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DEPARTMENT OF PROCESS ENGINEERING

Thesis

In the aim of obtaining the diploma of:

Master

Branch : Industrial Hygiene and Safety

Specialization : Industrial Process Safety and Risk Management

Risk Management of HDPE Reactor of CP2K Complex for the Process Safety Management System

"PSM" of SONATRACH

Condidate: - Hanane ALIDRA

Presented on June 24, 2026, in the presence of jury members:

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Year **2025- 2026**.

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MINISTÈRE DE L'ENSEIGNEMENT SUPÉRIEUR ET DE LA RECHERCHE SCIENTIFIQUE

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DÉPARTEMENT DE GÉNIE DES PROCÉDÉS

Mémoire

En vue de l'obtention du diplôme de :

Master

Filière : Hygiène et sécurité industrielle

Spécialité : Sécurité des procédés industriels et maîtrise des risques

Management des Risques dub Réacteur du PEHD du Complexe CP2K pour Système de Management de la Sécurité des Procédés "PSM" de SONATRACH

Réalisé par : - Hanane ALIDRA

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Année Universitaire **2025- 2026**.

Dedications:

My dedicates are addressed to:

My parents,

My family members,

My close and dear ones.

Gratitude's

I would like to express my gratitude to my Advisor, Doctor Manel HALASSI a Professor at University of August 20, 1955 – Skikda, for the trust she placed on me advice and encouragement;

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I want to express my gratitude to everyone who has helped me to make this work possible, no matter how little the contribution; in completing this project. Finally;

I can't end this without thanking my entire family, including close ones, for their support in completing my thesis.

Hanane

***Abstract*:**

Integrating process safety management system is increasingly essential for preventing accidents in chemical, petrochemical and petroleum process industry. This study addresses how practitioners perceive the PSM, identifying key benefits, barriers, and strategies for effective implementation. This approach was successfully applied in many industries in the world, SONATRACH also adopted it and developed a PSM reference and now integrating PSM system in all operational and units is in the top of its strategical objectives, and that to optimize resource use, reduce operational redundancies, and improve risk management. However, barriers such as knowledge gaps, resource constraints, and communication silos were identified. Respondents emphasized the importance of adopting a resilience-oriented approach involving proactive risk management, continuous improvement, and adaptability in both safety and security practices without missing Management of integrity and modifications. Critical enablers for integration include strong leadership, alignment of societal values, cross-disciplinary training, and integrated risk assessment methodologies. Emerging technologies and regulatory alignment were also identified as critical factors in facilitating integration. The study contributes to the theoretical understanding of integrated risk management by supporting resilience engineering and systems theory. It offers actionable strategies for overcoming barriers and leveraging enablers, laying the groundwork for developing a resilience-oriented framework for process safety and process security risk management. This investigation explores how practitioners view the PSM, pinpointing significant benefits, challenges, and tactics for effective execution. This strategy has been successfully implemented in numerous industries worldwide, and SONATRACH has similarly adopted it, establishing a PSM reference. Presently, the incorporation of the PSM system into all operational units is among its foremost strategic goals and this to optimize resource use, reduce operational redundancies, and improve risk management.

Keywords: *PSM, SONATRACH, Process Safety, Risk Management, HDPE Reactor, Hazards*

Résumé :

L'intégration d'un système de gestion de la sécurité des processus devient de plus en plus cruciale pour prévenir les accidents dans l'industrie chimique, pétrochimique et pétrolière. Cette étude examine la perception des praticiens concernant le PSM, en identifiant les principaux avantages, obstacles et stratégies pour une mise en œuvre efficace. Cette approche a été appliquée avec succès dans de nombreuses industries à travers le monde, SONATRACH l'a également adoptée et a développé une référence PSM. Actuellement, l'intégration du système PSM dans toutes les unités opérationnelles figure parmi ses objectifs stratégiques prioritaires, visant à optimiser l'utilisation des ressources, réduire les redondances opérationnelles et améliorer la gestion des risques. Cependant, des obstacles tels que les lacunes en matière de gestion des connaissances, les contraintes de ressources et de communication ont été identifiés ainsi que management de l'intégrité et de modification. Les répondants ont souligné l'importance d'adopter une approche axée sur la résilience, impliquant une gestion proactive des risques, une amélioration continue et une adaptabilité tant dans les pratiques de sécurité que de sûreté. Les facteurs clés pour l'intégration comprennent un leadership fort, l'alignement des valeurs sociétales, une formation interdisciplinaire et des méthodologies d'évaluation des risques intégrées. Les technologies émergentes et l'alignement réglementaire ont également été identifiés comme des facteurs critiques facilitant l'intégration. L'étude contribue à la compréhension théorique de la gestion des risques intégrés en soutenant l'ingénierie de la résilience et la théorie des systèmes. Elle propose des stratégies concrètes pour surmonter les obstacles et tirer parti des facilitateurs, posant ainsi les bases du développement d'un cadre axé sur la résilience pour la gestion des risques de sécurité des processus et de sûreté des processus. Cette enquête explore comment les praticiens perçoivent le PSM, en identifiant des avantages significatifs, des défis et des tactiques pour une exécution efficace. Cette stratégie a été mise en œuvre avec succès dans de nombreuses industries à l'échelle mondiale, et SONATRACH l'a également adoptée, établissant une référence PSM. Actuellement, l'incorporation du système PSM dans toutes les unités opérationnelles est l'un de ses principaux objectifs stratégiques, visant à optimiser l'utilisation des ressources, réduire les redondances opérationnelles et améliorer la gestion des risques.

Mots clés : *PSM, SONATRACH, Sécurité des Procédés, Maitrise des Risques, Réacteur du PEHD, Dangers*

الملخص:

إدماج نظام إدارة سلامة العمليات أصبح أمرًا ضروريًا بشكل متزايد لمنع الحوادث في عمليات الصناعة الكيميائية والبتروكيماوية وكدلك النفطية. تتناول هذه الدراسة كيف ينظر الممارسون إلى إدارة سلامة العمليات، مع تحديد الفوائد الرئيسية، والعوائق، والاستراتيجيات للتنفيذ الفعال. تم تطبيق هذا النهج بنجاح في العديد من الصناعات حول العالم، كما اعتمدته شركة سوناطراك وطورت مرجعًا لإدارة سلامة العمليات، والآن فإدماج نظام إدارة سلامة العمليات في جميع الوحدات التشغيلية هو من بين الأهداف الاستراتيجية العليا لها، وذلك لتحسين استخدام الموارد، وتقليل التكرار التشغيلي، وتحسين إدارة المخاطر. ومع ذلك، تم تحديد عوائق مثل فجوات إدارة المعرفة، الموارد، والاتصال، خاصة إدارة التكامل والتغيير. وأكد المستجيبون على أهمية اعتماد نهج يركز على المرونة يتضمن إدارة المخاطر بشكل استباقي، والتحسين المستمر، والقدرة على التكيف في كل من ممارسات السلامة والأمن. تشمل العوامل الحاسمة لعملية دمج القيادة القوية، وتوافق القيم المجتمعية، والتدريب عبر التخصصات، ومنهجيات تقييم المخاطر المتكاملة. كما تم تحديد التقنيات الناشئة والتوافق التنظيمي كعوامل حاسمة في تسهيل الدمج. تسهم هذه الدراسة في الفهم النظري لإدارة المخاطر المتكاملة من خلال دعم هندسة المرونة ونظرية الأنظمة. كما تقدم استراتيجيات قابلة للتنفيذ للتغلب على العوائق واستغلال العوامل المساعدة، مما يمهد الطريق لتطوير إطار عمل يركز على المرونة لإدارة مخاطر سلامة العمليات وأمن العمليات. تستكشف هذه التحقيقات كيف ينظر الممارسون إلى إدارة سلامة العمليات، مع تحديد الفوائد الكبيرة، والتحديات، والتكتيكات للتنفيذ الفعال. لقد تم تنفيذ هذه الاستراتيجية بنجاح في العديد من الصناعات حول العالم، وقد اعتمدتها سوناطراك أيضًا، حيث أنشأت مرجعًا لإدارة سلامة العمليات. حاليًا، فإن دمج نظام إدارة سلامة العمليات في جميع الوحدات التشغيلية هو من بين الأهداف الاستراتيجية العليا لها، وذلك لتحسين استخدام الموارد، وتقليل التكرار التشغيلي، وتحسين إدارة المخاطر.

Abbreviations and Symbols List

$Al_2 (CO_3)_3$	Aluminum carbonate
ACC	American Chemistry Council
AIChE	American Institute of Chemical Engineers
Al_2O_3	Alumina
API	American Petroleum Institute
ARH	Algerian regulatory authority
BAD	Blowdown Drum
BASF R3-15	BASF catalyst
BASF RO-20/13	BASF catalyst
C_2H_2	Acetylene
C2H4	Ethylene
CCPS	Center for Chemical Process Safety
CIA	Chemical Industries Association
CMA	Chemical Manufacturers Association
CO	Carbon monoxide
CO_3Na_2	Sodium carbonate
Cr^{+2}	Chromium oxidation state +2
Cr^{+3}, Cr^{+6}	Chromium oxidation change (oxidation increase)
Cr_2O_3	Chromium trioxide catalyst support
Cu_2(I)O, Cu(II)O	Copper oxides (I) and (II)
CuO	Copper oxide
DC-HSE	Central HSE Directorate (SONATRACH)
DIERS	Design Institute for Emergency Relief Systems
DRAGADOS	Spanish engineering company
EI	Energy Institute
ENIP	Engineering and Industrial Projects
EPA	Environmental Protection Agency
ERP	Emergency Response Plan
Ex-CP1K	Petrochemical Complex 1 of Skikda
FIR	Intervention and Reserve Force
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis

H_2	Hydrogen
H_2O	Water
HAZID	Hazard Identification
HAZOP	Hazard and Operability Study
HDPE	High-Density Polyethylene
HIRA	Hazard Identification and Risk Assessment
HSE-MS	Health, Safety&Environment Management System
IChemE	Institution of Chemical Engineers
INITEC	Spanish engineering company
IOGP	International Oil&Gas Producers
KPIs	Key Performance Indicators
LNG	Liquefied Natural Gas plants
LoPC	Loss of Primary Containment leading to loss of primary containment
MAPP	Major Accident Prevention Policy
MOC	Management of Change
N_2	Nitrogen
Na_2O	Sodium oxide
O_2	Oxygen
OCM	Organizational Change Management
OSHA	Occupational Safety and Health Administration
P&IDs	Piping and Instrumentation Diagrams
PC2K	Skikda's Petrochemical Complex
PDCA	Plan–Do–Check–Act cycle
PF process	Phillips's process
PHA	Process Hazard Analysis
POLYMED project	"Mediterranean of Polymers" project
PSCM	Process Safety Competency Matrix
PSE	Process Safety Events
PSFs	Process Safety Fundamentals
PSI	Process Safety Information
PSM	Process Safety Management
PSSR	Pre-Startup Safety Review
PTO	Product Take-Off

PTW	Permit-to-Work system
QRA	Quantitative Risk Assessment
R&O	Roles and Responsibilities management
RBPS	Risk-Based Process Safety
REPSOL QUIMICA	Spanish petrochemical company
RMP	Risk Management Plan
Selexsorb CD	Alumina adsorbent
Selexsorb COS	Alumina adsorbent
SONATRACH	Algerian national oil and gas company
SOPs	Standard Operating Procedures
STAA	Safer Technology and Alternatives Analysis
TECNICA REUNIDAS	Spanish engineering company
TQ	Threshold Quantity
XPF	Experimental Polymerization Formulation

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Chapter II: Process Safety Management "PSM" System

General Conclusion and Recommendations

General Introduction

General Introduction

The Process Industries successfully use hazardous materials and operate potentially hazardous processes safely every day. It is the very ability to do so that demonstrates the value of the process
industries to society. The safe and successful operation of these processes is only accomplished by companies and individuals who have demonstrated the ability to carry out their tasks correctly and
safely [1].

The Oil and Gas sectors are persistently working to enhance their production capabilities, achieve cost efficiencies, and explore technically demanding regions to sustain their market shares [2]. Achieving efficiency in Petrochemical operations while reducing products costs, with a strong emphasis on safety and asset integrity, continues to pose a challenge [3]. Likewise, maximizing the margin of refined oil barrels, increasing petrochemical production, and developing new high-value products to satisfy rising demand, along with boosting refining capacity, drive operational excellence in various operations [4]. The operation of aging facilities in harsh environmental conditions presents significant challenges for any Oil and Gas operator [5]. In the Oil and Gas sector, both refining and petrochemistry, there exists a substantial presence of hazardous chemicals at drilling or production sites [6].

Major incidents leading to loss of primary containment (LoPC) in the Oil and Gas industry, have intensified the focus on asset integrity, process safety, and operational excellence [7]. Various processes within the oil and gas sector carry the risk of chemical releases and associated fire, safety, and health hazards due to the inherent nature of these releases. Such losses can lead to asset damage, occupational injuries, environmental repercussions, and a decline in production or company reputation [8]. Process safety encompasses a blend of engineering and management controls designed to avert catastrophic incidents and near misses, including structural failures, fires and explosions, and the release of energy or hazardous substances like petrochemical and petroleum products [1].

All such failures undergo an incident investigation process aimed at identifying the root causes of the events and recommending corrective measures to prevent future occurrences [9].

Process safety practices and formal safety management systems have been established in certain companies for over a century. Process safety management (PSM) is largely recognized for its role in decreasing the risk of major accidents and enhancing the performance of the chemical industry [10]. However, numerous organizations continue to face difficulties in effectively executing the management systems they have created [11]. In 2005, the Center for Chemical Process Safety introduced the concept of Risk Based Process Safety (RBPS) to address what appeared to be a standstill in the advancement of process safety. A more detailed explanation of RBPS can be found in section 1.4 of this book [1].

The aim of this Guideline book is to assist organizations in designing and implementing the Process Safety Competency component of RBPS. This book offers strategies and techniques for defining job roles and proficiency levels within an organization, subsequently linking fundamental knowledge and skills to each job role/proficiency level combination through a Process Safety Competency Matrix (PSCM) [12].

The PSCM facilitates the improved execution of other RBPS elements, particularly Training and Performance Assurance, Management of Change, Organization Change Management (OCM), and Conduct of Operations. Furthermore, the PSCM empowers an organization to fulfill the objectives of Vision 20/20, a CCPS initiative aimed at helping organizations achieve superior process safety [13]. A thorough review of over fifty (50) process safety events (PSE), across both Upstream and Downstream segments, was conducted, and the findings and causes of these events were correlated with the Center for Chemical Process. Data suggests that the insufficient identification of worksite and job hazards, categorized under Management Supervision and Employee Leadership, was the primary root cause of process safety incidents, accounting for 26% of all identified root causes. This reflects deficiencies in task risk assessment, where specific risks were either not recognized or inadequately controlled. Nearly half (55%) of the causes of incidents fell under the categories of Hazard Identification and Risk Analysis, Auditing, Asset Integrity, and Reliability [14].

This innovative strategy aims to mitigate process safety incidents by integrating and enhancing process safety and operational excellence frameworks of Oil and Gas operations. It is designed to assist in preventing incidents and can be adapted by other operators and companies [14].

This thesis is structured as following:

- Three chapters, the first one, is a presentation of Skikda's Petrochemical Complex PC2K of SONATRACH, which served as the site for our practical internship and is the subject of the case study in this. While the second a theoretical overview of Process Safety

Management “PSM” in general in especially that one of CCPS. The third chapter which is the last one is dedicated to a detailed the SONATRACH’s PSM version.

We finish, the manuscript with a general conclusion followed by the scientific research publications related to our thesis project.

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Chapter I: Presentation of Petrochemical Complex of Skikda “CP2K”

I.1 Introduction

This chapter outlines the study unit (petrochemical complex 2 of SKIKDA "CP2K") where the professional internship took place; it includes the history, activities, organization, and operation of the unit, product control, and the production of HDPE Pipe at the complex, concluding with a discussion of the objectives achieved during the internship and the challenges we faced.

I.2. Historical Overview [1]

As part of the diversification of petrochemical products, ENIP and REPSOL decided in 1988 to include the POLYMED project, "Mediterranean of Polymers," which was established through an international partnership aligned with ENIP's development strategy. The project was confirmed in 1989, and in 1990, ENIP and REPSOL signed a memorandum of understanding, leading to the establishment of the mixed-economy company, the Algero-Spanish POLYMED, in December of that year (64% ENIP / 13% BAD / 23% REPSOL QUIMICA).

In April 1991, a contract for the project's execution was signed with a consortium of three Spanish companies: INITEC, DRAGADOS, and TECNICA REUNIDAS. This included the establishment of Spanish financing for a duration of four years until 1995, when engineering work resumed.

The construction site was opened in 1996, and civil engineering and infrastructure works commenced in 1997. By 2002, the construction of the plant was completed, and the financial restructuring of POLYMED was signed at the government leadership level.

On June 15, 2003, POLYMED's file was reviewed by an inter-ministerial council, and the government head approved its financial restructuring plan.

On January 16, 2004, SONATRACH's financing was released for the remaining work, and the POLYMED plant began operations. In January 2011, ENIP was reintegrated into the SONATRACH group at 100% as a Petrochemical Division (PEC), and the POLYMED plant was renamed CP2K, " Petrochemical Complex 2 of SKIKDA."

In 2016, during the restructuring of the SONATRACH group, the DCG/PEC came under the management of LRP (Liquefaction Refining and Petrochemistry).

I.3. Presentation of the CP2K Complex

The CP2K Petrochemical Complex is located within the industrial zone of Skikda, covering an area of 166,800 m², of which 10% is built upon. It is situated 6 km to the east of the capital of the Skikda province and has an average elevation of approximately 6 m above sea level. To the north, it is bordered by the Mediterranean Sea, to the south by the main road of the industrial zone, to the east by the intervention and reserve force (FIR), and to the west by Ex-CP1K (Petrochemical Complex 1 of SKIKDA), as illustrated in Figure I.1.

Figure I.1: Geographical Position of CP2K Complex

I.4. CP2K Complex Description [2]

The complex consists of four main areas listed below:

I.4.1. Off-site zone

It includes utilities such as boilers, air, nitrogen, distilled water, fire-fighting water, drinking water, and gas release, as well as the activation of the catalyst.

I.4.2. Wet zone

It is also referred to as a reaction zone; the raw materials, prior to entering the reactor, are processed by the treatment facilities to remove impurities.

I.4.3. Dry zone

It includes: the extruder, the blowers, the storage silos for the products (powder and granules), and the packaging.

I.4.4. Building Zone

It includes: the administrative block, the cafeteria and changing rooms, the security block and infirmary, the spare parts store and maintenance workshop, the operations block, the high and low voltage substation, as well as the control room and laboratory.

I.5. Process Installations [2]

The primary installations depicted in Figure 1.2 are:

1. The reactor: Closed-loop piping designed for polymerization;
2. The extruder: Product finishing system in the form of pellets;
3. The bagging: Automatic packaging system for HDPE.

Additionally, there are other auxiliary installations required for the process, which include:

1. Production of steam, electricity, air, etc.….;
2. Treatment of effluents;
3. Storage of raw materials and additives;
4. Finished product storage facility.

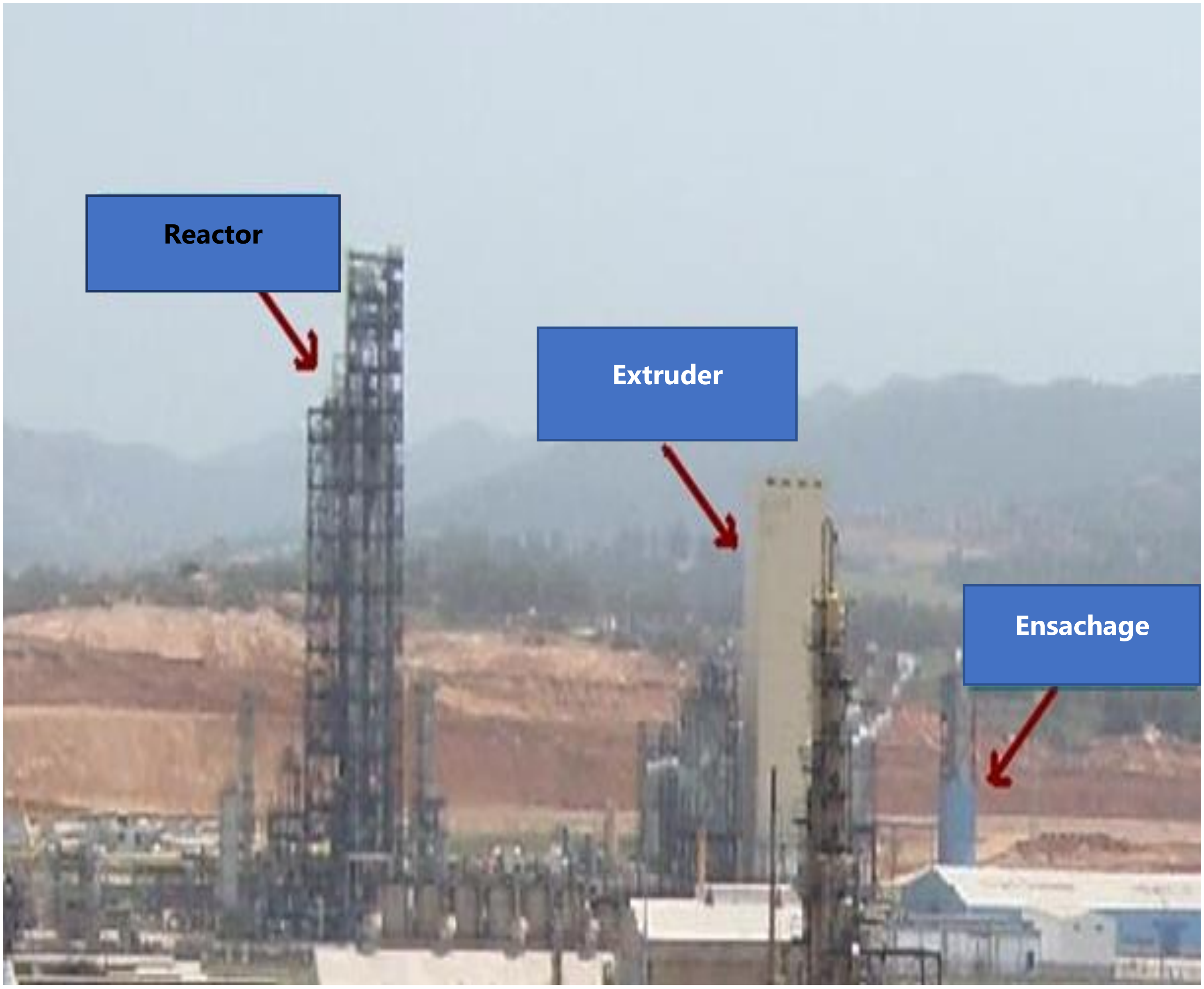

Figure I.2: Representative photo of the main installations of the CP2K unit.

I.6. CP2K complex Organization

The CP2K complex is structured as follows:

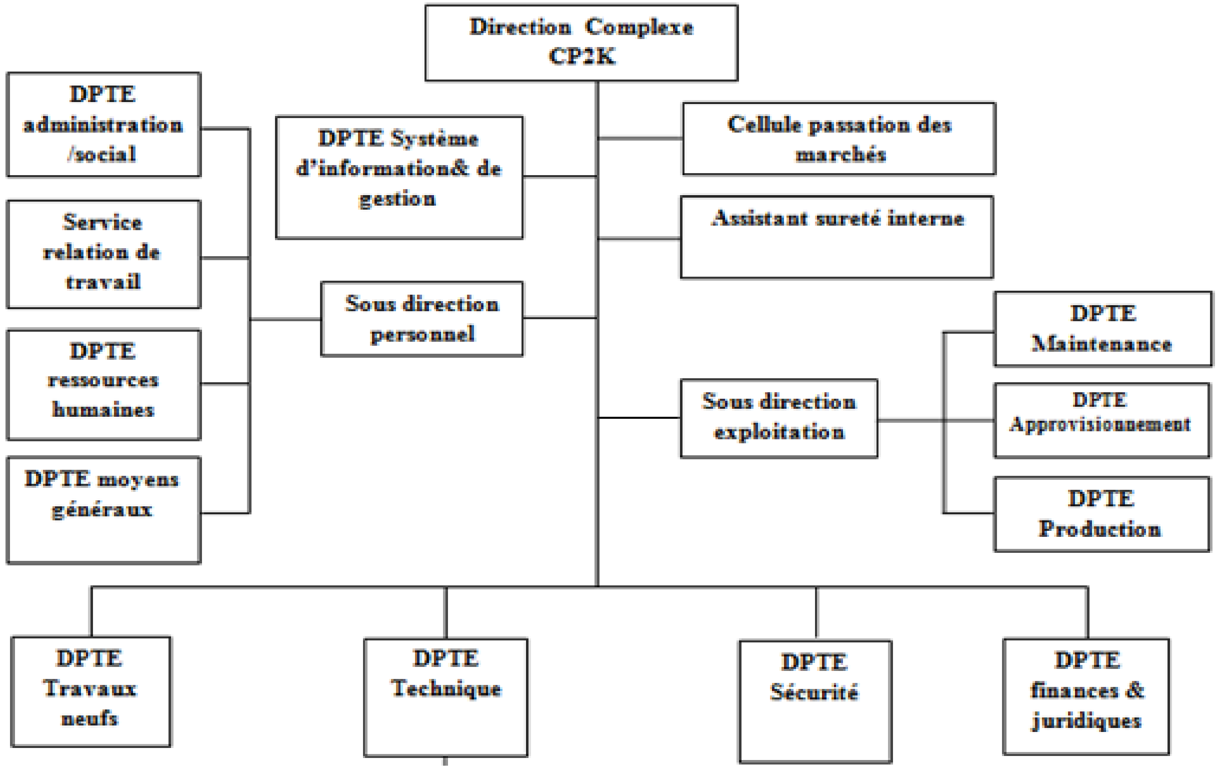

Figure I.3: Representative diagram of the CP2K complex organization

I.7. The PHILIPS Process [2]

The CP2K plant incorporates two production processes within a single facility:

- Phillips Process;
- Ziegler Process;

However, since its initial startup, it has exclusively utilized the Phillips process, as the catalyst employed in the Ziegler process is significantly more expensive than that used in the Phillips process.

The Phillips process, also referred to as the "PF process" or particle process, was designed for the POLYMED plant and requires a high purity of raw materials, allowing only trace amounts of impurities, as their presence can disrupt the reactor's operation or compromise the quality of the final product.

This process yields polymers with a melt flow index ranging from 0.10 to 36 and a density between 0.935 and 0.965.

I.7.1. The Used Charges

- Ethylene: the primary charge in the gaseous phase;
- Isobutane: the reaction medium in the liquid phase;
- Hexene: in the liquid phase;
- Hydrogen: in the gaseous phase in minimal quantities;
- Catalyst: Chromium trioxide (Cr_2O_3) on a silica support.

I.7.2. Operating Conditions for the Polymerization Reaction

The two essential conditions in the reactor are:

- Temperature: from 93 to 110°C, depending on the grade to be produced.
- Pressure: from 42 to 44 bars, depending on the opening or closing of the discharge valves.

I.7.3. PF Process Steps

The particle process "PF" is divided into a series of stages or systems:

1. Treatment of raw materials;
2. Activation and addition of the catalyst;
3. Polymerization in a loop reactor;
4. Flash system and drying of the polymer;
5. Purification and recovery of the recycling gas;
6. Finishing system;
7. Bagging

I.7.3.1. Processing of Raw Materials

The raw material undergoes a series of treatments before being injected into the reactor. Ethylene has multiple treatments, each designed to eliminate specific poisons in the following order: acetylene, oxygen, mono and then carbon dioxide, and finally moisture; however, other reactants such as isobutane (both fresh and recycled), hexene, and hydrogen each have only one treatment.

1. Ethylene

It is the primary raw material for the process, received at the plant through piping from the adjacent ethylene installation, at 16.9 kg/cm2g and at ambient temperature. To remove impurities found in ethylene resulting from its cracking, storage, or transport, it undergoes the steps illustrated in the diagram below:

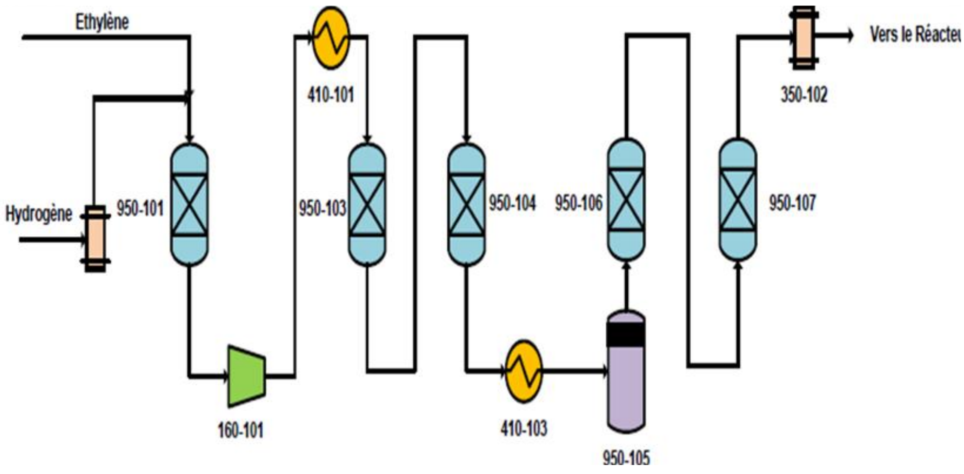

Figure I.4: Ethylene Processing System

1. The Acetylene Removal

Hydrogen is passed through the 350-133 filter, which eliminates solid particles, after which it is mixed with ethylene and both proceed to the acetylene converter 950-101.

2. The Oxygen Removal

The oxygen removal reactor contains 12,350 kg of the BASF R3-15 catalyst, as illustrated in Figure I.5.

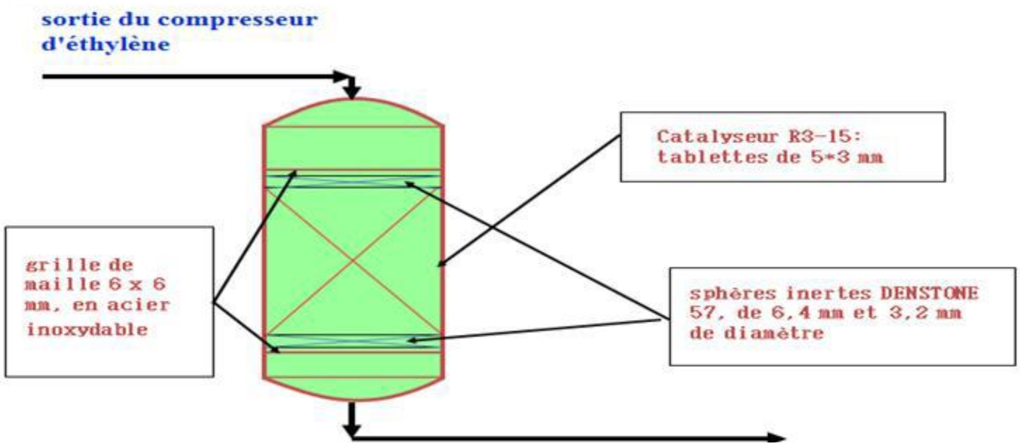

Figure I.5: Reactor for the O_2 removal of

3. The Carbon Monoxide (CO) Removal

The ethylene stream continues its journey through the carbon monoxide removal reactors 950-104 A/B, which contain 12,350 kg of a BASF R3-15 catalyst based on CuO, as illustrated in figure (I.6).

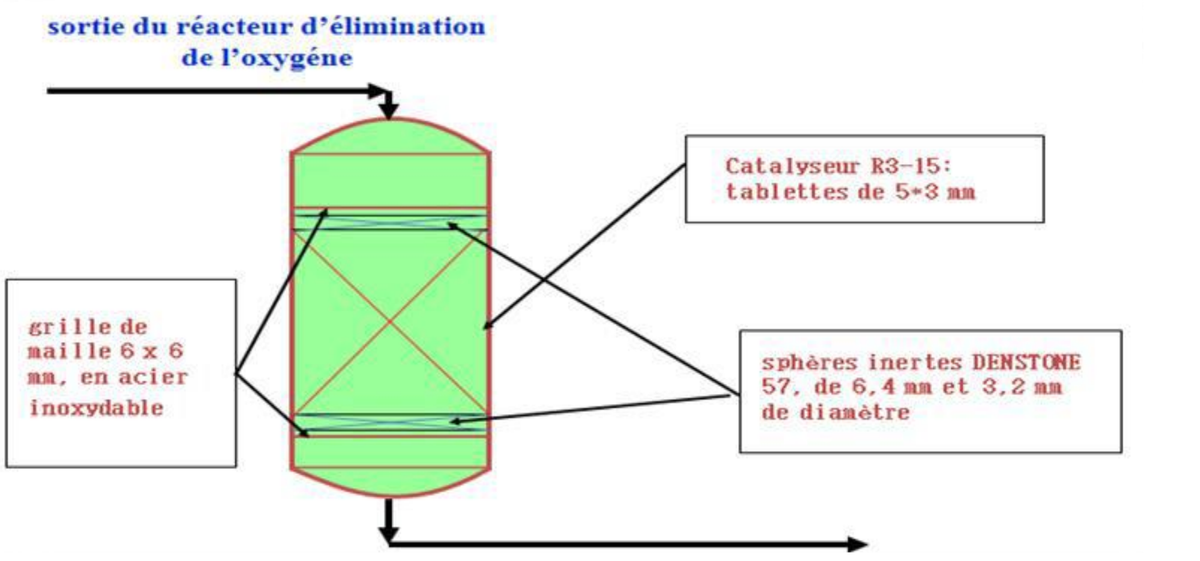

Figure I.6: Reactor of CO Removal

4. The Carbon Dioxide (CO_2) Removal

Carbon dioxide present in the ethylene stream must be eliminated, as it is a potent poison for the XPF catalyst utilized in the polymerization reaction. Reactors 950-106 A/B contain two types of alumina: Selexsorb CD and Selexsorb COS.

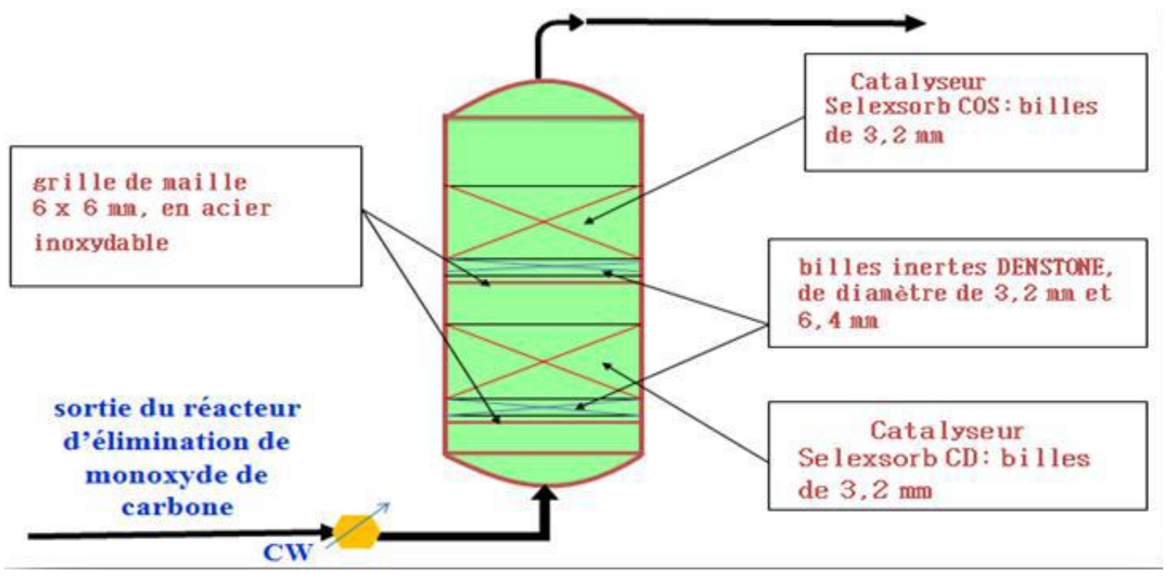

Figure I.7: Reactor of CO_2 Removal

5. The H_2O Removal

Ethylene is dried in dryers 950-107 A/B. The flow of ethylene passing through the bed is in an upward direction. Water and methanol, which are removed from the ethylene stream, are captured in a molecular sieve bed, ZEOCHEM 13X.

The dryer operates based on a principle of physical adsorption, which involves the attachment of H_2O molecules to the porous surface of the adsorbent until it reaches saturation, at which point it will be regenerated every 14 days using a stream of hot nitrogen.

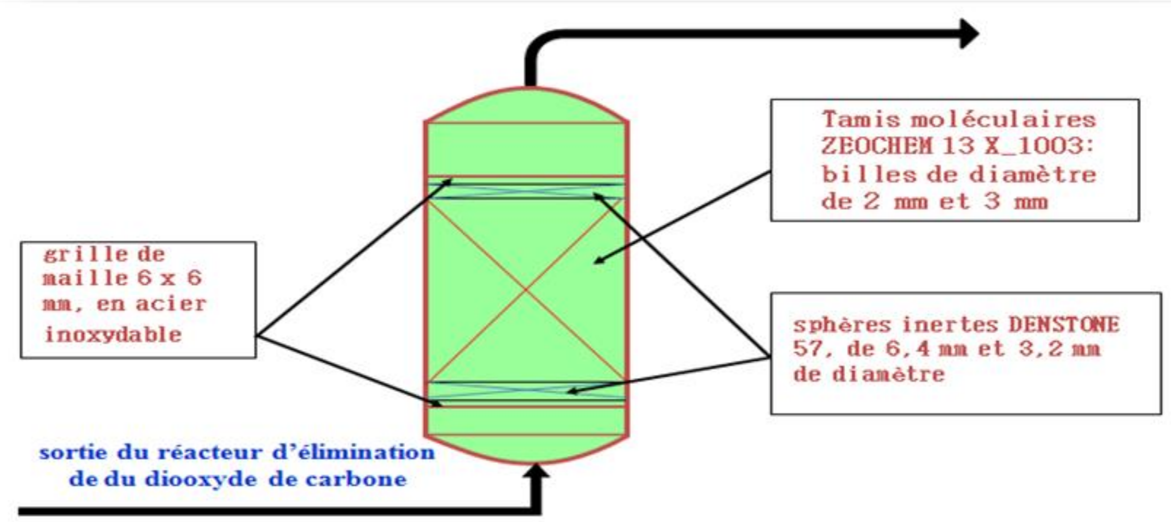

Figure I.8: Reactor of H_2O Removal

2. Hexene

Hexene is the compound that is added in small amounts to the reactor to produce copolymers; it alters the molecular structure of the polymer, thereby changing its physical properties.

Before entering the reactor, it undergoes several treatment stages, starting with the degassing column 950-111 to remove the gas absorbed in the stream, followed by drying in the water removal unit 950-114, which operates through adsorption on a molecular sieve ZEOCHEM 13X, type 1003.

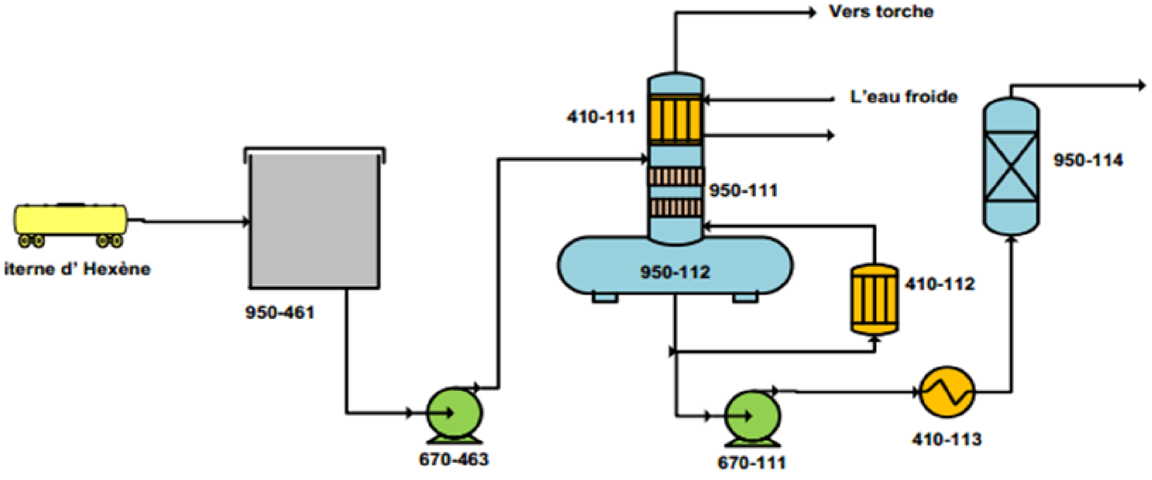

Figure I.9: Hexene Treatment Steps

3. Isobutane

There are two types of isobutanes: fresh isobutane and recycled isobutane.

A. Fresh Isobutane Treatment

Before being integrated into production, fresh isobutane undergoes several treatment stages. It first passes through the degassing column 950-121 to remove absorbed gas from the stream, and then it is dried in the water removal unit 950-124 A/B, which operates through adsorption on a molecular sieve ZEOCHEM 13X, type 1003. These dryers require regeneration every 30 days.

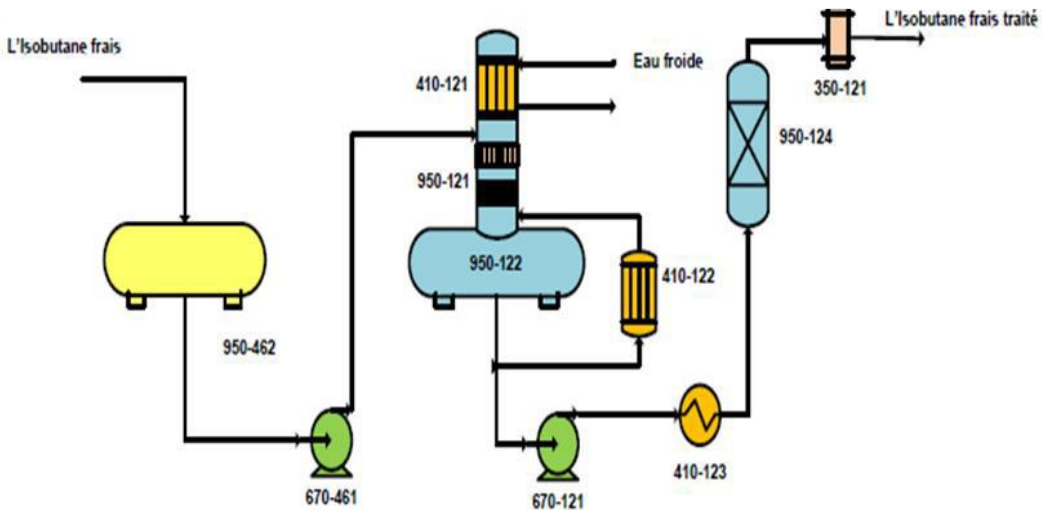

Figure I.10: Fresh Isobutane Treatment

B. Recycled Isobutane Treatment

This is the primary source of isobutane utilized within the unit, as it is nearly entirely recovered. It is pumped from storage tank 950-176 to the isobutane recycling dryers 950-125 A/B, which require regeneration every 30 days.

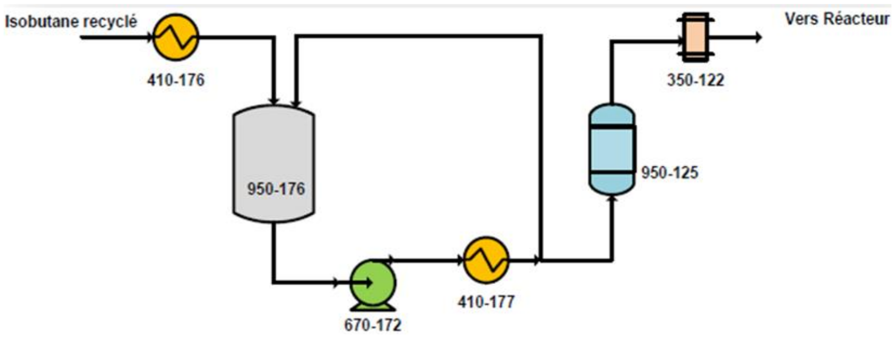

Figure I.11: Recycled Isobutane Treatment

4. Hydrogen

Hydrogen is added to the reactor to regulate the fluidity index while altering the polymer chain length. Prior to its incorporation, it must undergo a drying process in the dryers 950-132 A/B, where the water present in the hydrogen stream is retained on two stacked beds of the molecular sieve ZEOCHEM 13X.

I.7.3.2. Catalyst Activation & addition

The PF (PHILLIPS) type catalyst must be activated prior to its incorporation into the polymerization reactor; the purpose of this activation is to alter the oxidation state of chromium from Cr^{+3} to Cr^{+6} as indicated in reaction (I.10), facilitating the removal of water and volatiles through contact with dry, hot air in a fluidized bed.

FigureI.12: Catalyst Activation Steps

I.7.3.3. Polymerization of Ethylene

The polymerization reaction occurs within the closed-loop reactor 950-155, which consists of carbon steel piping with an internal diameter of 560 mm, comprising four vertical sections connected by horizontal segments. The external diameter of this reactor is 760 mm, and the reaction takes place under operational conditions of pressure and temperature of 42.2 kg/cm² and between 85 to 110 °C, respectively.

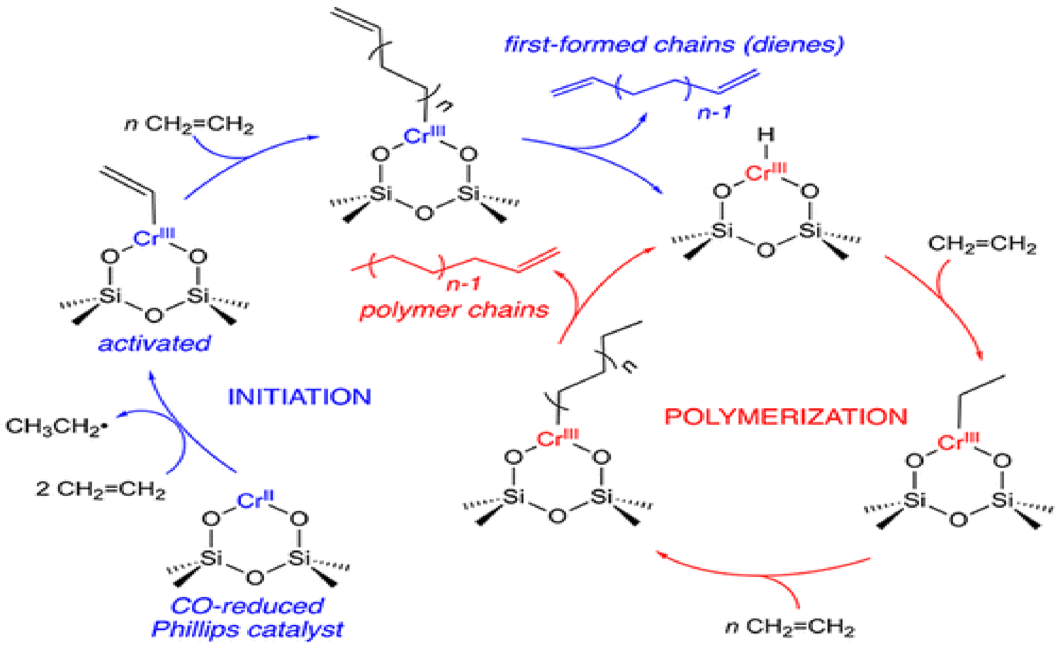

Figure I.12: PHILLIPS Polymerization Mechanism [3]

I.7.3.4. Flash and Polymer Drying System

The mixture discharged from the reactor through the "PTO" discharge valves at a pressure of 42.2 kg/cm^{2}g is transported via the reactor's flash lines to the flash chamber 950-161, where the normal operating pressure is 0.37 kg/cm^{2}g. In this chamber, the mixture is heated by hot water, which facilitates the vaporization of isobutane, ethylene, hexene, and hexane.

I.7.3.5. Purification and recovery of recycling gas

The flash gas originating from the head of the flash chamber or the alternative flash chamber will undergo a solid removal and solvent purification and recovery system. To achieve this, the flash gas, after passing through the cyclone, is directed to the bag filter and then to the guard filter. Once the solids are collected, the gas is routed to a gas purification system via the recycling gas compressor.

I.7.3.6. Finishing System

The produced polyethylene is transported in powder form from the discharge of the purge column to the storage silos or the feed tank of the extruder. This is accomplished using a closed-loop pneumatic transport system utilizing nitrogen.

I.7.3.7. The Ensachage

Is a complete line of an automated packaging system for granulated HDPE. This line features a bagging machine equipped with a net weight mass dozer and a bag sealer, a conveyor with a printer and a metal detector, a palletizer with a speed controller, and a packaging machine with a hooder and an oven, designed to produce a pallet consisting of 11 layers, each containing 5 bags of 25 kg.

I.7.4. Product Control and Release

The information provided to production regarding raw materials and reaction products is continuously supplied by the laboratory, which is regarded as the eyes of production, facilitating the monitoring and control of:

- The composition of raw materials and the products involved in the reaction, along with their purity status.
- Research studies: the addition of additives, fillers, etc.;
- The quality of the finished product, as well as the intermediate products essential for the proper operation of the unit; water, oils, catalysts, etc.;
- The finished product (HDPE) and addressing inquiries or complaints from customers;
- The technical data sheets prepared and issued, along with the quality certificates for the finished product.

Each grade corresponds to a technical data sheet that is released and provided to the client. This sheet includes all relevant information regarding the product.

I.8. Conclusion

The practical internship at the CP2K complex of SONATRACH has enabled us to effectively apply the theoretical knowledge we have acquired in the field of HSI, particularly regarding the management of risks associated with industrial installations. This experience has allowed us to become acquainted with the professional environment while enhancing our skills in the petrochemical industry.

At the end of our internship, we faced the issue of process safety, which is the focus of our study titled: Process Safety Management System "PSM" of SONATRACH.

References

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Chapter II: Process Safety Management

"PSM" System

II.1. Introduction

Integrating process safety management system is increasingly essential for preventing accidents in chemical, petrochemical and petroleum process industry. This study addresses how practitioners perceive the PSM, identifying key benefits, barriers, and strategies for effective implementation [1]. This approach was successfully applied in many industries in the world [1,2], SONATRACH also adopted it and developed a PSM reference and now integrating PSM system in all operational and units is in the top of its strategical objectives, and that to optimize resource use, reduce operational redundancies, and improve risk management [1]. However, barriers such as knowledge gaps, resource constraints, and communication silos were identified [1]. Respondents emphasized the importance of adopting a resilience-oriented approach involving proactive risk management, continuous improvement, and adaptability in both safety and security practices. Critical enablers for integration include strong leadership, alignment of societal values, cross-disciplinary training, and integrated risk assessment methodologies [1].

Emerging technologies and regulatory alignment were also identified as critical factors in facilitating integration [1]. The study contributes to the theoretical understanding of integrated risk management by supporting resilience engineering and systems theory [1]. It offers actionable strategies for overcoming barriers and leveraging enablers, laying the groundwork for developing a resilience-oriented framework for process safety and process security risk management [1]. This investigation explores how practitioners view the PSM, pinpointing significant benefits, challenges, and tactics for effective execution [1]. This strategy has been successfully implemented in numerous industries worldwide [1,2], and SONATRACH has similarly adopted it, establishing a PSM reference [1]. Presently, the incorporation of the PSM system into all operational units is among its foremost strategic goals and this to optimize resource use, reduce operational redundancies, and improve risk management [1].

II.2. History of Process Safety

Organizations within the process industries have historically prioritized process safety. Initially, organizations conducted safety reviews for processes based on the knowledge and skills of the reviewers. During the mid-20th century, more structured review methodologies began to emerge in the process industries [2]. These methodologies included the Hazard and Operability Study (HAZOP), which was developed by ICI in the 1960s (CIA 1977) [3], as well as Failure Modes and Effects Analysis (FMEA), Checklist reviews, and What-If analyses.

These methods are qualitative approaches for evaluating the hazards associated with a process or operation [4]. Quantitative analysis methods, such as Fault Tree Analysis (FTA), which had been utilized by the nuclear sector, along with Quantitative Risk Assessment (QRA) and Layer of Protection Analysis (LOPA), also started to gain traction in the process industries during the 1970s, 1980s, and 1990s [4,5].

Techniques for modeling were created to assess the repercussions of spills and releases, explosions, and toxic exposures. The Design Institute of Emergency Relief Systems (DIERS) was founded within the American Institute of Chemical Engineers (AIChE) in 1976 to devise strategies for the design of emergency relief systems capable of managing runaway reactions [6]. By the mid to late 1970s, process safety had become an acknowledged technical discipline. The American Institute of Chemical Engineers (AIChE) established the Safety and Health Division in 1979.

In 1976, a runaway reaction took place in Seveso, Italy, leading to the release of 2,3,7,8-tetrachlorodibenzo-p-dioxin, commonly referred to as dioxin, into the surrounding environment [7]. Dioxin is recognized as a hazardous chemical. Numerous individuals developed chloracne, a skin condition, and a 17 km2 (6.6 sq. mi.) region became uninhabitable. This event ultimately prompted the establishment of more stringent regulations for the process industries within the European Economic Community in 1982, known as the Seveso Directive (EC) [8].

A pivotal event in the chemical sector transpired in 1984. A discharge of methyl-isocyanate, a hazardous and combustible substance, took place at a chemical facility in Bhopal, India. This incident resulted in over 3,000 deaths [9]. The initial design of the chemical plant included numerous safety measures against such occurrences. However, these measures were not upheld, and many were inoperative at the time of the incident.

The Bhopal disaster underscored the reality that technical knowledge alone was insufficient, emphasizing that hazard and risk management were equally critical to the technical dimensions of process safety [9, 10]. Following the Bhopal incident, the Center for Chemical Process Safety (CCPS) was established in 1985 [2]. The CCPS is a non-profit entity affiliated with the U.S.-based American Institute for Chemical Engineers (AIChE), aiming to safeguard individuals, property, and the environment by disseminating the most effective process safety knowledge and practices to industry, academia, government, and the global public through shared insights, tools, training, and expertise [2].

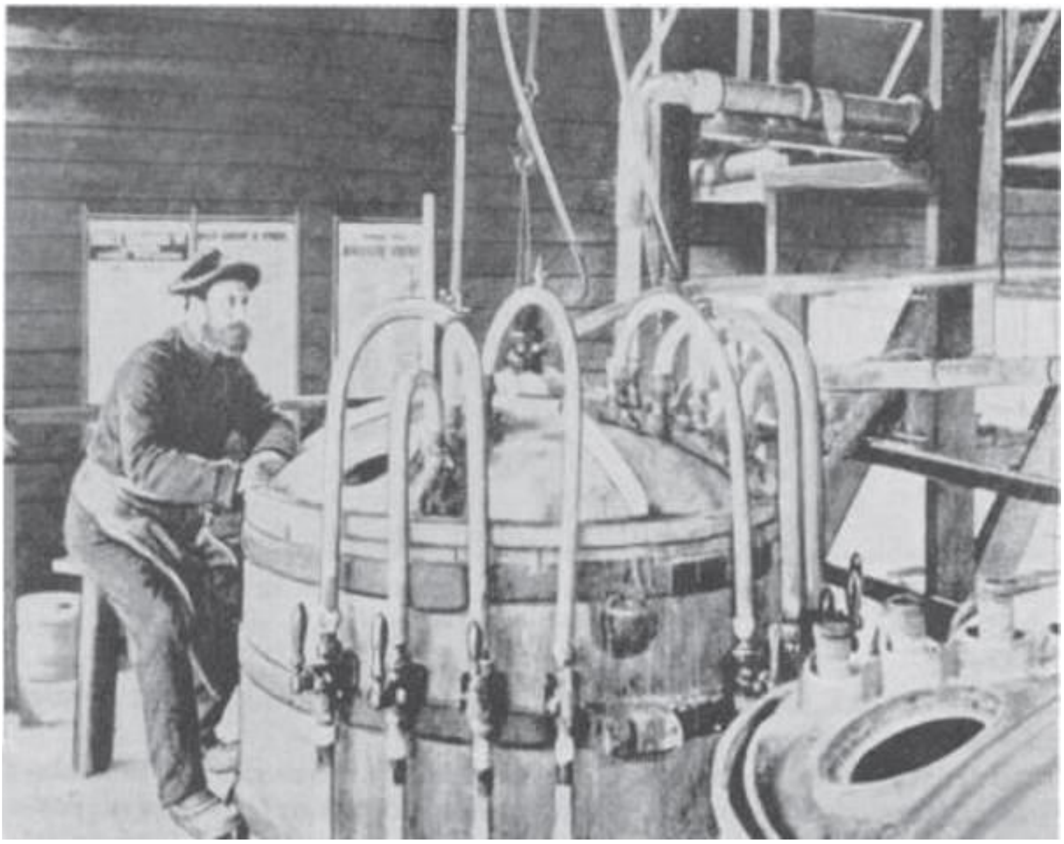

Figure II.1: Nitroglycerine reactor in the 19th century [11]

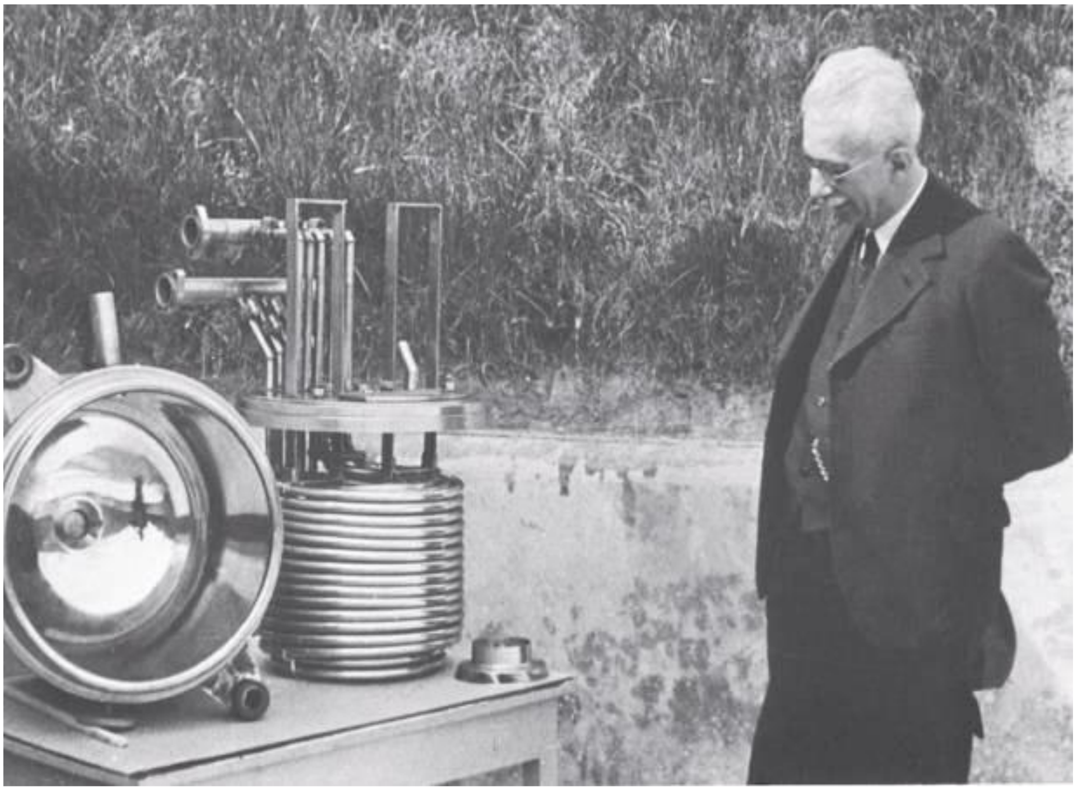

Figure II.2: Continuous nitroglycerine reactor [12]

In 1985 the Chemical Manufacturers Association (CMA), which later became the American Chemical Council (ACC) issued process safety management guidelines (CMA 1985) [15]. By 1989, the CCPS introduced a set of 12 process safety management elements (CCPS 1989) [16]. The American Petroleum Institute (API) also issued process safety management guidelines in 1990 (API RP 750) [17]. The CCPS studied the various approaches at the time and gleaned the 12 characteristics from interactions with its member companies and traditional business process consulting firms that had significant experience in evaluating management systems [16]. Those guidelines were the first generic set of principles to be compiled for use in designing and evaluating process safety management systems.

In 1992 the U.S. Occupational Safety and Health Administration (OSHA) issued the "Process Safety Management of Highly Hazardous Chemicals" (OSHA PSM 1910.119 regulation, which had its own, although similar, set of process safety management elements [18]. (OSHA) The U.S. Environmental Protection Agency (EPA) issued its own version in 1995 under the authority of the Clean Air Act [19]. This regulation is commonly referred to as RMP, or Risk Management Plan, since the regulation requires the development and submittal of a risk plan based on the regulatory definitions and requirements. (EPA) Both of these regulations are described in further detail in Chapter 3.

OSHA PSM regulations cover the impacts of hazards to workers on-site; EPA RMP covers the impacts of hazards off-site [18, 19]. Applicability for both regulations is triggered by having more than a specified amount, commonly referred to as a Threshold Quantity (TQ), of specified chemicals, usually called Highly Hazardous Chemicals, or by more than 4,500 kilograms (10,000 pounds) of a flammable material in one location. PSM as defined by the CCPS, which does not depend on threshold quantities, is much broader than OSHA PSM and EPA RMP [2].

Process safety practices and formal safety management systems have been in place in some companies for many years. Process safety management is widely credited for reductions in major accident risk and in improved process safety performance in the process industry [2, 20]. Nevertheless, many organizations continue to be challenged by inadequate management system performance, resource pressures, and stagnant process safety results. To promote process safety excellence and continuous improvement throughout the process industries, the CCPS created risk-based process safety (RBPS) as the framework for the next generation of process safety management (CCPS 2007). RBPS has the format of a good practice and not a regulatory requirement [2].

II.3. Definitions

II.3.1. Process Safety

A structured approach to managing the integrity of operational systems and processes that deal with hazardous substances through the application of sound design principles, engineering practices, and operational protocols [19].

The focus of process safety is on initiatives aimed at minimizing the risks associated with processes that handle hazardous materials and energies [20].

Efforts in process safety contribute to decreasing both the frequency and severity of potential incidents [21].

Such incidents may involve the release of toxic or flammable materials (loss events), leading to toxic effects, fires, or explosions. The repercussions of these incidents encompass harm to individuals (injuries, fatalities), environmental damage, property loss, production disruptions, and negative business publicity. [2, 5].

II.3.2. Process Safety Management (PSM)

Is a management system that is focused on prevention of, preparedness for, mitigation of, response to, and restoration from releases of chemicals or energy from a process associated with a facility [22].

II3.3. Hazard

Is an operation, activity, or material with the potential to cause harm to people, property, the environment, or business; or simply, a potential source of harm. Reinforcing this definition, a hazard is something with the potential to cause harm. Process safety is all about reducing the chance, the risk, that the harm will occur. A typical dictionary definition of risk, for example the Merriam-Webster online dictionary, is "the possibility of loss or injury" or "someone or something that creates or suggests a hazard". The CCPS definition considers the hazard (what can go wrong), the magnitude (how bad can it be), and the likelihood (how often can it happen) [22].

II.3.4. Risk

In management Systems Risks are potential negative impacts (threats) to objectives. Is a measure of human injury, environmental damage, or economic loss in terms of both the incident likelihood and the magnitude of the injury or loss. A simplified version of this relationship expresses risk as the product of the Frequency and the Consequence of an incident (i.e., Risk = Frequency x Consequence) [23].

II.3.5. Opportunities

In management Systems opportunities are potential positive impacts. The PSM frameworks emphasize the "opportunity" to improve operational excellence and reliability through disciplined safety practices [24].

II.3.6. Proactive Approach

R&O management is a continuous, proactive cycle—not merely reactive—that includes identifying, evaluating, and responding to factors.

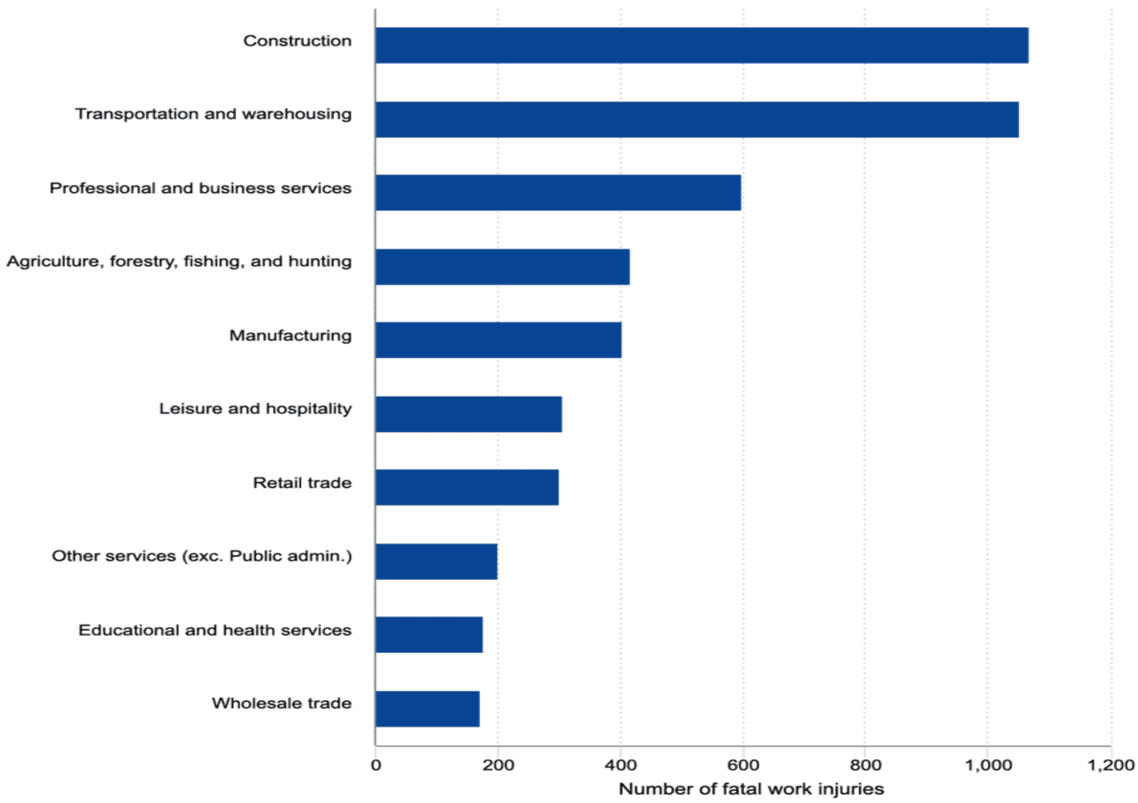

Figure II.3: Number of fatal work injuries, by industry sector, 2019 [25]

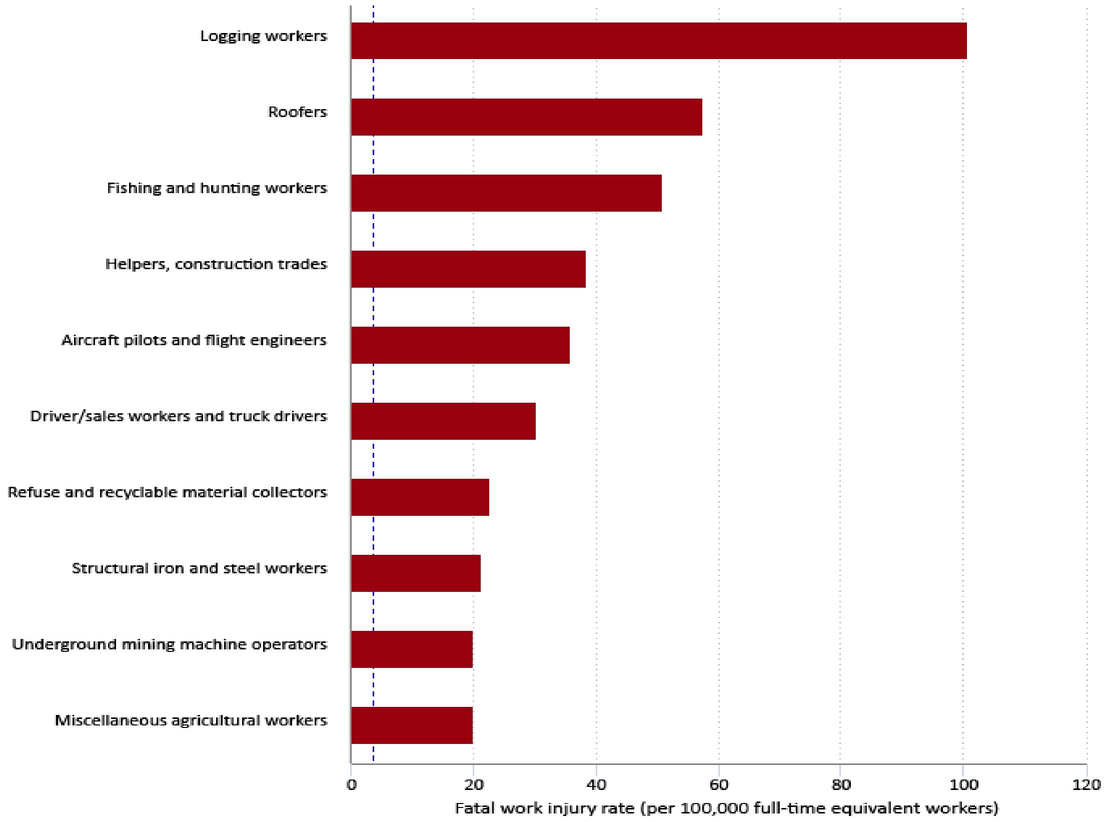

Figure II.4: Fatal work injury rate by industry sector, 2019 [25]

II.4. Process Safety Impact on Safety and Environmental

It is important in industry to manage risk at a level that the company decides it can tolerate. Individuals all have a different perception of tolerable risk; companies need to define a risk tolerance level understood by all [26]. As employees make decisions on how to conduct work, the implicit risk level should be consistent such that a single employee's decisions do not increase risks level beyond tolerability and thus, potentially impact all employees by degrading the company's performance [2].

Process safety is about managing risks. Fundamentally, process safety is about answering these questions [27]:

- What can go wrong? (Human injury, environmental damage, or business economic loss);
- How bad could it be? (Magnitude of the loss or injury);
- How often might it happen? (Likelihood of the loss or injury);
- How can the risk be prevented, or its impact minimized?.

Not all processes and operations have the same amount of risk. Understanding risk helps a company decide how to prioritize its efforts to manage process safety [2].

The concepts of "process safety", "occupational safety", and "environmental impact" are distinct, despite often being collectively referred to as "safety". Each of these areas warrants careful consideration [28].

It is erroneous to assume that improving one aspect will inherently enhance the others [28]. The Baker Panel report highlighted that although BP implemented systems aimed at promoting occupational safety, the organization failed to recognize that strong performance in occupational safety does not equate to effective process safety performance [29]. This idea can be exemplified by the following scenario: when selecting an airline, should one prioritize the airline with a commendable record regarding employee slips, trips, and falls, or the one with a lower incidence of crashes? [30].

Table II.1: Major Accident and Main Root Cause

Date	Location	Industry	Fatalities	Main/Root Causes	Ref.
10 July 1976	Seveso	Chemical	-	Human error, lack of process knowledge; Emergency preparedness	[31]
2 December 1984	Bhopal	Chemical	8000 immediately, 12,000 thereafter	Process safety and ageing management system; Emergency preparedness	[32–34]
26 April 1986	Chernobyl	Nuclear power plant	985,000	Human error in design; Production pressure; Absence of proof tests; Leader error	[35]
28 January 1986	Challenger space shuttle	Space	7	Organization failure; Pressure on success	[36]
6 July 1988	Piper Alpha Platform	Gas and oil	167	Management of change errors; Production pressure	[37]
3 October 1989	Philips, Texas	Chemical	23	Human error	[38]
13 May 2000	Enschede, The Netherlands	Manufacturing	22	Lack of operational discipline	[39]
21 September 2001	Toulouse	Chemical	30	Lack of knowledge; Poor hazard identification	[40,41]
23 March 2005	Texas City	Oil and gas	15	Failures in corporate management and culture	[42]
20 April 2010	Mexican Bay, USA	Oil and gas	11	Lack of supervision	[43]
17 April 2013	West, Texas	Logistics	15	Lack of risk awareness	[44]
12 August 2015	Tianjin, China	Logistics	173	Failures in management system	[55]

22 March 2018	Kralupy, Czech Republic	Chemical Refinery	6	Human error and lack of supervision	[46]
29 October 2018 / 10 March 2019	Boeing 737 – Indonesia / Ethiopia	Air traffic	181 / 157	Design errors; Production and profit pressure; Gaps in risk management	[47]
4 August 2020	Beirut port, Lebanon	Storage	204	Lack of risk awareness; Poor process safety management	[48]

II.5. Process Safety Management System "PSM"

Several international organizations and regulatory bodies have developed Process Safety Management (PSM) frameworks. While they share core principles like hazard analysis and management of change, they vary in their number of elements and specific focus areas. [1, 2, 3, 4, 5], here are the most important :

II.5.1. U.S. Occupational Safety and Health Administration (OSHA) [49]

The OSHA PSM standard (29 CFR 1910.119) is the primary regulatory requirement in the United States. It consists of 14 elements:

1. **Employee Participation:** Consulting with workers on PSM development;
2. **Process Safety Information (PSI):** Technical data on chemicals, technology, and equipment;
3. **Process Hazard Analysis (PHA):** Systematic identification and evaluation of hazards;
4. **Operating Procedures:** Written instructions for safe operations;
5. **Training:** Safety training for employees operating the process;
6. **Contractors:** Ensuring third-party safety performance and information sharing;
7. **Pre-Startup Safety Review (PSSR):** Safety checks before starting new or modified processes;
8. **Mechanical Integrity:** Maintenance and inspection of critical equipment;
9. **Hot Work Permit:** Controlling sparks/flames near processes;
10. **Management of Change (MOC):** Reviewing risks before making process modifications;
11. **Incident Investigation:** Root cause analysis of accidents and near-misses;
12. **Emergency Planning and Response:** Preparedness for releases or failures;
13. **Compliance Audits:** Evaluating PSM effectiveness at least every three years;
14. **Trade Secrets:** Ensuring necessary safety info is shared even if proprietary.

II.5.2. Energy Institute (EI) [50]

The Energy Institute's High-Level Framework based on 20 elements but organizes them under 4 Focus Areas:

1. **Process Safety Leadership:** Elements like leadership commitment, legislation compliance, and workforce involvement;
2. **Risk Identification and Assessment:** Hazard identification and knowledge management;
3. **Risk Management:** Operating procedures, MOC, operational readiness, and inspection;
4. **Review and Improvement:** Incident investigation and auditing/assurance.

II.5.3. EU Seveso III Directive [51]

Applicable across the European Union, this directive focuses on preventing major accidents. Key requirements include :

1. **Major Accident Prevention Policy (MAPP):** A core document outlining safety principles.
2. **Safety Report:** Detailed technical documentation for high-tier sites;
3. **Emergency Plans:** Both internal (site-level) and external (coordinated with local authorities);
4. **Public Information:** Proactive communication about risks to the surrounding community;
5. **Domino Effect Identification:** Assessing risks shared with neighboring facilities.

II.5.4. EPA Risk Management Plan (RMP) [52]

Similar to OSHA PSM but focused on protecting the surrounding community and environment rather than just workers. The U.S. EPA RMP rule (40 CFR Part 68) focuses on protecting the public and the environment from accidental chemical releases.

1. **Three Program Levels:** Requirements are tiered (Program 1, 2, or 3) based on a process's potential for offsite impact and its accident history;
2. **Hazard Assessment:** Includes modeling **worst-case** and alternative release scenarios to determine the "vulnerability zone" (the distance a chemical plume might travel);
3. **Prevention Program:** For complex "Program 3" sites, this is almost identical to OSHA PSM (e.g., PHA, MOC, training);
4. **Emergency Response:** Requires coordination with local responders and, in some cases, the facility having its own response team;
5. **Recent Updates (2024):** New mandates include performing "Safer Technology and Alternatives Analysis" (STAA) and considering climate change risks.

II.5.5. IOGP (International Association of Oil&Gas Producers) [53]

Focuses on "Process Safety Fundamentals" and, the frontline performance, the barrier-based management specific to offshore and upstream oil and gas industry activities and preventing high-severity events. The **Process Safety Fundamentals (PSFs):** A set of **10 core principles** designed for frontline workers to recognize and stop work if safety barriers are at risk.

The 10 Fundamentals :

1. Maintain Safe Isolation;
2. Walk the Line (physical verification);
3. Apply Procedures;
4. Sustain Barriers;
5. Control Ignition Sources;
6. Recognize Change (MOC awareness);
7. Respect Hazards;
8. Stay within Operating Limits;
9. Stop if the Unexpected Occurs;
10. Watch for Weak Signals.

II.5.6. IChemE Safety Center [54]

Uses **7 functional pillars**, including human factors and engineering design, to organize safety management. the pillars are recognized on **6 Functional Pillars** (plus Leadership) to help organizations manage safety as a "chain" of connected systems.

- **The 6 Pillars:**

    1. **Culture:** "The way we do things around here";
    2. **Knowledge and Competence:** Ensuring people understand the consequences of their decisions;
    3. **Engineering and Design:** Applying inherently safer design and the hierarchy of controls;
    4. **Systems and Procedures:** Governance and consistent on-the-job tasks;
    5. **Assurance:** Systematic monitoring, auditing, and testing;
    6. **Human Factors:** Exploring the interaction between the human, the job, and the organization.

- **Leadership:** An overarching element that drives commitment across all six pillars.

II.5.7. RBPS Risk-Based Process Safety Model [55]

The Center for Chemical Process Safety CCPS (AIChE) has developed the **Risk-Based Process Safety (RBPS)** model, which represents a next-generation process safety management system that comprises a comprehensive set of policies, procedures, and practices aimed at managing and prioritizing risks based on their significance, thereby allocating resources accordingly to effectively address high-risk areas.

The **RBPS** is organized into **4 Pillars** and **20 Elements**. Unlike older regulatory models, it is designed to be scalable, meaning a facility applies each element with an intensity that matches its specific risk profile.

- **Pillar 1: Commit to Process Safety**

This pillar focuses on the corporate culture and ensuring that leadership and the workforce are aligned.

1. **Process Safety Culture:** The collective values and behaviors that prioritize safety over production;

2. **Compliance with Standards:** Identifying and following applicable regulations, codes, and internal standards;
3. **Process Safety Competence:** Building and maintaining technical knowledge and expertise within the team;
4. **Workforce Involvement:** Actively involving employees and contractors in safety programs;
5. **Stakeholder Outreach:** Communicating with the local community, emergency responders, and authorities.

- **Pillar 2: Understand Hazards and Risks**

This is the “brain” of the system—it ensures the organization knows exactly what can go wrong.

6. **Process Knowledge Management:** Maintaining accurate technical documentation (P&IDs, safety data sheets, design basis);
7. **Hazard Identification and Risk Analysis (HIRA):** Systematic studies (like HAZOP or What-If) to assess the likelihood and severity of incidents.

- **Pillar 3: Manage Risk**

8. These are the operational controls used to keep the process within safe limits every day; **Operating Procedures:** Clear, written instructions for startup, normal operation, and emergency shutdowns.
9. **Safe Work Practices:** Administrative controls for non-routine work (Hot Work permits, Lockout/Tagout, etc.);
10. **Asset Integrity and Reliability:** Inspection, testing, and maintenance of critical equipment;
11. **Contractor Management:** Ensuring third-party workers are qualified and follow site safety rules;
12. **Training and Performance Assurance:** Verifying those personnel have the skills to perform their jobs safely;
13. **Management of Change (MOC):** Reviewing potential risks before any modification to equipment, chemicals, or personnel;
14. **Operational Readiness:** Pre-Startup Safety Reviews (PSSR) to ensure a system is safe to start.
15. **Conduct of Operations:** The “operational discipline” required to execute tasks correctly every time;
16. **Emergency Management:** Planning and practicing for when things go wrong to minimize consequences.

- **Pillar 4: Learn from Experience**

This pillar ensures the system evolves and improves by analyzing performance.

17. **Incident Investigation:** Identifying the root causes of accidents and “near-misses”;
18. **Measurement and Metrics:** Tracking leading (proactive) and lagging (reactive) indicators;
19. **Auditing:** Periodic internal and external reviews to ensure the PSM system is actually working;
20. **Management Review and Continuous Improvement:** Leadership evaluation of the system’s effectiveness and resource allocation.

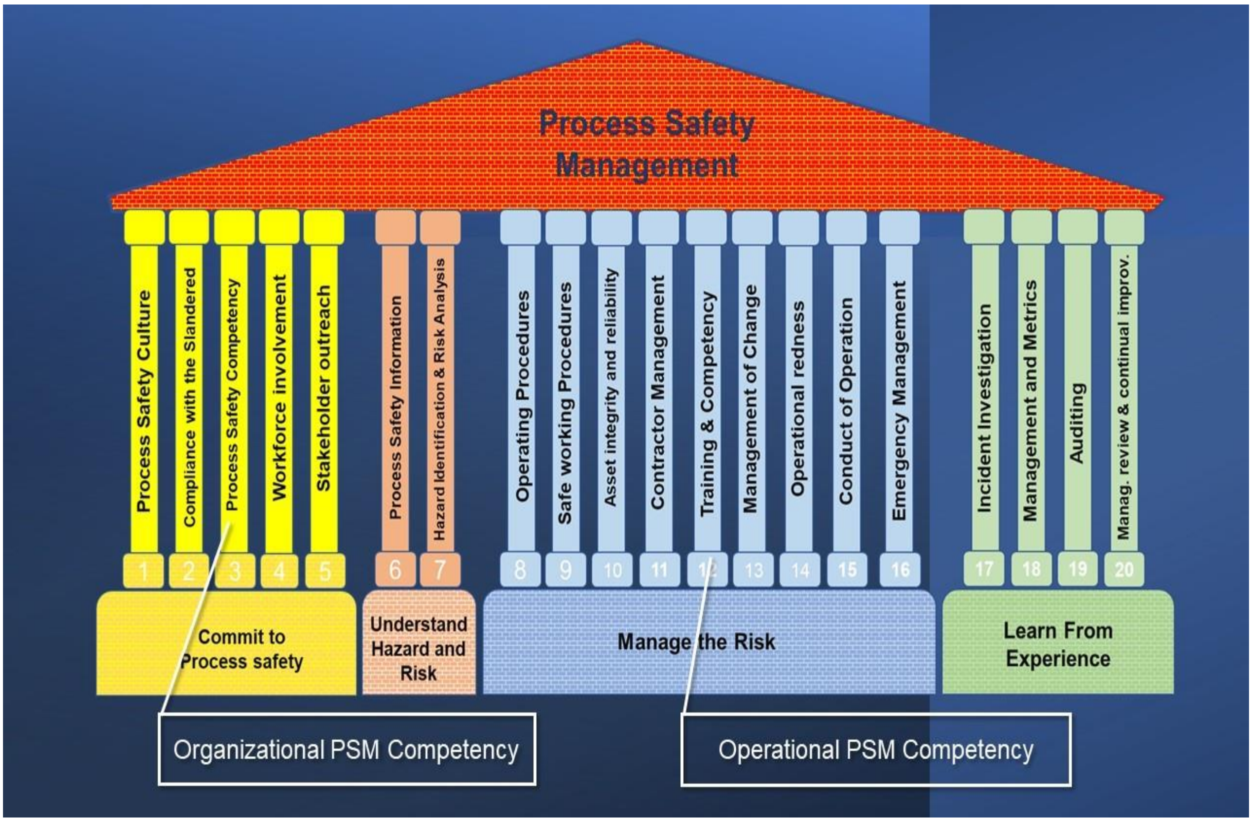

Figure II.5: RBPS Pillars Elements Organization [2]

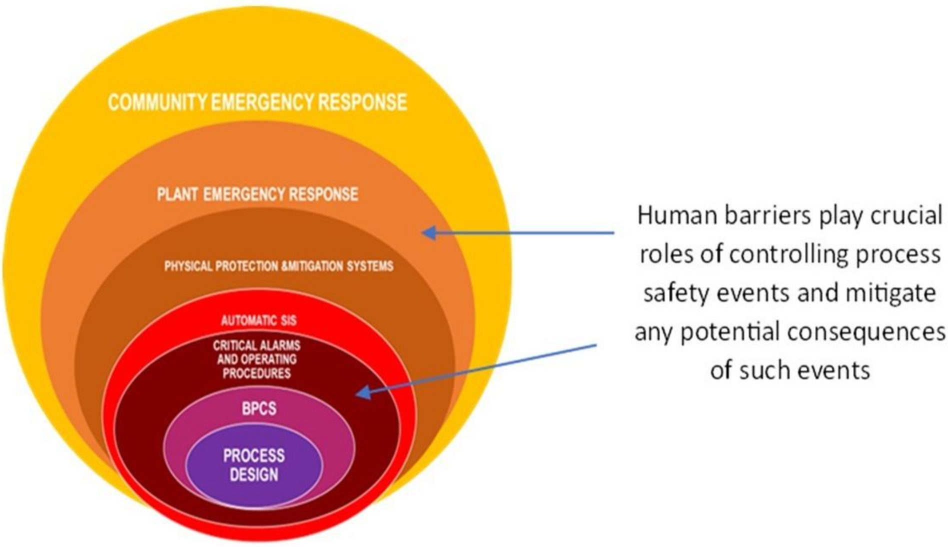

Figure II.6: RBPS Pillars Elements Organization [2]

II.6. Conclusion

In conclusion, Process Safety Management (PSM) has become a fundamental approach for preventing major industrial accidents and ensuring the safe operation of hazardous processes. Its development was strongly influenced by catastrophic events such as the Bhopal disaster and the Piper Alpha disaster, which highlighted the need for systematic safety practices and stronger regulations. Over time, PSM evolved from basic safety measures into a comprehensive management system focused on risk assessment, operational control, employee involvement, and continuous improvement. Today, PSM remains an essential element in industrial sectors, helping organizations reduce risks, protect human life, preserve the environment, and maintain operational reliability.

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Chapter III: Process Safety Management System

“PSM” of

SONATRACH Group

III.1. Introduction

This chapter presents the SONATRACH Group's Process Safety Management (PSM) Framework. The approach that was adopted to this system and its elements. we will also study the case if implementing the SONATRACH Group's Process Safety Management (PSM) on HDPE reactor.

III.2. Process Safety Management (PSM) Framework of SONATRACH [1]

III.2.1. SONATRACH Group's Purpose

The purpose of the SONATRACH Group's process safety management reference framework is to describe the various elements and requirements of PSM, which is based on the risk-based process safety (RBPS) model established by CCPS. The SONATRACH reference document codified as PSM_DIA_RF_01 REV.1 dated 23/04/2023.

III.2.2. SONATRACH Group's PSM Goal

The goal is to enhance the existing risk management practices at the refineries and operational complexes by adopting and implementing the requirements of the "Process Safety Management (PSM) framework of SONATRACH" from the PSM Project Directorate / DC – HSE.

III.2.3. SONATRACH Group's PSM Barriers

To develop the idea that Process Safety Management (PSM) at Sonatrach Group is a defense-in-depth strategy, you can structure your concept around three distinct layers of protection: Technical, Organizational, and Human barriers.

At Sonatrach, this strategy is formalized through the process safety management reference framework (PSM), which aims to protect "man, production tools, and the environment, and that as presenting in Figure III.1.

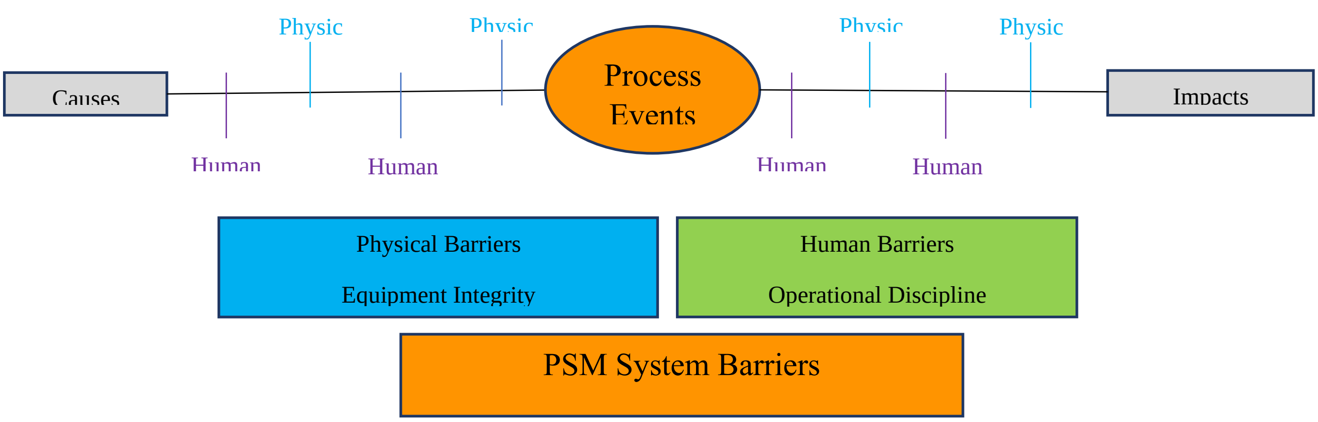

Figure III.1: SONATRACH Group's PSM Barriers.

III.2.4. SONATRACH Group's PSM PDCA Cycle

The PDCA cycle (Plan-Do-Check-Act) is the engine of Sonatrach Group's Process Safety Management (PSM) system. It transforms the "defense-in-depth" barriers from static concepts into a dynamic, continuous improvement process.

At **Sonatrach**, the PDCA cycle ensures that process safety isn't just a onetime setup but an evolving system that adapts to new risks and operational changes.

1. **Plan: Define the Strategy**

In this phase, Sonatrach defines the "what" and "how" of process safety by HSE Policy&Objectives, Process Hazard Analysis (PHA) and Resource Allocation.

2. **Do: Implementation**

This is where the planned barriers and procedures are put into action across facilities like refineries and LNG plants. Operational Controls, Training&Competence and Asset Integrity Maintenance.

3. **Check: Monitor & Evaluate**

Sonatrach uses this phase to verify if the barriers are actually working as intended. KPI Tracking, Compliance Audits and Incident Investigation.

4. **Act : Continuons Improvement**

The cycle completes (and restarts) by taking action based on the "Check" findings by Corrective Actions, Management Review and Update Standards & Policies.

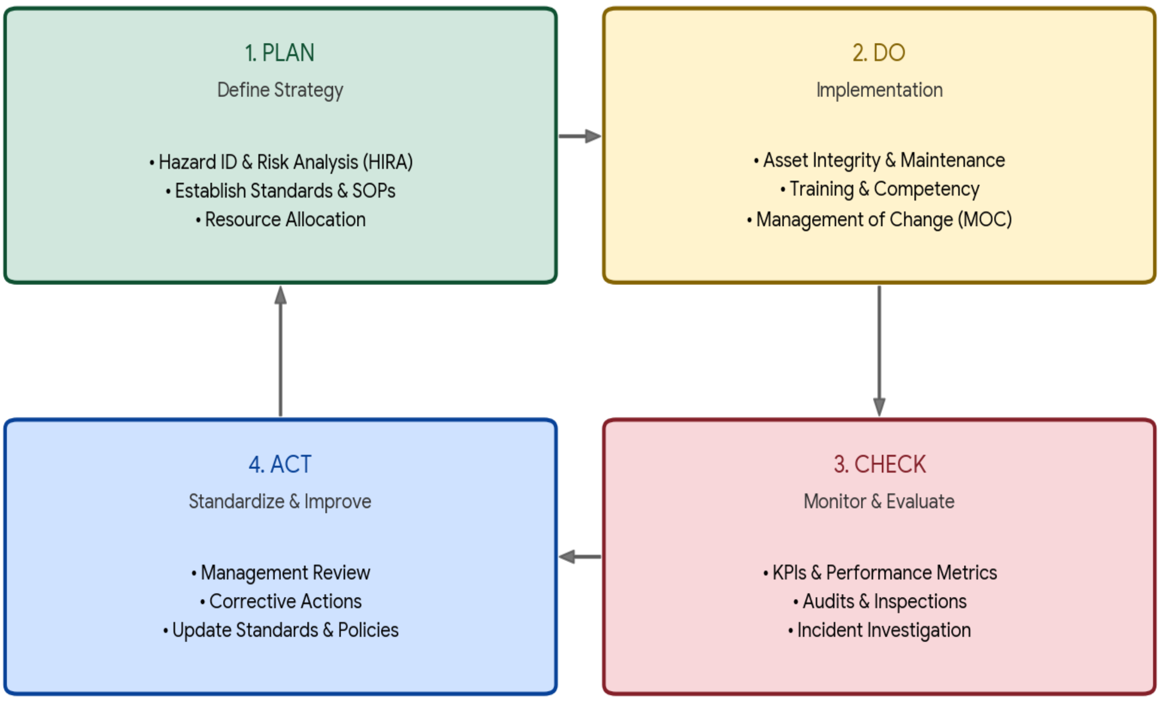

Figure III.2: PDCA cycle for SONATRACH PSM.

III.2.5. SONATRACH Group's PSM Interaction with other Systems

At Sonatrach Group, the Process Safety Management (PSM) system does not operate in isolation. It is a critical component of an Integrated Management System (SMI) that aligns technical safety and standards with health, environmental, and quality.

This interaction creates a "system of systems" where PSM provides the technical specialized barriers, and other systems provide the governance and organizational support, as showing in (Figure III.3).

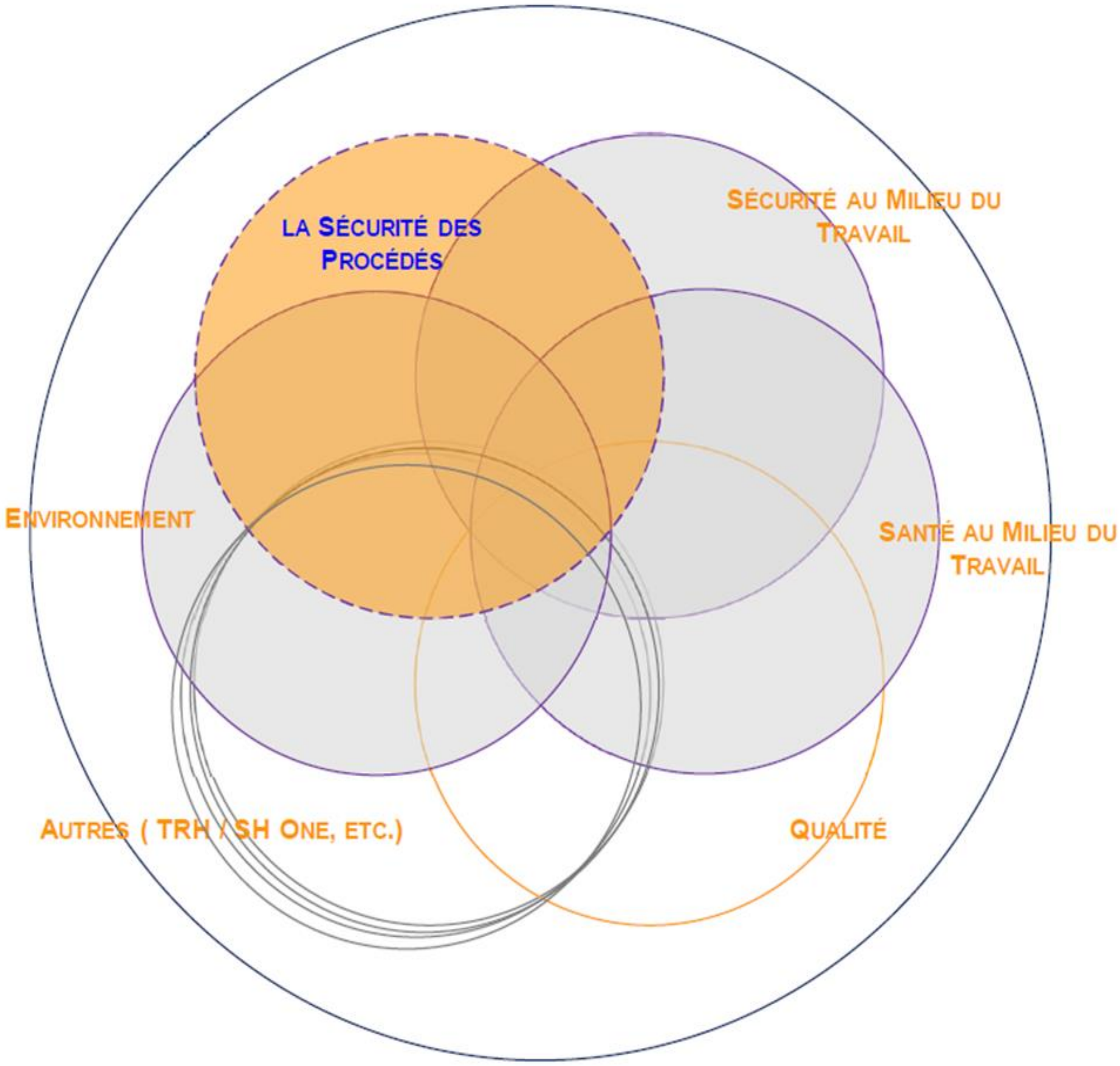

Figure III.4: SONATRACH Group's PSM Interaction with other Systems.

III.2.6. SONATRACH Group's PSM Elements

The four fundamental pillars of Process Safety Management:

Pillar One: Commit to process safety

Establish a robust safety culture and define responsibilities; A genuine commitment to process safety leads to excellence in this field. It is based on five key elements:

1. **Process Safety Culture**

   A workforce that believes safety is a core value of the organization is likely to act correctly, appropriately, and timely, even when not being observed. This behavior should be consistently encouraged and valued throughout the organization.

2. **Compliance with Regulations and Standards**

   Compliance relies on the identification, development, acquisition, evaluation, dissemination, and access to Algerian regulations (Law No. 19-13, Law No. 24-04, No. 21-319, 21-331, 21-315, etc.), as well as the standards and references of SONATRACH and international norms and standards.

3. **Process Safety Competencies**

   Competence focuses on organizational learning, where development and maintenance are based on the continuous improvement of knowledge, ensuring the availability of relevant information, and applying what has been learned. This element is closely linked to the ongoing training and validation of acquired skills.

4. **Employee Engagement and Involvement**

   Being the most exposed to risks and the most skilled in the operation and maintenance of facilities, site management must leverage this expertise by directly involving workers in their own safety.

   This involvement facilitates active participation in the design, development, implementation, and continuous improvement of the PSM system.

5. **Transparency with Stakeholders**

   This involves identifying the parties (individuals or organizations) that may be affected by site activities, such as (the ARH, local and national authorities, insurers, associations, etc.), and engaging in dialogue about process safety to establish relationships with interested parties and provide accurate information about hazards and risks.

Pillar Two: Understand hazards and risks

Identify potential threats and assess their likelihood and impact; This pillar is founded on understanding the inherent dangers and risks associated with sites, while considering the changes that may occur along with the associated risks,

6. Technical Process Information Knowledge Management

The availability of an effective documentation system that compiles a specific set of precise, complete, and up-to-date data, accessible to employees who need it.

7. Hazard Identification and Risk Analysis

This is a crucial element that outlines the requirements to assist sites in better managing aspects related to hazard identification and risk assessment (HIRA or PHA) throughout the entire lifecycle of a facility. There are several tools available to meet various analytical needs:

- Qualitative risk analyses such as HAZOP, SWIFT, FMEA, and FMECA
- Semi-quantitative risk analyses such as LOPA
- Quantitative risk analyses such as FTA, ETA, QRA, and FERA.

Pillar Three: Manage and control risks

Implement operational procedures and protective barriers;

8. Operating Procedure

The operational procedures are written instructions that outline the steps to be taken by operators to safely perform a given operation (startup, emergency shutdown, and normal shutdown). These procedures also detail the process, equipment, and tools necessary for the proper functioning of the process.

9. Safety Intervention Procedures

The primary goal of implementing safety procedures during work is to control hazards and manage the risks associated with potentially dangerous non-routine tasks. This includes any work that is not fully described in an operating procedure, such as operations involving heat, excavation work, and work in confined spaces.

10. Integrity and Reliability of Installations

This is done according to national regulations; integrity refers to the ability of an installation's equipment to perform its functions effectively and efficiently. The management of integrity and reliability of installations encompasses a set of approved practices recognized as credible for maintaining the integrity of equipment or installations, achievable through management support, practices, and documented procedures.

11. Contractor Management

This element ensures that third-party contractors operating on high-hazard sites adhere to the same safety barriers as Sonatrach staff.

- Selection & Evaluation: Screening contractors based on their safety performance and technical competence before awarding contracts.
- Site Induction: Mandatory safety briefings covering site-specific hazards and emergency procedures for all temporary workers.
- Monitoring: Continuous auditing of contractor work practices to ensure compliance with the reference framework HSE-MS.

12. Training And Performance Assurance

Focuses on building and verifying the technical competence of personnel who operate or maintain hazardous processes.

- Competency Matrices: Defining exact skills needed for each role (e.g., Control Room Operator).
- Refresher Programs: Regular training cycles to maintain high awareness of process hazards.
- Validation: Using performance testing (simulations or exams) to confirm that employees can respond correctly to process deviations.

13. Management of Change

The "gatekeeper" element that ensures modifications do not introduce unintended risks.

- Technical Review: Any change to equipment, chemicals, or staffing must undergo a risk assessment (like a mini-HAZOP).
- Documentation: Updating P&IDs, operating manuals, and training records before the change is considered "closed".
- Authorization: Requiring formal approval from specialized safety and technical authorities at the site or corporate level.

14. Operational Readiness

Often involving Pre-Startup Safety Reviews (PSSR), this element confirms a facility is safe to operate after a shutdown or change.

- PSSR Checklists: Verifying that construction meets design specs and that all safety devices are functional.
- Training Verification: Confirming that operators are trained on any new equipment or procedures before startup.
- Final Walkdown: A physical inspection to ensure the area is clear of debris and ready for hazardous materials

15. Conduct of Operations

This element focuses on the human and organizational discipline required for error-free daily performance.

- Operating Procedures: Maintaining clear, up-to-date Standard Operating Procedures (SOPs) for all phases—startup, normal operation, and emergency shutdown.
- Shift Handover: Structured communication between shifts to ensure new teams are aware of ongoing process issues or maintenance work.
- Safe Work Practices: Managing high-risk tasks through Permit-to-Work (PTW) systems, such as hot work or confined space entry.

16. Emergency Management

Ensures the organization is prepared to minimize the impact of a process safety event if it occurs.

- Emergency Response Plans (ERP): Detailed procedures for specific scenarios like fires, gas leaks, or toxic releases.
- Drills & Exercises: Regular simulations with site teams and local authorities (e.g., Protection Civile) to test response times and equipment.
- Resource Availability: Maintaining specialized fire-fighting equipment, medical supplies, and mobile command units in a state of high readiness
-

Pillar Four: Learn from experience

Analyze incidents and indicators for continuous improvement.

17. Accident Analysis and Lessons Learned

This section outlines the features of an effective program aimed at enhancing the incident investigation process, with the goal of implementing necessary measures to prevent recurrence. Therefore, it is essential to ensure that incidents are consistently reported and investigated, and that the actions and lessons identified are executed promptly with widespread dissemination across the organization.

18. Key Performance Indicators in Process Safety

KPIs Key performance indicators related to process safety are critical metrics for assessing the performance of a management system. A combination of retrospective and predictive indicators is often the best approach to provide a clear and comprehensive picture of the effectiveness of the process safety management system.

19. Audits

The audit of the process safety management system involves a systematic examination, following a written protocol, of all elements of the system to ensure they are in place and functioning to prevent incidents. The nature and frequency of audits are governed by factors such as the current phase of the installation's life cycle and the maturity (degree of implementation) of the PSM management system.

20. Management Review and Continuous Improvement

The management review is a regular assessment aimed at determining whether the process safety management system is functioning as intended and achieving the desired results as efficiently as possible. This review involves regularly monitoring the state of the system to identify and rectify any actual or emerging deficiencies before they are exposed by an audit or an incident.

III.2.7. PSM Compared to Health and Safety at Work [2,3]

Process safety management is frequently mistaken for occupational safety management. The most common reasons for this confusion include:

1. Differing Scales of Failure

- Occupational Safety: Focuses on high-frequency, low-consequence events that typically affect individuals (e.g., slips, trips, falls, or cuts).
- Process Safety: Focuses on low-frequency, high-consequence events that can affect entire facilities and communities (e.g., explosions, toxic releases, or fires).

2. The "Safety Triangle" Trap

Companies often mistakenly believe that a low rate of personal injuries (occupational safety) means the facility is safe from catastrophic failure.

- Misconception: If no one is slipping or tripping, the process must be under control.
- Reality: A refinery can have an excellent personal safety record while simultaneously being on the verge of a massive explosion due to degraded technical barriers, such as a faulty relief valve.

3. "How" vs. "What"

- Occupational Safety is often about how people do their work (e.g., wearing PPE, using ladders correctly).
- Process Safety is about what is being handled and the integrity of the system (e.g., pressure, temperature, and chemical containment).

4. Direct vs. Indirect Protection

- Occupational Safety protects people directly through behavioral interventions and personal equipment like gloves or helmets.
- Process Safety protects people indirectly by controlling the energy and hazardous materials within the system.

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If you are responsible for security and are considering this type of threat… You are likely involved in "PROCESS SAFETY MANAGEMENT (PSM)".

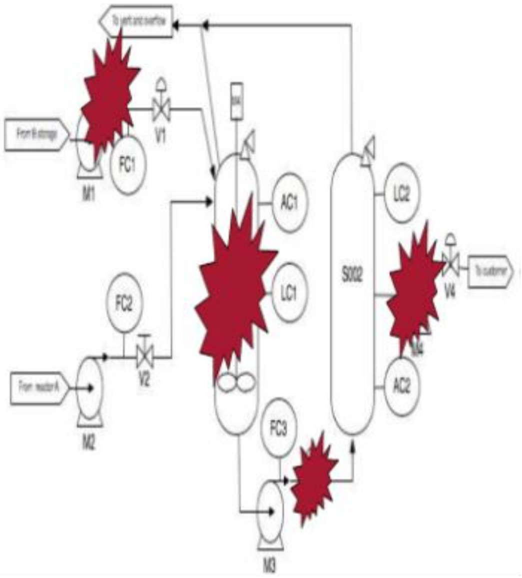

Figure III.5: SONATRACH Group's PSM Approach.

If you are responsible for security and are considering this type of threat……You are likely engaged in "WORKPLACE SAFETY"

Figure III.6: Workplace Safety Approach

III.3. Project of Implementation of SONATRACH Group's PSM System on the PHILLIPS HDPE Reactor (950-155)

The Phillips Petroleum Company's loop reactor process, developed in the early 1950s, remains one of the most widely utilized and efficient methods for producing HDPE. This process is characterized by the use of a chromium-based catalyst (often referred to as the "Phillips Catalyst") and a high-pressure loop reactor where polymerization occurs in a light hydrocarbon diluent, typically isobutane. The design is celebrated for its high productivity, excellent heat transfer capabilities, and the ability to produce a broad range of polymer grades with relatively simple mechanical configurations [4].

III.3.1. The Safety Imperative in Polymerization

Despite its industrial success, the Phillips process involves inherent risks that demand rigorous management. The polymerization of ethylene is a highly exothermic reaction, meaning it releases a significant amount of heat. In a loop reactor, this heat must be continuously removed through cooling jackets to maintain the temperature within a very narrow "safe operating window" typically between 80°C and 110°C [5].

If the rate of heat generation exceeds the rate of heat removal, a thermal runaway can occur. This leads to a rapid increase in pressure and temperature, potentially causing the polymer to melt and stick to the reactor walls (fouling), or in extreme cases, leading to the catastrophic mechanical failure of the reactor vessel [5]. Furthermore, the presence of large quantities of flammable isobutane and ethylene at high pressures means that any loss of containment could result in a major fire or vapor cloud explosion (VCE) [6].

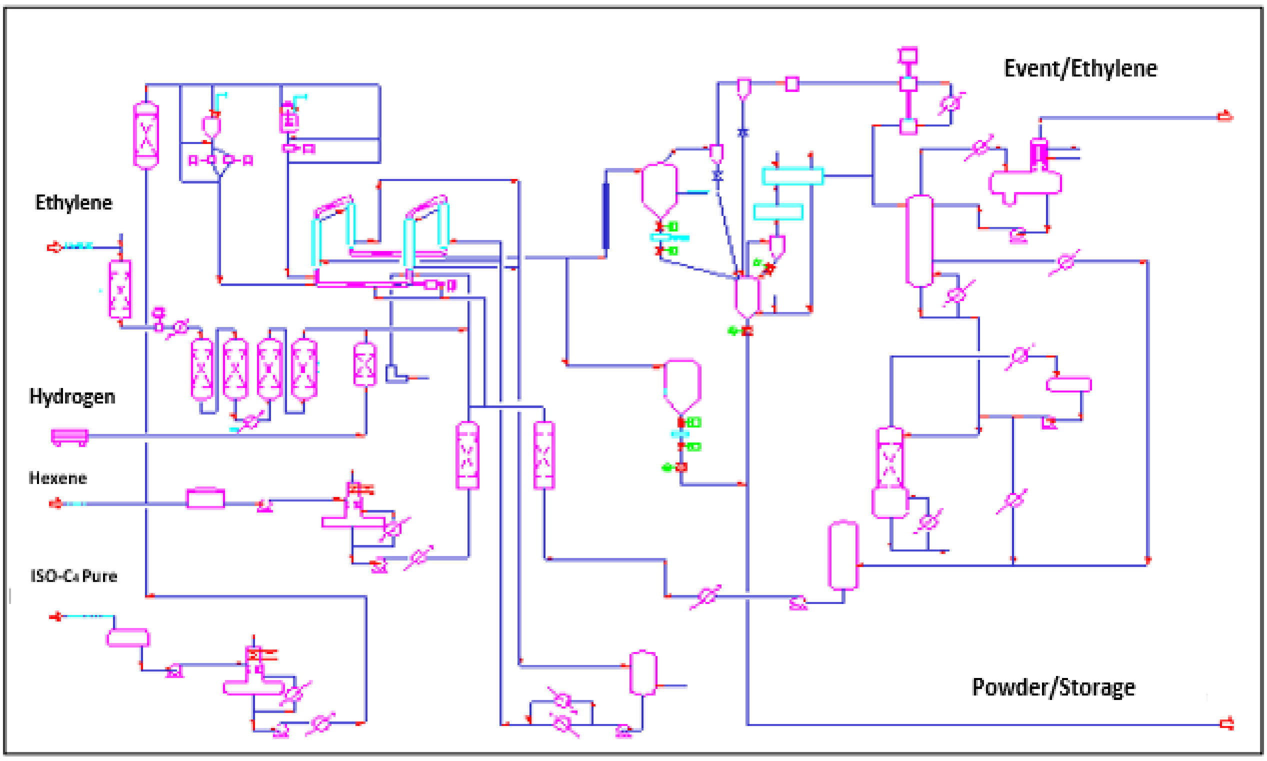

Figure III.6: Simplified HDPE Process diagram.

III.3.2. Problem Statement

Historically, safety in chemical plants has been managed through **compliance-based systems**, which focus on following a static set of rules. However, as processes like the Phillips HDPE reactor (950-155), become more complex and operate closer to their design limits, these traditional methods can fall short. Compliance-based systems often treat all hazards with the same level of priority, which can lead to "safety fatigue" or a failure to address the most critical risks with sufficient technical depth.

The core problem addressed in this project is the need to move beyond simple compliance and implement a SONATRACH Group's PSM System.

This shift is necessary to ensure that safety resources such as high-integrity safety instrumented systems and rigorous maintenance programs are directed specifically where the risk is highest: the loop reactor and its associated feed and cooling systems.

III.3.3. Objectives of the Project

The primary objective of this project work is to design and document a manuscript for the implementation of SONATRACH Group's PSM System tailored to a Phillips HDPE loop reactor. The specific sub-objectives include:

- ✓ Applying the 20 Elements of SONATRACH Group's PSM System: Integrating the four pillars of PSM into the management of the polymerization unit;
- ✓ Conducting Advanced Hazard Identification: Using HAZID, "What-If?", and HAZOP methodologies to map the specific failure modes of the loop reactor;
- ✓ Quantifying Risk via LOPA: Performing a Layer of Protection Analysis to determine if existing safeguards are sufficient to meet a target mitigated event frequency of 10^{-6}/year;
- ✓ Designing SIL-Rated Protections: Proposing a Safety Instrumented Function (SIF) for the "Emergency Catalyst Kill" system that meets Safety Integrity Level 2 (SIL 2) standards.

III.3.4. Scope and Significance

This project focuses on the **Reaction Node (950-155),** of the Phillips HDPE process. While the plant includes feed purification, diluent recovery, and extrusion sections, the loop reactor is the most critical area from a process safety perspective. The significance of this work lies in its ability to provide a blueprint for chemical engineers to enhance plant safety. By moving to an RBPS framework, the facility can achieve higher operational reliability, protect the surrounding community from potential industrial accidents, and ensure the long-term sustainability of the production site.

III.3.5. The Chemistry and Kinetics of Phillips HDPE Production

To manage the risk of the Phillips process, one must understand the underlying science. The reaction is an exothermic polymerization of ethylene (C_2H_4).

- **Exothermicity:** The reaction releases approximately 25,000 to 30,000 calories per mole of ethylene polymerized;
- **Heat Transfer:** The loop reactor is designed as a "Heat Exchanger" in itself. The high velocity of the slurry (8–10 m/s) is required to maintain a high heat transfer coefficient (U);
- **The "Runaway" Threshold:** If the temperature rises too high, the polymer particles soften and become "sticky". This leads to **fouling** on the reactor walls, which further reduces heat transfer, creating a dangerous positive feedback loop that ends in a runaway reaction.

III.3.6. Safety Instrumented Systems (SIS) and SIL

Modern literature emphasizes the role of **Safety Instrumented Systems (SIS)** in high-risk processes. These are automated systems, separate from the main control system, designed to take the process to a safe state.

The **Safety Integrity Level (SIL)** is a measure of the reliability of these systems. For a polymerization reactor, a **SIL 2** rating is generally considered the industry standard for the Emergency Kill System, meaning it has a probability of failure on demand (PFD) of less than 1%.

III.3.7. The Architecture of the Phillips Loop Reactor (950-155)

The heart of the Phillips HDPE process is the **Loop Reactor** (950-155), a unique configuration designed specifically to handle high-solids slurries and extreme heat loads. Unlike traditional stirred-tank reactors (CSTRs), the loop reactor consists of four to six vertical jacketed pipe legs, typically ranging from 20 to 30 inches in diameter, connected by 180-degree bends to form a continuous circuit.

This geometry is engineered to provide a high surface-area-to-volume ratio, allowing for maximum contact between the reacting slurry and the cooling medium in the jackets. The reactor operates "liquid-full," meaning there is no vapor space inside the loop, which simplifies pressure control and prevents the formation of explosive gas pockets.

III.3.7.1. Slurry Circulation and the Axial Pump

Maintaining the slurry in a state of high turbulence is the "lifeline" of the Phillips process. This is achieved by a high-capacity **Axial Flow Circulation Pump** located at the bottom of one of the reactor legs.

- **Circulation Velocity:** The pump maintains a slurry velocity of approximately **8 to 10 meters per second**. This high speed is necessary to keep the polymer "fluff" suspended in the isobutane diluent and to prevent it from settling and plugging the reactor;
- **Heat Transfer Enhancement:** High velocity creates intense turbulence, which significantly increases the heat transfer coefficient (U) between the slurry and the reactor walls;
- **Mechanical Integrity:** The pump seals and bearings are critical points of failure; loss of circulation leads almost immediately to localized hot spots and potential reactor solidification.

III.3.7.2. Feed Systems and Reaction Components

The polymerization reaction requires the precise simultaneous delivery of several components into the loop:

- ✓ **Ethylene (Monomer):** The primary feedstock, which is highly purified to remove oxygen, moisture, and carbon monoxide, all of which act as catalyst poisons;
- ✓ **Isobutane (Diluent):** Acts as a carrier for the catalyst and polymer particles, facilitating heat transfer and flow;
- ✓ **Hexene-1 (Co-monomer):** Added to control the density and mechanical properties of the final HDPE resin;
- ✓ **Hydrogen (H_2):** Used as a chain-transfer agent to control the Melt Index (molecular weight) of the polymer;
- ✓ **Chromium Catalyst:** Typically, a silica-supported chromium oxide, which is activated in a separate furnace before being injected as a slurry into the reactor.

III.3.7.3. Heat Removal and Temperature Control

The reaction temperature is the primary control variable for polymer quality and safety. Cooling is provided by **tempered water** circulating through the reactor jackets.

- ✓ **The Cooling Cascade:** The temperature control loop typically adjusts the setpoint of the cooling water temperature based on the reactor’s internal temperature;
- ✓ **Fouling Resistance:** Over time, a thin layer of polymer can build up on the internal reactor walls (fouling). This layer acts as an insulator, requiring the cooling water to be kept at progressively lower temperatures to maintain the reaction setpoint. When the cooling water reaches its lower limit, the reactor must be shut down and cleaned—a process known as a "de-fouling".

III.3.7.4. Product Discharge and the Fluff Tank

As the polymer concentration in the loop reaches the desired level (typically 35-45%), the slurry is discharged through **Product Take-Off (PTO)** valves. These valves lead to a **Flash Tank** or **Fluff Tank**, where the pressure is suddenly reduced.

The isobutane diluent and unreacted ethylene flash off as vapors to be recycled, while the solid polyethylene fluff falls to the bottom to be sent to the extrusion section.

III.3.8. Demonstration of the Study

The risk analysis primarily aims to identify sources of hazards and associated situations that may lead to harm to individuals, the environment, or property. Secondly, the analysis highlights existing safety barriers to prevent the emergence of a dangerous situation (preventive barriers) or to mitigate its consequences (protective barriers).

The overall approach to risk analysis related to the operation of the CP2K industrial facilities includes the following points:

- Identification of hazards with determination of causes;
- Estimation of the consequences and frequencies of these risks;
- Verification of the adequacy of safety barriers and recommending additional measures if they are insufficient;
- Calculation of the effects of risks deemed critical.

The sequence of these various phases is schematically illustrated in the figure below:

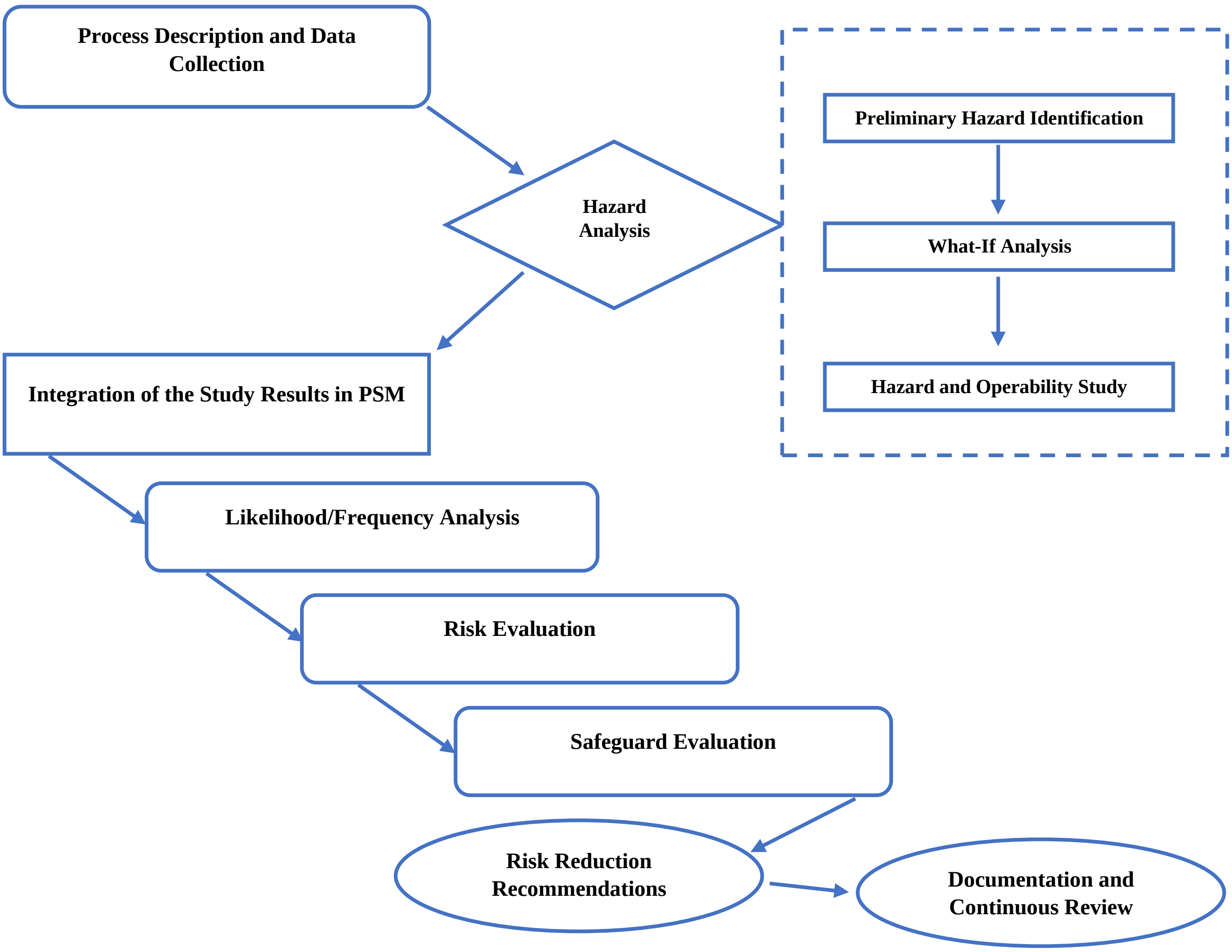

Figure III.7: The diagram illustrates the study approach

III.3.9. HDPE Reactor (950-155) Hazard Identification

Under the SONATRACH Group's PSM framework, hazard identification is not merely a task to be completed for regulatory approval; it is a fundamental process for "Understanding Hazards and Risk". For the Phillips HDPE polymerization reactor (950-155), this involves a multi-layered approach that moves from the macroscopic (HAZID) to the granular (HAZOP) and the creative (What-If). This ensures that both common operational failures and rare, high-consequence events are identified and addressed.

III.3.9.1. Preliminary Hazard Identification (HAZID)

The HAZID study identifies high-level threats to the HDPE Reactor (950-155), focusing on external factors, material properties, and major system failures.

The results of HAZID study are organized in Table III.1

Table III.1: Preliminary Hazard Identification HAZID of PHILLIPS HDPE Reactor

Category	Hazard Identified	Potential Impact on Phillips Process
Environmental/External	Total Power Failure	Loss of reactor circulation leads to rapid settlement and "plugging".
Material Properties	Ethylene&Isobutane Flammability	High potential for Jet Fire or Vapor Cloud Explosion (VCE) if a leak occurs.
Chemical Hazards	Highly Exothermic Reaction	Thermal runaway can exceed the mechanical limits of the reactor vessel.
Mechanical Hazards	High-Pressure Operation	Fatigue on 180° bends due to slurry impingement can cause loss of containment.
Operational	Catalyst Poisoning	Moisture ingress can cause unpredictable reaction kinetics or total shutdown.

III.3.9.2. "What-If" Analysis

The "What-If" analysis is a brainstorming technique used to explore scenarios that may fall between the gaps of more structured methods.

- What if the cooling water jacket develops a significant leak?
  - ***Consequence:*** Water enters the reactor at high pressure, poisoning the catalyst and potentially causing a rapid pressure surge due to steam formation.
- What if the axial circulation pump seal fails?
  - ***Consequence:*** Release of high-pressure isobutane and ethylene into the pump house, creating an immediate fire and explosion risk.
- What if there is a mistake in the catalyst grade loading?
  - ***Consequence:*** The reaction kinetics may be much faster than the cooling system can handle, leading to a runaway scenario within minutes.
- What if the Product Take-Off (PTO) valve sticks in the open position?
  - ***Consequence:*** Rapid depressurization of the reactor, leading to cavitation of the circulation pump and loss of heat transfer.

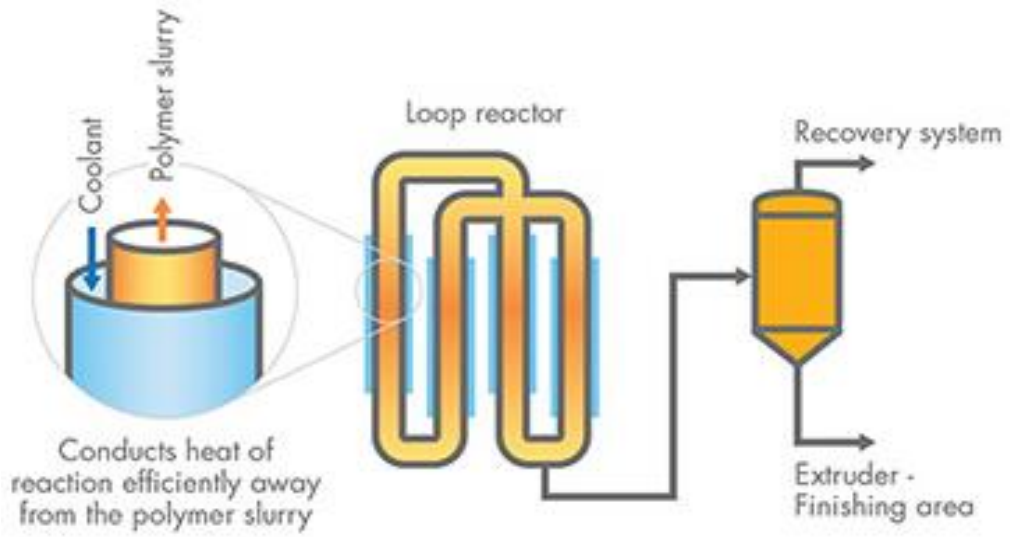

Figure III.8: PHILLIPS HDPE Reactor Loop [7]

III.3.9.3. Hazard and Operability Study (HAZOP)

The HAZOP study is the most rigorous part of the identification process. It uses "Guide Words" to explore deviations from the design intent of specific nodes. Table III.2, presents the HAZOP study.

Node 1: Reactor Loop (950-155) and Circulation System

Design Intent: Continuously circulate slurry at 8–10 m/s and maintain temperature between 80°C and 110°C.

Table III.2: Hazard and Operability Study (HAZOP) of PHILLIPS HDPE Reactor Loop and Circulation System.

Guide Word	Deviation	Possible Causes	Consequences	Safeguards
High	Temperature	Cooling water valve failure; catalyst over-feed; high ethylene concentration.	Polymer "stickiness" (fouling); Thermal runaway; Over-pressurization.	High-Temp Alarm (TAH); Emergency Catalyst Kill System (SIS); Redundant cooling pumps.
High	Pressure	Reactor runaway; Blocked discharge line; Over-filling the loop.	Mechanical rupture of reactor flanges; Activation of safety relief valves.	Pressure Safety Valves (PSVs); Rupture Disks; Automated feed shut-off (ESD).
Low	Flow / ΔP	Axial pump trip; High slurry density (solids > 45%); Blockage in a leg.	Polymer settlement; Loss of heat transfer; Localized hot spots; "Solid" reactor.	Low-Flow Alarm; Low-Differential Pressure (dP) Trip; Pump vibration monitors.
Other Than	Composition	Oxygen/Moisture in feed; Wrong catalyst grade; Impurities in diluent.	Catalyst poisoning; Sudden loss of production; Unpredictable temperature spikes.	Feed purification beds; Online analyzers (O_2/H_2O); Strict laboratory QC of feeds.

III.3.9.4. Consequence of Hazard Scenario

The consequence analysis evaluates the severity of the identified hazards associated with the PHILLIPS HDPE loop reactor process.

The analysis focuses on the effects on personnel, equipment, environment, and plant operation, the table below presents the possible consequences (Effects).

Table III.3: The analysis of Hazards Scenarios Effects

Hazard Scenario	Possible Consequences
Reactor runaway due to high temperature	Over-pressurization of reactor loop, vessel rupture, fire or explosion, severe equipment damage
Ethylene/isobutane leak	Jet fire, vapor cloud explosion (VCE), toxic smoke exposure, injuries and fatalities
Axial circulation pump failure	Loss of slurry circulation, polymer settling, localized hot spots, reactor plugging
Cooling water system leak	Catalyst poisoning, steam generation, rapid pressure increase
Product Take-Off (PTO) valve failure	Sudden depressurization, cavitation, reduced heat transfer efficiency
Oxygen or moisture ingress	Catalyst deactivation, unstable reaction kinetics, production shutdown
Blocked discharge line	Pressure accumulation and possible activation of relief systems

The analysis indicates that the most critical consequences involve thermal runaway, fire/explosion events, and reactor plugging, all of which may lead to catastrophic loss of containment.

III.3.9.5. Likelihood / Frequency Analysis

The likelihood analysis estimates the probability of occurrence of each identified hazard scenario based on equipment reliability, operating conditions, historical industrial incidents, and process complexity, as presented in Table III.4.

Table III.4: The Hazards Scenario Likelihood

Hazard Scenario	Likelihood	Basis
Cooling water valve failure	Medium	Mechanical wear and instrumentation failure are possible during long-term operation
Reactor runaway	Low	Normally controlled by SIS and cooling redundancy, but possible during multiple failures
Pump seal leakage	Medium	Rotating equipment seals are common failure points in slurry systems
Catalyst contamination	High	Moisture and oxygen ingress are frequent operational concerns
Blockage in reactor loop	Medium	Polymer fouling and slurry settling may occur during low circulation
Total power failure	Low	Rare event but with severe consequences

The results show that operational and mechanical failures have moderate probability, while catastrophic events remain low-frequency but high-consequence scenarios.

III.3.9.6. Risk Evaluation

The risk evaluation combines the likelihood and severity of each scenario using a qualitative risk matrix.

Table III.5: The Risk Evaluation.

Scenario	Severity	Likelihood	Risk Level
Reactor thermal runaway	Catastrophic	Low	High
Ethylene/isobutane release	Catastrophic	Medium	High
Pump trip and low circulation	Major	Medium	Medium
Catalyst poisoning	Moderate	High	Medium
Cooling water leakage	Major	Medium	High
Blocked discharge line	Major	Medium	High

Based on the evaluation, the reactor runaway and hydrocarbon release scenarios represent the highest process safety risks and therefore require multiple independent protection layers.

III.3.9.7. Safeguard Assessment

The existing safeguards implemented in the PHILLIPS HDPE loop reactor are evaluated below.

Table III.6: The Evaluation of the PHILLIPS HDPE loop reactor Safeguards

Hazard	Existing Safeguards	Protection
High Temperature	High-Temperature Alarm (TAH); Safety Instrumented System (SIS); redundant cooling pumps	Prevent runaway reaction
High pressure	Pressure Safety Valves (PSVs); rupture disks; Emergency Shutdown System (ESD)	Prevent vessel rupture
Pump trip / low flow	Low-flow alarms; differential pressure trips; vibration monitoring	Maintain slurry circulation
Hydrocarbon leakage	Gas detectors; fire and gas system; emergency isolation valves	Reduce fire and explosion risk
Catalyst contamination	Feed purification beds; oxygen/moisture analyzers	Maintain catalyst activity
Power failure	Backup power supply; emergency shutdown procedures	Maintain safe shutdown conditions

The safeguards provide both preventive and mitigative protection layers to reduce process risk to acceptable levels.

III.3.9.8. Risk Reduction Recommendations

Based on the risk assessment results, the following recommendations are proposed to further improve the safety performance of the HDPE reactor loop system:

1. Install redundant temperature transmitters in critical reactor sections;
2. Improve predictive maintenance for axial circulation pump seals and bearings;
3. Increase inspection frequency for 180° loop bends exposed to slurry erosion;
4. Implement automatic emergency feed isolation during abnormal temperature rise;

5. Upgrade gas detection coverage in the pump house and reactor area;
6. Introduce advanced operator training for runaway reaction scenarios;
7. Periodically validate SIS and ESD system response times;
8. Enhance emergency response planning for vapor cloud explosion scenarios.
9. These recommendations aim to minimize the probability of loss of containment, improve process reliability, and strengthen overall Process Safety Management performance.

III.3.9.9. Documentation and Continuous Review

All hazard identification studies, HAZOP findings, safeguard evaluations, and corrective actions should be properly documented and periodically reviewed throughout the operational lifecycle of the PHILLIPS HDPE loop reactor.

Regular audits, management of change (MOC), incident investigations, and periodic revalidation of the HAZOP study are necessary to ensure continued compliance with Process Safety Management principles and maintain acceptable risk levels.

III.3.10. Integration of the Hazard Study into SONATRACH Group's PSM

The HAZID, What-If analysis, and HAZOP studies performed for the PHILLIPS HDPE loop reactor can be fully integrated into a Process Safety Management (PSM) system to improve risk control, operational reliability, and regulatory compliance. The integration can be structured according to the major PSM elements.

1. Process Safety Information (PSI)

The results of the hazard studies become part of the Process Safety Information database of the HDPE unit.

- ✓ Reactor design conditions (pressure, temperature, flow);
- ✓ Material safety data for ethylene, isobutane, and catalyst;
- ✓ Process Flow Diagrams (PFDs) and P&IDs;
- ✓ Relief system design basis ;
- ✓ Identified hazards and accident scenarios ;
- ✓ Safe operating limits from HAZOP analysis.

The PSI ensures that operators and engineers understand the hazards associated with the reactor loop process.

2. Process Hazard Analysis (PHA)

The HAZID, What-If, and HAZOP studies collectively form the core of the Process Hazard Analysis element of PSM. The studies help to:

- ✓ Identify process deviations ;

- ✓ Evaluate consequences and likelihoods ;
- ✓ Assess existing safeguards ;
- ✓ Recommend corrective actions.

The PHA should be revalidated periodically (typically every 5 years) or after major modifications to the HDPE unit.

3. Operating Procedures

The identified hazards are translated into detailed operating procedures.

- ✓ Startup and shutdown procedures ;
- ✓ Emergency reactor depressurization ;
- ✓ Catalyst handling procedures ;
- ✓ Response to high-temperature alarms ;
- ✓ Procedures for low circulation or pump trip conditions.

Operating limits identified during HAZOP become part of standard operating instructions.

4. Training and Competency

The risk scenarios identified in the study are used for operator training programs.

- ✓ Reactor runaway recognition ;
- ✓ Emergency shutdown response ;
- ✓ Hydrocarbon leak response ;
- ✓ Catalyst contamination prevention ;
- ✓ Loss of cooling scenarios.

Simulation-based training can improve operator response during abnormal situations.

5. Mechanical Integrity

The hazard analysis identifies critical equipment requiring inspection and preventive maintenance.

- ✓ Axial circulation pumps ;
- ✓ 180° reactor bends exposed to erosion ;
- ✓ Pressure Safety Valves (PSVs) ;
- ✓ Rupture disks ;
- ✓ Cooling water systems ;
- ✓ SIS and ESD instrumentation.
- ✓ Inspection intervals can be risk-based according to the severity identified in the PHA.

6. Management of Change (MOC)

Any modification to the HDPE process must be evaluated against the hazard study findings.

- ✓ Changing catalyst grade ;
- ✓ Modifying reactor operating pressure ;
- ✓ Replacing pumps or control systems ;
- ✓ Altering feed composition ;
- ✓ The MOC procedure ensures that new hazards are identified before implementation.

7. Safety Instrumented Systems (SIS)

The study supports the design and verification of protective systems such as:

- ✓ High-temperature.

III.4. Risk-Opportunity

This section provides a high-level overview of the transition to SONATRACH Group's PSM framework and evaluates the balance between operational risks and the strategic opportunities presented by this system.

This project work has detailed the implementation of SONATRACH Group's PSM system for a Phillips HDPE loop reactor, moving away from traditional, static compliance models. The study followed a structured path:

- **Technical Baseline:** Establishing the chemical and mechanical parameters of the loop reactor, identifying the axial pump and cooling jackets as critical components;

- **Hazard Identification:** Utilizing a multi-layered approach (HAZID, What-If, and HAZOP) to identify thermal runaway as the primary catastrophic threat.

The implementation of SONATRACH Group's PSM system is a complex undertaking that presents a unique set of challenges and benefits for the facility.

III.4.1. Operational and Strategic Risks

- **System Complexity:** The introduction of SIL-rated hardware and separate safety PLCs increases the technical complexity of plant maintenance;
- **Nuisance Trips:** If not properly designed (e.g., failing to use 2oo3 logic), highly sensitive safety systems can cause frequent unplanned shutdowns, leading to significant production losses;
- **Cultural Resistance:** Moving to an SONATRACH Group's PSM requires a shift in mindset; workers must prioritize safety over production quotas, which can be difficult to sustain during high-demand periods;

- **Data Integrity:** The effectiveness of LOPA depends entirely on the accuracy of initiating event frequencies. Underestimating the failure rate of a cooling pump, for example, invalidates the entire risk model.

III.4.2. Strategic Opportunities

- ✓ **Optimized Resource Allocation:** SONATRACH Group's PSM allows the plant to focus its budget on "Safety Critical Equipment" (like the Kill System) rather than wasting resources on low-risk compliance tasks;
- ✓ **Enhanced Process Reliability:** By better understanding the "Safe Operating Limits" (SOL), the plant can operate closer to maximum capacity without increasing the likelihood of an accident;
- ✓ **Regulatory Leadership:** Implementing a SONATRACH Group's PSM framework places the facility at the forefront of global safety standards, potentially lowering insurance premiums and improving public relations;
- ✓ **Knowledge Retention:** The rigorous documentation required for Process Knowledge Management ensures that critical engineering expertise is preserved even as the workforce retires.

III.5. Conclusion

This chapter presented a comprehensive process hazard analysis of the PHILLIPS HDPE loop reactor using SONATRACH Group's PSM methodologies. The study applied HAZID, What-If analysis, and HAZOP techniques to identify major process hazards associated with high-pressure operation, flammable hydrocarbons, highly exothermic reactions, and catalyst sensitivity. The analysis showed that the most critical risks are related to thermal runaway, loss of circulation, hydrocarbon leakage, and reactor overpressure, all of which may lead to severe safety, environmental, and economic consequences. Existing safeguards such as Safety Instrumented Systems (SIS), Pressure Safety Valves (PSVs), gas detection systems, and emergency shutdown procedures provide important protection layers to reduce these risks.

The findings also highlighted the importance of preventive maintenance, reliable cooling systems, operator training, and continuous monitoring to maintain safe reactor operation. Overall, the study demonstrates that integrating hazard identification and risk analysis within a Process Safety Management framework significantly improves the safety, reliability, and operational integrity of the PHILLIPS HDPE unit.

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General Conclusion and Recommendations

This project has systematically demonstrated that the management of high-consequence risks in the Phillips HDPE polymerization process is best achieved through SONATRACH Group's PSM framework rather than a traditional compliance-only approach. By focusing on the loop reactor as the most critical node, the study has bridged the gap between theoretical chemical kinetics and practical safety engineering. The integration of advanced hazard identification (HAZOP/What-If) with semi-quantitative risk assessment (LOPA) provided a clear technical justification for the implementation of a SIL 2 Safety Instrumented System.

The study successfully proved that by utilizing a 2oo3 sensor voting logic and a 1oo2 final element architecture, the frequency of a catastrophic thermal runaway can be reduced to an acceptable level of 10^{-6} per year. Ultimately, process safety in the Phillips process is not a static destination but a continuous operational culture. The implementation of the pillars of SONATRACH Group's PSM specifically Process Knowledge Management, Asset Integrity, and Training ensures that the technical safeguards designed in this manuscript remain reliable throughout the lifecycle of the plant. This comprehensive approach not only protects the facility’s assets but, more importantly, safeguards the workforce and the environment.

Based on the technical findings of this manuscript, the following actions are recommended for the successful management of the Phillips HDPE unit:

❖ **Technical Recommendation’s :**

1. Immediate Retrofitting: Upgrade all reactor temperature and pressure transmitters to SIL-rated units and implement 2oo3 voting logic to maximize both safety and availability;
2. Redundant Cooling Power: Install a dedicated emergency backup power supply (UPS) specifically for the cooling water pumps and the axial circulation pump to prevent the most common initiating events of a runaway;
3. Real-Time Monitoring: Implement an automated dashboard to track "Leading Indicators," such as the number of times the reactor temperature enters the "Alarm" zone before reaching the "Trip" zone.

❖ **Organizational and Management Recommendations:**

1. Safety Culture Development: Establish a "Stop Work Authority" program, where any operator has the absolute right to shut down the reactor if they suspect an unsafe condition, with zero penalty for lost production;
2. Rigorous Proof Testing: Mandate a non-negotiable 12-month proof-test interval for the Emergency Catalyst Kill System, including a full-stroke test of the injection valves during planned shutdowns;
3. Dynamic Training: Utilize the results of the HAZOP and What-If studies to create high-fidelity simulator training for board operators, focusing specifically on recovering from a loss of circulation or a cooling failure.