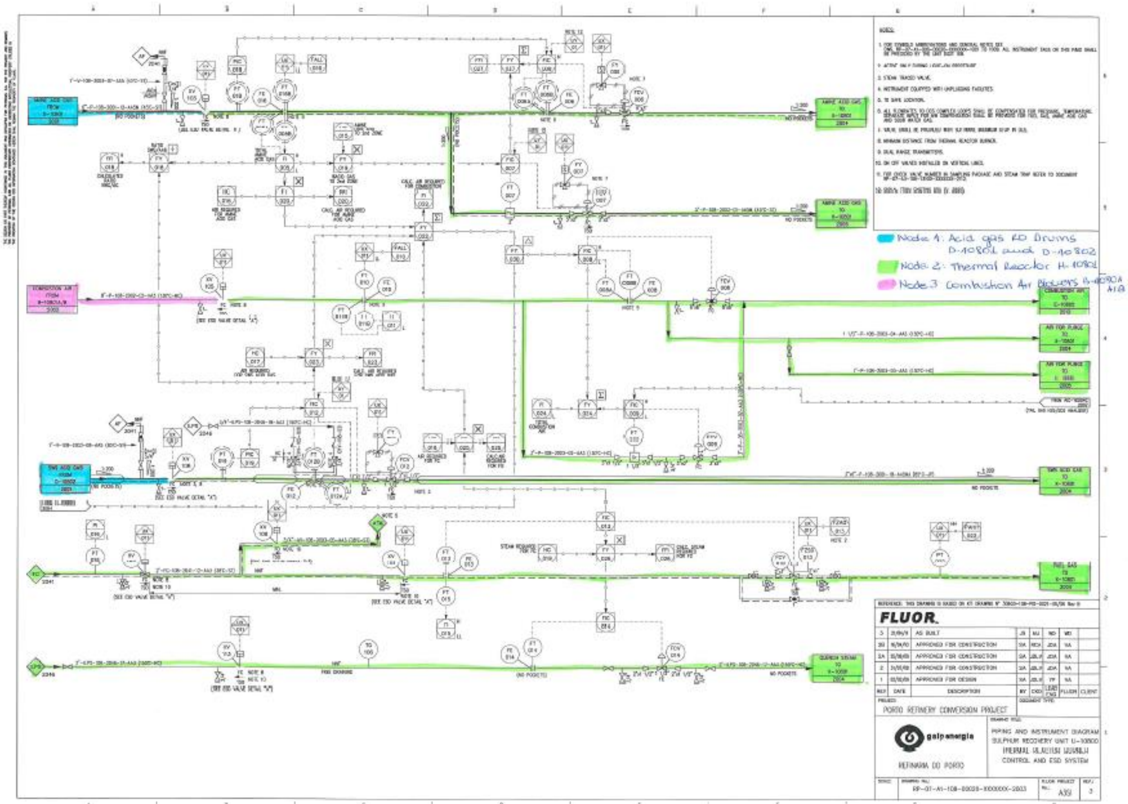


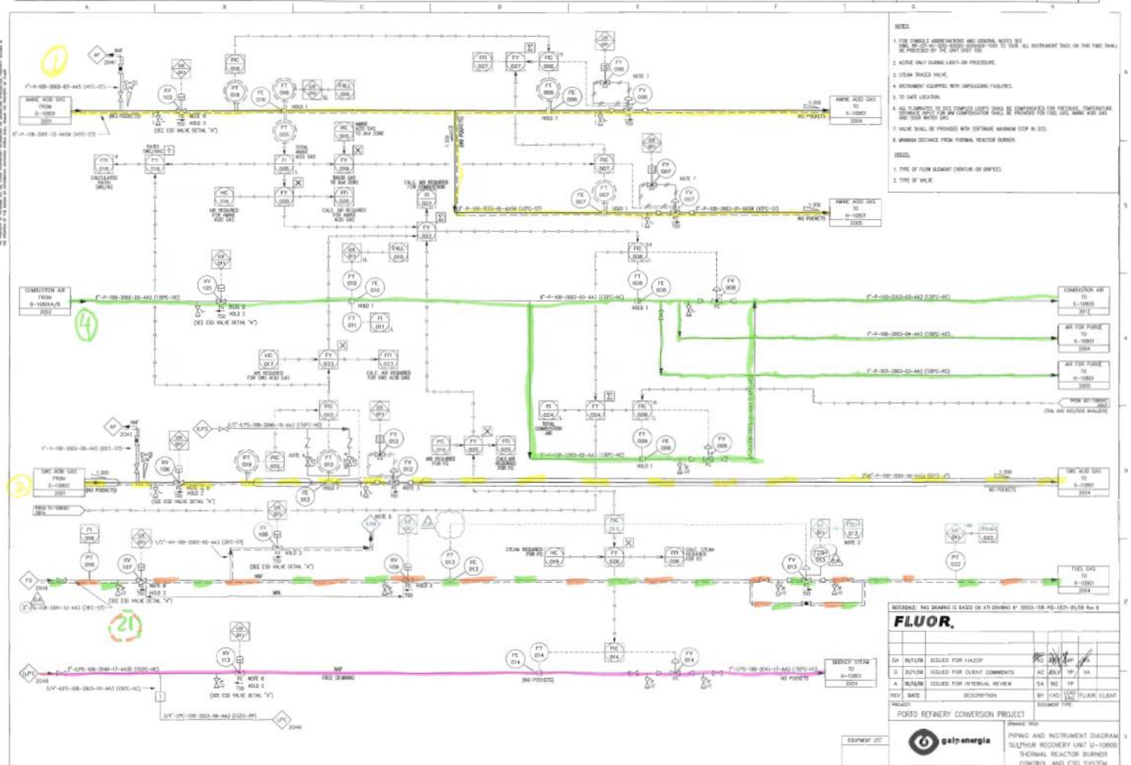
HAZOP CLAUS – Project




B-10801A/B
COMBUSTION AIR BLOWERS
NOTES:
B-10801A
B-10801B
Node 3: Combustion Air Blowers B-10801 A/B
FLUOR
PORTO REFINERY CONVERSION PROJECT
galpenergia
REFINARIA DO PORTO
PIPING AND INSTRUMENT DIAGRAM
SULPHUR RECOVERY UNIT
U-10800
COMBUSTION AIR BLOWERS


B-10801A/B
COMBUSTION AIR BLOWERS
NOTES:
B-10801A
B-10801B
4
FLUOR
PORTO REFINERY CONVERSION PROJECT
galpenergia
REFINARIA DO PORTO
PIPING AND INSTRUMENT DIAGRAM
SULPHUR RECOVERY UNIT
U-10800
COMBUSTION AIR BLOWERS


Node 1: Acid gas KO Drums D-10801 and D-10802
Node 2: Thermal Reactor H-10801
Node 3 Combustion Air Blowers B-10801A/B
FLUOR
PORTO REFINERY CONVERSION PROJECT
galpenergia
REFINARIA DO PORTO
PIPING AND INSTRUMENT DIAGRAM
SULPHUR RECOVERY UNIT U-10800
CONTROL AND ESD SYSTEM


FLUOR
PORTO REFINERY CONVERSION PROJECT
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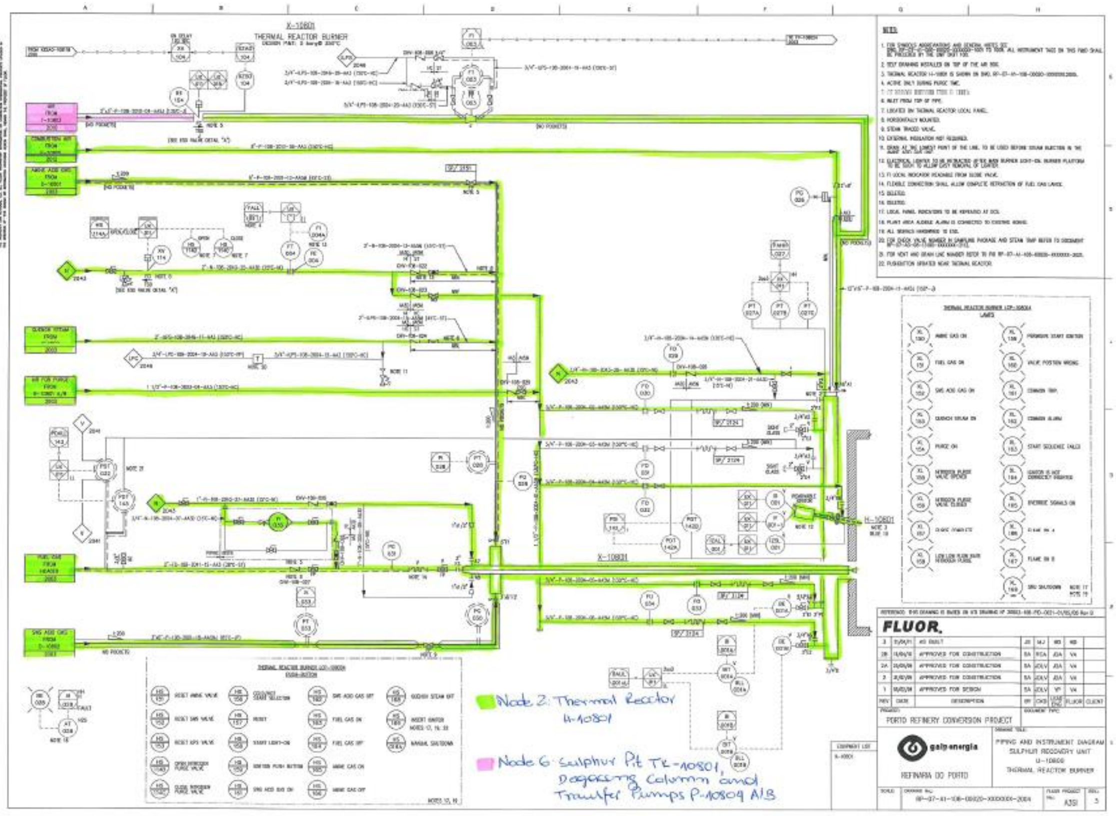
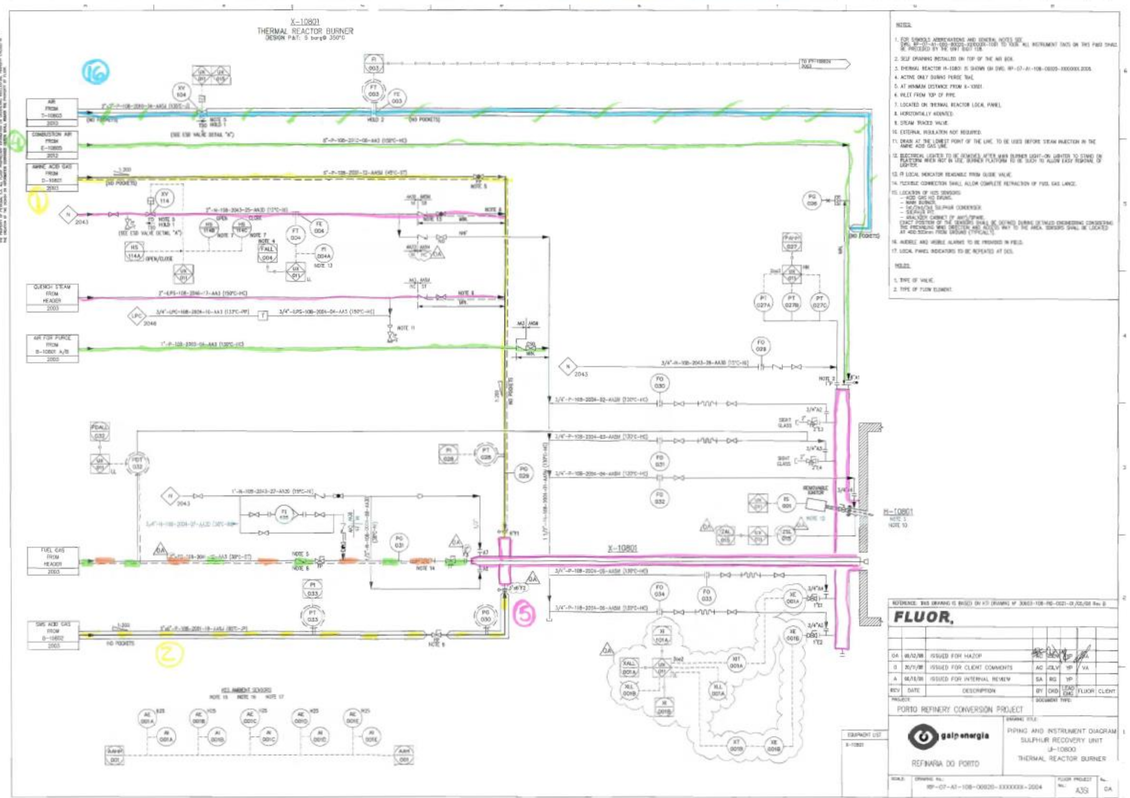
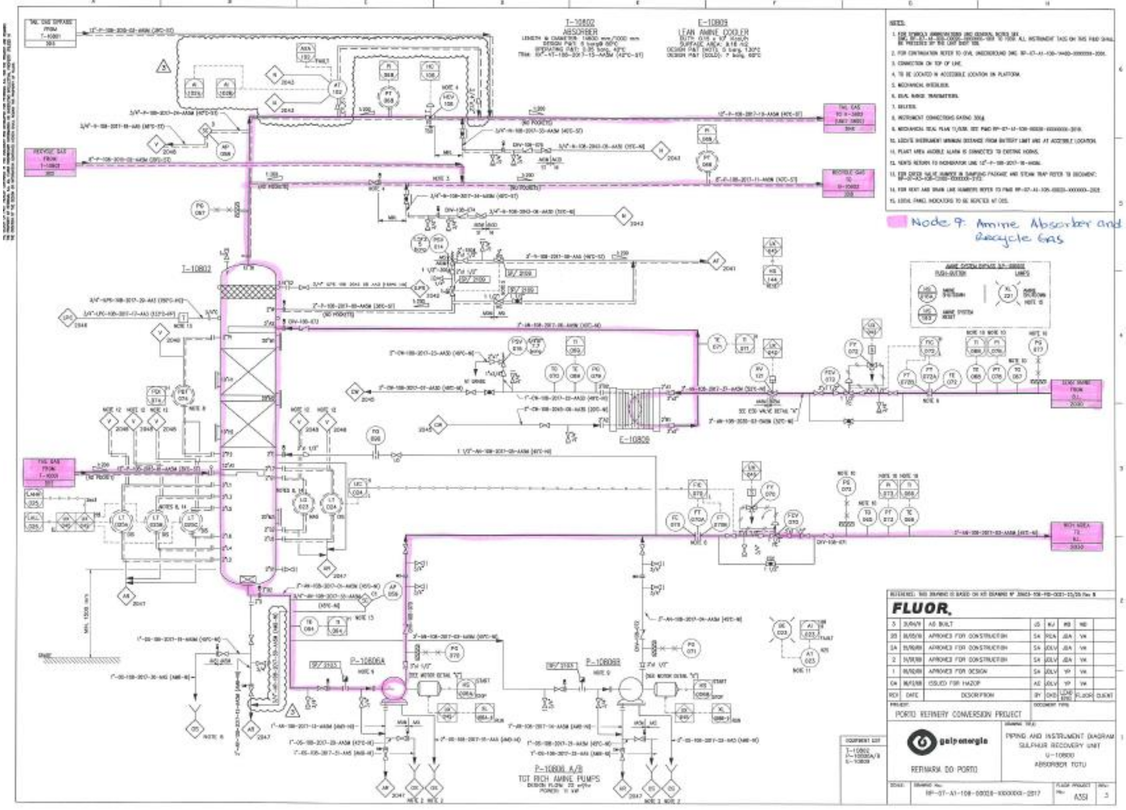
REFINARIA DO PORTO
PIPING AND INSTRUMENT DIAGRAM
SULPHUR RECOVERY UNIT U-10800
THERMAL REACTOR BURNER
CONTROL AND ESD SYSTEM

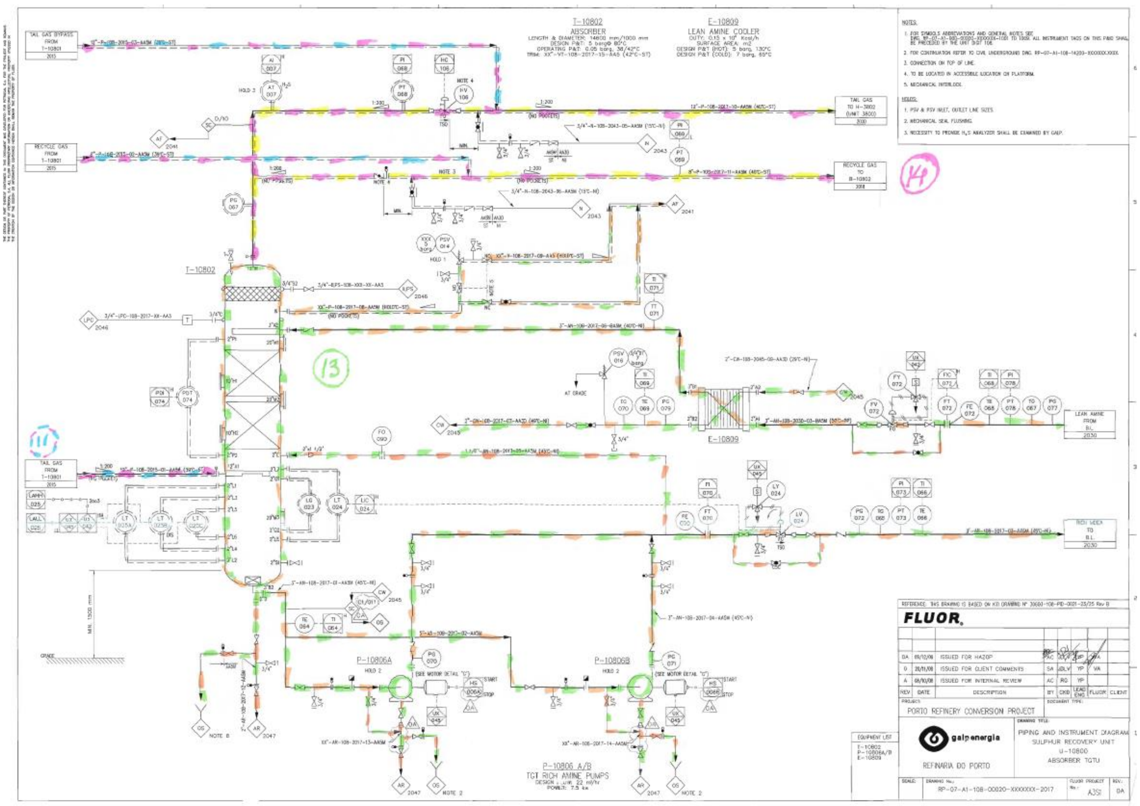

X-10801
THERMAL REACTOR BURNER
Node 2: Thermal Reactor H-10801
Node 6: Sulphur Pit TK-10801, Degassing Column and Transfer Pumps P-10804 A/B
FLUOR.
PORTO REFINERY CONVERSION PROJECT
galp energia
REFINARIA DO PORTO
PIPING AND INSTRUMENT DIAGRAM
SULPHUR RECOVERY UNIT
U-10800
THERMAL REACTOR BURNER


X-10801
THERMAL REACTOR BURNER
FLUOR.
PORTO REFINERY CONVERSION PROJECT
galp energia
REFINARIA DO PORTO
PIPING AND INSTRUMENT DIAGRAM
SULPHUR RECOVERY UNIT
U-10800
THERMAL REACTOR BURNER

Absorber T-10802 - Project



Absorber T-10802 - Revalidation



HAZOP CLAUS – Revalidation - T-10802 – node 9

(9) AMINE ABSORBER T-10802 AND RECYCLE GAS	RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2018 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3 RP-07-A1-108-00020-XXXXXXX-2048 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2045 Rev. 3 RP-07-A1-108-00030-XXXXXXX-2047 Rev. 3 061745-1 a00 DCM407209 Rev. 1	II	R.9.1	Indicate in PID RP-07-A1-108-00020-XXXXXXX-2017 Rev. 3 that AI-102 A/B measures H2S and COS

HAZOP CLAUS – Project - T-10802 – nodes 11, 13 and 14

NODE 13	No Flow of Lean Amine.	228. Loop FIC-072 failure.	228.1. Loss of recovery sulphur efficiency.	AIH-007 (H2S analyzer).Hold 3 in P&Id 2017 Stack analyzer (SO2 and H2S)	228.1.1. AT-007 installation will depend on if it serves to measure the unit U-10800 efficiency. KTI will provide the efficiency method required.	KTI
	No Flow of Rich Amine	230. Loop LIC-024 failure	230.1. Increase in absorber level.	LAHH-025 A/B/C (2oo3): activating UX-042	230.1.1. Modify the LIC-024 putting it in cascade with FIC-070.	Fluor
NODE 14	Higher Pressure	256. Tube rupture in E-10810	256.1. Potential mechanical damage to system.	PSV-010	256.1.1. KTI will check the necessity and purpose of PSV-010 and the check valve at the inlet of the blower.	KTI
	Less Pressure	258. Blower B-10802 stopped during start-up or shutdown.	258.1. No recycle gas flow with potential reverse flow towards blower (mechanical damage)	Check valve	258.1.1. When blower details are known a Hazop must be made.	Galp / Fluor
	Less Temperature	261. Steam traps malfunctioning.	261.1. Cold recycle gas causing sulphur condensation when mixed with gas from Claus unit.	No safeguards identified	261.1.1. Add a TAL to TE-045	KTI/ Fluor