REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

École Nationale Polytechnique

المدرسة الوطنية المتعددة التقنيات
Ecole Nationale Polytechnique

EXPRO

Department: Industrial Risk Management Engineering

Specialty: QHSE-GRI

End of Studies Project Thesis

In fulfillment of the requirements for: QHSE-GRI Engineer's Degree

Fire and Explosion Risk Assessment: Carrying out a FERA Study within EXPRO's XPII EPF

SOLTANI Hadjer & AIDI Nedjat

Directed By

Mr. BOUBAKEUR Mohammed	Assistant professor A at ENP
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Mr. NASRI Said	Process safety engineer at EXPRO

Presented and defended publicly on 21 - 06 - 2023 in front of the jury composed of

President	M^{r}. CHERGUI Abdelmalek	Professor	ENP
Examiners	M^{r}. SENOUCI BEREKSI Malik	Associate professor B	ENP
	M^{me}. MERZOUGUI HIND	Doctoral student	ENP

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EXPRO

Département: Maîtrise des Risques Industriels et Environnementaux
Filiére: QHSE-GRI

Mémoire de projet de fin d'études

pour l'obtention du diplôme d'ingénieur d'état en QHSE – GRI

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Dedication

To my family, you have been my rock, my guiding light, and my greatest source of encouragement. This work is thus dedicated to you, for your unwavering faith in me and your boundless love….

Hadjer

To my dear parents

To my unique sister

To my unique, closest and loyal friend

To my project partner

To All my Friends and colleagues

And to all my supportive Family,

This engineering thesis is dedicated to each of you, Thank you for being a part of my journey and for shaping the person, I have become.

Nadjet

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We would like to express our deepest gratitude to the Almighty God, who has always guided us and given us the strength and courage to complete this work and bring an end to all these years of study.

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To the members of the jury, we sincerely appreciate the honor you bestow upon us by taking the time to read and evaluate this work. We express our gratitude for your valuable input and assessment.

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We extend our thanks to all those who have contributed to our success, both directly and indirectly, as well as to all the teachers of the MRIE department (QHSE-GRI) for their continuous support during our training.

Our deepest gratitude goes to our beloved parents, whose unwavering encouragement and support have always been with us. We hope that this work reflects our sincere gratitude and profound respect for them.

ملخص:

تقدم هذه المذكرة تقييما لمخاطر الحريق و الانفجار داخل منشاة الإنتاج الأولي **XPII EPF** التابعة لشركة **EXPRO**،الهدف من هذه الدراسة هو فهم الحالة الحالية للمنشأة بشكل شامل، مع التركيز على المخاطر الكبرى مثل الحرائق والانفجارات. يتم تقييم مدى تكرار وخطورة هذه الحوادث. وتتضمن منهجية الدراسة تحديد المخاطر، تعريف مناطق الحرائق ،تحليل نتائج هذه الحوادث و احتمالية حدوثها بالاضافة الى تقييم المخاطر وتقديم التوصيات .تركز الدراسة بشكل خاص على حماية المعدات بناءً على طبيعة الموقع والعدد المحدود من الموظفين. من خلال إجراء هذا التقييم أثناء مرحلة تصميم المنشأة، تتمكن الشركة من الحصول على موافقة التشغيل العملية من سلطة ضبط المحروقات (ARH) الهدف النهائي هو إنشاء بيئة تشغيلية آمنة ومحمية، تضمن الحفاظ على المنشآت ذات القيمة .من خلال إجراء تحليل شامل لمخاطر الحرائق والانفجار.

الكلمات المفتاحية: تقييم المخاطر، سلطة ضبط المحروقات، نمذجة، المخاطر الكبرى، الحرائق، الانفجارات.

Résumé:

Cette mémoire présente une évaluation des risques d'incendie et d'explosion menée dans l'installation de production précoce d'EXPRO (EPF XPII). Elle vise à comprendre l'état actuel de l'installation, en se concentrant sur les accidents majeurs tels que les incendies et les explosions. La méthodologie de l'évaluation des risques d'incendie et d'explosion comprend l'identification des dangers, l'analyse des zones d'incendie, l'analyse des conséquences et de la fréquence, l'évaluation des risques et les recommandations. L'accent est mis sur la protection des biens en raison de la nature du site et de sa main-d'œuvre limitée. La réalisation de cette évaluation au cours de la phase de conception de l'installation est cruciale pour obtenir l'approbation opérationnelle d'Autorité De Régulation Des Hydrocarbures (ARH).

Mots clés: l'évaluation des risques, ARH, modélisation, risques majeurs, incendies, explosions.

Abstract:

This engineering thesis presents a fire and explosion risk assessment conducted in EXPRO's early production facility (EPF XPII). It aims to understand the facility's current condition, focusing on major accidents like fires and explosions. The methodology of FERA includes hazard identification, fire zone analysis, consequences and frequency analysis, risk evaluation, and recommendations. Asset protection is emphasized based on the site's nature and limited workforce. Conducting this assessment during the facility's conception phase is crucial for obtaining operational approval from the Hydrocarbons Regulatory Authority (HRA).

Key words: Risk assessment, ARH, modeling, major risks, fires, explosions.

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Acronyms list

ALARP	As Low As Reasonably Practicable
ARIA	Analyse, Recherche et Information sur les Accidents
BDV	Blowdown Valve
BOD	Basis of Design
DST	Drill Stem Testing
EP	Early Pool Fire
EPF	Early Production Facility
FC	Failure Case
FERA	Fire and Explosion Risk Assessment
FEf	Fire & Explosion frequency
FPSO	Floating Production Storage and Offloading
FT	Flow Transmitter
FZ	Fire Zone
HAZID	Hazard Identification
HAZOP	Hazard and Operability analysis
IOGP	International Association of Oil and Gas Procedures
KOV	Knock out Vessel
LCV	Level Control Valve
LPG	Liquefied Petroleum Gas
LOC	Loss of containment
LP	Late Pool Fire
MOPU	Mobile Offshore Production Units
O&M	Operations and Maintenance
P&ID	Piping and Instrumentation Diagram

PEX	Probability of Explosion
PFD	Process Flow Diagram
PII	Probability of Immediate Ignition
PDI	Probability of Delayed Ignition
PSI	Process Safety Information
PSM	Process Safety Management
PTI	Probability of Total Ignition
SDV	Shutdown Valve
TCP	Tubing Conveyed Perforating
VCE	Vapor Cloud Explosion
WUU	Well Unloading Units

General Introduction

In today's industrial landscape, ensuring the safety of personnel and protecting critical assets from potential fire and explosion hazards are paramount concerns for any organization. The oil and gas industry, with its complex infrastructure and high-risk operations, requires stringent measures to mitigate these risks and maintain a safe working environment. In this context, the present study focuses on conducting a comprehensive fire and explosion risk assessment within the XP II early production facility of EXPRO Company.

Considering the composition of the EPF XPII facility, which mainly consists of equipment and has minimal personnel presence, the emphasis of this study is directed towards protecting valuable assets. While personnel safety remains critical in any industrial setting, the specific focus here is to identify and mitigate risks associated with fires and explosions that could potentially cause damage to equipment and disrupt production operations.

The primary objective of this study is to gain a comprehensive understanding of the current condition of the EPF XPII early production facility, with a specific focus on major accidents. By employing a rigorous evaluation and assessment process, we seek to determine the frequency and severity of these incidents, thereby identifying potential risks to the facility's assets.

Moreover, it is crucial to recognize the significance of conducting this risk assessment during the conception phase of the facility, according to the regulations set by the Hydrocarbons Regulatory Authorities (ARH) to acquire the operational exploitation approval. Therefore, conducting this study not only ensures compliance with regulatory obligations but also actively contributes to establishing a safe and secure operational environment during the facility's conception phase.

The methodology employed in this study consists of several key steps. Firstly, a thorough hazard identification process is conducted to identify potential sources of fires and explosions. Subsequently, fire zones are identified, followed by a comprehensive analysis of the consequences that could arise from such incidents. Frequency analysis is then used to evaluate the likelihood of these events occurring. Finally, the risk associated with fires and explosions is evaluated, leading to the formulation of effective recommendations to enhance asset protection measures.

The findings and recommendations derived from this study not only aid in safeguarding valuable assets within the EPF XPII early production facility but also contribute to establishing a solid foundation for the safe and efficient operation of the facility during its initial phases. Proactively addressing fire and explosion risks in the conception phase can prevent or effectively manage potential incidents, minimize disruptions, ensure continuity of production, and ultimately achieve the objectives set forth by regulatory authorities.

Chapter 1. Context of the Project

Introduction

In the following chapter, we shall initially introduce the multinational corporation EXPRO, accompanied by an overview of the early production facility (EPF) referred to as XPII. Subsequently, our attention will be directed towards the fire and explosion risk assessment (FERA) conducted specifically for this EPF. Furthermore, there will be subsequent segments dedicated to discussing the study's objectives, its intended aims, and its noteworthy implications for the organization.

1.1 Presentation of EXPRO

1.1.1 EXPRO Algeria overview

EXPRO has established a presence in Algeria since 1995, with two bases spanning an extensive area of 22,000 square meters in Hassi Messaoud. Additionally, the company maintains an office proximate to Sonatrach in Algiers, serving as a hub for administrative, financial, and legal support pertaining to its operational activities. EXPRO's commitment to delivering enhanced value to its clientele is exemplified through the development of innovative solutions. The expertise and knowledge garnered from EXPRO's ventures in the North Sea have been effectively transferred to the Algerian context, thereby benefiting over 14 distinct clients.

1.1.2 Services provided

- Well Testing,
- Slickline,
- DST,
- PVT lab studies,
- Sonar flow measurement,
- Mobile Production facilities (EPFs).
- Compressors Cased hole logging
- QI: Coilhose + Annulus intervention service

1.1.3 EXPRO Algeria Content

EXPRO currently employs a workforce of 686 individuals in Algeria, with 96% comprised of local personnel and 4% consisting of expatriates. The distribution of these employees is as follows:

Table 1-1 EXPRO Algeria employees

SEGMENT	HC	%
OPERATIONS	517	75%
DIRECT SUPPORT	48	7%
WORKSHOP & MAINTENANCE	41	6%
INDIRECT	80	12%
TOTAL	686	

For technical staff or operations, the head count divided is as follows:

Table 1-2 EXPRO Algeria services

SERVICES	HC
WELL INTERVENTION	96
DST	21
DAQ/LOGGING/CHS	71
METERS	22
WELL TESTING	274
WELL SERVICES	00
PRODUCTION	33
LABORATOIRE	08

1.1.4 EXPRO facilities in Algeria

Since 1995, EXPRO has maintained its presence in Hassi Messaoud, where it has established itself as a prominent entity. The company provides exceptional support services across North Africa West, bolstered by its modernized infrastructure. In 2013, EXPRO inaugurated a state-of-the-art combined life camp and operations facility spanning an impressive area of 25,000 square meters, further enhancing its capabilities in the region. Additionally, in 2019, the company expanded its operations with the establishment of a new second base, thereby reinforcing its commitment to delivering comprehensive services and support to its clientele.

1.1.4.1 HASSI MESSAOUD Office

EXPRO maintains two bases in Hassi Messaoud in order to support Expro operations in Algeria, which contain:

- Accommodation, restaurant and recreational facilities are provided for both staff National and expatriates.
- Total storage yard and workshop

• Well test Operations
• Wireline Operations
• Gold PVT Lab (The GOLD PVT laboratory is housed in the workshop).
• DST Operations
• Cased hole and electrical operation PLT, RCT, Cats and DHVC
• Production

- Full maintenance facility including

• Independent Pressure Test Bay with fixed blast walls
• Instrument calibration laboratory

- Dedicated Training facilities
- Control room for real time monitoring and follow up data from EPF sites

Figure 1-1 EXPRO Main Base

Figure 1-2 Expro in GoogleMAP

Figure 1-3 IKRAM Base

1.2 General description of XPII EPF

The EPF (Early Production Facilities) unit which is the subject of this study is a hydrocarbon installation subject to an environmental impact assessment and a hazard assessment as mentioned in table (A) of appendix 01 of executive decree no. 21-319 [4].

1.2.1 PROCESS DESCRIPTION

The process principle aims to utilize the contrasting properties between the target compound (gas, crude oil, or water) and the remaining mixture (crude oil) to create a distinct pathway for the desired phase. This separation is achieved by subjecting the mixture to a specific force field, allowing the desired phase to deviate and be effectively isolated for individual recovery. At the XPII site, density serves as the key chemical property exploited to enable this separation process.

1.2.1.1 Gas phase

Approximately half of the gas will be sent to GBR on a 12” Gas line while the rest will be torched on site [1].

1.2.1.2 Oil phase

The condensate from the three-phase separator is sent to the surge tank for gas particle recovery and protection of the oil export pumps from cavitation. The booster and export pumps then expedite the condensate to X-Cina at the desired pressure [1].

The facility receives well fluids through the inlet manifold, which is equipped with monitoring systems for pressure and temperature. Furthermore, a shutdown valve is installed as part of the inlet manifold. To ensure operational safety, an inlet high-pressure trip mechanism, along with an associated shutdown valve, is incorporated. This safety measure becomes active if the inlet pressure exceeds 44.6 barg. Additionally, an inlet pressure safety valve is in place to safeguard the downstream system in the event of excessive inlet pressure. In the event of detecting high pressure at the inlet of the facility, the inlet shutdown valve (SDV) will promptly close to mitigate any potential risks [1].

1.2.1.3 Horizontal Separator

The liquids from the inlet header are directed to the inlet of the Horizontal Separator, which is designed to [1] consists of the following components:

- An oil outlet connected to the surge tank, equipped with a manual isolating valve, a flow meter (FT) with a flow transmitter sending data to the control room, a bypass with isolation valves, and an automatic level control valve (LIC) [1], [2].

- A water outlet connected to the liquid export system, equipped with a manual isolating valve, a flow meter (FT) with a flow transmitter sending data to the control room, and an automatic level control valve (LIC) [1], [2].

- A gas outlet connected to the knock out vessel, with an option for decompression to the hot flare line. This outlet is equipped with an orifice meter, a ball valve on the flare line, a shutdown valve (SDV) on the process gas line, a manual isolating valve, a flow meter (FT) with a flow transmitter sending data to the control room, and an automatic pressure control valve (PV) with a bypass [1]–[3].

- A data recording system for the three phases (oil, water, and gas), with transmission of data to the data acquisition cabin [1].

- Pressure safety valves for protection [1], [2].

- Level indication (local and on the data acquisition system).

- Pressure indication (local and on the data acquisition system).

1.2.1.4 Knock-Out Vessel

The gas, after leaving the outlet of the 3-phase separator, undergoes pressure regulation through pressure control valve PCV-004, which is equipped with a pressure indicator controller. Subsequently, the gas is directed to the inlet of the knock-out vessel [1].

The purpose of the knock-out vessel is to effectively separate any liquids that may have passed through the inlet 3-phase separator and remain entrained within the gas. The knock-out vessel is designed specifically for this purpose and includes the following components [1]:

• One liquid outlet, equipped with manual isolation valve, flow meter (FT) with flow transmitter to the control room and bypass with isolation valves and (FT).

• One gas outlet line to **EPF XP II** gas export line, equipped with pressure gauge and manual isolation valves.

• Pressure safety valves for protection.

1.2.1.5 Surge tank

The liquids from the separator liquids outlet are directed through a flow meter and a level control valve before entering the inlet of the surge tank. The surge tank is designed to effectively separate the incoming liquids from any accompanying gas. Its primary purpose is then to facilitate the second stage separation, ensuring that no gas is present in the liquids sent to the EXPRO export pumps for export. The surge tank comprises the following components [1]:

- One liquid outlet equipped with manual isolating valve.
- Pressure safety valves for protection.

1.2.1.6 Booster Pumps

The arrangement of the booster pumps in the pump system is strategically positioned upstream of the oil export pumps to ensure a constant flow rate and the required pressure at the export pumps. This configuration is designed to optimize the performance and efficiency of the pump system [1].

By placing the booster pumps upstream, they play a vital role in increasing the pressure of the crude oil and maintaining a steady flow rate. This is particularly important to meet the specific requirements of the oil export pumps, taking into account their minimum required net positive suction head (NPSHr) [1]. The NPSHr represents the minimum pressure needed at the pump inlet to prevent cavitation, a phenomenon that can lead to reduced pump performance and potential damage.

1.2.1.7 Export pumps

The pump system consists of export pumps that are high-pressure multistage centrifugal pumps. Their primary function is to increase the pressure of the oil condensate to a level suitable for reaching the designated export destination [1].

1.2.1.8 Unit Blowdown

During a level 0 shutdown, all rotating equipment is stopped, and all facility inlet and outlet points are closed. To ensure safety, any high-pressure gas exceeding 50% of the design operating pressure is released to the flare system. This is achieved by opening the BDV4-2 (Blowdown valve) while the SDV4-1 (Shutdown valve) is closed, allowing controlled gas release and preventing excess pressure buildup [1].

1.2.1.9 Flare System

EXPRO offers a comprehensive relief system for facilities, including a hot flare system and a cold pit for pressure relief. It extends to the surge tank and knock-out vessel. The hot flare line has an automatic ignition system for safe combustion of gases. A flare header purge system enhances operational reliability and safety. This system ensures controlled and secure release of excess pressure, minimizing potential risks [1].

1.2.1.10 Instrument Air system

The instrument air system consists of redundant air compressors, refrigerant drying system for moisture removal, and strategically placed air receiver to meet demand. This setup ensures a reliable and consistent supply of dry and compressed air for operational needs [1].

1.2.1.11 Control and Shutdown System

The facility's control system is a hybrid combination of programmable logic controllers (PLCs) serving as both a process control system (PCS) and an emergency shutdown system (ESD). It regulates process control functions and establishes communication links with EXPRO's control system and the existing company control system, if necessary Fire and gas detection systems are also implemented, [1].

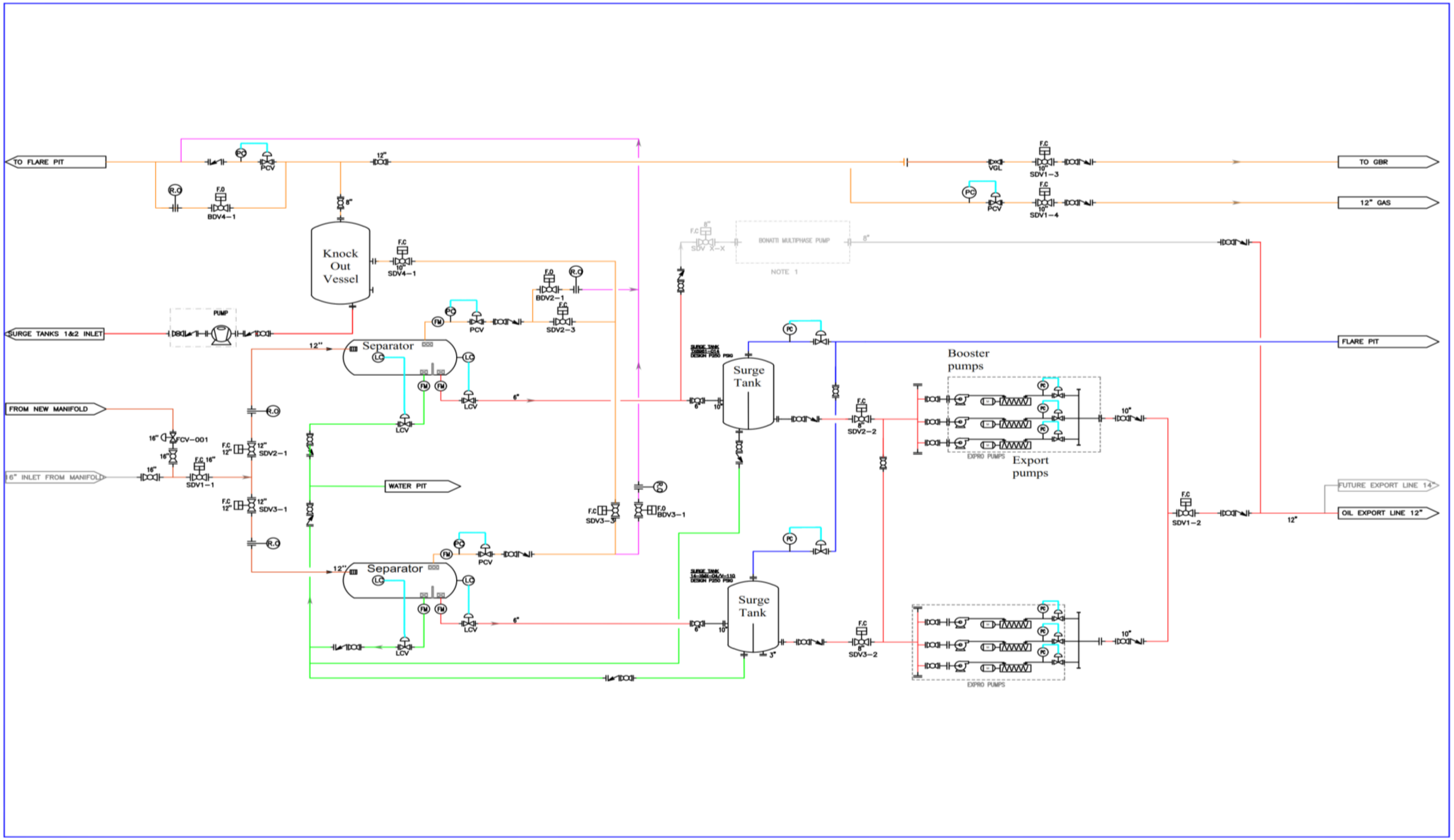

Figure 1-4 Process Flow Diagram for XPII EPF

1.3 Purpose of the study

The objective of the current study is to gain a comprehensive understanding of the current condition of the **EPF XPII** early production facility, specifically concerning major accidents such as fires and explosions. This will be achieved through the evaluation and assessment of the frequency and severity of these incidents.

Typically, inherently safer designs are implemented as a preventive measure before conducting fire risk assessments. However, the findings of the fire and explosion risk assessment (FERA) may indicate the need for additional investigations into the facility's design. FERA serves as a valuable tool in identifying potential areas of improvement and suggesting further studies or modifications to enhance the safety and protection measures against fire and explosion hazards. The study aims to enhance the overall safety a resilience of the **EPF XPII** facility through informed decision-025aking based on the results of the assessment.

1.4 Research background and significance

1.4.1 Accidentology

The study of Accidentology is a valuable resource that provides a wealth of information to support the analysis of hazardous phenomena. It offers insights into various aspects, including:

Incident Causes: Accidentology helps identify the root causes and contributing factors that lead to accidents. It allows for a thorough examination of the underlying reasons, such as equipment failures, human errors, organizational deficiencies, or environmental factors.
Accident Patterns: By studying past accidents, Accidentology reveals patterns and trends in the occurrence of hazardous events. It helps identify common scenarios, sequences of events, or critical conditions that contribute to accidents, enabling proactive measures to be taken to prevent or mitigate similar incidents in the future.
Consequences: Accidentology provides a deep understanding of the consequences resulting from accidents, including the impact on human life, property, and the environment. It helps assess the severity of the effects, such as injuries, fatalities, damage, environmental pollution, and economic losses.
Lessons Learned: Analyzing accident data and case studies allows for the extraction of valuable lessons learned. It helps identify best practices, effective safety measures, and areas where improvements can be made to prevent or mitigate accidents in similar contexts.

Risk Assessment and Management: Accidentology serves as a foundation for risk assessment and management processes. By examining past incidents, it helps identify high-risk areas, potential hazards, and vulnerabilities, which inform the development and implementation of appropriate risk reduction strategies and safety protocols.

Overall, Accidentology plays a crucial role in enhancing safety practices, shaping policies, and guiding decision-taking processes to prevent accidents and improve safety performance in various domains. In order to carry out the risk analysis, it is necessary to know the experience feedback in terms of accidents on compressor stations. This allows us to identify the risk factors that have actually occurred and the associated dangerous phenomena.

1.4.1.1 Evaluation of the Accidentology with the Analysis of Similar Installations

In order to conduct a risk analysis, it is essential to have access to the experience feedback regarding accidents in compression stations.

This enables the identification of the actual risk factors that have occurred and the associated hazardous phenomena.

This analysis was conducted based on the accidents recorded by BARPI (Bureau d'Analyse des Risques et Pollution Industriels), which falls under the French Ministry responsible for the environment. BARPI is responsible for compiling, analyzing, and disseminating information and experience feedback on industrial and technological accidents. This compilation is carried out in the ARIA (Analyse Recherche et Information sur les Accidents) database.

These accidents can be found in Appendix A, The data covers accidents that occurred during the period from 1998 to 2014 which highlights the main sources of hazards that could potentially lead to an accident at the EPF site of EXPRO.

1.4.2 Significance of the Study

The significance of conducting a FERA study lies in its potential to enhance the safety and resilience of the facility or operation. Key aspects of the research significance include:

1- Risk Reduction: FERA studies aim to identify potential fire and explosion hazards, assess their associated risks, and propose effective measures to reduce or eliminate these risks. By understanding and addressing these risks, the study contributes to creating a safer working environment for personnel and protecting valuable assets.

Regulatory Compliance: The FERA study is essential for ensuring compliance with safety regulations, codes, and standards. It helps identify areas of non-compliance and suggests improvements to enhance safety measures. By conducting the study, companies can meet regulatory requirements, such as those outlined in executive decree n°21-319 by the Hydrocarbons Regulatory Authority (ARH). The ARH mandates the inclusion of an HSE preliminary file, which typically includes the FERA study along with other assessments [4]. Compliance with the FERA study findings helps companies maintain a legally compliant operation and align with safety regulations set by regulatory authorities.

Business Continuity: Fires and explosions can have severe consequences, including injuries, loss of life, property damage, environmental pollution, and operational disruptions. By identifying and mitigating potential fire and explosion risks, the FERA study helps safeguard business continuity, minimize downtime, and protect the reputation of the facility and the organization.

Stakeholder Confidence: Demonstrating a proactive approach to fire and explosion risk management through a comprehensive FERA study enhances stakeholder confidence. It assures employees, investors, clients, and regulatory bodies that the facility's safety measures are robust, and the organization is committed to protecting people, property, and the environment.

Conclusion

In conclusion, this chapter has provided a comprehensive overview of the objectives of the Fire and Explosion Risk Assessment (FERA) study, as well as key details about the multinational company, EXPRO where the study is implemented. Furthermore, a detailed description of the XPII EPF facility was provided, emphasizing its importance as the focal point of the FERA study. Key features, such as the early production facility's structure, equipment, and processes, were outlined, setting the stage for a comprehensive risk assessment.

Lastly, the significance of the study was highlighted, emphasizing its role as a decision-025aking tool for addressing fire and explosion protection issues. While inherently safer designs are typically implemented prior to conducting fire risk assessments, the findings from the FERA study may suggest the need for further design evaluation and improvements.

By combining the objectives, company presentation, facility description, and study significance, this chapter sets the foundation for the subsequent detailed analysis and evaluation of fire and explosion risks within the XPII EPF facility.

Chapter 2. State of the Art

Introduction

In various industries and sectors, the risk of fire and explosion poses significant threats to assets, including facilities, equipment, and infrastructure. The consequences of such incidents can range from property damage and operational disruptions to environmental impacts. In order to proficiently handle these risks, organizations need to carry out thorough evaluations of fire and explosion risks that are specifically customized to their assets. This chapter delves into the methodology and tools used in fire and explosion risk assessment, providing a comprehensive understanding of the process. We will explore the definition of FERA, the key steps involved, the methodology employed, and the essential tools utilized in this crucial endeavor.

2.1 Fire and Explosion Risk Assessment FERA

2.1.1 Definition

The Fire & Explosion Risk Assessment (FERA) constitutes a structured and methodical process aimed at discerning and evaluating the risks engendered by fire and explosion hazards. This indispensable undertaking plays a pivotal role in upholding the safety of a facility and its occupants. The examination entails identifying potential origins of fire and explosion, as well as events triggered by Loss of Containments (LOCs) within the premises, while simultaneously assessing the probability and potential ramifications of these perils. The conclusions derived from FERA serve as the basis for establishing secure facility layouts, stipulating passive and active fire protection prerequisites.

2.1.1 Necessary tools

2.1.1.1 Process Flow Diagram

A process flow diagram (PFD) is a schematic representation of a process or system, illustrating the sequence of major steps, equipment, and materials involved. It provides a visual overview of the process, highlighting the flow of materials, energy, and information. They are mainly used to:

- To know Process topology.
- For conveying the heat and material balances.
- For conveying major pieces of equipment.
- For conveying processing conditions.
- For conveying utilities.

2.1.1.2 Piping and Instrumentation Diagram

A Piping and Instrumentation Diagram - P&ID, is a schematic illustration of functional relationship of piping, instrumentation and system equipment components, it contains mainly:

- Major and minor equipment
- Valves
- Instrumentation
- Stand-alone controllers
- Buttons used to control motors and devices
- Motors and drives
- Limit and point devices
- Piping
- Virtual devices

The mainly uses are:

- Act as the definitive representation of the process from which all engineering, fabrication, construction, and operational activities derive their foundation.
- Serve as reference for Process Safety Information (PSI) in Process Safety Management (PSM).

2.1.1.3 Basis of Design

The basis of design (BOD) is a concise document that outlines the fundamental principles, requirements, and criteria for the design and construction of a project or system. It serves as a guiding framework for the design team, providing a clear understanding of the project objectives, constraints, and performance expectations.

2.2 Methodology of FERA

The FERA methodology is based on the following steps :

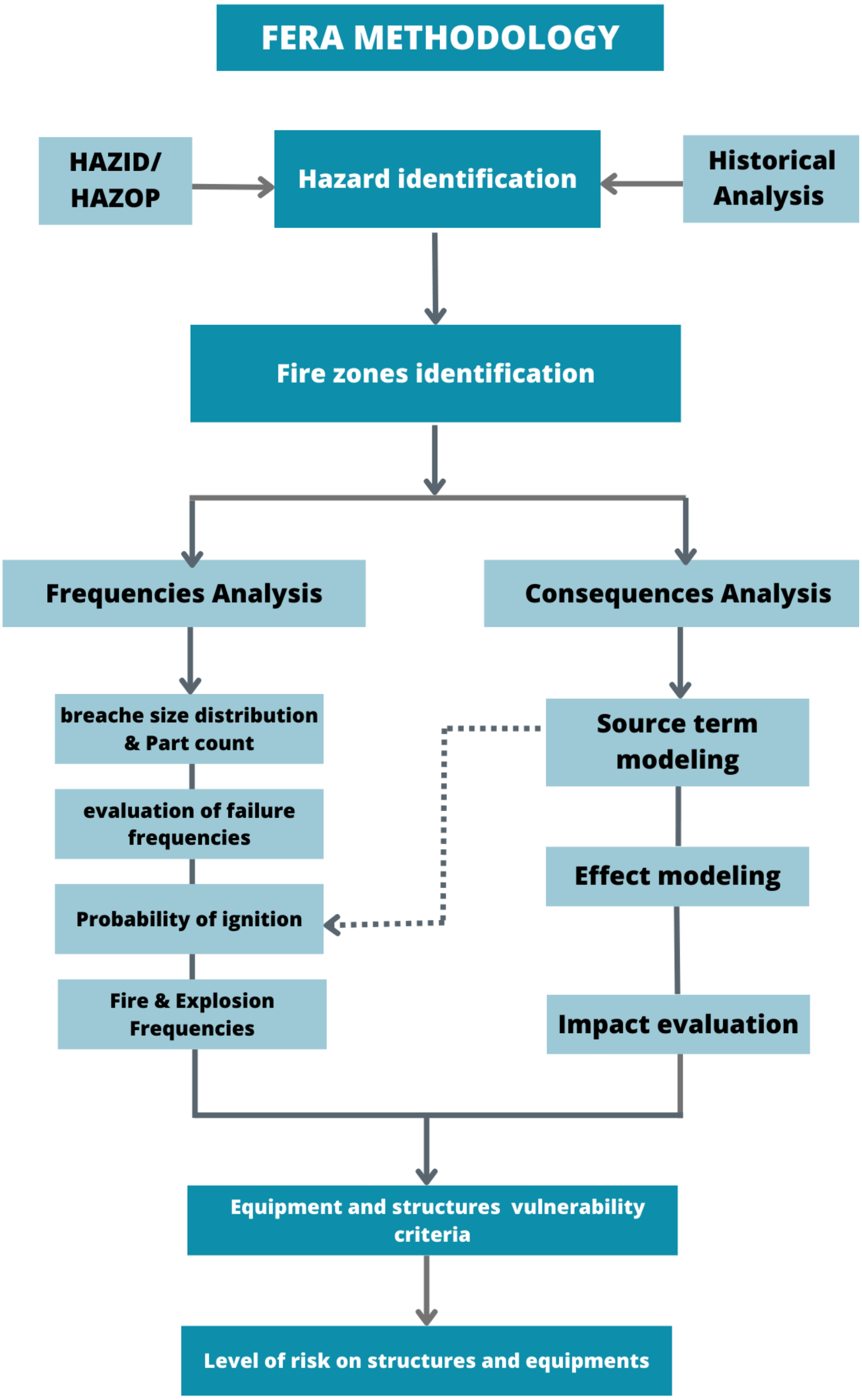

Figure 2-1 FERA Methodology [5], [6]

2.2.1 Hazard identification

The initial phase of the Fire & Explosion Risk Assessment (FERA) involves a systematic approach to hazard identification, which serves as a crucial foundation for the assessment. Like figure shows, studies like HAZOP and HAZID can serve as inputs for conducting hazard identification within a facility as well as Accidentology that shows the history of similar instillations accidents.

2.2.2 Frequency analysis

2.2.2.1 Event Tree

Post-release frequency analysis involves utilizing event trees, which are graphical representations of logic models or truth tables. These trees are based on logic theory and are used to calculate the frequency of different outcomes. The frequency of a specific outcome is determined by multiplying the frequency of the initiating event and the probabilities of subsequent conditional events that may lead to that outcome as illustrated in figure [5], [6].

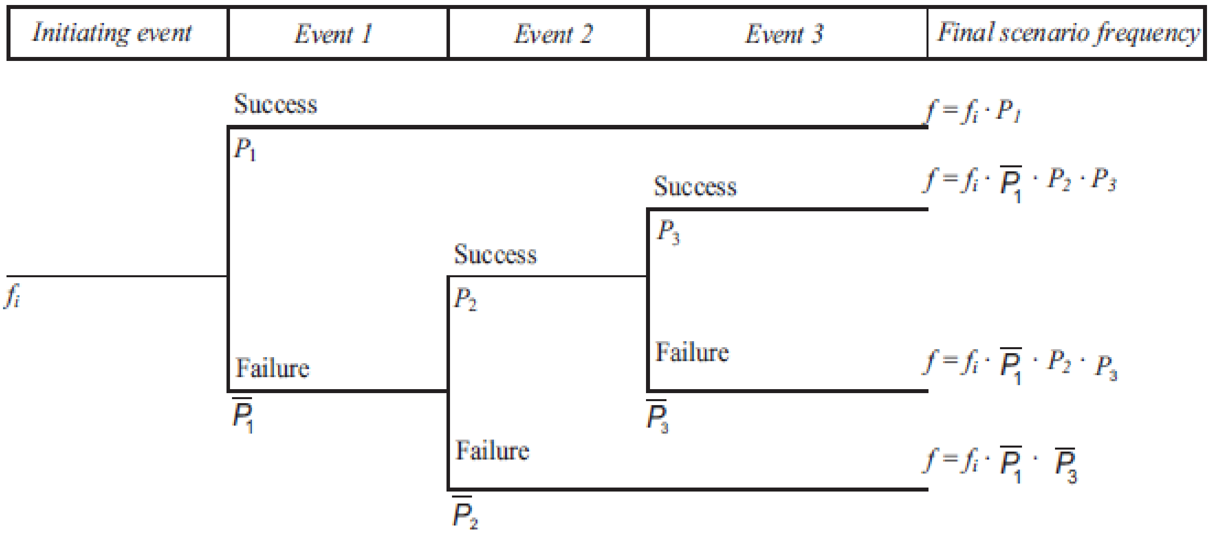

Figure 2-2 General Overview about an Event Tree

In the oil and gas sector, the initiating event is typically the loss of containment in equipment. Its frequency can be determined through established approaches like part count analysis and failure frequency data from databases. Subsequent events that determine the occurrence of specific phenomena include immediate ignition, delayed ignition, and explosion.

2.2.2.2 Part count analysis

A Part Count Analysis is performed to calculate the frequencies of failure events for the different fire zones sections for different breach diameters. This analysis take into consideration leaks from all equipment (pipelines, valves, flanges, instrumentation, scrapper stations...) specifying the lengths for pipelines and the number for the rest of the equipment. In addition, it allows us to calculate the frequency of a breach diameter taking into consideration all possible failure cases. Such as containment system integrity and material properties. This information helps identify vulnerabilities, determine critical breach diameters, and guide risk reduction measures.

The loss of containments frequencies are mainly taken from the ***"Risk assessment data directory - Process Release Frequencies" database, version 2019.*** For piping, the frequencies are given in failures per meter per year.

The failure frequencies are obtained for each breach diameter and it is the sum of multiplication of the part count and the loss of containment frequencies of the equipment, the calculation results are summarized in Appendix C.

2.2.2.3 Probabilities of ignition

a. Immediate ignition

Simultaneous inflammation occurs alongside the initial release and is typically triggered by mechanisms associated with the leak's cause. These mechanisms can include sparks from a rupture, electrical sparks from the flow, or external impacts that cause both leakage and ignition to happen simultaneously. The Probability of Ignition (PII) is taken as 0.001 [8].

b. Delayed ignition

Delayed ignitions refer to leaks that are initially inflamed but do not immediately ignite. The calculation of ignition probability refers to the use of the IOGP 434-6 "Risk assessment data directory - Ignition Probabilities" from 2019, which includes a log-log graph.

On log-log axes, each segment of the curves depicting ignition probability versus release rate forms a straight line. These curves represent the overall likelihood of ignition. According to the method, the immediate probability of ignition is assumed to be 0.001 and is not influenced by the release rate. Consequently, all curves start at 0.001 with a release rate of 0.1 kg/s. The delayed ignition probabilities are calculated by subtracting 0.001 from the total ignition probability [8].

Delayed ignition probability = Total ignition probability – immediate ignition probability

$$PDI = PTI - PII \tag{2-1}$$

It is important to mention that the curves are classified according to certain scenarios; in the present study, we have chosen the 6th one "Small Plant Liquid" for the liquid parts without bunds, the 7th one for parts with bunds and the 5th one "Small Plant Gas LPG" for the gas parts according to the area of the facility, The aforementioned ignition probabilities can be read from the graphs in Figure 2-4.

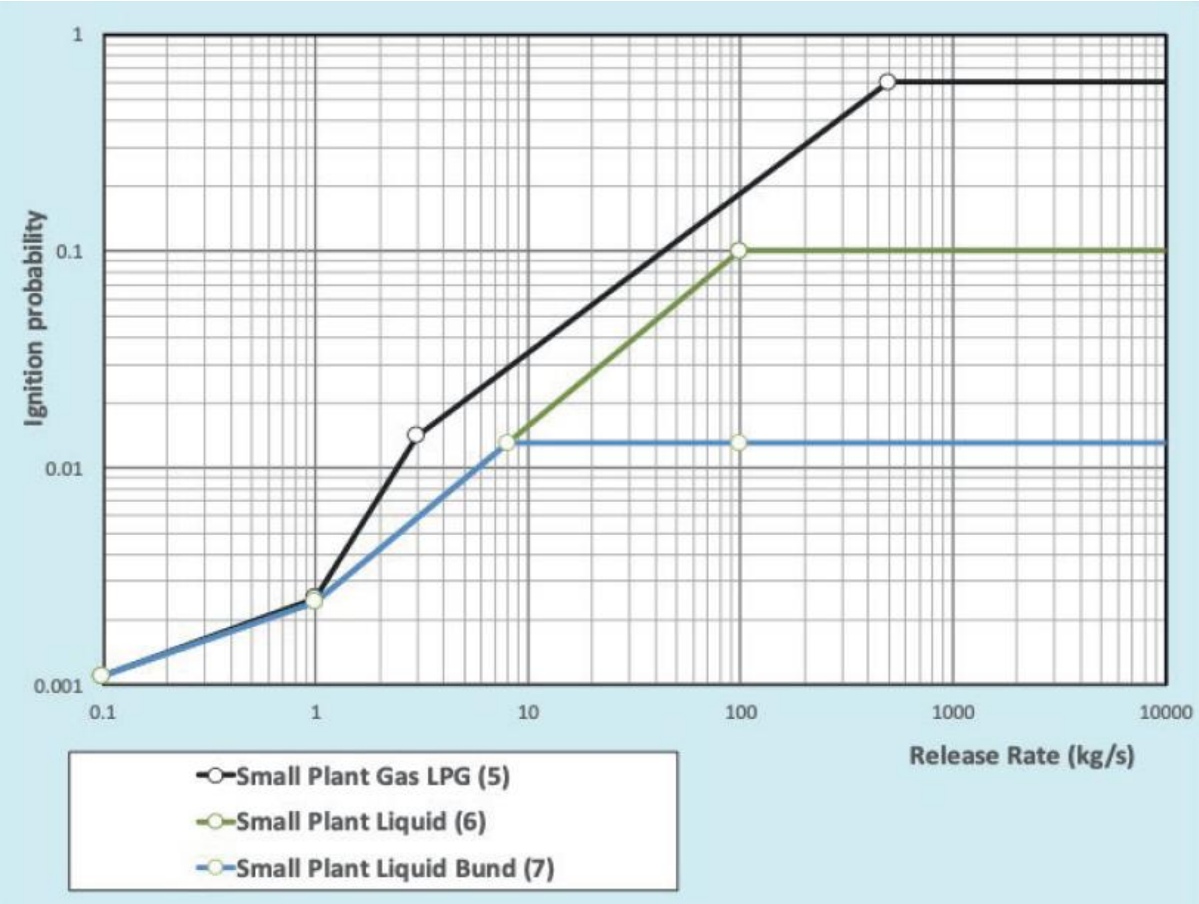

Figure 2-3 Probability of ignition versus release rate [8]

2.2.2.4 Evaluation of failure Frequencies

The step of calculating failure frequencies for breach diameters is essential in fire and explosion risk assessment. It involves quantitatively analyzing the likelihood of breaches occurring for each component such as pipes, flanges, valves or even instruments.

2.2.2.5 Probability of explosion (flame acceleration)

The probability of explosion is the likelihood of a flammable cloud forming a blast waves once the flame acceleration take place. It is a function of the amount spilled because the flame front must attain a high speed and produce a large amount of overpressure after a specific amount of time and reasonably high flammable concentrations as shown in the table below [6]:

Table 2-1 Explosion probabilities

Activity	Amount spilled (Kg)	Generic Explosion probability	Specific explosion probability			
			LPG	Light fraction	Crude oil	Diesel oil
Fixed plants	1-100	0.06	0.043	0.067	0.088	0.044
	100-10,000	0.30	0.22	0.34	0.44	0.22
	>10,000	0.40	0.29	0.45	0.58	0.29

2.2.2.6 Fires & Explosions frequencies

After determining the failure frequency of each fire zone and calculating the probabilities of immediate and delayed ignition, as well as the probability of explosion, the next step in the FERA method is to compute Fires & Explosions frequencies. This is achieved by utilizing an event tree specific to the type of fluid spilled.

2.2.3 Consequences Analysis

2.2.3.1 Source term modeling

To assess the consequences of fires and explosions, it is essential to determine the discharge rate that occurs during a loss of containment event. This can be achieved by employing empirical and mathematical models specifically developed for various configurations. These models provide estimates of the release rates of hazardous materials based on factors such as vessel size, pressure, temperature, and properties of the substance involved. By accurately calculating the discharge rate, it becomes possible to evaluate the potential extent and impact of the resulting fire or explosion.

Details on the different correlations used to evaluate the discharge rate can be found in Appendix B.

2.2.3.2 Release duration

Effective detection and isolation mechanisms are crucial in shortening the length of hazardous material releases. This is particularly important for estimating the impacts of toxic releases, as the severity of effects depends on concentration and duration of exposure. Choosing the release duration can then be defined according to the following steps [7]:

- Find out if the unit has any detection or isolation systems.
- Define the classes of these systems according to table.
- Using the classification obtained and table, choose the maximum release duration for each breach.

Table 2-2Detection and Isolation Classification [7]

Type of detection system	Detection classification
Instrumentation designed specifically to detect material losses by changes in operating conditions (i.e. loss of pressure or flow) in the system.	A
Suitably located detectors to determine when the material is present outside the pressure-150ontaining envelope.	B
Visual detection, cameras, or detectors with marginal coverage.	C
Type of isolation system	**Isolation classification**
Isolation or shutdown systems activated directly from process instrumentation or detectors, with no operator intervention.	A
Isolation or shutdown systems activated by operators in the control room or other suitable locations remote from the leak.	B
Isolation dependent on manually operated valves.	C

Table 2-3 Maximum Leak Durations [7]

Detection system rating	Isolation system rating	Maximum leak duration
A	A	20 minutes for 6.4 mm leaks 10 minutes for 25 mm leaks 5 minutes for 102 mm leaks
A	B	30 minutes for 6.4 mm leaks 20 minutes for 25 mm leaks 10 minutes for 102 mm leaks
A	C	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	A or B	40 minutes for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
B	C	1 hour for 6.4 mm leaks 30 minutes for 25 mm leaks 20 minutes for 102 mm leaks
C	A or B or C	1 hour for 6.4 mm leaks 40 minutes for 25 mm leaks 20 minutes for 102 mm leaks

2.2.3.3 Fire accidents modeling

In this study, the Mudan model was selected to assess the consequences of pool fires, while the Chamberlain method was chosen for modeling jet fires. These models, described in detail in Appendix B, provide valuable tools for evaluating the potential impacts and severity of fire accidents. By utilizing these models, the study aims to gain insights into the behavior and characteristics of pool fires and jet fires, enabling a more accurate assessment of their consequences.

2.2.3.4 Vapor cloud explosion modeling

For vapor cloud explosion modeling, the study employed the multi-energy TNO model. The specific details of this model can be found in Appendix B.

2.2.4 Equipment Vulnerability Criteria

2.2.4.1 Thermal Radiation Effects on Assets

After modeling a fire, it is crucial to assess its consequential effects. Fires generate gases, flames, heat, and smoke, which vary in composition and intensity depending on the materials involved. The outputs of a fire can cause various damages, such as discoloration, deformation, ignition, breaking, and structural failure, which are influenced by thermal radiation intensity and material and physical characteristics [5].

Several methodologies exist to evaluate these effects. Comparing computational findings against predetermined benchmarks allows for assessment based on established requirements [6]. A conservative approach assumes equilibrium, while a comprehensive approach considers heat transfer and temperature thresholds for structural failure due to decreased yield strength under elevated temperatures [5]. However, in the absence of sufficient data on specific construction types and material characteristics, implementing the latter approach may not be feasible.

a. <u>Thermal Impact Evaluation Criteria</u>

When evaluating the heat flux effects, it is mandatory to define the thresholds limits beforehand. Typical thermal radiation intensity levels were proposed in various references. In table (), the thresholds chosen in this study are shown:

Table 2-4 Thermal Impact Evaluation Criteria

Thermal Effects	Exposure Temperature (°C)	Exposure Duration (min)	Consequences on Assets	References
Pool Fire Impingement	816	≥10	Equipment failure *	[5]
Jet fire Impingement	1100	≥05	Equipment failure *	[5]
37.5 $kW.m^{-2}$	575	> 10	Equipment failure *	[5]–[7], [9]
12.5 $kW.m^{-2}$	350	> 10	Equipment damaged **	[5], [6], [9]
*: Lost of containment **: Normal paint discolors, electrical & electronic equipment's permanent damage				

b. Fire impingement

Fire impingement occurs when flames directly contact a surface, transferring heat energy and potentially causing ignition or thermal damage. It involves rapid heat transfer through radiation, convection, and conduction. Fire impingement can lead to material deterioration, melting, or combustion, ranging from surface effects to structural collapse. Flame jet impingement generates high heat fluxes, surpassing those of pool fires, with significant convective and radiative contributions [5]. Estimations indicate maximum radiation intensity of 200 kW.m-2 for natural gas jets [6].

c. Exposure Time

Exposure time to flames can be defined as the interval of time, typically measured in seconds or minutes, during which an object or individual is subjected to the direct heat transfer mechanisms associated with the combustion process, including radiation, convection, and conduction. This duration of exposure plays a crucial role in assessing the potential risks and determining the likelihood of heat-related damage, ignition, or injury. To establish a quantitative measurement of exposure time to flames, it is adequate to calculate the burning duration of the flame in the case of pool fires. Conversely, for jet flames, the exposure time is essentially equivalent to the duration of the release itself.

- Burning duration in Early Pool Fires:

Early pool fires, as aforementioned, are a result of the prompt ignition of a flammable pool, leading to a longer duration compared to late pool fires.

The estimation of exposure time can be accomplished under the assumption that the peak fire size is rapidly reached and remains constant as long as there is an adequate supply of fuel. Subsequently, the burning duration can be calculated utilizing the general provided expression [7], [10]:

$$t_b = \frac{M}{A_{pool}.m_{inf}"} \tag{2-2}$$

Where M (Kg) is the fuel mass available to burn.

In this particular scenario, where the fuel ignites upon its release into the environment, the burning duration can be conceptually divided into two distinct components: t_{b1} (s) and t_{b2} (s).

These terms represent the duration of the fire for the entire period of fuel release and the duration following the cessation of the leak, respectively.

$$t_{b1} = \frac{\dot{m}.t_{spill}}{A_{pool}.m_{inf}"} \qquad (2\text{-}3)$$

$$t_{b2} = \frac{h_{min}.\rho}{m_{inf}"} \qquad (2\text{-}4)$$

Where $\dot{m}$ (Kg.s^{-1}) is the discharge rate and t_{spill} (s) is the duration of the leak that is specified in Table 2-2.

The total burning duration is thus:

$$t_b = t_{b1} + t_{b2} \qquad (2\text{-}5)$$

- Burning duration for Late Pool Fires:

Late pool fires, conversely, originate from the delayed ignition of fuel subsequent to the termination of its release. In this case, the available mass to sustain combustion can be readily determined by evaluating the mass flow rate and spill duration. As a result, the estimation of the fires burning duration is accomplished employing equation (2-3).

- Burning duration for jet fires:

Since jet fires are related to the immediate ignition of gas releases, the burning duration can be obtained using the release duration which can be found in Table 2-2.

2.2.4.2 Explosions impact on assets

The vulnerability of a building or industrial facility to damage caused by an overpressure wave is contingent upon various factors, which include the peak overpressure, impulse, and additional considerations such as potential reflection due to partial confinement, turbulence effects, and the structural strength of the installation [6].

a. <u>Overpressure impact evaluation criteria:</u>

Table provides a comprehensive understanding of the assessment criteria utilized to evaluate the effects and potential damage resulting from overpressure waves.

Table 2-5 Overpressure Impact Evaluation Criteria

Overpressure	Damage nature	Reference
200 mbar	Heavy machines suffer little damage	[6]
350 mbar	Displacement of pipe bridge, failure of piping, equipment failure	[6], [7]
700 mbar	Total structural damage and heavy machines moved and badly damaged	[6]

2.2.5 Risk Assessment

Once consequences and frequency analysis have been completed, two approaches can employed in risk assessment:

- **First level evaluation**: the first approach involves a general evaluation of the identified hazardous events using a risk matrix. The steps that should be followed in this approach are:

- Risk matrix application: utilize a risk matrix that should be defined beforehand, which provides a frameworks for categorizing and evaluating risks based on the combined severity and likelihood scores. Match the assessed parameters of each hazardous event with corresponding matrix cells to determine the overall risk level.
- Critical scenario identification: Analyze the results from the risk matrix evaluation to identify the most critical events. These are the events that pose higher risks based on the assessed parameters and are therefore prioritized for further risk mitigation and control measures.

- **Second level evaluation:** the second procedure involves a more detailed approach that focuses on calculating the individual risk at each point within the plant site. This method requires dividing the plant into grids of small enough size to capture specific locations and equipment. In order to apply it, we can proceed as follows [6]:

- Grid division: Divide the plant site into grids or sections of appropriate size to ensure that individual areas and equipment can be assessed accurately.
- Hazardous Event Contribution: Identify the hazardous events that may contribute to the failure of equipment or pose risks within each grid.
- Individual Risk Calculation: Calculate the individual risk at each grid by considering the aggregated frequency of hazardous events contributing to equipment failure. This provides an understanding of the probability of failure at each point within the plant site.

- Risk assessment for assets: Risk on assets should then evaluated using the same matrix but this time using the aggregated failure frequency instead of the hazardous event frequency of occurrence. After that, safeguards should be recommended in case the risk was deemed high or medium, for the latter we ought to do a cost-benefit analysis to see if the risk is tolerable, i.e. the safeguards do not have to be implemented and vice-versa.

By employing these two procedures, organizations can gain a comprehensive understanding of the overall risk levels and critical scenarios within their facility. The general evaluation using the risk matrix provides a broad assessment of risk, while the detailed approach of calculating individual risk allows for a more granular analysis at specific locations. Both procedures contribute to effective risk management strategies by identifying and prioritizing areas that require mitigation and control measures.

2.2.5.1 Risk Matrix

A risk matrix is a helpful visual tool for identifying high-risk areas by classifying hazards based on their frequency and severity. It provides a clear representation of the risk level associated with each risk bundle by considering the accident's frequency and severity categories [7].

Conclusion

In conclusion, the FERA method is a comprehensive approach used to assess and mitigate fire and explosion risks in various industrial settings. Throughout this chapter, we have explored the fundamental aspects of FERA, including its definition, essential tools, and detailed methodology. FERA consists of several key steps. The first step is hazard identification, which involves gathering information from various sources such as HAZOP (Hazard and Operability Study), HAZID (Hazard Identification Study), and industry accident history to identify potential hazards.

The next step is fire zone definition, where the facility is divided into specific zones based on the identified hazards and their potential consequences. This step aids in determining the appropriate firefighting and safety measures for each zone. Consequences analysis is another critical step in FERA, where the potential impacts of fire and explosion events are evaluated. This analysis considers factors such as property damage, environmental impact, and potential disruption to operations. Frequency analysis is conducted to assess the likelihood of fire and explosion events occurring. This involves analyzing historical data, industry statistics, and expert judgment to estimate the frequency of such incidents.

Finally, risk assessment is performed to evaluate the overall risk associated with identified hazards. This assessment takes into account parameters such as frequency of occurrence, financial loss, and exposure time. A risk matrix, based on the company's predefined criteria, is often utilized to determine critical scenarios and prioritize risk mitigation efforts.

By following the FERA methodology and diligently conducting each step, organizations can gain a comprehensive understanding of their fire and explosion risks, enabling them to implement appropriate preventive and protective measures to safeguard their assets, personnel, and the surrounding environment.

Chapter 3. Frequency Analysis

Introduction

In this chapter, we will explore the fundamental concepts and methodologies of frequency analysis, focusing specifically on the calculation of failure frequencies and accident probabilities based on event trees, and the calculation of different ignition probabilities using The IOGP databases and a specific calculation approach.

3.1 Event Tree

The probabilities of accidents are calculated using event trees according to different scenarios:

1. For the gas leak, there is three possible events: Immediate ignition, Delayed ignition, and flame acceleration, which can result in the accidents below:
   - ➢ Immediate ignition can lead to a jet fire
   - ➢ Delayed ignition will result in a flash fire or a VCE depending on the flame acceleration.
   - ➢ If none of the above events is present, the gas will disperse leading to air pollution.

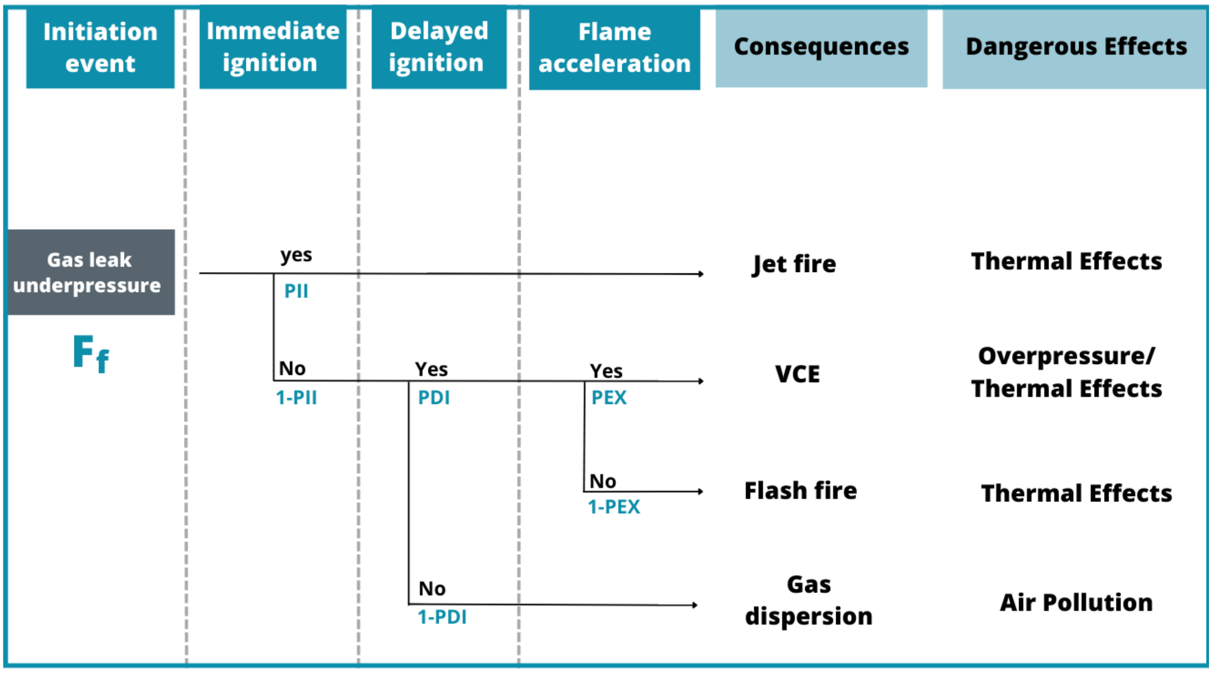

Figure 3-1 Event tree of gas leak

a. **Jet fire:**

$$FEf = Ff * PII \tag{3-1}$$

b. <u>Flash fire:</u>

$$FEf = Ff * (1 - PII) * PDI * (1 - PEX) \quad (3\text{-}2)$$

c. <u>Explosion :</u>

$$FEf = Ff * (1 - PII) * PDI * PEX \quad (3\text{-}3)$$

2. For the oil leak the possible events that can happen are: : Immediate ignition, Delayed ignition, and flame acceleration, which can result in the accidents below:
   - Immediate ignition can results on an early pool fire.
   - Delayed ignition can lead to a late pool fire or flash fire, a VCE also can happen if there is a flame acceleration.
   - If none of the above events is present, the vapor will disperse resulting in air and sol pollution.

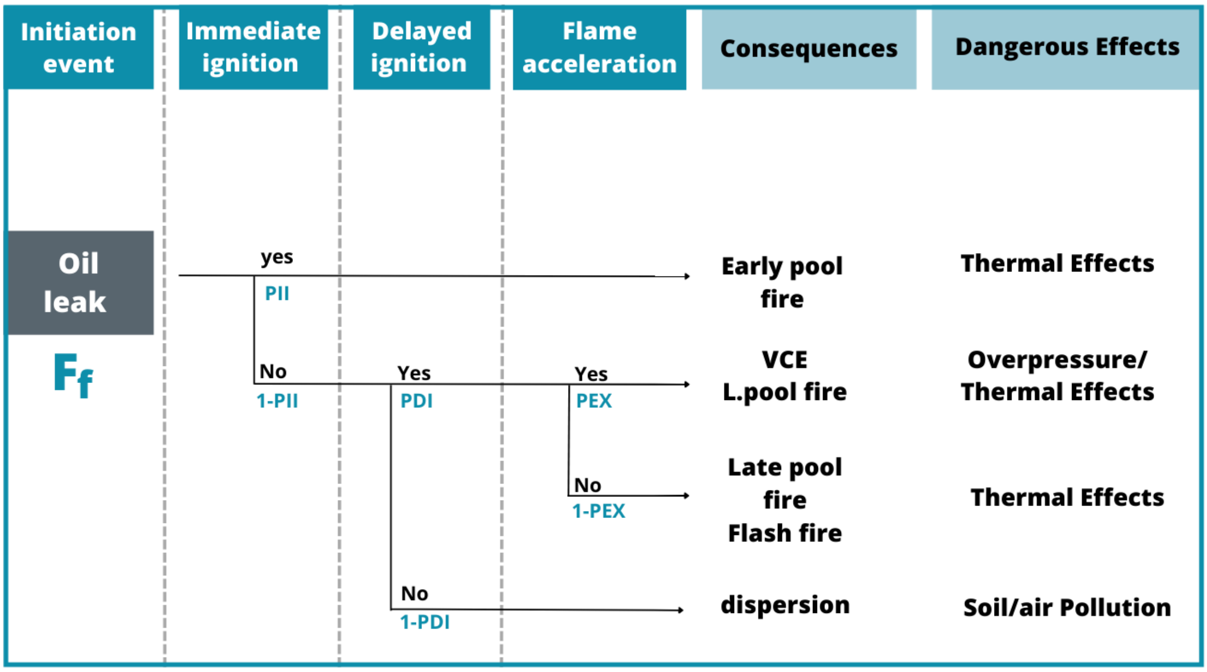

Figure 3-2 Event tree for Oil leak

a. <u>Early pool fire:</u>

$$FEf = Ff * PII \quad (3\text{-}4)$$

b. Late pool fire

$$FEf = Ff * (1 - PII) * PDI * (PEX + 1 - PEX) = Ff * (1 - PII) * PDI \quad (3\text{-}5)$$

c. Flash fire:

$$FEf = Ff * (1 - PII) * PDI * (1 - PEX) \quad (3\text{-}6)$$

d. Explosion:

$$FEf = Ff * (1 - PII) * PDI * PEX \quad (3\text{-}7)$$

3.2 Breach diameter Distribution

Breach diameters are identified using IOGP 434-1 « Risk assessment data directory - Process Release Frequencies » version 2019 database.

Table 3-1 Breach diameter Distribution [13]

Breach diameter	Breach diameter interval (mm)	Breach diameter (mm)
Small	3-10	5
Medium	10-50	25
Large	50-150	100
Rupture	>150	>150

3.3 Fires & Explosions frequencies Calculation

Frequencies calculation was based on one train since the trains are identical, the results for the second train will be the same as the first.

Table 3-2 Fires & Explosions Frequencies Calculations

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
Fire Zone 1 'Inlet line'	FZ 01 : Inlet line 16"	5mm	E. Pool fire	7,52E-04	0,001	0,001	979.2	0,44	7,52E-07
			L. Pool fire	7,52E-04	0,001	0,001		0,44	7,51E-07
			Flash fire	7,52E-04	0,001	0,001		0,44	4,21E-07
			Explosion	7,52E-04	0,001	0,001		0,44	3,31E-07
		25mm	E. Pool fire	2,06E-04	0,001	0,019	12244.2	0,58	2,06E-07
			L. Pool fire	2,06E-04	0,001	0,019		0,58	3,91E-06
			Flash fire	2,06E-04	0,001	0,019		0,58	1,64E-06
			Explosion	2,06E-04	0,001	0,019		0,58	2,27E-06
		100mm	E. Pool fire	6,18E-05	0,001	0,099	83121	0,58	6,18E-08
			L. Pool fire	6,18E-05	0,001	0,099		0,58	6,11E-06
			Flash fire	6,18E-05	0,001	0,099		0,58	2,57E-06
			Explosion	6,18E-05	0,001	0,099		0,58	3,55E-06
		150mm	E. Pool fire	1,38E-04	0,001	0,099	37404.5	0,58	1,38E-08
			L. Pool fire	1,38E-04	0,001	0,099		0,58	1,36E-05

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
			Flash fire	1,38E-04	0,001	0,099		0,58	5,73E-06
			Explosion	1,38E-04	0,001	0,099		0,58	7,92E-06
	FZ 01 : Inlet line 12"	5mm	E. Pool fire	2,69E-04	0,001	0,001	830.4	0,44	2,69E-07
			L. Pool fire	2,69E-04	0,001	0,001		0,44	2,69E-07
			Flash fire	2,69E-04	0,001	0,001		0,44	1,50E-07
			Explosion	2,69E-04	0,001	0,001		0,44	1,18E-07
		25mm	E. Pool fire	1,35E-04	0,001	0,019	10389	0,58	1,35E-07
			L. Pool fire	1,35E-04	0,001	0,019		0,58	2,56E-06
			Flash fire	1,35E-04	0,001	0,019		0,58	1,08E-06
			Explosion	1,35E-04	0,001	0,019		0,58	1,49E-06
		100mm	E. Pool fire	4,05E-05	0,001	0,099	67 957,20	0,58	4,05E-08
			L. Pool fire	4,05E-05	0,001	0,099		0,58	4,01E-06
			Flash fire	4,05E-05	0,001	0,099		0,58	1,68E-06
			Explosion	4,05E-05	0,001	0,099		0,58	2,32E-06

Fires & Explosions frequencies									
Fire Zone	Sec	Breach diameter	Dangerous Phenomenon	Ff (1/year)	PII	PDI	Amount of liquid released (Kg)	PEX	FEf (1/year)
		150mm	E. Pool fire	5,80E-05	0,001	0,099	33 514,80	0,58	5,80E-08
			L. Pool fire	5,80E-05	0,001	0,099		0,58	5,74E-06
			Flash fire	5,80E-05	0,001	0,099		0,58	2,41E-06
			Explosion	5,80E-05	0,001	0,099		0,58	3,33E-06
Fire zone 2'SEPARATOR'	Separator (liquid phase)	5mm	E. Pool fire	1,07E-03	0,001	0,001	556.92	0,44	1,07E-06
			L. Pool fire	1,07E-03	0,001	0,001		0,44	1,07E-06
			Flash fire	1,07E-03	0,001	0,001		0,44	5,99E-07
			Explosion	1,07E-03	0,001	0,001		0,44	4,70E-07
		25mm	E. Pool fire	4,08E-04	0,001	0,0014	6960	0,44	4,08E-07
			L. Pool fire	4,08E-04	0,001	0,0014		0,44	5,71E-07
			Flash fire	4,08E-04	0,001	0,0014		0,44	3,20E-07
			Explosion	4,08E-04	0,001	0,0014		0,44	2,51E-07
		100mm	E. Pool fire	1,01E-04	0,001	0,099	55686	0,58	1,01E-07
			L. Pool fire	1,01E-04	0,001	0,099		0,58	9,99E-06
			Flash fire	1,01E-04	0,001	0,099		0,58	4,20E-06

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
			Explosion	1,01E-04	0,001	0,099		0,58	5,79E-06
		150mm	E. Pool fire	8,36E-05	0,001	0,099	40598.4	0,58	8,36E-08
			L. Pool fire	8,36E-05	0,001	0,099		0,58	8,27E-06
			Flash fire	8,36E-05	0,001	0,099		0,58	3,47E-06
			Explosion	8,36E-05	0,001	0,099		0,58	4,80E-06
	Separator (Gas phase)	5mm	Jet fire	1,13E-03	0,001	0	27.6	0,043	1,13E-06
			Flash fire	1,13E-03	0,001	0		0,043	0,00E+00
			Explosion	1,13E-03	0,001	0		0,043	0,00E+00
		25mm	jet fire	5,72E-04	0,001	0,001	331.74	0,22	5,72E-07
			Flash fire	5,72E-04	0,001	0,001		0,22	4,46E-07
			Explosion	5,72E-04	0,001	0,001		0,22	1,26E-07
		100mm	Jet fire	8,27E-05	0,001	0,029	2655	0,22	8,27E-08

Fires & Explosions frequencies									
Fire Zone	Sec	Breach diameter	Dangerous Phenomenon	Ff (1/year)	PII	PDI	Amount of liquid released (Kg)	PEX	FEf (1/year)
			Flash fire	8,27E-05	0,001	0,029		0,22	1,87E-06
			Explosion	8,27E-05	0,001	0,029		0,22	5,27E-07
		150mm	Jet fire	7,11E-05	0,001	0,079	1926.3	0,22	7,11E-08
			Flash fire	7,11E-05	0,001	0,079		0,22	4,38E-06
			Explosion	7,11E-05	0,001	0,079		0,22	1,23E-06
	THE GAS LINE 10"-PV-03B3-1800 FROM SEPARATOR TX1H-046 TO KOV(L=26,2)	5mm	Jet fire	3,82E-04	0,001	0	26.4	0,043	3,82E-07
			Flash fire	3,82E-04	0,001	0		0,043	0,00E+00
			Explosion	3,82E-04	0,001	0		0,043	0,00E+00
		25mm	jet fire	1,80E-04	0,001	0,001	331.8	0,22	1,80E-07
			Flash fire	1,80E-04	0,001	0,001		0,22	1,40E-07
			Explosion	1,80E-04	0,001	0,001		0,22	3,96E-08
		100mm	Jet fire	4,38E-05	0,001	0,029	2650.5	0,22	4,38E-08
			Flash fire	4,38E-05	0,001	0,029		0,22	9,90E-07
			Explosion	4,38E-05	0,001	0,029		0,22	2,79E-07
		150mm	Jet fire	6,96E-05	0,001	0,079	1854.6	0,22	6,96E-08

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
			Flash fire	6,96E-05	0,001	0,079		0,22	4,28E-06
			Explosion	6,96E-05	0,001	0,079		0,4	2,20E-06
	Pipe between separator and Surge tank (6"/91m)	5mm	E. Pool fire	1,22E-03	0,001	0	306	0,44	1,22E-06
			L. Pool fire	1,22E-03	0,001	0		0,44	0,00E+00
			Flash fire	1,22E-03	0,001	0		0,44	0,00E+00
			Explosion	1,22E-03	0,001	0		0,44	0,00E+00
		25mm	E. Pool fire	4,94E-04	0,001	0,019	3 826,80	0,44	4,94E-07
			L. Pool fire	4,94E-04	0,001	0,019		0,44	9,38E-06
			Flash fire	4,94E-04	0,001	0,019		0,44	5,25E-06
			Explosion	4,94E-04	0,001	0,019		0,44	4,13E-06
		100mm	E. Pool fire	1,12E-04	0,001	0,099	30 614,40	0,58	1,12E-07
			L. Pool fire	1,12E-04	0,001	0,099		0,58	1,11E-05
			Flash fire	1,12E-04	0,001	0,099		0,58	4,65E-06
			Explosion	1,12E-04	0,001	0,099		0,58	6,42E-06

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
		150mm	E. Pool fire	9,88E-05	0,001	0,099	13 776,54	0,58	9,88E-08
			L. Pool fire	9,88E-05	0,001	0,099		0,58	9,77E-06
			Flash fire	9,88E-05	0,001	0,099		0,58	4,10E-06
			Explosion	9,88E-05	0,001	0,099		0,58	5,67E-06
Fire zone3 'Surge Tank'	Surge tank	5mm	E. Pool fire	2,30E-03	0,001	0	326.4	0,44	2,30E-06
			L. Pool fire	2,30E-03	0,001	0		0,44	0,00E+00
			Flash fire	2,30E-03	0,001	0		0,44	0,00E+00
			Explosion	2,30E-03	0,001	0		0,44	0,00E+00
		25mm	E. Pool fire	1,14E-03	0,001	0,014	4056	0,44	1,14E-06
			L. Pool fire	1,14E-03	0,001	0,014		0,44	1,59E-05
			Flash fire	1,14E-03	0,001	0,014		0,44	8,93E-06
			Explosion	1,14E-03	0,001	0,014		0,44	7,02E-06
		100mm	E. Pool fire	1,87E-04	0,001	0,099	32400	0,58	1,87E-07

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
			L. Pool fire	1,87E-04	0,001	0,099		0,58	1,85E-05
			Flash fire	1,87E-04	0,001	0,099		0,58	7,77E-06
			Explosion	1,87E-04	0,001	0,099		0,58	1,07E-05
		150mm	E. Pool fire	1,55E-04	0,001	0,099	23571	0,58	1,55E-08
			L. Pool fire	1,55E-04	0,001	0,099		0,58	1,53E-05
			Flash fire	1,55E-04	0,001	0,099		0,58	6,44E-06
			Explosion	1,55E-04	0,001	0,099		0,58	8,89E-06
	Pipe between surge tank and export pumps (8"/43,2m)	5mm	E. Pool fire	3,74E-04	0,001	0	354	0,44	3,74E-07
			L. Pool fire	3,74E-04	0,001	0		0,44	0,00E+00
			Flash fire	3,74E-04	0,001	0		0,44	0,00E+00
			Explosion	3,74E-04	0,001	0		0,44	0,00E+00
		25mm	E. Pool fire	1,66E-04	0,001	0,019	4 426,20	0,44	1,66E-07
			L. Pool fire	1,66E-04	0,001	0,019		0,44	3,15E-06
			Flash fire	1,66E-04	0,001	0,019		0,44	1,76E-06
			Explosion	1,66E-04	0,001	0,019		0,44	1,39E-06

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
		100mm	E. Pool fire	3,93E-05	0,001	0,099	35 412,30	0,58	3,93E-08
			L. Pool fire	3,93E-05	0,001	0,099		0,58	3,89E-06
			Flash fire	3,93E-05	0,001	0,099		0,58	1,63E-06
			Explosion	3,93E-05	0,001	0,099		0,58	2,25E-06
		150mm	E. Pool fire	3,35E-05	0,001	0,099	15 935,58	0,58	3,35E-08
			L. Pool fire	3,35E-05	0,001	0,099		0,58	3,31E-06
			Flash fire	3,35E-05	0,001	0,099		0,58	1,39E-06
			Explosion	3,35E-05	0,001	0,099		0,58	1,92E-06
Fire zone 4 'Knock Out Vessel'	KOV	5mm	Jet fire	1,97E-03	0,001	0	21.23	0,043	1,97E-06
			Flash fire	1,97E-03	0,001	0		0,043	0,00E+00
			Explosion	1,97E-03	0,001	0		0,043	0,00E+00
		25mm	jet fire	9,81E-04	0,001	0,001	265.38	0,22	9,81E-07
			Flash fire	9,81E-04	0,001	0,001		0,22	7,64E-07
			Explosion	9,81E-04	0,001	0,001		0,22	2,16E-07

Fires & Explosions frequencies									
Fire Zone	Sec	Breach diameter	Dangerous Phenomenon	Ff (1/year)	PII	PDI	Amount of liquid released (Kg)	PEX	FEf (1/year)
		100mm	Jet fire	1,59E-04	0,001	0,029	2123.1	0,22	1,59E-07
			Flash fire	1,59E-04	0,001	0,029		0,22	3,59E-06
			Explosion	1,59E-04	0,001	0,029		0,22	1,01E-06
		150mm	Jet fire	1,56E-04	0,001	0,059	1540.8	0,22	1,56E-07
			Flash fire	1,56E-04	0,001	0,059		0,22	7,17E-06
			Explosion	1,56E-04	0,001	0,059		0,22	2,02E-06
Fire zone 5 'EXPRO Pumps'	Booster pumps	5mm	E. Pool fire	5,67E-03	0,001	0	685,2	0,44	5,67E-06
			L. Pool fire	5,67E-03	0,001	0		0,44	0,00E+00
			Flash fire	5,67E-03	0,001	0		0,44	0,00E+00
			Explosion	5,67E-03	0,001	0		0,44	0,00E+00
		25mm	E. Pool fire	1,50E-03	0,001	0,019	4056	0,44	1,50E-06
			L. Pool fire	1,50E-03	0,001	0,019		0,44	2,85E-05
			Flash fire	1,50E-03	0,001	0,019		0,44	1,59E-05
			Explosion	1,50E-03	0,001	0,019		0,44	1,25E-05

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
		100mm	E. Pool fire	2,64E-04	0,001	0,099	32400	0,58	2,64E-07
			D. Pool fire	2,64E-04	0,001	0,099		0,58	2,61E-05
			Flash fire	2,64E-04	0,001	0,099		0,58	1,10E-05
			Explosion	2,64E-04	0,001	0,099		0,58	1,51E-05
		150mm	E. Pool fire	4,74E-05	0,001	0,099	23571	0,58	4,74E-08
			L. Pool fire	4,74E-05	0,001	0,099		0,58	4,69E-06
			Flash fire	4,74E-05	0,001	0,099		0,58	1,97E-06
			Explosion	4,74E-05	0,001	0,099		0,58	2,72E-06
	Export pumps	5mm	E. Pool fire	5,85E-03	0,001	5,00E-04	1096,2	0,44	5,85E-06
			L. Pool fire	5,85E-03	0,001	5,00E-04		0,44	2,92E-06
			Flash fire	5,85E-03	0,001	5,00E-04		0,44	1,64E-06
			Explosion	5,85E-03	0,001	5,00E-04		0,44	1,29E-06
		25mm	E. Pool fire	2,10E-03	0,001	0,029	4056	0,44	2,10E-06

Fires & Explosions frequencies									
Fire Zone	**Sec**	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
			L. Pool fire	2,10E-03	0,001	0,029		0,44	6,08E-05
			Flash fire	2,10E-03	0,001	0,029		0,44	3,41E-05
			Explosion	2,10E-03	0,001	0,029		0,44	2,68E-05
		100mm	E. Pool fire	4,32E-04	0,001	0,099	32400	0,58	4,32E-07
			L. Pool fire	4,32E-04	0,001	0,099		0,58	4,27E-05
			Flash fire	4,32E-04	0,001	0,099		0,58	1,79E-05
			Explosion	4,32E-04	0,001	0,099		0,58	2,48E-05
		150mm	E. Pool fire	1,11E-04	0,001	0,099	23571	0,58	1,11E-08
			L. Pool fire	1,11E-04	0,001	0,099		0,58	1,10E-05
			Flash fire	1,11E-04	0,001	0,099		0,58	4,61E-06
			Explosion	1,11E-04	0,001	0,099		0,58	6,37E-06
Fire zone 6 'Oil Expedition line'		5mm	E. Pool fire	2,12E-03	0,001	0	744	0,44	2,12E-06
			L. Pool fire	2,12E-03	0,001	0		0,44	0,00E+00
			Flash fire	2,12E-03	0,001	0		0,44	0,00E+00

Fires & Explosions frequencies								
Fire Zone	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
		Explosion	2,12E-03	0,001	0		0,44	0,00E+00
	25mm	E. Pool fire	1,02E-03	0,001	0,019	9 312	0,44	1,02E-06
		L. Pool fire	1,02E-03	0,001	0,019		0,44	1,94E-05
		Flash fire	1,02E-03	0,001	0,019		0,44	1,08E-05
		Explosion	1,02E-03	0,001	0,019		0,44	8,52E-06
	100mm	E. Pool fire	2,06E-04	0,001	0,099	74 536,80	0,58	2,06E-08
		L. Pool fire	2,06E-04	0,001	0,099		0,58	2,04E-05
		Flash fire	2,06E-04	0,001	0,099		0,58	8,56E-06
		Explosion	2,06E-04	0,001	0,099		0,58	1,18E-05
	150mm	E. Pool fire	2,85E-04	0,001	0,099	33 541,62	0,58	2,85E-08
		L. Pool fire	2,85E-04	0,001	0,099		0,58	2,82E-05
		Flash fire	2,85E-04	0,001	0,099		0,58	1,18E-05
		Explosion	2,85E-04	0,001	0,099		0,58	1,63E-05

Fires & Explosions frequencies								
Fire Zone	**Breach diameter**	**Dangerous Phenomenon**	**Ff (1/year)**	**PII**	**PDI**	**Amount of liquid released (Kg)**	**PEX**	**FEf (1/year)**
Fire zone 7 'Gas Expedition line'	5mm	Jet fire	2,18E-03	0,001	0	20,4	0,043	2,18E-06
		Flash fire	2,18E-03	0,001	0		0,043	0,00E+00
		Explosion	2,18E-03	0,001	0		0,043	0,00E+00
	25mm	jet fire	1,07E-03	0,001	0	257,4	0,22	1,07E-06
		Flash fire	1,07E-03	0,001	0		0,22	0,00E+00
		Explosion	1,07E-03	0,001	0		0,22	0,00E+00
	100mm	Jet fire	1,70E-04	0,001	0,019	2058	0,22	1,70E-07
		Flash fire	1,70E-04	0,001	0,019		0,22	2,52E-06
		Explosion	1,70E-04	0,001	0,019		0,22	7,10E-07
	150mm	Jet fire	2,11E-04	0,001	0,039	926,7	0,22	2,11E-07
		Flash fire	2,11E-04	0,001	0,039		0,22	6,41E-06
		Explosion	2,11E-04	0,001	0,039		0,22	1,81E-06
Fire zone 8' Storage tanks	Bund Fire							2,26E-06

The frequency analysis provides valuable insights into the occurrence probabilities of various failure cases and breach diameters. The summarized results in the table showcase the frequencies associated with each scenario. One notable observation is that the highest frequencies, reaching 10^{-5}, are predominantly attributed to late pool fires along with explosions. This indicates that late pool fires pose a greater risk in terms of frequency compared to other Dangerous phenomenons.

On the other hand, early pool fires exhibit lower frequencies, never reaching the 10^{-5} threshold. This suggests that the occurrence of early pool fires is relatively less frequent compared to late pool fires and explosions. Additionally, certain hazardous phenomena show a frequency of 0, which is attributed to the discharge rate being too small, resulting in practically no delayed ignition rate. These events may be considered less significant in terms of frequency due to their minimal likelihood of occurrence.

Another noteworthy finding is that some failure cases, specifically for breach diameters of 100 mm and above, exhibit a frequency of 10^{-8}, which is negligible. This aligns with the assumptions made during the consequences modeling phase. As a best practice, events with frequencies of 10^{-8} and less are typically not considered credible and should be disregarded for risk assessment purposes.

Conclusion

By quantifying all the probabilities, we gain valuable insights into the frequencies of the dangerous events occurring within the EPF XP II, so we can assess the likelihood of major Hazardous Event occurrences and implement effective risk mitigation strategies to enhance overall safety and reliability.

Chapter 4. Consequences Analysis

Introduction

This chapter focuses on the consequences analysis within Expro's Early Production Facility as part of the Fire and Explosion Risk Assessment (FERA) process. It covers several key points, including hazard identification using historical data and hazard studies, congested area definition for vapor cloud explosions, fire zone identification, inputs for consequences modeling (operational and meteorological), source term modeling results, and fire accidents and vapor cloud explosions modeling results. These elements contribute to a comprehensive understanding of the potential impacts of fire and explosion events, aiding in risk mitigation and ensuring the safety of personnel and assets.

4.1 Hazard Identification

By utilizing data obtained from the Accidentology, HAZOP study, and HAZID findings, we have successfully identified the failure cases and associated hazardous phenomena that can potentially occur within our study subject. It is important to note that the majority of these failure cases primarily involve instances of loss of containment. The potential dangerous phenomena that can compromise the safety of assets are as follows:

- **Pool Fire:** This phenomenon arises when a pool of flammable liquid ignites following a release, such as the loss of containment of liquid or vapor accompanied by rain-out. The resulting fire emits thermal radiation, which poses a significant risk within the studied system [5], [6], [9].
- **Jet Fire:** highly dynamic directional fires that emit significant amounts of thermal radiation. These fires occur as a result of the ignition of high-pressure hydrocarbons in scenarios involving gaseous releases [5], [6].
- **Flash Fire:** The rapid ignition of a gas cloud. This ignition occurs as a result of a gas leak or the gas phase of a bi-phase release, or it can also result from the evaporation of a non-ignited pool of liquid. It is important to note that this ignition is accompanied by negligible overpressure [11].
- **Vapor Cloud Explosion:** The instantaneous ignition of a gas cloud resulting from a gas leak, bi-phase release, or evaporation of a non-ignited liquid pool. This ignition is accompanied by the formation of a shockwave due to the acceleration of the flame front through congestion effects, leading to overpressure [6], [11].

4.1.1 Congested Area Definition

It is important to define the congested zone since it is one of the main causes for flame acceleration and as a consequence, explosions.

The following figure illustrates the congested area that was identified within XPII EPF, see Appendix B for details about the procedure that was followed.

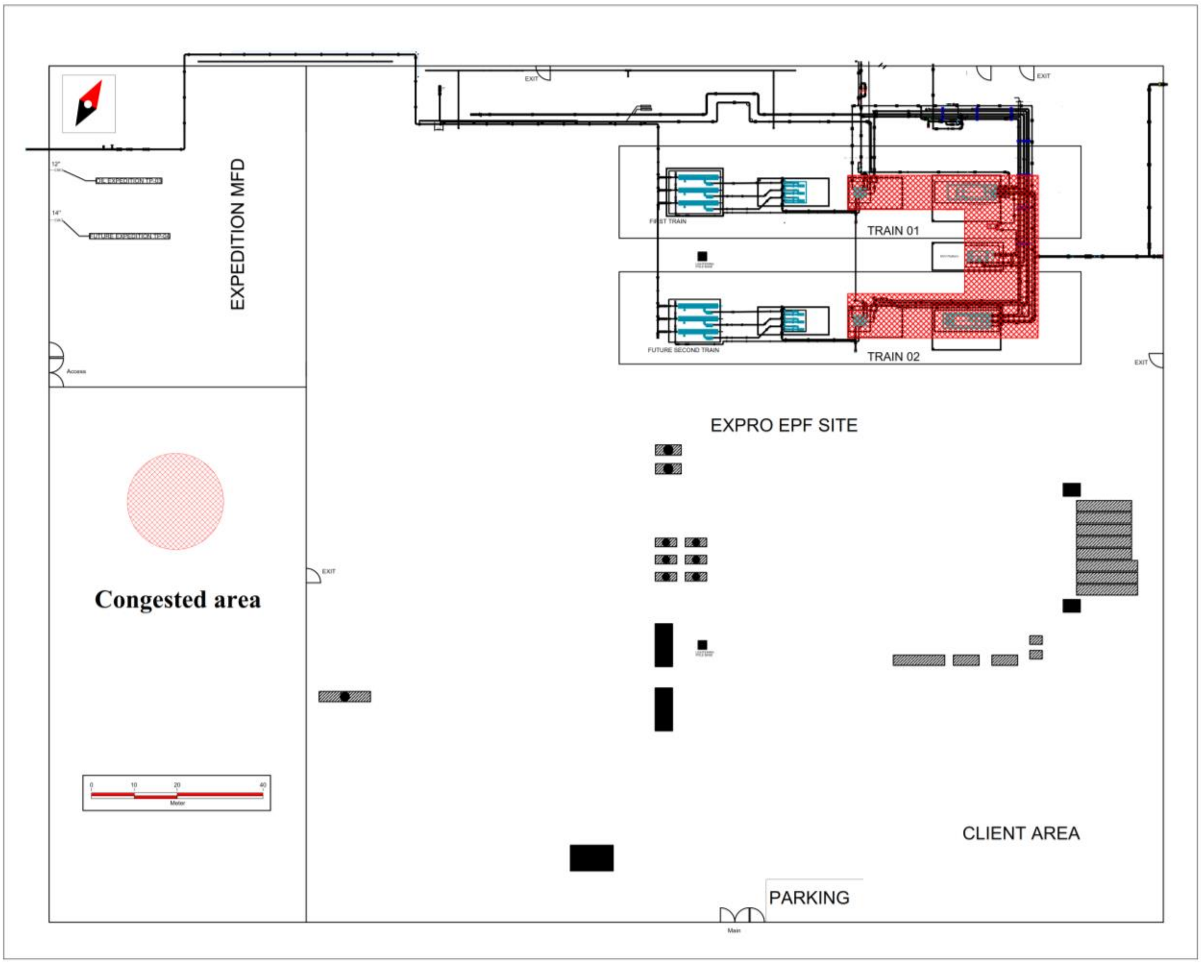

Figure 4-1 Congested Aread Definition in XPII EPF

4.2 Fire Zones Identification

The fire zones are identified by dividing the XPII EPF site into different geographic zones according to the near distance between equipment and each fire zone is divided into sections, which is characterized, by a single equipment and a specific fluid (Gas/Liquid), See Table 4-1 and Figure 4-2.

Table 4-1 Fire Zone Identification

Fire zone	Failure case	Code	Fluid	Dangerous phenomena			
				Flash fire	Jet fire	VCE	Pool fire
FZ 01	Loss of containment in the end of Inlet Pipe 16”-PF-06B3-1400	FC-1.1	Crude oil	✓	X	✓	✓
	Loss of containment in the end of Inlet pipe 12”-PF 03B3-1401	FC-1.2	Crude oil	✓	X	✓	✓
FZ 02	Loss of containment in Separator TX1H-046 ‘Liquid part’	FC-2.1	Crude oil	✓	✓	✓	✓
	Loss of containment in Separator TX1H-046 ‘Gas part’	FC-2.2	Natural Gas	✓	✓	✓	X
	Loss of containment in the end of gas line 10”-PV-03B3-1800 from separator TX1H-046 TO KOV	FC-2.3	Natural Gas	✓	✓	✓	X
	Loss of containment in the end of Pipe between separator and Surge tank	FC-2.4	Crude oil	✓	X	✓	✓
FZ 03	Loss of containment in Surge Tank TX6961-014	FC-3.1	Crude oil	✓	X	✓	✓
	Loss of containment in the end of Pipe between surge tank and booster pumps	FC-3.2	Crude oil	✓	X	✓	✓
FZ 04	Loss of containment in KOV 01-XRZ-009	FC-4	Natural Gas	✓	✓	✓	X
FZ 05	Loss of containment in Booster Pumps	FC-5.1	Crude oil	✓	X	✓	✓
	Loss of containment in Export pumps	FC-5.2	Crude oil	✓	X	✓	✓
FZ 06	Loss of containment in the Oil Expedition line	FC-6.1	Crude oil	✓	✓	X	✓
	Loss of containment in the Gas Expedition line	FC-6.2	Natural Gas	✓	✓	✓	X
FZ 07	Loss of containment in Diesel Tank	FC-7	Diesel	✓	X	✓	✓

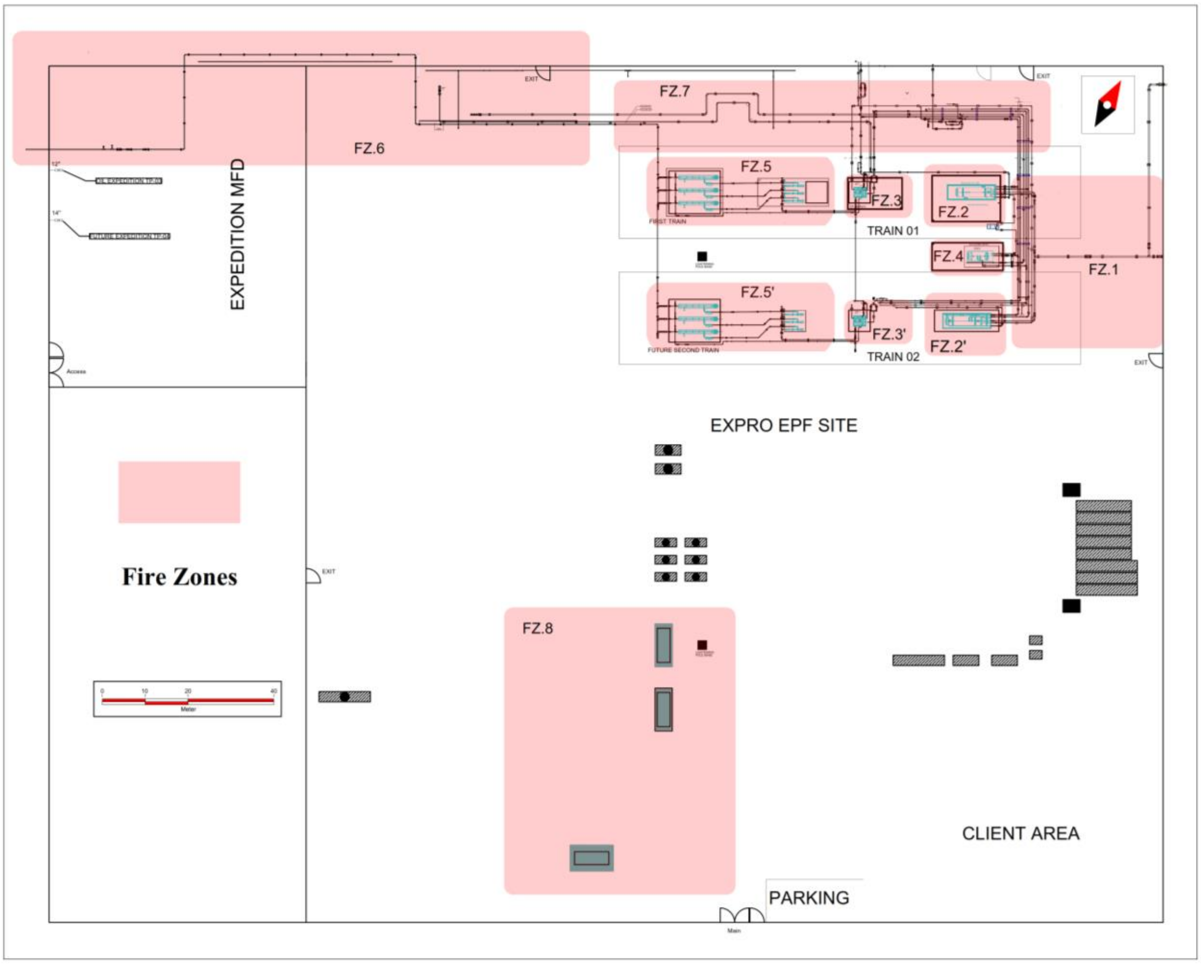

Figure 4-2 Fire Zones Definition

4.3 Input of Consequences Analysis

4.3.1 Meteorology

a. Temperature

The hot season lasts for 3.2 months, from June 6 to September 13, with an average daily high temperature above 96°F. The hottest month of the year is July, with an average high of 104°F and low of 80°F. The cool season lasts for 3.5 months, from November 20 to March 6, with an average daily high temperature below 70°F. The coldest month of the year is January, with an average low of 42°F and high of 62°F [12].

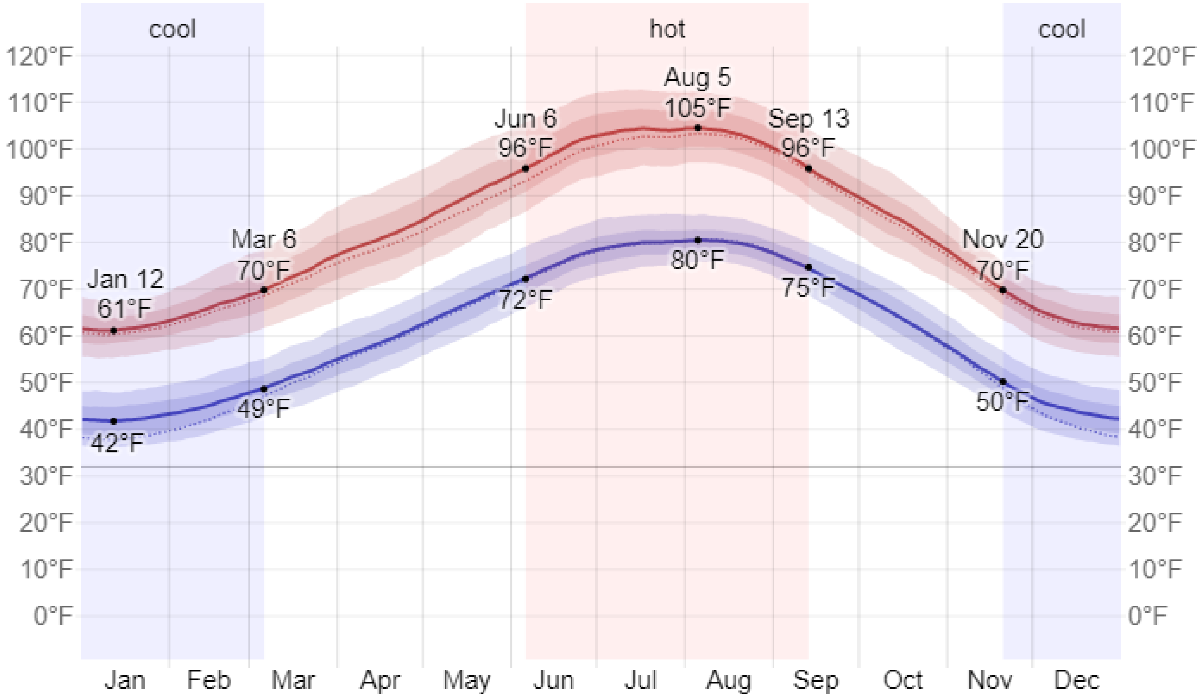

Figure 4-3 Average High and Low Temperature [12]

b. <u>Humidity</u>

In the site location, the period with higher humidity levels spans approximately 3.0 months, starting from July 16 and lasting until October 17. During this time, the comfort level can be described as muggy, oppressive, or even miserable, occurring for at least 4% of the time. The month of September experiences the highest number of muggy days in El Oued, with approximately 3.9 days considered muggy or worse [12].

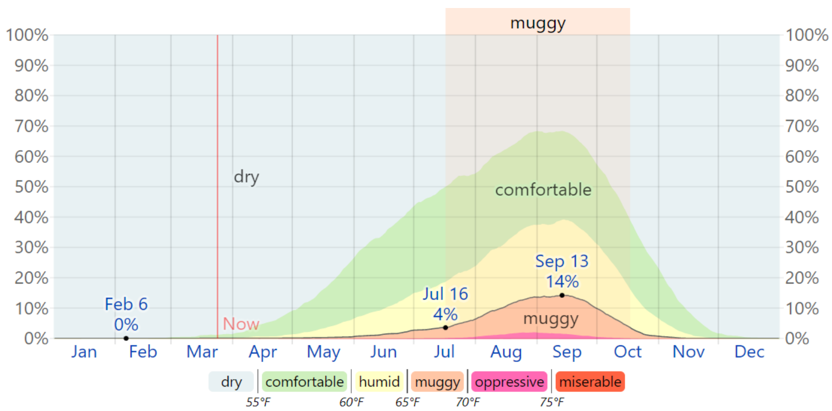

Figure 4-4 Humidity [12]

c. <u>Wind</u>

The windier part of the year lasts for 4.3 months, from March 17 to July 27, with average wind speeds of more than 9.2 miles per hour. The windiest month of the year is June, with an average hourly wind speed of 10.5 miles per hour. The calmer time of year lasts for 7.7 months, from July 27 to March 17. The calmest month of the year is November, with an average hourly wind speed of 7.9 miles per hour [12].

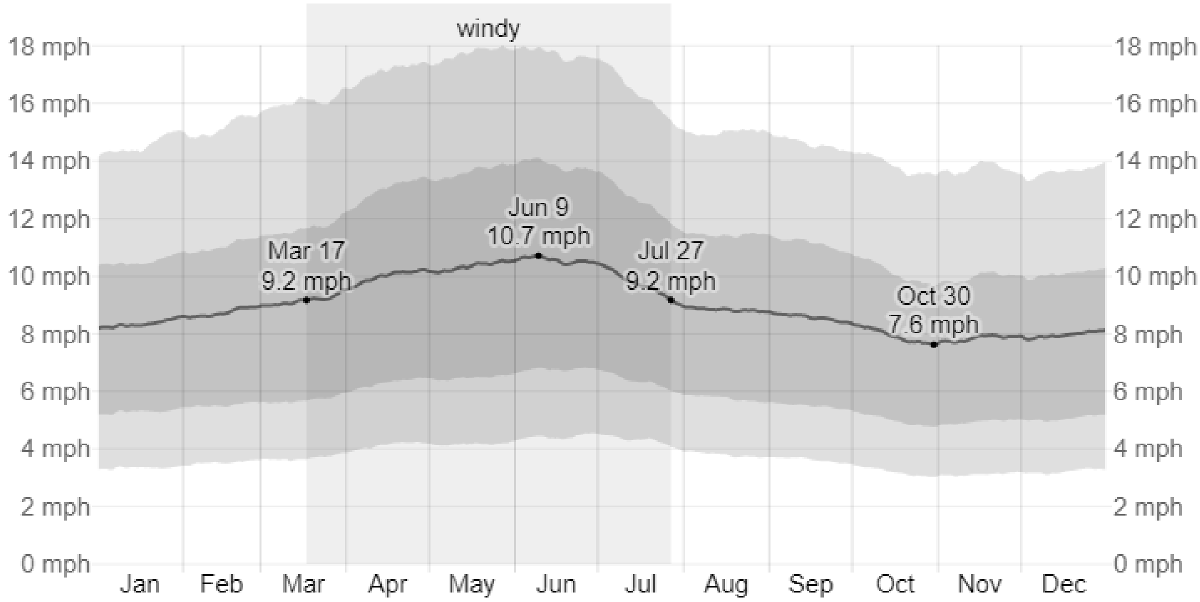

Figure 4-5 Average Wind Speed [12]

4.3.2 Operating Data and Fluids Properties

a. <u>Production Data</u>

Table 4-2 Production data [1]

Properties	Unit	EPF XPII
Gas Flowrate	Sm^3/d	1,200,000
Maximum expected flow rate	-	1,500,000
Gas SG	-	0.8
Gas Density	Kg/Sm^3	0.62
Oil Flowrate (Min/Max)	m^3/d	9,540 (60,000 BOPD)
Water Flowrate (Min/Nor/Max)	m^3/d	Normal 0
Oil Density at 15°C	Kg/m^3	808
Inlet Pressure (Min/Nor/Max)	Barg	8/10/11
Operating Temperature	°C	0-50
Oil Discharge Pressure @ B/L	Bar g	10
Gas Discharge Pressure @ B/L	Bar g	52 to 55
Oil & Gas Max Discharge Temperature@ B/L	°C	70

b. <u>Meteorological Data</u>

Table 4-3 Meteorological data [1], [12]

	Summer	Winter
Ambient temperature (°C)	50	12
Wind velocity ($m.s^{-1}$)	4.6	3.47
Relative humidity (%)	15	50

4.4 Results of Consequences Modeling

Consequences modeling was performed on train 1 only because the equipment are identical and have the same operating parameters. Calculations were performed using MATLAB programs that are based on the correlations and models specified in Appendix B.

4.4.1 Source Term modeling

Table 4-4 Source Term Modeling Results

Fire zone	Failure case	Breach Diameter (mm)	Discharge rate (Kg.s^{-1})
FZ 01	FC-1.1	5	0.82
		25	20.41
		100	277.07
		>150	623.41
	FC-1.2	5	0.69
		25	17.32
		100	226.52
		>150	558.58
FZ 02	FC-2.1	5	0.46
		25	11.60
		100	185.62
		>150	673.64
	FC-2.2	5	0.02
		25	0.55
		100	8.85
		>150	32.11
	FC-2.3	5	0.02
		25	0.53
		100	8.83
		>150	30.89
	FC-2.4	5	0.25
		25	6.38
		100	102.05
		>150	229.61
FZ 03	FC-3.1	5	0.27
		25	6.81
		100	108. 95
		>150	245.14
	FC-3.2	5	0.29
		25	7.38
		100	118.04
		>150	265.59
FZ 04	FC-4	5	0.01
		25	0.44
		100	7.08

Fire zone	Failure case	Breach diameter (mm)	Discharge rate ($Kg.s^{-1}$)
		>150	25.68
FZ 05	FC-5.1	5	0.57
		25	14.29
		100	228.68
		>150	514.53
	FC-5.2	5	1.16
		25	29.39
		100	464.52
		>150	868.61
FZ 06	FC-6	5	0.62
		25	15.52
		100	248.45
		>150	559.03
FZ 07	FC-7	5	0.01
		25	0.43
		100	6.86
		>150	15.44

Based on the source term modeling, several observations can be made regarding the characteristics of releases.

Firstly, it is evident that liquid releases exhibit larger discharge rates in comparison to gas releases since it has higher density. This implies that in the event of a release, liquids are more likely to be discharged at a higher rate, potentially leading to a more rapid spread of the hazardous material. . Furthermore, the discharge rate is influenced by the size of the breach.

Larger breaches result in higher discharge rates, emphasizing the importance of effectively managing breaches to minimize potential hazards.

Although smaller sizes are the ones that are more harder to detect. Additionally, pressure plays a crucial role in determining the strength of a release. Higher pressures are associated with more forceful and intense releases, which can lead to increased risks and potential consequences.

4.4.2 Fire accidents modeling results

Table 4-5 Fire Accidents Modeling Results

Fire zone	Failure case	Dangerous Phenomenon	Breach diameter (mm)	Thermal radiation extents (m)	
				12.5 $Kw.m^{-2}$	37.5 $Kw.m^{-2}$
FZ 01	FC1.1	Early Pool fire	5	7.48	6.60
			25	26.50	3.30
			100	N/A	N/A
			>150	N/A	N/A
		Late Pool Fire	5	14.00	11.57
			25	37.27	2.40
			100	45.60	3.50
			>150	80.10	Not reached
	FC-1.2	Early Pool Fire	5	7.02	6.40
			25	25.56	15.50
			100	N/A	N/A
			>150	N/A	N/A
		Late Pool Fire	5	13.11	10.90
			25	34.76	3.94
			100	41.70	3.60
			>150	76.35	Not reached
FZ 02	FC-2.1	Early Pool Fire	5	5.76	5.30
			25	6.30	Not reached
			100	6.30	Not reached
			>150	N/A	N/A
		Late Pool Fire	5	14.50	12.46
			25	6.30	Not reached
			100	6.30	Not reached
			>150	6.30	Not reached
	FC-2.2	Jet Fire	5	1.91	Not reached
			25	8.11	3.61
			100	29.49	13.93
			>150	53.88	26.04
	FC-2.3	Jet Fire	5	1.84	Not reached
			25	7.99	3.54
			100	29.46	13.92
			>150	52.92	25.55

Fire zone	Failure case	Dangerous Phenomenon	Breach diameter (mm)	Thermal radiation extents (m)	
				12.5 $Kw.m^{-2}$	37.5 $Kw.m^{-2}$
	FC-2.4	Early Pool Fire	5	4.15	4.20
			25	17.31	13.80
			100	52.26	2.30
			>150	N/A	N/A
		Late Pool Fire	5	11.78	9.69
			25	31.15	3.23
			100	73.35	Not reached
			>150	52.10	2.44
FZ 03	FC-3.1	Early Pool Fire	5	4.45	4.30
			25	7.23	Not reached
			100	7.23	Not reached
			>150	7.23	Not reached
		Late Pool Fire	5	11.99	10.24
			25	7.23	Not reached
			100	7.23	Not reached
			>150	7.23	Not reached
	FC-3.2	Early Pool Fire	5	4.65	4.50
			25	18.35	14.10
			100	N/A	N/A
			>150	N/A	N/A
		Late Pool Fire	5	12.30	10.31
			25	33.15	3.20
			100	33.90	3.80
			>150	41.60	3.65
FZ 04	FC-4	Jet Fire	5	1.67	Not reached
			25	7.31	3.24
			100	26.57	12.51
			>150	48.53	23.36
FZ 05	FC-5.1	Early Pool Fire	5	6.44	5.80
			25	7.57	Not reached
			100	7.57	Not reached
			>150	7.57	Not reached
		Late Pool Fire	5	16.02	12.91
			25	7.57	Not reached
			100	7.57	Not reached
			>150	7.57	Not reached

Fire zone	Failure case	Dangerous Phenomenon	Breach diameter (mm)	Thermal radiation extents (m)	
				12.5 Kw.m^{-2}	37.5 Kw.m^{-2}
	FC-5.2	Early Pool Fire	5	6.74	Not reached
			25	6.74	Not reached
			100	6.74	Not reached
			>150	6.74	Not reached
		Late Pool Fire	5	6.74	Not reached
			25	6.74	Not reached
			100	6.74	Not reached
			>150	6.74	Not reached
FZ 06	FC-6	Early Pool Fire	5	6.61	6.10
			25	24.58	11.10
			100	N/A	N/A
			>150	N/A	N/A
		Late Pool Fire	5	16.40	13.16
			25	45.05	2.78
			100	42.90	3.61
			>150	76.15	Not reached
FZ 07	FC-7	Jet Fire	5	1.67	0.73
			25	7.21	3.22
			100	26.19	12.40
			>150	38.25	18.36
FZ 08	FC-8	Pool Fire		6.20	Not reached

According to the observations made, we can interpret the results as follows:

- Breach diameter and Pool Fires: For a breach diameter of 150 mm, instantaneous releases occur, making the modeling of early pool fires not applicable. However, for a breach diameter of 100 mm, the distinction between continuous and instantaneous releases needs to be verified based on specific conditions outlined in Appendix B. This differentiation is important for accurately modeling and assessing the corresponding fire behavior.
- Pool Fire Radiation Intensity: The thermal radiation intensity of pool fires is influenced by various factors, including pool diameter, view factor, flame shape, and atmospheric transmissivity. It is important to note that even with a significant discharge rate, the radiative impact may not be significant when the pool diameter increases. The emissive power tends to

decline with larger pool diameters, often resulting in the 37.5 kW/m^2 threshold not being reached in larger sizes.

- Pool Fires and Retention Dikes: The presence of a retention dike for pool fires can limit the spread of the pool to other equipment. However, it also concentrates the danger on the equipment source. The rectangular flame shape associated with pool fires contributes to reducing the danger as the view factor for this configuration is smaller compared to a cylindrical flame. Consequently, a rectangular bund is considered more suitable as a passive protection measure in such scenarios.

- Jet Fires and Thermal Radiation Intensity: Jet fires exhibit an increase in the extent of thermal radiation intensity with the breach diameter, as there is a direct relationship between discharge rate and radiation intensity. This indicates that larger breaches result in more severe thermal radiation effects.

- Jet Fires vs. Pool Fires: Jet fires are generally more dangerous than pool fires due to the absence of mitigation measures like bunds to reduce their consequences' severity. The thermal radiation intensity of jet fires often exceeds the 37.5 kW/m^2 threshold, except for very small breaches.

4.4.3 Vapor Cloud Explosion Modeling Results

Table 4-6 VCE Modeling Results

Fire zone	Failure case	Breach diameter (mm)	Blast Overpressure extents (m)		
			200 mbar	350 mbar	700 mbar
FZ 01	FC-1.1	5	50	35	21
		25	59	41	25
		100	63	43	27
		>150	65	45	28
	FC-1.2	5	42	29	18
		25	56	39	24
		100	62	43	27
		>150	65	45	28
FZ 02	FC-2.1	5	39	27	17
		25	45	31	19
		100	45	31	19
		>150	45	31	19
	FC-2.2	5	17	12	8

Fire zone	Failure case	Breach diameter (mm)	Blast Overpressure extents (m)		
			200 mbar	350 mbar	700 mbar
		25	26	18	12
		100	34	24	15
		>150	33	23	14
	FC-2.3	5	18	13	8
		25	29	20	13
		100	37	26	16
		>150	36	25	16
	FC-2.4	5	29	20	13
		25	36	25	16
		100	56	39	24
		>150	41	29	18
FZ 03	FC-3.1	5	35	22	14
		25	34	23	15
		100	34	23	15
		>150	34	23	15
	FC-3.2	5	Not reached	Not reached	Not reached
		25	19	13	Not reached
		100	24	17	11
		>150	31	21	13
FZ 04	FC-4	5	16	11	7
		25	27	19	12
		100	38	26	16
		>150	37	25	16
FZ 05	FC-5.1	5	Not reached	Not reached	Not reached
		25	Not reached	Not reached	Not reached
		100	Not reached	Not reached	Not reached
		>150	Not reached	Not reached	Not reached
	FC-5.2	5	Not reached	Not reached	Not reached
		25	Not reached	Not reached	Not reached
		100	Not reached	Not reached	Not reached
		>150	Not reached	Not reached	Not reached
FZ 06	FC-6.1	5	Not reached	Not reached	Not reached
		25	Not reached	Not reached	Not reached
		100	Not reached	Not reached	Not reached
		>150	Not reached	Not reached	Not reached
FZ 07	FC-7	5	Not reached	Not reached	Not reached

Fire zone	Failure case	Breach diameter (mm)	Blast Overpressure extents (m)		
			200 mbar	350 mbar	700 mbar
		25	Not reached	Not reached	Not reached
		100	Not reached	Not reached	Not reached
		>150	Not reached	Not reached	Not reached

The VCE modeling results shed light on the consequences of potential VCE incidents in the early production facility. The adopted modeling approach, using the TNO multi energy model, considered the presence of congested areas. In areas without obstacles or minimal congestion, the blast strength was assumed to be low, resulting in the explosion thresholds not being reached. This suggests relatively lower impact and severity of VCE explosions in these unobstructed zones. However, in congested areas, the severity of VCE explosions depended on the size of the intersection volume between the vapor cloud and congestion. Larger intersection volumes correlated with more severe explosions. This highlights the significant influence of congestion on the potential consequences and magnitude of VCE incidents.

Conclusion

This chapter has provided an overview of the consequences analysis within Expro's Early Production Facility as part of the Fire and Explosion Risk Assessment (FERA) process. By incorporating hazard identification from various sources such as historical data, HazOp, and HazId studies, the identification of congested areas critical to vapor cloud explosions, and the definition of fire zones, the chapter has laid the foundation for assessing the potential consequences of fire and explosion events.

Furthermore, the chapter highlighted the importance of accurate inputs for consequences modeling, considering both operational factors and meteorological conditions. Through source term modeling, valuable insights into the release of hazardous substances were obtained, enabling a better understanding of the potential extent and impact of accidents. The modeling results of fire accidents and vapor cloud explosions further enhance the understanding of the potential consequences, aiding in risk evaluation and the development of effective mitigation measures. By assessing the potential impacts on personnel, assets, and the surrounding environment, proactive measures can be implemented to prevent or minimize the severity of such incidents.

Overall, the consequences analysis presented in this chapter serves as a crucial step in the FERA process, enabling the identification of high-risk areas and guiding decision-making for safety improvements.

Chapter 5. Risk Assessment

Introduction

This chapter delves into the crucial process of evaluating and quantifying risks within the context of the early production facility. This chapter focuses on the application of two essential procedures that have been discussed in previous chapters: general risk evaluation using risk matrices and individual risk calculation. These procedures serve as valuable tools for comprehensively assessing and managing risks associated with various hazards and potential incidents.

5.1 Risk Matrix

To assess the risk for the XPII early production facility, we used EXPRO's risk matrix. The matrix comprises six categories for both frequency and severity. These categories serve as a framework for evaluating the likelihood and impact of potential incidents or accidents. The severity categories not only consider the safety aspects but also take into account the financial implications associated with each event. The specific details and classification of these categories can be found in the provided tables.

5.1.1 Frequency Levels

Table 5-1 Frequency Levels

Category	Frequency level	Description	Frequency Range 1/year
1	Unlikely / Unknown	Not expected to occur	$F < 10^{-6}$
2	Remote	A remotely possible but known occurrence	$10^{-6} \leq F \leq 10^{-5}$
3	Occasional	Could occur but probably not more than once	$10^{-5} < F \leq 10^{-4}$
4	Probable	Likely to occur occasionally more than once	$10^{-4} < F \leq 10^{-3}$
5	Frequent	Likely to occur regularly	$10^{-3} < F \leq 10^{-2}$
6	Highly likely	Likely to occur very regularly/always present	$F > 10^{-2}$

5.1.2 Severity Levels

Table 5-2 Severity Levels

Category	Financial Loss range in £
1	$F_{loss} < 1000£$
2	$1000£ \leq F_{loss} < 5000£$
3	$5000£ \leq F_{loss} < 50000£$
4	$50000£ \leq F_{loss} < 100000£$
5	$100000£ \leq F_{loss} \leq 1000000£$
6	$F_{loss} > 1000000£$

Table 5-3 EXPRO Risk Matrix

		Frequency (1/year)					
Severity	Category	1	2	3	4	5	6
	1	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24
	5	5	10	15	20	25	30
	6	6	12	18	24	30	36
Low Risk		Acceptable risk, no further measure are required					
Medium Risk		ALARP region, proposed safeguards should be implemented if the sacrifice is not in gross disproportion with the benefit.					
High Risk		Inacceptable risk, further measures are required					

5.2 First Level Risk Assessment

As highlighted in Chapter II, the initial step in the assessmetn process involves conducting a comprehensive assessment that takes into account various factors such as likelihood, exposure time in the event of fire accidents, and financial implications. To facilitate this evaluation, it is crucial to gather information pertaining to equipment costs within the early production facility. This data will aid in determining the potential financial loss associated with different incidents or accidents.

Table 5-4 Critical Equipment Cost in Pound

Equipment	Cost in £
Separator including instruments and valves	200000
Surge tank including instruments and valves	100000
Knock out vessel including instruments and valves	150000
Booster pump	10000
Export pump	20000
Diesel tank	3000
10” pipe	50/meter
12” pipe	60.80/meter
16” pipe	75/meter

Using the above information and the contours in Appendix D, we can conduct the general risk evaluation as depicted in Table 5-5, with hazardous events coded as follow:

FZ-N.P-DPh-S

Where:

FZ: Fire Zone

N: Numbering of fire zone

P: Numbering of failure case

DPh: Type of dangerous phenomenon (EP, LP, JF or VCE)

S: Breach diameter

Table 5-5 First Level Risk Evaluation within XPII EPF

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-1.1-EP-005	Early Pool Fire	Pipes 16”,12”,10”	37.5 KW.m^2	26 min 30 s	7,52E-07	1	7481	3	Low Risk
			Fire Impingement				1961	2	Low Risk
FZ-1.1-EP-025	Early Pool Fire	Pipe 16”	37.5 Kw.m^2	13 min 45 s	2,06E-07	1	4380	2	Low Risk
			Fire Impingement				6889.76	3	Low Risk
FZ-1.2-EP-005	Early Pool Fire	Pipes 16”,12”,10” and Train 1 separator	37.5 Kw.m^2	27 min	2,69E-07	1	284900	5	Medium Risk
		Train 1 Separator and 12” pipe	Fire Impingement				225000	5	Medium Risk
FZ-1.2-EP-025	Early Pool fire	Pipes 16”,12”,10”	37.5 Kw.m^2	13 min 35 s	1,35E-07	1	69780	4	Low Risk
		Train 1 Separator, KOVand 12” pipe	Fire Impingement				360000	5	Medium Risk
FZ-1.2’-EP-005	Early Pool fire	Pipes 16”,12”,10” and Train 2 separator	37.5 Kw.m^2	27 min	2,69E-07	1	284900	4	Low Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
		Train 2 Separator and 12" pipe	Fire Impingement				225000	4	Low Risk
FZ-1.2'-EP-025	Early Pool Fire	Pipes 16",12",10"	37.5 $Kw.m^2$	13 min 35 s	1,35E-07	1	69780	4	Low Risk
		Train 2 Separator, KOVand 12" pipe	Fire Impingement				360000	5	Medium Risk
FZ-1.1-LP-005	Late Pool Fire	Pipes 16" and 12"	37.5 $Kw.m^2$	2 min 15 s	7,51E-07	1	5300	2	Low Risk
			Fire Impingement				1500	2	Low Risk
FZ-1.1-LP-025	Late Pool Fire	16" pipe	37.5 $Kw.m^2$	2 min 14 s	3,91E-06	2	1000	2	Low Risk
		Train 1 and 2 separators, KOV, 16",12",10"	Fire Impingement				4000		Low Risk
FZ-1.1-LP-100	Late Pool Fire	16"	37.5 $Kw.m^2$	2 min 13 s	6,11E-06	2	1000	2	Low Risk
		Train 1 and 2 separators, KOV, 16",12",10"	Fire Impingement				4000		Low Risk
FZ-1.1-LP-150	Late Pool Fire	Train 1 and 2 separators, surge tanks,	Fire Impingement	2 min 15 s	1,36E-05	3	10000	3	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-1.2-LP-005	Late Pool Fire	16”,12” and 10” pipes	37.5 $Kw.m^2$	2 min 16 s	2,69E-07	1	1600	2	Low Risk
		Train 1 separator and 12” pipe	Fire Impingement				3000	2	Low Risk
FZ-1.2-LP-025	Late Pool Fire	12” inlet pipe	37.5 $Kw.m^2$	2 min 15 s	2,56E-06	2	1000	2	Low Risk
		Train 1 separator, KOV and 12 pipe	Fire Impingement				3500	2	Low Risk
FZ-1.2-LP-100	Late Pool Fire	12” inlet pipe	37.5 $Kw.m^2$	2 min 17 s	4,01E-06	2	1000	2	Low Risk
		Train 1 and 2 separators, KOV, Train 1 surge tank	Fire Impingement				5200	3	Medium Risk
FZ-1.2-LP-150	Late Pool Fire	Train 1 and 2 separators, surge tanks KOV	Fire Impingement	2 min 14 s	5,74E-06	2	6000	3	Medium Risk
FZ-1.2’-LP-005	Late Pool Fire	16”,12” and 10” pipes	37.5 $Kw.m^2$	2 min 16 s	2,69E-07	1	1600	2	Low Risk
		Train 2 separator and 12” pipe	Fire Impingement				3000	2	Low Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-1.2'-LP-025	Late Pool Fire	12" inlet pipe	37.5 $Kw.m^2$	2 min 15 s	2,56E-06	2	1000	2	Low Risk
		Train 2 separator, KOV and 12 pipe	Fire Impingement				3500	2	Low Risk
FZ-1.2'-LP-100	Late Pool Fire	12" inlet pipe	37.5 $Kw.m^2$	2 min 17 s	4,01E-06	2	1000	2	Low Risk
		Train 1 and 2 separators, KOV, Train 2 surge tank	Fire Impingement				5200	2	Low Risk
FZ-1.2'-LP-150	Late Pool Fire	Train 1 and 2 separators, surge tanks KOV	Fire Impingement	2 min 14 s	5,74E-06	2	6000	2	Low Risk
FZ-1.1-VCE-005	Vapor Cloud Explosion	Train 1 and 2 separators, Kov and piping	350 mbar overpressure	/	3,31E-07	1	160000	5	Medium Risk
FZ-1.1-VCE-025	Vapor Cloud Explosion	Train 1 and 2 separators Surge tanks, KOV piping	350 mbar overpressure	/	2,27E-06	2	203000	4	Medium Risk
FZ-1.1-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators Surge tanks, KOV piping	350 mbar overpressure	/	3,55E-06	2	203000	4	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-1.1-VCE-150	Vapor Cloud Explosion	Train 1 and 2 except export pumps	350 mbar overpressure	/	7,92E-06	2	263000	5	Medium Risk
FZ-1.2-VCE-005	Vapor Cloud Explosion	Train 1 and 2 separators,KOV and piping	350 mbar overpressure	/	1,18E-07	1	158000	5	Medium Risk
FZ-1.2-VCE-025	Vapor Cloud Explosion	Train 1 and 2 separators, Surge tanks, KOVpiping	350 mbar overpressure	/	1,49E-06	2	203000	5	Medium Risk
FZ-1.2-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators, Surge tanks, KOVpiping	350 mbar overpressure	/	2,32E-06	2	203000	5	Medium Risk
FZ-1.2-VCE-150	Vapor Cloud Explosion	Train 1 and 2 except export pumps	350 mbar overpressure	/	7,92E-06	2	263000	5	Medium Risk
FZ-1.2’-VCE-005	Vapor Cloud Explosion	Train 1 Separators, KOV and piping	350 mbar overpressure	/	1,18E-07	1	203000	5	Medium Risk
FZ-1.2’-VCE-025	Vapor Cloud Explosion	Train 1 and 2 separators, train 1 surge tank, KOV and piping	350 mbar overpressure	/	1,49E-06	2	198000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-1.2'-VCE-100	Vapor Cloud Explosion	Train 1 and 2 Surge tanks, separators, KOV piping	350 mbar overpressure	/	2,32E-06	2	203000	5	Medium Risk
FZ-1.2'-VCE-150	Vapor Cloud Explosion	Train 1 and 2 except export pumps and piping	350 mbar overpressure	/	7,92E-06	2	263000	5	Medium Risk
FZ-2.1-EP-005	Early Pool fire	Train 1 separator	37.5 Kw.m^2 / Fire Impingement	28 min 26 s	1,07E-06	2	200000	5	Medium Risk
FZ-2.1-EP-025	Early Pool Fire	Train 1 separator	Fire Impingement	16 min	4,08E-07	1	200000	5	Medium Risk
FZ-2.1-EP-100	Early Pool Fire	Train 1 separator	Fire Impingement	96 min 50s	1,01E-07	1	200000	5	Medium Risk
FZ-2.1-LP-005	Late Pool Fire	Train 1 separator	37.5 Kw.m^2 / Fire Impingement	2 min 14 s	1,07E-06	2	2000	2	Low Risk
FZ-2.1-LP-025	Late Pool Fire	Train 1 separator	Fire Impingement	11 min 31 s	5,71E-07	1	200000	5	Medium Risk
FZ-2.1-LP-100	Late Pool Fire	Train 1 separator	Fire Impingement	92 min 21 s	9,99E-06	2	64000	4	Medium Risk
FZ-2.1-LP-150	Late Pool Fire	Train 1 separator	Fire Impingement	67 min	8,27E-06	2	64000	4	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2.1-VCE-005	Vapor Cloud Explosion	Train 1 and 2 separators; train 1 surge tank, KOV	350 mbar overpressure	/	4,70E-07	1	198000	5	Medium Risk
FZ-2.1-VCE-025	Vapor Cloud Explosion	Train 1 and 2 separators; train 1 surge tank, KOV	350 mbar overpressure	/	2,51E-07	1	198000	5	Medium Risk
FZ-2.1-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators; train 1 surge tank, KOV	350 mbar overpressure	/	5,79E-06	2	198000	5	Medium Risk
FZ-2.1-VCE-150	Vapor Cloud Explosion	Train 1 and 2 separators; train 1 surge tank, KOV	350 mbar overpressure	/	4,80E-06	2	198000	5	Medium Risk
FZ-2.2-JF-005	Jet Fire	/	Fire Impingement	20 min	1,13E-06	2	/	1	Low Risk
FZ-2.2-JF-025	Jet Fire	Train 1 separator	37.5 $Kw.m^2$	10 min	5,72E-07	1	200000	5	Medium Risk
FZ-2.2-VCE-025	Vapor Cloud Explosion	Train 1 separator , KOV and piping	350 mbar overpressure	/	1,26E-07	1	350000	5	Medium Risk
FZ-2.2-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators	350 mbar overpressure	/	5,27E-07	1	550000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2.2-VCE-150	Vapor Cloud Explosion	Train 1 and 2 separators , KOV and piping	350 mbar overpressure	/	1,23E-06	2	550000	5	Medium Risk
FZ-2.3-JF-005	Jet Fire	/	37.5 Kw.m^2	20 min	3,82E-07	1	/	1	Low Risk
FZ-2.3-JF-025	Jet Fire	Train 1 separator	37.5 Kw.m^2	10 min	1,80E-07	1	200000	5	Medium Risk
FZ-2.3-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators , train 1 surge tank KOV and piping	350 mbar overpressure	/	2,79E-07	1	650000	5	Medium Risk
FZ-2.3-VCE-150	Vapor Cloud Explosion	Train 1 and 2 separators , KOV and piping	350 mbar overpressure	/	2,20E-06	2	550000	5	Medium Risk
FZ-2.4-EP-005	Early Pool Fire	Train 1 separator and surge tank	37.5 Kw.m^2	32 min	1,22E-06	2	300000	5	Medium Risk
		Train 1 surge tank	Fire Impingement				100000	4	Medium Risk
FZ-2.4-EP-025	Early Pool Fire	Train 1 separator, surge tank and KOV	37.5 Kw.m^2	12 min 24 s	4,94E-07	1	450000	5	Medium Risk
		Train 1 surge tank	Fire Impingement				100000	4	Low Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2.4-EP-100	Early Pool Fire	Train 1 separator, surge tank and KOV	Fire Impingement	9 min 30s	1,12E-07	1	2000	2	Low Risk
FZ-2.4-LP-025	Late pool fire	Pipe 10”	37.5 Kw.m^2	2 min 15s	9,38E-06	2	900	1	Low Risk
		Train 1 surge tank	Fire Impingement				1600	2	
FZ-2.4-LP-100	Late pool fire	Train 1 and 2	Fire Impingement	2 min 15s	1,11E-05	3	15000	3	Medium Risk
FZ-2.4-LP-150	Late Pool Fire	Pipe 10”	37.5 Kw.m^2	2 min 15s	9,77E-06	2	900	1	Low Risk
		Train 1 separator, surge tank, booster pumps, train 2 surge tank	Fire Impingement				9000	3	Medium Risk
FZ-2.4-VCE-025	Vapor Cloud Explosion	Train 1 separator, surge tank, booster pumps and KOV	350 mbar overpressure	/	4,13E-06	2	480000	5	Medium Risk
FZ-2.4-VCE-100	Vapor Cloud Explosion	Train 1 and 2 except export pumps	350 mbar overpressure	/	6,42E-06	2	1100000	6	Medium Risk
FZ-2.4-VCE-150	Vapor Cloud Explosion	Train 1 and 2 except export pumps	350 mbar overpressure	/	5,67E-06	2	1100000	6	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2'.1-EP-005	Early Pool fire	Train 2 separator	37.5 $Kw.m^2$ Fire impingement	28 min 26 s	1,07E-06	2	200000	5	Medium Risk
FZ-2'.1-EP-025	Early Pool Fire	Train 2 separator	Fire Impingement	16 min	4,08E-07	1	200000	5	Medium Risk
FZ-2'.1-EP-100	Early Pool Fire	Train 2 separator	Fire Impingement	96 min 50s	1,01E-07	1	200000	5	Medium Risk
FZ-2'.1-LP-005	Late Pool Fire	Train 2 separator	37.5 $Kw.m^2$ Fire Impingement	2 min 14 s	1,07E-06	2	2000	2	Low Risk
FZ-2'.1-LP-025	Late Pool Fire	Train 2 separator	Fire Impingement	11 min 31 s	5,71E-07	1	200000	5	Medium Risk
FZ-2'.1-LP-100	Late Pool Fire	Train 2 separator	Fire Impingement	92 min 21 s	9,99E-06	2	200000	5	Medium Risk
FZ-2'.1-LP-150	Late Pool Fire	Train 2 separator	Fire Impingement	67 min	8,27E-06	2	200000	4	Medium Risk
FZ-2'.1-VCE-005	Vapor Cloud Explosion	Train 1 and 2 separators; train 2 surge tank, KOV	350 mbar overpressure	/	4,70E-07	1	450000	5	Medium Risk
FZ-2'.1-VCE-025	Vapor Cloud Explosion	Train 1 and 2 separators; train 2 surge tank, KOV	350 mbar overpressure	/	2,51E-07	1	450000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2'.1-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators; train 2 surge tank, KOV	350 mbar overpressure	/	5,79E-06	2	450000	5	Medium Risk
FZ-2'.1-VCE-150	Vapor Cloud Explosion	Train 1 and 2 separators; train 2 surge tank, KOV	350 mbar overpressure	/	4,80E-06	2	450000	5	Medium Risk
FZ-2'.2-JF-005	Jet Fire	/	Fire Impingement	20 min	1,13E-06	2	/	1	Low Risk
FZ-2'.2-JF-025	Jet Fire	Train 2 separator	37.5 $Kw.m^2$	10 min	5,72E-07	1	200000	5	Medium Risk
FZ-2'.2-VCE-025	Vapor Cloud Explosion	Train 2 separator , KOV and piping	350 mbar overpressure	/	1,26E-07	1	350000	4	Medium Risk
FZ-2'.2-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators , KOV and piping	350 mbar overpressure	/	5,27E-07	1	550000	5	Medium Risk
FZ-2'.2-VCE-150	Vapor Cloud Explosion	Train 1 and 2 separators , KOV and piping	350 mbar overpressure	/	1,23E-06	2	550000	5	Medium Risk
FZ-2'.3-JF-005	Jet Fire	/	Fire impingement	20 min	3,82E-07	1	/	1	Low Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2'.3-JF-025	Jet Fire	Train 2 separator	37.5 Kw.m^2	10 min	1,80E-07	1	200000	5	Medium Risk
FZ-2'.3-VCE-100	Vapor Cloud Explosion	Train 1 and 2 separators , train 2 surge tank KOV and piping	350 mbar overpressure	/	2,79E-07	1	650000	5	Medium Risk
FZ-2'.3-VCE-150	Vapor Cloud Explosion	Train 1 and 2 separators , KOV and piping	350 mbar overpressure	/	2,20E-06	2	550000	5	Medium Risk
FZ-2'.4-EP-005	Early Pool Fire	Train 2 separator and surge tank	37.5 Kw.m^2	32 min	1,22E-06	2	300000	5	Medium Risk
		Train 2 surge tank	Fire Impingement				100000	4	Medium Risk
FZ-2'.4-EP-025	Early Pool Fire	Train 2 separator, surge tank and KOV	37.5 Kw.m^2	12 min 24 s	4,94E-07	1	450000	5	Medium Risk
		Train 2 surge tank	Fire Impingement				100000	4	Low Risk
FZ-2'.4-EP-100	Early Pool Fire	Train 2 surge tank and KOV	Fire Impingement	9 min 30s	1,12E-07	1	2000	2	Low Risk
FZ-2'.4-LP-025	Late pool fire	Pipe 10"	37.5 Kw.m^2	2 min 15s	9,38E-06	2	900	1	Low Risk
		Train 2 surge tank	Fire Impingement				1700	2	Low Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-2'.4-LP-100	Late pool fire	Train 1 and 2	Fire Impingement	2 min 15s	1,11E-05	3	15000	3	Medium Risk
FZ-2'.4-LP-150	Late Pool Fire	Pipe 10"	37.5 Kw.m^2	2 min 15s	9,77E-06	2	900	1	Low Risk
		Train 2 surge tank	Fire Impingement				1000	2	Low Risk
FZ-2'.4-VCE-025	Vapor Cloud Explosion	Train 2 separator, surge tank, booster pumps and KOV	350 mbar overpressure	/	4,13E-06	2	480000	5	Medium Risk
FZ-2'.4-VCE-100	Vapor Cloud Explosion	Train 1 and 2 except export pumps	350 mbar overpressure	/	6,42E-06	2	1000000	6	Medium Risk
FZ-2'.4-VCE-150	Vapor Cloud Explosion	Train 1 and 2 except export pumps	350 mbar overpressure	/	5,67E-06	2	1000000	6	Medium Risk
FZ-3.1-EP-005	Early Pool Fire	Train 1 surge tank	37.5 Kw.m^2 Fire Impingement	31 min 38 s	2,30E-06	2	100000	4	Medium risk
FZ-3.1-EP-025	Early Pool Fire	Train 1 surge tank	Fire Impingement	17 min 13 s	1,14E-06	2	100000	3	Medium risk
FZ-3.1-EP-100	Early Pool Fire	Train 1 surge tank	Fire Impingement	106 min 13 s	1,87E-07	1	100000	4	Low Risk
FZ-3.1-LP-025	Late Pool Fire	Train 1 surge tank	Fire Impingement	12 min 43 s	1,59E-05	3	100000	3	Medium risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-3.1-LP-100	Late Pool Fire	Train 1 surge tank	Fire Impingement	101 min 23 s	1,85E-05	3	100000	3	Medium risk
FZ-3.1-LP-150	Late Pool Fire	Train 1 surge tank	Fire Impingement	48 min	1,53E-05	3	100000	3	Medium risk
FZ-3.1-VCE-025	Vapor Cloud Explosion	Train 1 separator, surge tank and booster pump	350 mbar overpressure	/	7,02E-06	2	330000	5	Medium Risk
FZ-3.1-VCE-100	Vapor Cloud Explosion	Train 1 separator, surge tank and booster pump	350 mbar overpressure	/	1,07E-05	3	330000	5	Medium Risk
FZ-3.1-VCE-150	Vapor Cloud Explosion	Train 1 separator, surge tank and booster pump	350 mbar overpressure	/	8,89E-06	2	330000	5	Medium Risk
FZ-3.2-EP-005	Early pool fire	Train 1 surge tank,booster pumps and export pumps	37.5 Kw.m^2	31 min	3,74E-07	1	190000	5	Medium Risk
		Booster pumps	Fire Impingement				30000	3	Low Risk
FZ-3.2-EP-025	Early pool fire	Train 1 surge tank, booster pumps and export pumps	37.5 Kw.m^2	12 min 36 s	1,66E-07	1	130000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
		Booster pumps	Fire Impingement				30000	3	Low Risk
FZ-3.2-LP-025	Late Pool fire	Pipe between ST and pumps	37.5 $Kw.m^2$	2 min 15s	3,15E-06	2	900	1	Low Risk
		Train 1 booster pumps	Fire Impingement				1100	2	Low Risk
FZ-3.2-LP-100	Late Pool fire	Pipe between ST and pumps	37.5 $Kw.m^2$	2 min 16 s	3,89E-06	2	900	1	Low Risk
		Train 1 booster pumps	Fire Impingement				1100	2	Low Risk
FZ-3.2-LP-150	Late Pool fire	Pipe between ST and pumps	37.5 $Kw.m^2$	2 min 13 s	3,31E-06	2	300	1	Low Risk
		Train 1 booster pumps	Fire Impingement				1100	2	Low Risk
FZ-3.2-VCE-025	Vapor Cloud Explosion	Train 1 surge tank and booster pumps	350 mbar overpressure	/	1,39E-06	2	130000	5	Medium Risk
FZ-3.2-VCE-100	Vapor Cloud Explosion	Train 1 surge tank and booster pumps	350 mbar overpressure	/	2,25E-06	2	130000	5	Medium Risk
FZ-3.2-VCE-150	Vapor Cloud Explosion	Train 1 surge tank and booster pumps	350 mbar overpressure	/	1,92E-06	2	130000	5	Medium Risk
FZ-3'.1-EP-005	Early Pool Fire	Train 2 surge tank	37.5 $Kw.m^2$ / Fire Impingement	31 min 38 s	2,30E-06	2	100000	4	Medium risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-3'.1-EP-025	Early Pool Fire	Train 2 surge tank	Fire Impingement	17 min 13 s	1,14E-06	2	100000	4	Medium risk
FZ-3'.1-EP-100	Early Pool Fire	Train 2 surge tank	Fire Impingement	106 min 13 s	1,87E-07	1	100000	4	Low Risk
FZ-3'.1-LP-025	Late Pool Fire	Train 2 surge tank	Fire Impingement	12 min 43 s	1,59E-05	3	100000	4	Medium risk
FZ-3'.1-LP-100	Late Pool Fire	Train 2 surge tank	Fire Impingement	101 min 23 s	1,85E-05	3	100000	4	Medium risk
FZ-3'.1-LP-150	Late Pool Fire	Train 2 surge tank	Fire Impingement	48 min	1,53E-05	3	100000	4	Medium risk
FZ-3'.1-VCE-025	Vapor Cloud Explosion	Train 2 separator, surge tank and booster pump	350 mbar overpressure	/	7,02E-06	2	330000	5	Medium Risk
FZ-3'.1-VCE-100	Vapor Cloud Explosion	Train 2 separator, surge tank and booster pump	350 mbar overpressure	/	1,07E-05	3	330000	5	Medium Risk
FZ-3'.1-VCE-150	Vapor Cloud Explosion	Train 2 separator, surge tank and booster pump	350 mbar overpressure	/	8,89E-06	2	330000	5	Medium Risk
FZ-3'.2-EP-005	Early pool fire	Train 2 surge tank, booster pumps and export pumps	37.5 $Kw.m^2$	31 min	3,74E-07	1	330000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
		Booster pumps	Fire Impingement				30000	3	Low Risk
FZ-3'.2-EP-025	Early pool fire	Train 2 surge tank, booster pumps and export pumps	37.5 $Kw.m^2$	12 min 36 s	1,66E-07	1	190000	5	Medium Risk
		Booster pumps	Fire Impingement				30000	3	Low Risk
FZ-3'.2-LP-025	Late Pool fire	Pipe between ST and pumps	37.5 $Kw.m^2$	2 min 15s	3,15E-06	2	900	1	Low Risk
		Train 2 booster pumps	Fire Impingement				1100	2	Low Risk
FZ-3'.2-LP-100	Late Pool fire	Pipe between ST and pumps	37.5 $Kw.m^2$	2 min 16 s	3,89E-06	2	900	1	Low Risk
		Train 2 booster pumps	Fire Impingement				1100	2	Low Risk
FZ-3'.2-LP-150	Late Pool fire	Pipe between ST and pumps	37.5 $Kw.m^2$	2 min 13 s	3,31E-06	2	900	1	Low Risk
		Train 2 booster pumps	Fire Impingement				1100	2	Low Risk
FZ-3'.2-VCE-025	Vapor Cloud Explosion	Train 2 surge tank and booster pumps	350 mbar overpressure	/	1,39E-06	2	130000	5	Medium Risk
FZ-3'.2-VCE-100	Vapor Cloud Explosion	Train 2 surge tank and booster pumps	350 mbar overpressure	/	2,25E-06	2	130000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-3'.2-VCE-150	Vapor Cloud Explosion	Train 2 surge tank and booster pumps	350 mbar overpressure	/	1,92E-06	2	130000	5	Medium Risk
FZ-4-JF-005	Jet Fire	/	/	20 min	1,97E-06	2	/	1	Low Risk
FZ-4-JF-025	Jet Fire	KOV	37.5 $Kw.m^2$	10 min	9,81E-07	1	150000	5	Medium Risk
FZ-4-JF-100	Jet Fire	KOV	37.5 $Kw.m^2$	2 min 30s	1,59E-07	1	150000	2	Low Risk
		Train 1 separator or train 2 separator	Fire Impingement				1000	2	Low Risk
FZ-4-JF-150	Jet Fire	Train 1 and 2 separators and KOV	37.5 $Kw.m^2$	1 min	1,56E-07	1	3000	2	Low Risk
		Train 1 separator or train 2 separator	Fire Impingement				1000	2	Low Risk
FZ-4-VCE-025	Vapor Cloud Explosion	Train 1 and train 2 separators and KOV	350 mbar overpressure	/	2,16E-07	1	550000	5	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-4-VCE-100	Vapor Cloud Explosion	Train 1 and train 2 separators and KOV	350 mbar overpressure	/	1,01E-06	2	550000	5	Medium Risk
FZ-4-VCE-150	Vapor Cloud Explosion	Train 1 and train 2 separators and KOV	350 mbar overpressure	/	2,02E-06	2	550000	5	Medium Risk
FZ-5.1-EP-005	Early pool fire	Train 1 booster pumps	37.5 $Kw.m^2$ Fire Impingement	27 min 36s	5,67E-06	2	30000	3	Medium Risk
FZ-5.1-EP-025	Early pool fire	Train 1 booster pumps	Fire Impingement	27 min 30 s	1,50E-06	2	30000	3	Medium Risk
FZ-5.1-EP-100	Early pool fire	Train 1 booster pumps	Fire Impingement	189 min	2,64E-07	1	30000	3	Low Risk
FZ-5.1-LP-025	Late Pool Fire	Train 1 booster pumps	Fire Impingement	23 min	2,85E-05	3	30000	3	Medium Risk
FZ-5.1-LP-100	Late Pool Fire	Train 1 booster pumps	Fire Impingement	184 min 30s	2,61E-05	3	30000	3	Medium Risk
FZ-5.1-LP-150	Late Pool Fire	Train 1 booster pumps	Fire Impingement	83 min	4,69E-06	2	30000	3	Medium Risk
FZ-5.2-EP-005	Early pool fire	Train 1 export pumps	Fire Impingement	7 min 12 s	5,85E-06	2	1000	2	Low Risk
FZ-5.2-EP-025	Early pool fire	Train 1 export pumps	Fire Impingement	38 min 44 s	2,10E-06	2	60000	4	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-5.2-EP-100	Early pool fire	Train 1 export pumps	Fire Impingement	275 min	4,32E-07	1	60000	4	Low Risk
FZ-5.2-LP-005	Late Pool Fire	Train 1 export pumps	Fire Impingement	2 min 40s	2,92E-06	2	1000	2	Low Risk
FZ-5.2-LP-025	Late Pool Fire	Train 1 export pumps	Fire Impingement	34 min 42 s	6,08E-05	3	60000	4	Medium Risk
FZ-5.2-LP-100	Late Pool Fire	Train 1 export pumps	Fire Impingement	270 min 40 s	4,27E-05	3	60000	4	Medium Risk
FZ-5.2-LP-150	Late Pool Fire	Train 1 export pumps	Fire Impingement	101 min 12 s	1,10E-05	3	60000	4	Medium Risk
FZ-5'.1-EP-005	Early pool fire	Train 2 booster pumps	37.5 $Kw.m^2$ Fire Impingement	27 min 36s	5,67E-06	2	30000	3	Medium Risk
FZ-5'.1-EP-025	Early pool fire	Train 2 booster pumps	Fire Impingement	27 min 30 s	1,50E-06	2	30000	3	Medium Risk
FZ-5'.1-EP-100	Early pool fire	Train 2 booster pumps	Fire Impingement	189 min	2,64E-07	1	30000	3	Low Risk
FZ-5'.1-LP-025	Late Pool Fire	Train 2 booster pumps	Fire Impingement	23 min	2,85E-05	3	30000	3	Medium Risk
FZ-5'.1-LP-100	Late Pool Fire	Train 2 booster pumps	Fire Impingement	184 min 30s	2,61E-05	3	30000	3	Medium Risk
FZ-5'.1-LP-150	Late Pool Fire	Train 2 booster pumps	Fire Impingement	83 min	4,69E-06	2	30000	3	Medium Risk
FZ-5'.2-EP-005	Early pool fire	Train 2 export pumps	Fire Impingement	7 min 12 s	5,85E-06	2	1000	2	Low Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
FZ-5'.2-EP-025	Early pool fire	Train 2 export pumps	Fire Impingement	38 min 44 s	2,10E-06	2	60000	4	Medium Risk
FZ-5'.2-EP-100	Early pool fire	Train 2 export pumps	Fire Impingement	275 min	4,32E-07	1	60000	4	Low Risk
FZ-5'.2-LP-005	Late Pool Fire	Train 2 export pumps	Fire Impingement	2 min 40s	2,92E-06	2	1000	2	Low Risk
FZ-5'.2-LP-025	Late Pool Fire	Train 2 export pumps	Fire Impingement	34 min 42 s	6,08E-05	3	60000	4	Medium Risk
FZ-5'.2-LP-100	Late Pool Fire	Train 2 export pumps	Fire Impingement	270 min 40 s	4,27E-05	3	60000	4	Medium Risk
FZ-5'.2-LP-150	Late Pool Fire	Train 2 export pumps	Fire Impingement	101 min 12 s	1,10E-05	3	60000	4	Medium Risk
FZ-6.1-EP-005	Early Pool Fire	Train 1 export Pumps	37.5 Kw.m^2	25 min	2,12E-06	2	60000	4	Medium Risk
		Expedition pipe	Fire Impingement				4500	2	Low Risk
FZ-6.1-EP-025	Early Pool Fire	Train 1 export Pumps	37.5 Kw.m^2	13 min 30s	1,02E-06	2	60000	4	Medium Risk
		Expedition pipe	Fire Impingement				4500	2	Low Risk
FZ-6.1-LP-025	Late Pool Fire	Train 1 export Pumps	37.5 Kw.m^2	2 min 17 s	1,94E-05	3	1600	2	Medium Risk
		Expedition pipe	Fire Impingement				1000	1	Low Risk
FZ-6.1-LP-100	Late Pool Fire	Train 1 export Pumps	37.5 Kw.m^2	2 min 17 s	2,04E-05	3	1600	2	Medium Risk

Hazardous Event	Dangerous phenomenon	Target equipment	Thermal radiation /blast exposure	Exposure Time	Frequency	Frequency category	Financial loss in £	Outcome category	Level of risk
		Expedition pipe	Fire Impingement				1000	1	Low Risk
FZ-6.1-LP-150	Late Pool Fire	Expedition pipe	Fire Impingement	2 min 17 s	2,82E-05	3	1000	1	Low Risk
FZ-6.2-JF-005	Jet Fire	KOV and expedition pipe	37.5 $Kw.m^2$	20 min	2,18E-06	2	160000	5	Medium Risk
FZ-6.2-JF-025	Jet Fire	KOV and expedition pipe	37.5 $Kw.m^2$	10 min	1,07E-06	2	160000	5	Medium Risk
FZ-6.2-JF-100	Jet Fire	KOV and expedition pipe	37.5 $Kw.m^2$	2 min 30s	1,70E-07	1	2500	2	Low Risk
FZ-6.2-JF-150	Jet Fire	KOV and expedition pipe	37.5 $Kw.m^2$	1 min	2,11E-07	1	2500	2	Low Risk
FZ-7-PF	Pool Fire	/	/	/	2,26E-06	2	/	1	Low Risk

Based on the general risk assessment table above and for different types of hazardous events we can interpret the results as follows:

- Late pool fires in pipelines generally pose a low risk level due to their limited exposure time, which remains below the defined threshold in the evaluation criteria for equipment vulnerability. As a result, these fires have relatively limited potential impact and consequences.
- Vapor cloud explosions (VCE) typically present a medium risk level as they have a larger footprint compared to fires, affecting a wider area. The extended contours of VCE incidents increase the potential risks and hazards associated with them.
- Impingement in pipeline pool fires has minimal impact on equipment, thanks to the presence of a retention dike wall that prevents the fire from reaching the equipment. Consequently, the risk of damage or adverse effects on the equipment is reduced.
- Pool fires resulting from breaches in process vessels or pumps expose equipment primarily to fire impingement. The significant thickness of the flammable liquid in these incidents leads to a longer burning duration and exposure time, surpassing the specified threshold in Chapter II.
- Early pool fires pose a greater danger compared to late pool fires due to their significantly longer burning duration. The prolonged duration increases the exposure time and potential risks associated with these fires.
- Jet fires, on the other hand, exhibit a low risk level for larger breaches, as they result in a rapid pressure drop and shorter burning time.

Thus for a more thorough evaluation, specific considerations should be taken into account. For a threshold of 37.5 $Kw.m^{-2}$, early pool fires in pipelines, jet fires for smaller breaches (where the exposure time exceeds 10 minutes), and early pool fires in separators and surge tanks for a 5 mm breach diameter should be considered. All incidents of vapor cloud explosions require assessment. Regarding pool fire impingement, pool fires in equipment with retention dikes should be considered, taking into account an exposure time equal to or greater than 10 minutes. Lastly, for jet fire impingement, the exposure time should exceed 5 minutes to be considered a hazardous event.

By evaluating and considering these risk levels and factors, appropriate measures can be implemented to enhance safety, mitigate potential hazards, and minimize the associated risks within the early production facility.

5.3 Second Level Risk Assessment

Following the steps outlined in chapter II, a MATLAB program was developed based on image recognition. It consists of the following steps:

- The code starts by defining the path to a folder containing contour images (See Appendix D) and selects the appropriate file type in that folder.
- The contour image is divided into grids, with each grid having a specified size.
- An array of values is defined, representing the accidents frequencies associated with each image and thus with each hazardous event.
- Cell arrays are initialized to store the grids, their coordinates, whether they are colored or not, and the values associated with each grid.
- A target color palette is defined according to the targeted zones for example in case of vapor cloud explosions the failure zone in question is the one delimited with the blue color while for fires the failure zone is the red (See Appendix), which will be used to identify colored grids in the images.
- The code processes each image individually by performing the following steps:
    - The image is read.
    - Grids are created within the image based on the specified grid size, a grid of 5 m was chosen.
    - Each grid is checked to determine if it is colored or not based on the average color within the grid region.
    - Values are assigned to the colored grids based on the provided array of values.
    - If the current image index is greater than 1 and the previous grid is colored, the value of the current grid is updated to include the value of the previous grid, this will result in the aggregation of contributing events frequencies.
- The code then visualizes the results by creating a blank canvas and displaying it. It iterates through each image and each grid, determining the appropriate color based on the associated frequency. grids are plotted on the blank canvas with the assigned color.

In summary, the code performs calculations and visualizations to analyze the grids and associated values within a set of images. It identifies colored grids based on average colors, assigns values to the colored grids, and generates a visual representation of the results on a blank canvas.

5.3.1 Exposure to 37.5 KW.m^{-2}

5.3.1.1 Frequency Mapping

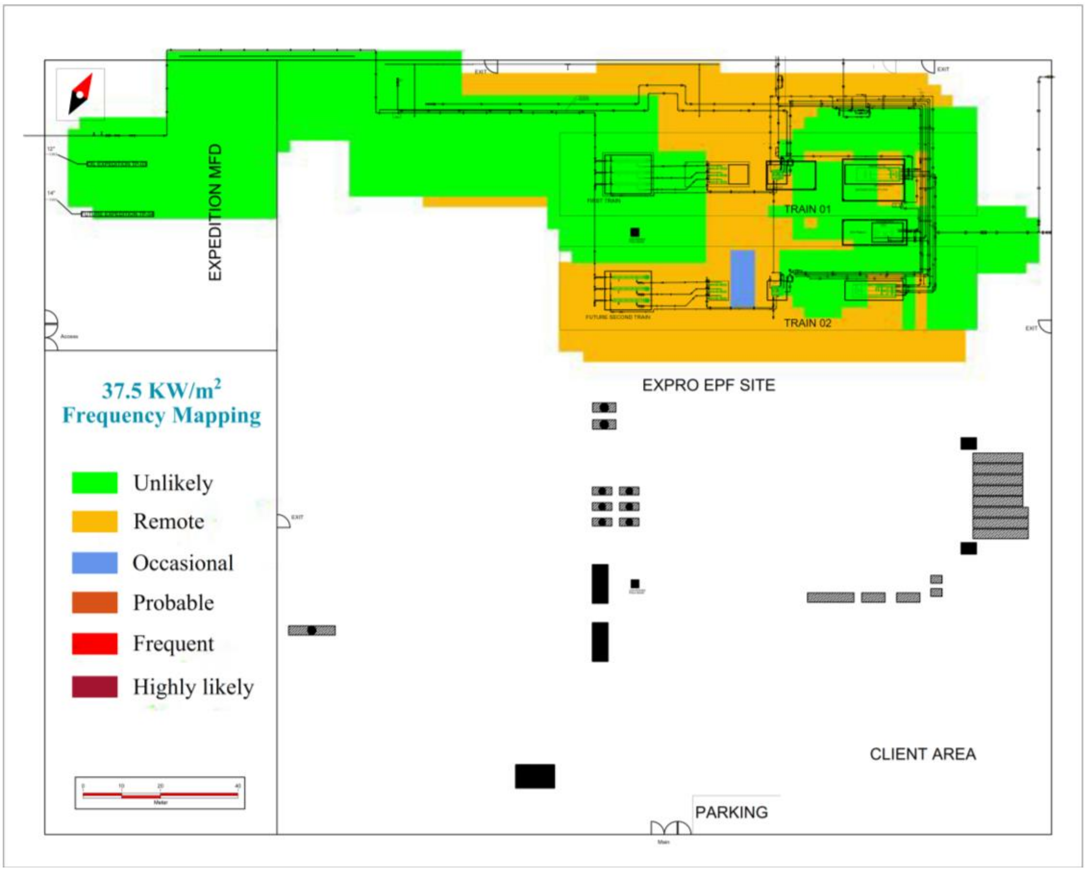

Figure 5-1 Frequency Mapping for 37.5 kW.m^{-2}Thermal Radiation Intensity

The frequency mapping figure illustrates the distribution of frequencies for hazardous events that have the potential to cause equipment failures, considering a threshold of 37.5 kW/m^2. The white space in the mapping represents frequencies that are below 10^{-8}, indicating very low probabilities of occurrence.

Analyzing the figure, it can be observed that:

- Both trains separators exhibit parts with failure frequencies below 10^{-6}, indicating a relatively low likelihood of failure in those sections. Additionally, there are other parts where the failure frequencies range between 10^{-6} and 10^{-5}, suggesting a slightly higher probability of failure in those areas.
- Most pipelines in the system demonstrate failure frequencies below 10^{-6}, indicating a generally low risk of failure along their routes. This suggests that the pipelines are adequately designed and maintained to minimize the occurrence of hazardous events.

- The presence of retention dikes proves to be beneficial, as it significantly reduces the likelihood of failure for critical equipment. The majority of critical equipment is unlikely to experience failures, enhancing the overall safety and reliability of the facility.
- However, it is worth noting that the train 2 booster pumps occasionally exhibit failures, as indicated by their higher failure frequencies compared to other equipment. This highlights the importance of closely monitoring and maintaining these pumps to mitigate the associated risks.

5.3.1.2 Risk Assessment for Assets

Table 5-6 Risk Assessment for Assets Exposed to 37.5 kW.m^{-2} Thermal Radiation Intensity

Equipment	Overall frequency range	Category	Outcome in £	Category	Risk Level	Safeguard	Cost in £ or trouble	Is it reasonably practicable? (Yes/No))
Train 1 Separator	$10^{-6} \le F \le 10^{-5}$	2	200000	5	Medium Risk	Fire and gas system	40000	Yes
						Firefighting system	20000	Yes
						Spacing	Technically not possible	No
						On site surveillance within relatively short periods	Personnel availability	Yes
Train 2 Separator	$10^{-6} \le F \le 10^{-5}$	2	200000	5	Medium Risk	Same as train 1 separator		
KOV	$F < 10^{-6}$	1	150000	5	Medium Risk	Same as train 1 separator		
Train 1 Surge Tank	$F < 10^{-6}$	1	100000	4	Low Risk	/	/	/
Train 2 Surge Tank	$F < 10^{-6}$	1	100000	4	Low Risk	/	/	/
Train 1 booster pumps	$10^{-6} \le F \le 10^{-5}$	2	30000	3	Medium Risk	Fire and gas system	40000	No
						Firefighting system	20000	Yes

Equipment	Overall frequency range	Category	Outcome in £	Category	Risk Level	Safeguard	Cost in £ or trouble	Is it reasonably practicable? (Yes/No))
						Spacing	Technically not possible	No
						On site surveillance within relatively short periods	Personnel availability	Yes
Train 2 booster pumps	$10^{-5} < F \leq 10^{-4}$	3	30000	3	Medium Risk	Same as previous		
Train 1 Export pumps	$F < 10^{-6}$	1	60000	4	Low Risk	/	/	/
Train 2 Export pumps	$10^{-6} \leq F \leq 10^{-5}$	2	60000	4	Medium Risk	Fire and gas system	40000	Yes
						Firefighting system	20000	Yes
						Spacing	Technically not possible	No
						On site surveillance within relatively short periods	Personnel availability	Yes

5.3.2 Exposure to Pool Fire impingement

5.3.2.1 Frequency Mapping

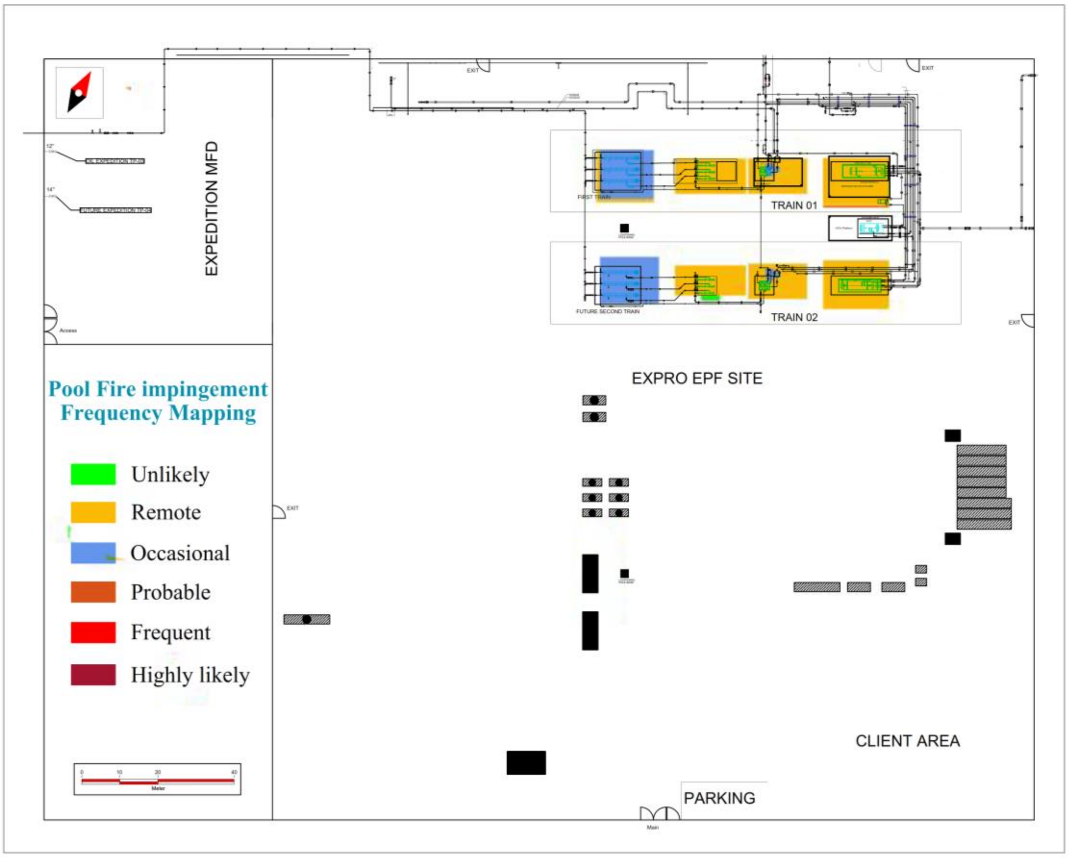

Figure 5-2 Frequency Mapping for Pool Fire Impingement

The frequency mapping figure presented depicts the distribution of frequencies for pool fire impingement events, with the white spaces indicating frequencies below 10^-8, signifying extremely low probabilities of occurrence.

Upon examining the figure, it becomes evident that both trains, with the exception of the export pumps, demonstrate a frequency level classified as "remote." This classification suggests that the likelihood of pool fire impingement on most components within the trains is relatively low.

5.3.2.2 Risk Assessment for Assets

Table 5-7 Risk Assessment for Assets Exposed to Pool Fire Impingement

Equipment	Overall frequency range	Category	Outcome in £	Category	Risk Level	Safeguard	Cost in £ or trouble	Is it reasonably practicable? (Yes/No)
Train 1 Separator	$10^{-6} \leq F \leq 10^{-5}$	2	200000	5	Medium Risk	Fire and gas system	40000	Yes
						Fireproofing	5906.4	Yes
						Deluge system	30000	Yes
						Firefighting system	20000	Yes
						Drainage system for retention dikes	30000	Yes
						On site surveillance within relatively short periods	Personnel availability	Yes
Train 2 Separator	$10^{-6} \leq F \leq 10^{-5}$	2	200000	5	Medium Risk	Same as previous		
KOV	$F < 10^{-8}$	1	/	1	Low Risk	/	/	/
Train 1 Surge Tank	$10^{-6} \leq F \leq 10^{-5}$	2	100000	4	Medium Risk	Fire and gas system	40000	Yes
						Fireproofing	2468	Yes
						Deluge system	30000	Yes
						Firefighting system	20000	Yes
						Drainage system for retention dikes	30000	Yes

Equipment	Overall frequency range	Category	Outcome in £	Category	Risk Level	Safeguard	Cost in £ or trouble	Is it reasonably practicable? (Yes/No))
						On site surveillance within relatively short periods	Personnel availability	Yes
Train 2 Surge Tank	$10^{-6} \leq F \leq 10^{-5}$	2	100000	4	Medium Risk	Same as previous		
Train 1 booster pumps	$10^{-6} \leq F \leq 10^{-5}$	2	30000	3	Medium Risk	Fire and gas system	40000	No
						Fireproofing	1000	Yes
						Firefighting system	20000	Yes
						Drainage system for retention dikes	30000	Yes
						On site surveillance within relatively short periods	Personnel availability	Yes
Train 2 booster pumps	$10^{-6} \leq F \leq 10^{-5}$	2	30000	3	Medium Risk	Same as previous		
Train 1 Export pumps	$10^{-5} \leq F \leq 10^{-4}$	3	60000	4	Medium Risk	Fire and gas system	40000	Yes
						Fireproofing	1000	Yes
						Firefighting system	20000	Yes
						Drainage system for retention dikes	30000	Yes

						On site surveillance within relatively short periods	Personnel availability	Yes
Train 2 Export pumps	$10^{-5} \leq F \leq 10^{-4}$	3	60000	4	Medium Risk	Same as previous		

5.3.3 Exposure to Jet Fire impingement

5.3.3.1 Frequency Mapping

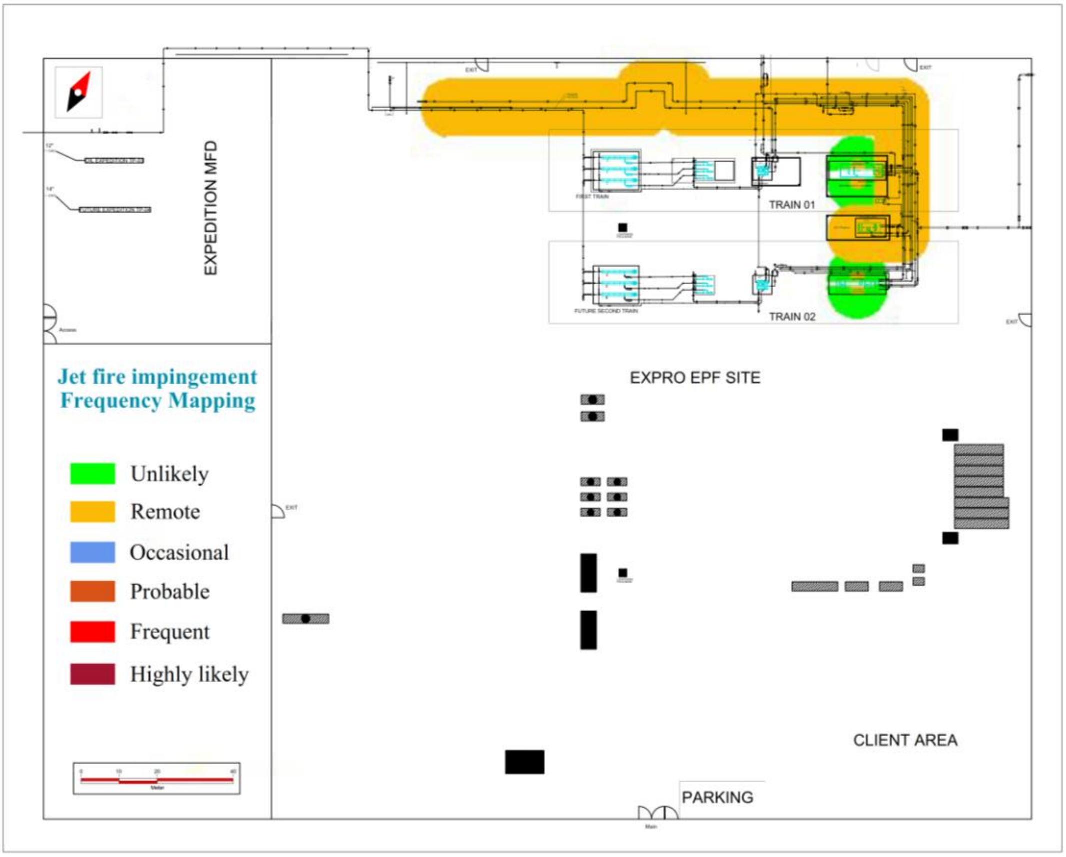

Figure 5-3 Frequency Mapping for Jet Fire Impingement

The frequency mapping for jet fire provides important insights into the probabilities of failure in different areas. The white space in the mapping indicates very low frequencies, with a likelihood of less than 10^{-8}. This suggests that these areas have a minimal probability of experiencing jet fire incidents.

In particular, the failure frequency at the train 2 separator is also less than 10^{-8}, indicating a very low probability of failure in this component. However, it is important to note that the Knock out Vessel is more susceptible to jet fire impingement. This is because both the gas export line and the pipe coming from the separators are in close proximity to it. The failure frequency for the Knock out Vessel is classified as remote, indicating a higher probability of failure compared to other components.

On the other hand, part of the train 1 separator, specifically the area where the inlet is located, is expected to be exposed to jet fire impingement. The failure frequency for this section is also at a remote level, suggesting a relatively higher probability of failure in this specific area.

Furthermore, it is worth noting that as we follow the gas export line, the oil export line is also at risk of being affected by jet fire incidents. The frequency mapping helps identify these potential areas of concern and allows for targeted safety measures and risk mitigation strategies to be implemented to minimize the likelihood and impact of jet fire events.

5.3.3.2 Risk Assessment for Assets:

Table 5-8 Risk Assessment for Assets Exposed to Jet Fire Impingement

Equipment	Overall frequency range	Category	Outcome in £	Category	Risk Level	Safeguard	Cost in £ or trouble	Is it reasonably practicable? (Yes/No)
Train 1 Separator	$10^{-6} \leq F \leq 10^{-5}$	2	200000	5	Medium Risk	Fire and gas system	40000	Yes
						Fire proofing	5906.4	Yes
Train 2 Separator	$F < 10^{-8}$	1	200000	5	Low Risk	/	/	/
KOV	$10^{-6} \leq F \leq 10^{-5}$	2	150000	5	Medium Risk	Fire and gas system	40000	Yes
						Fire proofing	2500	Yes
Train 1 Surge Tank	$F < 10^{-8}$	1	100000	4	Low Risk	/	/	/
Train 2 Surge Tank	$F < 10^{-8}$	1	100000	4	Low Risk	Same as train 1 surge tank		
Train 1 booster pumps	$F < 10^{-8}$	1	30000	3	Low Risk	/	/	/
Train 2 booster pumps	$F < 10^{-8}$	1	30000	3	Low Risk	Same as train 1 booster pumps		
Train 1 Export pumps	$F < 10^{-8}$	1	60000	4	Low Risk	/	/	/
Train 2 Export pumps	$F < 10^{-8}$	1	60000	4	Low Risk	Same as train 1 export pumps		

5.3.4 Exposure to 350 mbar

5.3.4.1 Frequency Mapping

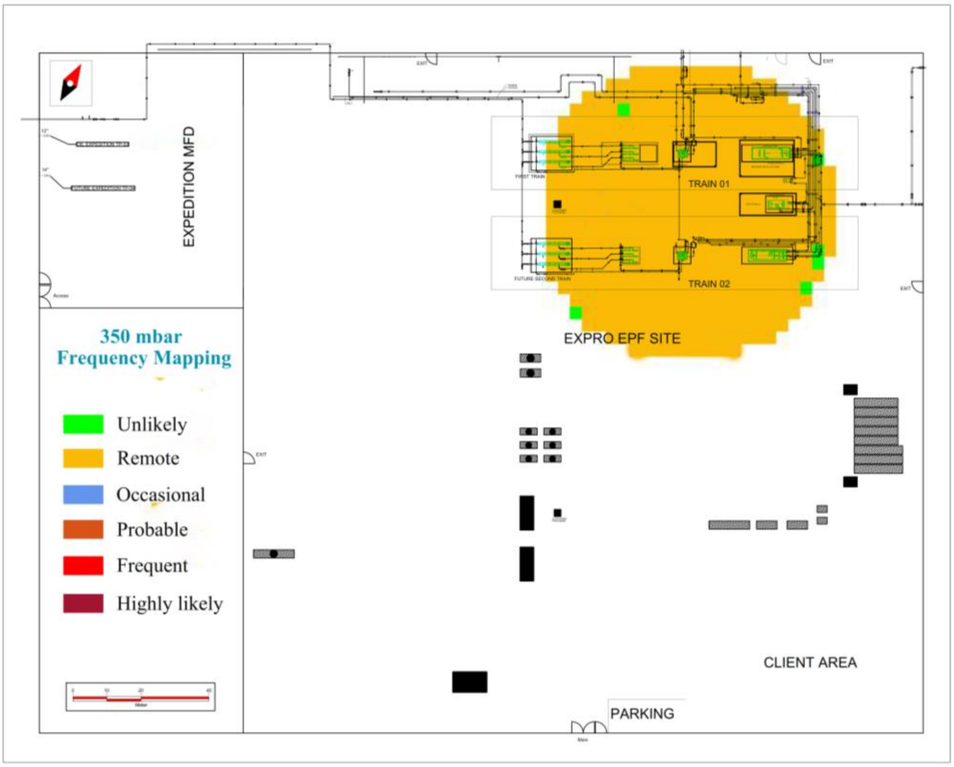

Figure 5-4 Frequency Mapping for 350 mbar

The frequency mapping figure presented illustrates the distribution of failure frequencies for hazardous events capable of causing equipment failures, considering a pressure threshold of 350 mbar. The white spaces within the figure represent frequencies below 10^{-8}, indicating extremely low probabilities of occurrence. Upon analyzing the figure, it becomes evident that both trains, with the exception of the export pumps, exhibit a failure frequency level classified as "remote." This classification suggests a relatively low likelihood of failure for most components within the trains, emphasizing their overall robustness and reliability.

5.3.4.2 Risk Assessment for Assets

Table 5-9 Risk Assessment for Assets Exposed to 350 mbar

Equipment	Overall frequency range	Category	Outcome in £	Category	Risk Level	Safeguard	Cost in £ or trouble	Is it reasonably practicable? (Yes/No)
Train 1 Separator	$10^{-6} \leq F \leq 10^{-5}$	2	200000	5	Medium Risk	Fire and gas system	40000	Yes
Train 2 Separator	$10^{-6} \leq F \leq 10^{-5}$	2	200000	5	Medium Risk	Same as train 1 separator		
KOV	$10^{-6} \leq F \leq 10^{-5}$	2	150000	5	Medium Risk	Fire and gas system	40000	Yes
Train 1 Surge Tank	$10^{-6} \leq F \leq 10^{-5}$	2	100000	4	Medium Risk	Fire and gas system	40000	Yes
Train 2 Surge Tank	$10^{-6} \leq F \leq 10^{-5}$	2	100000	4	Medium Risk	Same as train 1 surge tank		
Train 1 booster pumps	$10^{-6} \leq F \leq 10^{-5}$	2	30000	3	Medium Risk	Fire and gas system	40000	No
Train 2 booster pumps	$10^{-6} \leq F \leq 10^{-5}$	2	30000	3	Medium Risk	Same as train 1 booster pumps		
Train 1 Export pumps	$F < 10^{-8}$	1	60000	4	Low Risk	/	/	/
Train 2 Export pumps	$F < 10^{-8}$	1	60000	4	Low Risk	Same as train 1 export pumps		

5.4 Recommendations to Prevent Equipment Failure

To prevent equipment failure when exposed to hazardous events, we can recommend the following:

- Implement temperature-monitoring systems to detect abnormal temperature increases promptly.
- Optimize process conditions to minimize excessive heat generation.
- Establish a regular maintenance program to inspect and clean equipment exposed to high temperatures.
- Use materials with high-temperature resistance and appropriate heat tolerance.
- Install emergency shutdown systems that activate when equipment temperatures exceed safe limits.
- Provide training to operators and maintenance personnel on temperature-related risks and proper equipment handling.
- Ensure compliance with industry standards, codes, and regulations for equipment design and operation in high-temperature environments.
- Implement blow-down and depressurizing systems in case of excess pressure inside the vessel.

5.5 Retention Dike dimensioning

This section focuses on the essential task of determining the appropriate height for a retention dike to effectively contain oil releases. Building upon the findings of the previous FERA study, conducting dike-sizing calculations is highly recommended to enhance safety measures. Specifically, the calculations consider a breach diameter of 25 mm in critical equipment such as Separators, Surge Tanks, Booster Pumps, and Export Pumps, a 5 mm will cause underestimating of the height while a large breach will lead to obtaining an unreasonable dimensioning. By accurately determining the required dike height based on reliable modeling data, the lateral spread of oil can be prevented, minimizing the risks associated with fire, environmental contamination, and other hazards. This section outlines the calculation methodology used, aiming to ensure compliance with regulations and industry standards while promoting effective oil spill containment and emergency response strategies.

5.5.1 Dike sizing calculation details

1**. Volume Calculation** : The volume calculated is the maximum possible liquid volume that could be released in case of a breach of 25 mm.

2**. Surface area:** The existing dimensions of the dike were measured using Autocad and considered in the calculation (the platform surface is not counted)

Surface area = Dike surface-Platform surface

3. Dike height: The recommended approach was to design the dike to have a volume 110 percent greater than the total volume of the liquid to be contained. This ensured an additional safety margin for potential expansion, rainfall, or unforeseen variations.

Dike Volume = 1.1 * Volume of Liquid

Dike Height = Dike Volume / Surface Area

The results of the dike height recommended are shown in the table below:

Table 5-10 Results for Retention Dike Dimensioning

Equipment	M(kg)	V_{liquid} (m^3)	V_{Dike} (m^3)	Dike surface(m^2)	Dike height(m)
Separator	6961	8,615	9,477	92,440	0,103
Surge Tank	4085	5,056	5,561	64,386	0,086
Booster pumps	8575	10,613	11,674	53,411	0,218
Export pumps	17636,4	21,827	24,010	22,962	1,045

In conclusion, based on the findings of the previous study, the recommendation for dike sizing is justified as a practical and effective measure to mitigate risks associated with the handling and storage of the oil liquid released.

Conclusion

In this chapter, we delved into the practical application of risk assessment within the XPII EPF to identify and address potential hazards and risks. Our aim was to ensure the safety of personnel and protect the integrity of the facility. We embarked on both a general evaluation of all hazardous events and a more detailed assessment focused on critical assets failure frequencies.

By analyzing the frequency mapping results, we gained valuable insights into the likelihood of different hazardous events. We discovered that most of the identified risks, such as pool fires and vapor cloud explosions, had relatively low frequencies, indicating a lower chance of occurrence. Armed with this knowledge, we were able to prioritize our efforts and allocate resources effectively. To mitigate these risks, we proposed a range of safeguards tailored to the specific hazards. Moreover, we carefully considered the cost and benefits of these measures, ensuring that they were not only effective but also practical and justifiable.

Additionally, we recognized the crucial role of the retention dike as a passive protection measure. Through meticulous calculations and modeling analysis, we determined the optimal height of the dike. By properly dimensioning the dike, we can prevent the lateral spread of flammable liquids, reducing the potential for fire propagation and environmental contamination.

General Conclusion

Throughout this project, we have delved into the critical area of safety and risk management in industrial facilities, with a particular focus on the Fire and Explosion Risk Assessment (FERA) methodology. FERA has emerged as a comprehensive approach encompassing hazard identification, fire zone definition, consequences modeling, frequency analysis, and risk assessment. By utilizing FERA, we have gained invaluable insights and developed effective strategies to enhance safety and mitigate potential risks.

The first phase of the FERA methodology involved rigorous hazard identification, wherein potential fire and explosion hazards were systematically identified within the industrial facility. This step laid the foundation for subsequent analyses by providing a comprehensive understanding of the risks at hand. Subsequently, fire zones were defined, taking into account various factors such as layout, equipment, and materials present, further refining our understanding of potential fire scenarios.

Consequences modeling enabled us to evaluate the potential impact of fires and explosions within the facility. By considering factors such as thermal radiation and overpressures we were able to quantify the potential consequences and assess the level of risk associated with each identified hazard. Frequency analysis further refined our understanding by quantifying the likelihood of occurrence for each hazard, allowing us to prioritize mitigation efforts.

The culmination of the FERA methodology was the risk assessment, which encompassed both a first level evaluation and a second level evaluation. The first level evaluation provided a broad overview of the facility's overall risk profile according to each hazardous event, identifying the events that are capable of causing equipment failure. In contrast, the second level evaluation focused on critical assets, thoroughly assessing their vulnerability to fire and explosion hazards using frequency mappings and implementing targeted safeguards to minimize the associated risks.

Overall, the application of the FERA methodology has significantly enhanced safety and risk management within the industrial facility. By following a systematic and comprehensive approach, we have successfully identified and evaluated potential hazards, quantified their consequences and likelihood of occurrence, and implemented appropriate risk mitigation measures. The FERA methodology serves as a valuable tool for ongoing safety improvement, ensuring that the facility is well-prepared to prevent and effectively respond to fire and explosion risks.

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Appendix A. Accidentology

Table A-1 Accidentology [25]

N°	Year	Location	Substance	Phenomena	Causes	Consequences	Equipment	Summary
55597	2020	France	Petrol	Leak	Corrosion	Pollution	Pipeline	Traces of hydrocarbons were identified on both sides of a sub-catchment wall in a crude oil. A first non-destructive test shows internal and external corrosion of the section of line. As a consequence 810 kg of crude oil were released
53177	2018	CANADA	Petrol	Leak	Maintenance	Pollution	Valve/Flange/ seal/associated equipment.	An oil leak occurs on a 3/4 inch screwed fitting of a flow meter, installed in 2009, in a pipeline pumping station. Wear and tear caused by vibrations of the flowmeter's support spigot was the cause of its rupture. As a result, 4.8 m^3 of crude oil spilled into the ground of the station.

								Some product was found on the vegetation beyond the site. The pumping of fluids was suspended for 15 hours.
45159	2014	France	Petrol	Leak	Human Error,	Pollution	Valve/Flange/ seal/associated equipment.	A leak of 30 m3 of crude oil occurred at a hydrocarbon storage site. A spill of 25 m3 spilled into a retention tank and into a buffer tank. The remaining 5 m3 spilled onto the surface of a brine retention area (spread over several hundred m2 contained by a dam). The leak is due to a purge valve opened by mistake.
34636	2008	France	Oil	Leak	Equipment	Pollution	canalization	At 3:30 pm, a crude oil pool of several square meters was reported near the storage tanks of a pipeline transport company.

								Pumping equipment was deployed on site and 7 m³ of water-crude mixture was recovered. The pollution was caused by a leak on a 34" pipeline.
32777	2007	France	Natural gas	Explosion	Constructions	Injuries	canalization	A construction accident involving a mechanical shovel led to the damage of a natural gas boiler room connection, causing an explosion and subsequent fire. The boiler room, semi-buried and adjacent to a building, suffered from gas leakage through a torn pipe and a crack in the technical shaft. The ignition occurred upon contact with an electric motor or burner flame, resulting in minor injuries to six individuals,

								including workers on-site. Adherence to safety protocols and accurate knowledge of network layouts are crucial to prevent such incidents and ensure the safety of personnel and structures.
34641	2007	USA	Natural gas	Explosion	Not disclosed	Injuries	Treatment unit	An explosion occurred around 11:30 a.m. local time in a natural gas processing plant. Four people were injured, two of them seriously.
34641	2007	USA	Natural gas	Explosion	Not disclosed	Injuries	Treatment unit	An explosion occurred around 11:30 a.m. local time in a natural gas processing plant. Four people were injured, two of them seriously.

31324	2006	Norway	Natural gas	Leak	Weather conditions	Pollution	Canalization	A significant gas leak on an oil platform led to the temporary halt of hydrocarbon production. Smoke and gas detectors prompted the evacuation of 17 workers out of 91. The leak resulted in a production loss of 35,000 barrels of oil and 5 million cubic meters of natural gas. Investigations are underway to determine the leak's origin and prevent potential explosions. The dispersion of gas by wind reduced immediate risks, and production will resume once deemed safe.
31324	2006	Norway	Natural gas	Leak	Weather conditions	Pollution	Canalization	A significant gas leak on an oil platform led to the temporary halt of hydrocarbon production. Smoke and gas detectors

								prompted the evacuation of 17 workers out of 91. The leak resulted in a production loss of 35,000 barrels of oil and 5 million cubic meters of natural gas. Investigations are underway to determine the leak's origin and prevent potential explosions. The dispersion of gas by wind reduced immediate risks, and production will resume once deemed safe.
32443	2006	France	Oil	Leak	Equipment	Pollution	Tank	An oil depot guard discovered a leak near Tank 121 containing 32,000 m^3 of crude oil with a low flash point. Multiple leakage points were observed around the tank's base, resulting in an estimated leakage rate of 1 m^3/h. Immediate response measures

								were taken, including stopping operations, deploying safety equipment, and initiating tank emptying at a reduced rate. Ongoing monitoring and atmospheric measurements were conducted to assess the situation.
33574	2006	USA	Oil	Explosion	Maintenance	Fatalities	Tank	An explosion occurs during the installation of a connection between 2 hydrocarbon storage tanks in an oil field depot. While welding, sparks ignited hydrocarbon vapors escaping from a nearby open pipe.
30082	2005	France	Natural gas	Fire	Other	Material damage	Compression station	A fire in a natural gas recompression station triggered a level 2 alert. The automatic CO2 extinguishing system contained the fire, and site

								personnel used a portable extinguisher to suppress flames when opening the turbine casing. The fire was extinguished by 5pm, and the station was temporarily shut down for 3-4 hours. The incident was caused by the ignition of lubricating oil in a turbine seal.
30861	2005	France	Natural gas	Others	Others	None	Pumps /Compressors	At a natural gas extraction site, a gas alarm is triggered due to a technical issue with a compressor. The maintenance team safely shuts down the unit, and the POI is not activated. Following a thorough inspection, a 100,000 m³ crude oil tanker is returned to service at a marine terminal. However, a significant drop of 300 m³ of oil

								is detected, with oil appearing in the valve chamber manhole. An excavation on 02/09 uncovers product around an 8" drain pipe used for tank bottom water drainage.
28247	2004	France	Oil	Leak	Corrosion	Pollution	Canalization	At a natural gas extraction site, a gas alarm is triggered due to a technical issue with a compressor. The maintenance team safely shuts down the unit, and the POI is not activated. Following a thorough inspection, a 100,000 m^3 crude oil tanker is returned to service at a marine terminal. However, a significant drop of 300 m^3 of oil is detected, with oil appearing in the valve chamber manhole.

Appendix B. Fire and Explosion Consequences Modeling

B.1 Source term

In this section we will discuss the most typical loss-of-containment events' source term models which are as follows:

- Release of liquid from a vessel breach.
- Release of liquid from a pipe wall breach.
- Compressed gases release from a hole in a vessel.
- Compressed gases release from a hole in a pipe.
- Evaporation of a liquid from a pool.

This study does not encompass pressurized liquefied gases, as the fluids examined in the initial pretreatment facility consist of oil, a non-volatile liquid, and natural gas.

B.1.1 Liquid release through a vessel breach

When a vessel breach occurs, resulting in the release of liquid (as depicted in the provided Figure), the hydrostatic pressure within the vessel is a determining factor that influences the mass flow rate of the outflow. This hydrostatic pressure is directly influenced by the disparity in height between the liquid level and the point of outflow. The outflow mass flow rate can be computed utilizing the following expression [9]:

$$\dot{m} = \rho C_d A_{or}\sqrt{2\frac{P - P_0}{\rho}} \tag{B-1}$$

Where $\dot{m}$ is the mass flow rate (kg.s^{-1}), C_d (-) denotes the discharge coefficient, ρ (kg.m^{-3}) is the liquid density, A_{or} (m^2) the cross-sectional area of the orifice, P (Pa) the total pressure in the breach and P_0 is the outside pressure which usually is the atmospheric pressure.

The discharge coefficient C_d (-) is a function that depends on the hole geometry, d_{or}/d_{pipe}, and the Reynolds number inside of it. In case the Reynolds numbers greater than 10^4, C_d (-) will approximately be 0.61 for all values of d_{or}/d_{pipe} [14]. Although usual values may be found in engineering handbooks depending on the type of breaches: 0.62 for sharp-edged orifices, straight orifices $C_d = 0.82$, rounded orifices $C_d = 0.97$ and for full-bore rupture $C_d = 1$ [6].

The total pressure P (Pa) is determined by adding the hydrostatic pressure, P_h (Pa), resulting from the liquid level in the vessel, to the absolute pressure P_{cont} (Pa) exerted on the liquid's surface inside the vessel, that is [9]:

$$P = P_h + P_{cont} = \rho g h_l + P_{cont} \tag{B-2}$$

Where h_l (m) is the height of liquid above the leak and g (m.s^{-2}) denotes the gravitational acceleration (=9.81 m.s^{-2}).

By replacing P with its expression (B-2) in (B-1) we obtain the mass flow rate final expression:

$$\dot{m} = \rho C_d A_{or} \sqrt{2gh_l + 2\frac{P_{cont} - P_{amb}}{\rho}} \tag{B-3}$$

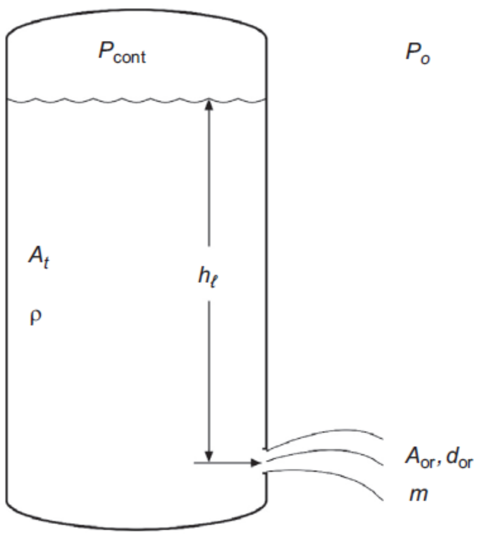


Figure B-1 Liquid Release through Vessel Breach [6]

It is crucial to acknowledge that, in the context of risk analysis, the approach for determining the mass flow rate is contingent upon the type of vessel under consideration. Two primary scenarios can be distinguished: an atmospheric/pressurized storage tank and a process vessel. The disparity between these cases lies in the liquid height above the position of the leak and its temporal evolution.

a. <u>Storage tanks:</u>

As the liquid is discharged, the liquid level within the tank diminishes, consequently causing a reduction in the flow rate through the orifice. To ascertain the mass discharge rate at any given time 't' for vessels characterized by a constant cross-sectional area, the subsequent expression can be utilized [15]:

$$\dot{m}(t) = \rho C_d A_{or}\sqrt{2gh_{l_{initial}} + 2\frac{P_{cont} - P_{amb}}{\rho} - \frac{\rho g C_d^2 A_{or}^2}{A_t}t} \qquad \text{(B-4)}$$

b. <u>Process vessel:</u>

Regarding process vessels and within the scope of consequences analysis it is assumed that the liquid level in the vessel will remain approximately constant under the condition of a consistently present input flow rate.

B.1.2 Liquid release through a pipe breach

For a liquid release through a pipe breach and a given flow rate, the fluid experiences a pressure drop. The Fanning equation can be used to calculate the relationship between the later and fluid velocity for an incompressible liquid flowing through a piping system [6]:

$$u = \sqrt{\frac{\Delta P d_p}{2 f_F \rho l_p}} \qquad \text{(B-5)}$$

With ΔP (Pa) being the pressure drop, f_F (-) is the Fanning friction factor, ρ (Kg.m^{-3}) the liquid density, u (m.s^{-1}) is the fluid velocity, l_p (m) is the pipe length and d_p (m) being the pipe diameter.

Fluid velocity can also be calculated using the Reynolds number:

$$u = \frac{\mu Re}{d_p \rho} \qquad \text{(B-6)}$$

With μ (Pa.s or N.s.m^{-2} or Kg.s^{-1}.m^{-1}) is the fluid dynamic viscosity.

The leak flow rate can then be calculated using the expression below [9]:

$$\dot{m} = A_{or}\rho u \tag{B-7}$$

As for the Fanning friction factor, it depends on Reynolds number and the pipe roughness ε (see Table B-1) [16]:

$$f_F = f[\binom{Reynolds\ number:}{a\ combination\ of\ d_p, u, \mu, \rho}, \binom{pipe}{roughness, \varepsilon}] \tag{B-8}$$

In the case of laminar flow (Re<2100), f_F can be found from the following expression derived by Poiseuille [16]:

$$f_F = \frac{16}{Re} \tag{B-9}$$

While for the turbulent regime (Re>4000) the friction factor can be obtained using either the Moody chart (See Figure B-2) or the Colebrook equation [6]:

$$\frac{1}{\sqrt{f_F}} = -4\log(\frac{1}{3.7}.\frac{\varepsilon}{d_p} + \frac{1.255}{Re\sqrt{f_F}}) \tag{B-10}$$

Table B-1 Pipe roughness [6]

Pipe Material	Pipe roughness ε
Riveted steel	1-10
Concrete	0.3-3
Wood stave	0.2-1
Cast iron	0.25-0.26
Galvanized iron	0.15
Asphalted cast iron	0.12
Commercial steel or wrought iron	0.043-0.046
Drawn tubing	0.0015
Glass / Plastic	0

Equation (B-10) can be either solved by trial and error or by the expression obtained symbolically using the function SOLVE in MATLAB

$$f_F = \frac{86248369 d_p^2 \log(10)^2}{[37148 d_p lambertW(0, x) - 2000 \log(10)\ \varepsilon Re]^2} \tag{B-11}$$

Where

$$x = \frac{10^{\frac{500\varepsilon Re}{9287 d_p}} 50 \log(10)\, Re}{251} \tag{B-12}$$

With d_p (m) being the pipe diameter and $lambertW(0, x)$ also called the omega function returns the principal branch of the Lambert W function meaning it gives us a set of solutions for the equation:

$$x = W(x)e^{W(x)} \tag{B-13}$$

While for a fully developed turbulent flow, the factor doesn't depend on Reynolds number and can be found simply with [15]:

$$\frac{1}{\sqrt{f_F}} = 4\log(3.7\frac{d_p}{\varepsilon}) \tag{B-14}$$

For smooth pipes ($\varepsilon = 0$) and Re<100,000, the Fanning friction factor can be calculated as follows [6]:

$$f_F = 0.0791 Re^{-0.25} \tag{B-15}$$

And when Re>100,000, the expression down below can be used instead [6]:

$$f_F = 0.0232 Re^{-0.1507} \tag{B-16}$$

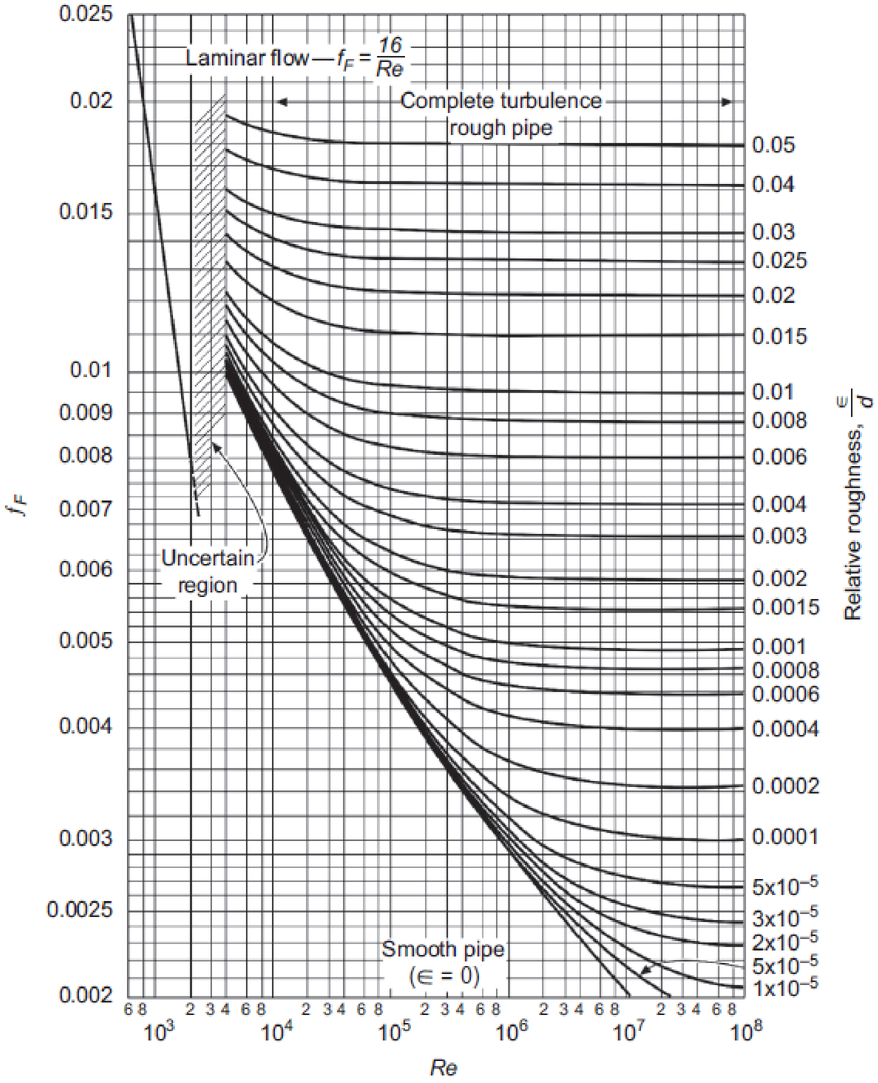


Figure B-2 Moody Chart [6]

Given the unknown Reynolds number, the accurate estimation of the Fanning friction factor necessitates employing a trial-and-error methodology, following the procedure outlined below:

1- Define the initial point (1) and the final point (2) explicitly, where the latter designates the location of the breach orifice or the point of rupture.

2- Calculate the pressure drop between the two points.

3- Assume an initial value for Reynolds number then calculate the friction factor using the solution of the Colebrook equation (B-10).

4- Calculate fluid velocity using equation (B-5).

5- Compute fluid velocity using Reynolds number, equation (B-6).

6- Compare the two values, if they are not equal; apply a correction on the Reynolds number assumed earlier.

7- The resulted fluid velocity will be used to calculate the mass discharge rate utilizing (B-7).

B.1.3 Gas release through a vessel breach

In a situation where gas flows through a breach, we should first consider the existence of two distinguished cases: where it exits with a sonic velocity (choked flow) or with a subsonic one (non-choked flow) which has a relation with the pressure inside the tank P_{cont} and the hole outlet pressure P_{choked} [6].

Using isentropic expansion as an assumption we can express the relationship between the two pressures as follows [6]:

$$\frac{p_{choked}}{P_{cont}} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma-1}} \quad \text{(B-17)}$$

Where γ (-) denotes the Poisson ratio or the ratio of specific heat capacity at constant pressure.

For atmosphere releases, the gas will exit with a sonic velocity if the condition below is fulfilled [9]:

$$\frac{P_{cont}}{P_a} \geq (\frac{\gamma + 1}{2})^{\frac{\gamma}{\gamma-1}} \quad \text{(B-18)}$$

This will come in handy when calculating the mass flow rate of gas exiting an orifice where we can use the expression [6]:

$$\dot{m} = C_d A_{or} P_{cont} \varphi \sqrt{\gamma (\frac{2}{\gamma + 1})^{\frac{\gamma+1}{\gamma-1}} \frac{W_g}{ZRT_{cont}}} \quad \text{(B-19)}$$

With C_d(-) being the discharge coefficient discussed above, A_{or}(m^2) is the cross-sectional area of the orifice, P_{cont} (Pa) is the pressure inside the container, φ (-) is a factor that depends on the gas velocity,

W_g (Kg.mol^{-1}) is the gas molar weight, Z (-) denotes the compressibility factor for gases at P_{cont}(Z=1 for ideal gases), T_{cont} (K) is the temperature inside the vessel and R (J.mol^{-1}.K^{-1}) is the ideal gases constant.

Where for sonic gas velocity [17]:

$$\varphi^2 = 1 \tag{B-20}$$

As for a subsonic velocity, the factor can be calculated as follows [17]:

$$\varphi^2 = \frac{2}{\gamma - 1}\left(\frac{\gamma + 1}{2}\right)^{\frac{\gamma+1}{\gamma-1}} \left(\frac{P_a}{P_{cont}}\right)^{\frac{2}{\gamma}}\left[1 - \left(\frac{P_a}{P_{cont}}\right)^{\frac{\gamma-1}{\gamma}}\right] \tag{B-21}$$

B.1.4 Gas release through a pipe rupture or breach

A gas leak can take place if there is a full-bore rupture or a breach in the pipe wall. The pressure in the pipe must be measured at a position just in front of the opening (Figure B-3) in both circumstances. This necessitates knowing the gas flow rate, which is determined by the pressure drop between the upstream constant pressure source and the aforementioned point. As a consequence, we should proceed in a trial-and-error manner [6].

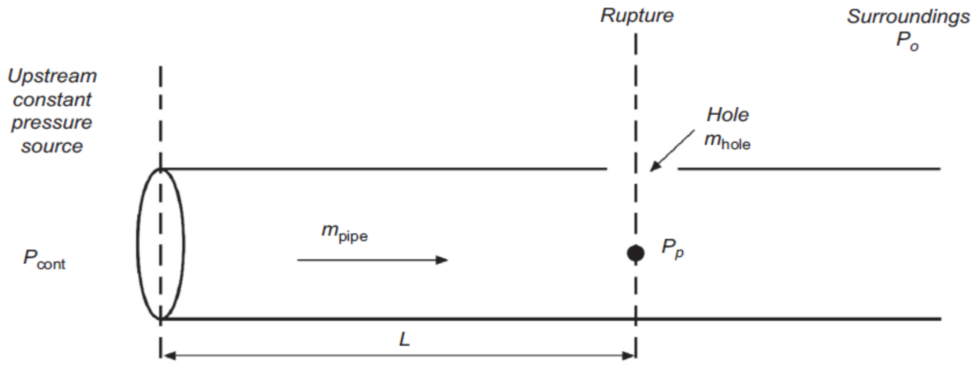


Figure B-3 Gas flow through Pipe Breach [6]

Thus, the equation (B-19) in this case becomes:

$$\dot{m}_{hole} = C_d A_{or} P_p \varphi \sqrt{\gamma\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}} \frac{W_g}{ZRT_p}} \tag{B-22}$$

Where P_p (Pa) is the pipe pressure just in front of the orifice and T_p (K) being the gas temperature also in front of the opening.

These two parameters can be estimated using a trial and error procedure so that the following condition can be verified [9]:

$$\dot{m}_{pipe} = \dot{m}_{hole} \tag{B-23}$$

The gas mass flow rate in the pipe $\dot{m}_{pipe}$ (Kg/s) can in its turn be found using the equation below [9]:

$$\dot{m}_{pipe} = A_p \sqrt{\frac{\rho P_a}{2 f_f \left(\frac{l_p}{d_p}\right)} \frac{\gamma}{1+\gamma} \left(\left(\frac{P_a}{P_p}\right)^{\frac{1+\gamma}{\gamma}} - 1\right)} \qquad \text{(B-24)}$$

To find the mass flow rate in question and since the pressure in front of the orifice is unknown we can proceed as follow:

1- Propose an initial value for P_p so that: $P_a < P_p < P_{cont}$.

Calculate the Fanning friction factor using equation (B-14) assuming that the gas is circulating with a fully developed turbulent flow [15].

2- Estimate the temperature in front of the opening using the following correlations [6]:

$$Y_i = 1 + \frac{\gamma - 1}{2} {Ma_i}^2 \qquad \text{(B-25)}$$

$$\frac{T_p}{T_{cont}} = \frac{Y_{cont}}{Y_p} \qquad \text{(B-26)}$$

$$\frac{\gamma + 1}{2} \ln\left(\frac{Ma_p^2 Y_{cont}}{Ma_{cont}^2 Y_p}\right) - \left(\frac{1}{Ma_{cont}^2} - \frac{1}{Ma_p^2}\right) + \gamma\left(\frac{4 f_F l_p}{d_p}\right) = 0 \qquad \text{(B-27)}$$

In the case where we have a sonic velocity $Ma_p = 1$ thus, the equations above can become:

$$\frac{T_p}{T_{cont}} = \frac{2 Y_{cont}}{\gamma + 1} \qquad \text{(B-28)}$$

$$\frac{\gamma + 1}{2} \ln\left(\frac{2 Y_{cont}}{(\gamma + 1) Ma_{cont}^2}\right) - \left(\frac{1}{Ma_{cont}^2} - 1\right) + \gamma\left(\frac{4 f_F l_p}{d_p}\right) = 0 \qquad \text{(B-29)}$$

3- Calculate the mass flow rate at the hole using the equation (B-22).

4- Calculate the pipe mass flow rate using the equation (B-24).

5- Compare the two values, in case the two aren't equal make some corrections about the pressure P_p.

B.1.5 Evaporation of a liquid from a pool

When the source term is a liquid and when spilled it remains as a pool on the ground, the liquid is going to evaporate with time forming a flammable cloud which can in its turn cause a vapor cloud explosion if ignited. It is important to note that liquid vaporization depends highly on the vapor pressure of the substance which also changes according to the temperature as follows using the Clapeyron-Clausius expression [10]:

$$P_v = 133.3 \times 10^{-0.2185\left(\frac{E}{T}\right)+F} \tag{B-30}$$

Where P_v (Pa) is the substance vapor pressure, T (K) is the ambient temperature, and the constants E and F have values for each substance (See Table B-2).

Table B-2 Clapeyron-Clausius equation constants for common organic compounds [10]

	E	F	Temperature range
n-Pentane	6595.1	7.4897	-77 °C to 191°C
n-Hexane	7627.2	7.7171	-54 °C to 209 °C
n-Heptane	8928.8	8.2585	/
iso-Octane	8548.0	7.9349	-36 °C to 99 °C

The substance vapor pressure P_v can then be used to find its mass evaporation rate by the Mackey and Matsugu model [6]:

$$Ev = 2.10^{-3} A_{pool}\, u_w^{0.78}\, r^{-0.11} \frac{P_a\, W_g}{RT} \ln\left(1 + \frac{P_v - P_{amb}}{P_a - P_v}\right) \tag{B-31}$$

A_{pool} (m^2) Is the pool area, while u_w is the wind velocity measured 10m above the ground. P_v (Pa), P_{amb} (Pa), And W_g (Kg.Kmol^{-1}) are the vapor pressure, the partial pressure of the liquid in the atmosphere and the molecular mass of the spilled substance and T is the pool temperature in K. r (m) is the pool radius.

B.2 Fire accidents modeling:

Fire is typically the accident type in the process sector whose consequences are noticed over relatively shorter distances, while hazardous gas clouds and explosions typically cover considerably wider areas. The thermal flux following a fire, however, can have detrimental effects on other machinery (domino effect), leading to other incidents, which can greatly increase the magnitude of the catastrophe. It is for that reason fire modeling came into existence since it helps us estimate and evaluate accidents' consequences and design appropriate preventive measures [6].

In this section we will focus on two fire types often encountered in the oil and gas sector: Pool fires and Jet fires.

B.2.1 Pool Fires

Four techniques for calculating radiation from pool fires have been identified and assessed. Two procedures can be categorized as simple screening approaches, which are the point source model and the Shokri & Beyler correlation, while we have the Mudan method and the shokri & Beyler model as the more thorough ones. The table shows the range of applicability for each method [10].

In this study, the Mudan model was selected since contrary to the other methods it is applicable for all heat fluxes regardless of the target's position, besides the fact that it takes into consideration the effect of the wind in its calculations.

Table B-3 flame models and their applicability [10]

Method	Range of use (KW/m^2)
Shokri and Beyler correlation	All heat fluxes, ground level only
Point source model	0–5 kW/m2
Shokri and Beyler model	≥5 kW/m2
Mudan model	All heat fluxes

Although for all methods, especially for the ones based on the solid flame approach, it is necessary to know its shape and estimate the flame size.

B.2.1.1 Flame shape:

In a solid flame model such as the Mudan method, the flame is supposed as a grey body that remains still [6]. It is important then, to identify its shape beforehand since it affects the view factor, which will be discussed later on, and can be critical in evaluating the consequences of a fire accident.

For pool fires, if the pool is circular the flame will be almost cylindrical while a parallelepiped shape can be assumed if the liquid is contained within a retention dike (Figure B-4).

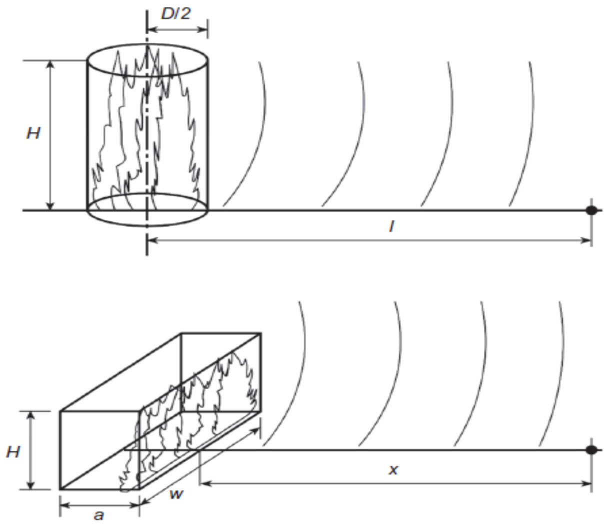


Figure B-4 Solid Flame Shape [6]

a. **Pool Diameter:**

Once we have modeled the source term and obtained the leak mass flow rate, we can calculate the diameter of the pool formed. Depending on the layout of the ground and the characteristics of the fluid, different approaches might be utilized. In general, it's reasonable to assume that the liquid spreads

instantly, either to cover the full containment area (a retention dike for example) or, in the case of an uncontained spill, to reach a minimal pool thickness, this can be expressed mathematically using [10]:

$$A_p = \min(A_{eq}, A_{dike}) \tag{B-32}$$

Where A_{dike} (m^2) is the containment area and A_{eq} (m^2) depends on whether the ignition is immediate, producing an early pool fire while the vessel or pipe is still leaking or delayed causing a late pool fire.

In the first case, A_{eq} can be expressed as follows [6] :

$$A_{eq} = \frac{\pi D_{eq}^2}{4} \text{ With } D_{eq} = 2\left(\frac{\dot{m}}{\pi m}\right)^{\frac{1}{2}} \tag{B-33}$$

m (Kg.m^{-2}s^{-1}) being the liquid burning rate which can be calculated either by [6]:

$$m = 0.001 \frac{\Delta H_c}{\Delta H_v + c_p(T_0 - T_a)} \tag{B-34}$$

Where ΔH_c (KJ.Kg^{-1}) is the combustion heat, ΔH_v (KJ.Kg^{-1}) at T_0 (K), is the liquid's boiling temperature.

Or:

$$m = m_\infty(1 - e^{-KD_{pool}}) \tag{B-35}$$

With m_∞ (Kg.m^{-2}s^{-1}) being the burning velocity for an infinite diameter pool and K (m^{-1}) being a constant.

Since we are essentially trying to estimate the pool diameter, equation (B-34) is more suitable.

As for late pool fires, the area A_{eq} is calculated using the spilled liquid volume V_l (m^3) and the minimum thickness h_{min} (m) [10]:

$$A_{eq} = \frac{V_l}{h_{min}} \tag{B-36}$$

The minimum thickness can be expressed in its turn as [10]:

$$h_{min} = \max(\sqrt{\frac{2\sigma(1 - cos\theta)}{g\rho}}, \varepsilon) \tag{B-37}$$

With σ being the surface tension, θ is the contact angle, and ε is the surface roughness.

In reality, when a leak takes place, the pool is usually formed on concrete or soil where the roughness factor dominates the effect of surface tension, i.e $h_{min} = \varepsilon$ [10]. Examples of usual pool thickness are given in the table below [18].

Table B-4 Minimum pool thickness [10]

Surface	Minimum pool thickness (m)
Dry soil	0.02
Wet soil	0.01
Concrete	0.005

Another thing that should be taken into consideration is that if the release is instantaneous, the equivalent diameter should be calculated as follows [26]:

$$\mathrm{D} = 2\sqrt[8]{\frac{V_l^3 . g}{m}} \tag{B-38}$$

To verify whether the release is instantaneous or not, a dimensionless time should be estimated using the expression down below [26]:

$$t_{cr} = \frac{t_{spill} . m}{\sqrt[3]{V_l}} \tag{B-39}$$

If t_{cr} (-) is greater than 0.002 then the release is instantaneous.

b. <u>Flame Height:</u>

The flame height in this method depends upon the pool diameter and the burning rate and under the influence of the wind, the following correlation was given by Thomas [9]:

$$H = 55D_{pool}\left(\frac{m}{\rho\sqrt{gD_{pool}}}\right)^{0.67} (u^*)^{-0.21} \tag{B-40}$$

Where u^* (-) is the non-dimensional wind velocity and it can be obtained through the expression below [6]:

$$u^* = \frac{u_w}{\left(\frac{gmD_{pool}}{\rho_a}\right)^{\frac{1}{3}}} \tag{B-41}$$

u_w (m.s^{-1}) denotes the wind velocity.

B.2.1.2 <u>View Factor:</u>

The view factor is originally expressed as a closed integral The view factor is originally expressed as a closed integral [6]:

$$F_{dA_2 \to A_1} = \oint \frac{cos\varphi_1 cos\varphi_2}{\pi d^2} dA_1 \tag{B-42}$$

The variables in the equation above are represented in the figure.

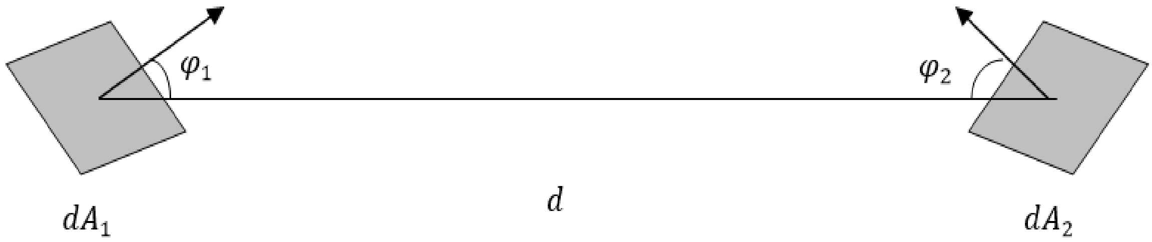


Figure B-5 Configuration for radiative exchange between two differential elements[6]

In this paper, correlations derived from calculations based on specific and somewhat idealized shapes were employed. As mentioned earlier, when examining pool fires, two frequently encountered shapes can be distinguished: cylindrical and parallelepipedic.

a. Cylindrical flame:

An uncontained pool fire can be represented with a tilted vertical cylinder (under the influence of the wind) with a height H (m) and a diameter D (m) (See figure). The view factor of a plane surface can then be found using the correlations below [10] :

For a vertical target on ground level ($\theta = 0$), the view factor is given by:

(B-43)

$$\pi F_v = \frac{acos\theta}{b - asin\theta}\frac{a^2 + (b+1)^2 - 2b(1 + asin\theta)}{\sqrt{AB}}\tan^{-1}\sqrt{\frac{A}{B}\left(\frac{b-1}{b+1}\right)^{\frac{1}{2}}} + \frac{cos\theta}{\sqrt{C}}[\tan^{-1}\frac{ab - (b^2-1)sin\theta}{\sqrt{b^2-1}\sqrt{C}} + \tan^{-1}\frac{(b^2-1)sin\theta}{\sqrt{b^2-1}\sqrt{C}}] - \frac{acos\theta}{(b - asin\theta)}\tan^{-1}\sqrt{\frac{b-1}{b+1}}$$

For a horizontal target on ground level ($\theta = \pi/2$), the view factor is given by:

$$\pi F_H = \tan^{-1}\sqrt{\frac{b-1}{b+1}} - \frac{a^2+(b+1)^2-2(b+1+absin\theta)}{\sqrt{AB}}\tan^{-1}\sqrt{\frac{A}{B}}\left(\frac{b-1}{b+1}\right)^{\frac{1}{2}} + \frac{sin\theta}{\sqrt{C}}[\tan^{-1}\frac{ab-(b^2-1)sin\theta}{\sqrt{b^2-1}\sqrt{C}} + \tan^{-1}\frac{(b^2-1)sin\theta}{\sqrt{b^2-1}\sqrt{C}}] \qquad \text{(B-44)}$$

Where:

$$a = \frac{H}{R} \qquad b = \frac{d}{R}$$

$$A = a^2 + (b+1)^2 - 2a(b+1)sin\theta$$

$$B = a^2 + (b-1)^2 - 2a(b-1)sin\theta \qquad \text{(B-45)}$$

$$C = 1 + (b^2-1)\cos^2\theta$$

With H (m) being the flame height, R (m) the pool radius, d (m) denotes the distance between the fire and the target and θ is the tilt angle because of the wind effect. Its value can be estimated using the dimensionless wind velocity u^* (-) according to The American Gas Association (AGA) [10]:

$$cos\theta = 1 \qquad \text{For } u* \leq 1 \qquad \text{(B-46)}$$

$$cos\theta = \frac{1}{\sqrt{u^*}} \qquad \text{For } u* > 1 \qquad \text{(B-47)}$$

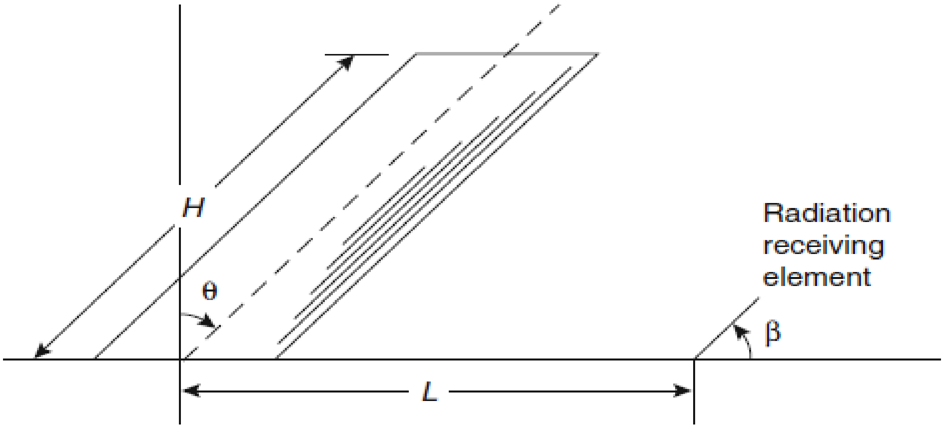


Figure B-6 Tilted cylinder configuration [10]

b. Rectangular Flame:

For a horizontal target on ground level ($\theta = \pi/2$), the view factor is given by [11]:

$$F_h = \frac{1}{2\pi}\left[\tan^{-1}\frac{1}{X_r} - AX_r \tan^{-1} A\right] \tag{B-48}$$

For a vertical target on ground level (θ =0), the view factor is given by [11]:

$$F_v = \frac{1}{2\pi}\left[h_r\, A\tan^{-1} A + \frac{B}{h_r}\tan^{-1} B\right] \tag{B-49}$$

With [11]:

$$h_r = \frac{H}{w}$$

$$X_r = \frac{d}{w}$$

$$A = \frac{1}{\sqrt{h_r^2 + X_r^2}}$$

$$B = \frac{h_r}{\sqrt{1 + X_r^2}}$$

For both configurations, the maximum view factor can be obtained using [11]:

$$F = \sqrt{F_h^2 + F_v^2} \tag{B-50}$$

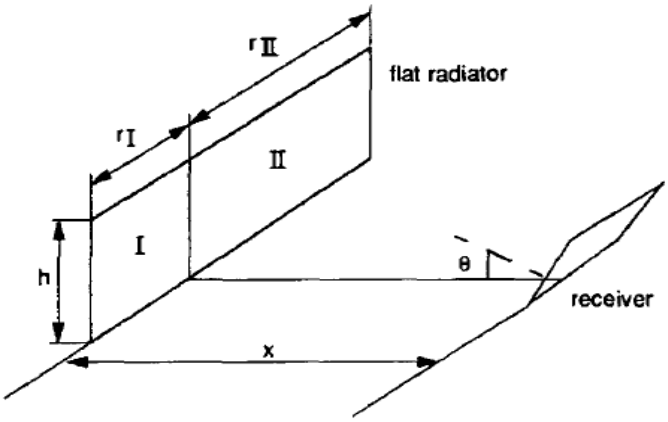


Figure B-7 View factor of a vertical plane surface [11]

B.2.1.3 Emissive power:

The radiative characteristics of a fire can be expressed through a parameter called emissive power which can be defined as: "the radiant heat emitted per unit surface of the flame and per unit time ($kW.m^{-2}$)". Two types of emissive powers can be differentiated [6]:

- Point emissive power, relating to the value measured over a small area of the flame only.
- Average emissive power is the emissive power of the entire flame surface. The one taken into account in this study.

While it is commonly stated that an average emissive power is estimated by considering the entirety of the flame surface, it is important to recognize that flames typically consist of two distinct zones: a luminous zone and a non-luminous zone. Consequently, the emissive power can be expressed as the sum of these two zones [6]:

$$E = \chi_{lum} E_{lum} + E_{soot}[1 - \chi_{lum}] \tag{B-51}$$

Where E_{lum} ($kW.m^{-2}$) corresponds to the emissive power for the luminous zone of the flame while E_{soot} ($kW.m^{-2}$) is for the non-luminous one. χ_{lum}, on the other hand, denotes the proportion of the fire surface that is covered by the luminous flame.

Experiences for gasoline and diesel oil pool fires indicated that E_{soot} is constant regardless of the diameter, and a value was obtained: $E_{soot} = 40\ kW.m^{-2}$. On the contrary, E_{lum} varies with the pool diameter as follows [6]:

$$E_{lum(gasoline)} = 53.64D^{0.474} \; ; \; E_{lum(diesel)} = 28.03D^{0.877} \quad for\ D \leq 5\ m \qquad \text{(B-52)}$$

$$E_{lum} = 115\ \text{kW.m}^{-2} \quad for\ D \geq 5\ m \qquad \text{(B-53)}$$

As for the proportion of the fire surface that is covered by the luminous flame. It is constant for $D \leq 5\ m$ $\chi_{lum} = 0.45$, from that extent, it begins to decrease gradually until it reaches 0 for diameters superior to 20 m, in other words $E \approx E_{soot}$ for this range.

Some authors expressed this factor as a function of the diameter and the extinction coefficient s (m^{-1})[10]:

$$\chi_{lum} = e^{-sD} \qquad \text{(B-54)}$$

Equation (B-51) becomes then:

$$E = E_{lum}e^{-sD} + E_{soot}[1 - e^{-sD}] \qquad \text{(B-55)}$$

The evolution of the average emissive power can be represented according to the figure below.

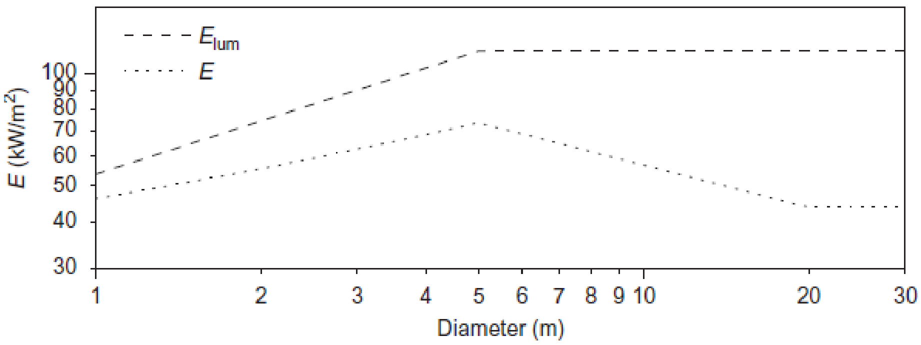


Figure B-8 Evolution of the average emissive power E (kW.m-2) in the function of the pool diameter D (m) [6]

B.2.1.4 <u>Atmospheric Transmissivity:</u>

The radiation emitted by the fire is attenuated by absorption and scattering as it traverses the surrounding medium. Water vapor (H_2O) and carbon dioxide (CO_2) are the primary constituents of the atmosphere responsible for absorbing heat radiation. Absorption and scattering along the intervening passage will mitigate the radiation from the fire to nearby objects. Water vapor

(H_2O) and carbon dioxide (CO_2) are the primary elements of the atmosphere that absorb heat radiation [10].

The carbon dioxide concentration in the atmosphere remains relatively constant, whereas the water vapor content is influenced by temperature and humidity levels. The transmissivity of the atmosphere is also contingent upon the distance between the flame and the target. Therefore, it can be computed using the following set of equations [6]:

$$\tau = 1.53(P_w.d)^{-0.06}\ for\ P_w.d < 10^4\ N.m^{-1} \tag{B-56}$$

$$\tau = 2.02(P_w.d)^{-0.09}\ for\ 10^4 \leq P_w.d \leq 10^5\ N.m^{-1} \tag{B-57}$$

$$\tau = 2.85(P_w.d)^{-0.12}\ \ for\ P_w.d > 10^5\ N.m^{-1} \tag{B-58}$$

Where P_w(N.m-1) is the partial pressure of water in the atmosphere and d (m), is the distance between the flame surface and the target.

The partial pressure of the water can be estimated using the expression [6]:

$$P_w = P_{wa}\frac{H_R}{100} \tag{B-59}$$

With P_{wa} (N.m^{-1}) being the saturated water vapor pressure at the atmospheric temperature, and H_R (%) being the relative humidity.

P_{wa} in its turn can be obtained by [6]:

$$\ln P_{wa} = 23.18986 - \frac{3816.42}{T - 46.13} \tag{B-60}$$

B.2.1.5 **Thermal radiation intensity**

The Mudan model has proposed a correlation for thermal radiation intensity that depends on the parameters discussed above, the flame configuration that is expressed through a view factor for the two most common flame shapes, the emissive power that depends on the diameter, and the atmospheric transmissivity. It can then be expressed as follows [10]:

$$q^{"} = \tau FE \tag{B-61}$$

B.2.2 Jet fire

Jet fires refer to extensive turbulent diffusion flames observed within processing facilities due to either unintended releases of hydrocarbon vapors or intentional disposal of unwanted gases through flaring methods [10]. Consequently, it is crucial to ascertain the characteristics of jet flames and quantify the amount of radiant energy that can potentially impact a particular target [19].

Multiple models have been proposed to precisely estimate the dissipated thermal radiation intensity from jet fires. These models can be categorized into three distinct categories:

a. <u>Semi-empirical Models</u>

They were developed to predict a jet fire's size and the heat it produces. Their advantage is that they are relatively simple to compute. They in turn include sub-models such as:

- Point source model **PSM** (API-521 model), it's a method where the flame is reduced to a single point as the source of radiation.
- Multiple point source models **MPSM**, on the other hand, attempts to go further by representing the flame as a centerline with multiple point sources distributed on it.
- Surface emitter models **SEM**, are closer to reality than the models above since the flame is considered a solid object (a cone or a cylinder usually).

a. <u>Field models:</u>

These models are based on time-dependent Navier-Stocks equation solutions, they are thus more complicated and difficult to code but the most accurate in modeling since they take into consideration physical and chemical processes taking place during a combustion reaction [19].

b. <u>Integral models:</u>

Integral models were developed trying to simplify field models through assumptions and thus turning the partial differential equation in the previous model into ordinary ones which helped reduce the effort needed to compute and the time to run the necessary calculations.

The model adopted to estimate the thermal radiation intensity is the model of Chamberlain, a semi-empirical model and one of the SEM models discussed above. It describes the flame characteristics analytically such as the flame length, width, and tilt. This model was developed at Shell Oil Company's Thornton Research Center and validated with wind tunnel experiments and onshore and offshore field tests [9].

B.2.2.1 Fire Shape:

The Chamberlain model represents the flame as a solid object resembling a cone frustum, as depicted in the figure. This approach eliminates the geometric inaccuracies encountered in the PSM model and offers easier implementation compared to the MPSM method. Furthermore, the Chamberlain model exhibits significantly shorter run times while maintaining the same level of accuracy.

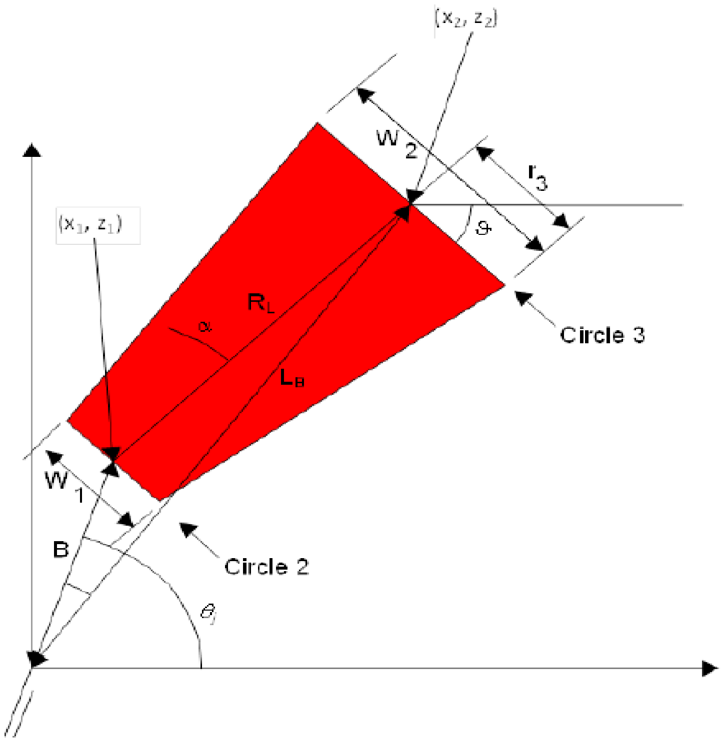


Figure B-9 Jet Fire Flame Shape [19]

With:

L_B: The flame length.

α: The tilt angle between the hole axis and the flame axis.

B: The frustum lift-off distance.

Θ_j: The angle between the hole axis and the wind vector.

R_L: The length of the frustum.

W_1: Frustum base width.

W_2: Frustum's tip width.

B.2.2.2 Exit Velocity of The Jet:

Before trying to estimate the flame dimensions, the exit velocity u_j (m.s^{-1}) of the jet is needed which is often expressed with respect to the Mach number according to the equation below [9]:

$$M_j = \frac{u_j}{u_{sound}} \tag{B-62}$$

Where u_{sound} (m.s^{-1}) is the sound velocity and for ideal gases it is often calculated using the expression [9]:

$$u_{sound} = \sqrt{\frac{\gamma RT}{W_g}} \tag{B-63}$$

By replacing u_{sound} by its expression (B-63) in (B-62) the exit velocity can easily be determined as follows:

$$u_j = M_j \sqrt{\frac{\gamma RT}{W_g}} \tag{B-64}$$

Where the Mach number depends on the type of the flow: sonic or subsonic. The condition indicates inequality (B-18).

For sonic flows it can be then estimated through the correlation [9]:

$$M_j = \sqrt{\frac{(\gamma+1)(\frac{P_{or}}{P_a})^{\frac{\gamma-1}{\gamma}} - 2}{\gamma - 1}} \tag{B-65}$$

Where P_{or} (Pa) is the pressure at the exit point.

While in a subsonic regime, the Mach number is obtained with the expression [9]:

$$M_j = \sqrt{\frac{\sqrt{1 + 2(\gamma-1)u_{0r}^2} - 1}{\gamma - 1}} \tag{B-66}$$

With u_{or} (m.s^{-1}) being the velocity at the exit point and is expressed with the relation [9]:

$$u_{or} = \frac{4\dot{m}}{\pi d_{or}^2} \cdot \frac{1}{P_a} \cdot \sqrt{\frac{RT_s}{\gamma W_g}} \tag{B-67}$$

Assuming an adiabatic flow the pressure and the temperature at the jet can be calculated using the relations [6]:

$$P_{or} = P_{cont} (\frac{2}{\gamma + 1})^{\frac{\gamma}{\gamma-1}} \tag{B-68}$$

$$T_j = T_s (\frac{P_a}{P_{cont}})^{\frac{\gamma-1}{\gamma}} \tag{B-69}$$

Where P_{cont} (Pa) and T_s (K) are the pressure and the temperature in the vessel respectively.

B.2.2.3 <u>The Effective Orifice Diameter:</u>

The effective orifice diameter D_S refers to the hypothetical diameter of an orifice through which air would be released at the same flow rate as the gas being released. This concept is defined in terms of the density of air [19]. In the case of choked flow, the effective orifice diameter can be determined using the following relationship [6]:

$$D_S = D_j \sqrt{\frac{\rho_j}{\rho_{air}}} \tag{B-70}$$

Where D_j (m) is the diameter of the expanded jet at the gas outlet and it can be obtained as follows [6]:

$$D_j = \sqrt{\frac{4\dot{m}}{\pi \rho_j u_j}} \tag{B-71}$$

ρ_j (Kg.m^{-3}) is the expanding jet density at the release point. It can be easily determined through the classic ideal gases equation:

$$\rho_j = \frac{P_{or}.W_g}{RT_j} \tag{B-72}$$

B.2.2.4 Size of the Jet Fire

a. The Flame Length

The flame length in the Chamberlain model is calculated using the correlation below [9]:

$$L_B = L_{B0}(0.51e^{-0.4u_w} + 0.49)[1 - 0.00607(\Theta_j - 90)] \tag{B-73}$$

Where [9]:

$$\mathrm{L_{B0}{=}YD_S} \tag{B-74}$$

With Y being the solution of the equation by trial and error [9]:

$$\left[0.024\left(\frac{gD_S}{u_j^2}\right)^{\frac{1}{3}}\right]Y^{\frac{5}{3}} + 0.2Y^{\frac{2}{3}} - \left[\left(\frac{2.85}{W}\right)^{\frac{2}{3}}\right] = 0$$

$$and\ \ \mathrm{W} = \frac{W_g}{15.816W_g + 0.0395} \tag{B-75}$$

While Θ_j the angle between the hole axis and the wind vector as illustrated in the Figure B-9.

b. The Tilt Angle

The tilt angle can be calculated using the set of equations depending on certain conditions [6]:

$$\alpha = 8000\frac{R_w}{Ri(L_{B0})} + (\Theta_{jv} - 90)(1 - e^{-25.6R_w}) \qquad for\ R_w \le 0.05 \tag{B-76}$$

$$\alpha = \frac{1726\sqrt{R_w - 0.026} + 134}{Ri(L_{B0})} + (\Theta_{jv} - 90)(1 - e^{-25.6R_w}) \quad for\ R_w > 0.05 \tag{B-77}$$

With R_w the ratio of the wind and the jet velocity:

$$R_w = \frac{u_w}{u_j} \tag{B-78}$$

And $Ri(L_{B0})$ is the Richardson number based on L_{B0} [6]:

$$Ri(L_0) = L_0(\frac{g}{{D_S}^2{u_j}^2})^{1/3} \tag{B-79}$$

c. **The Lift-Off Distance**

On the other hand, the frustum' lift-off distance b (m) can be calculated geometrically as follows [9]:

$$b = L\frac{sin(K\alpha)}{sin(\alpha)} \tag{B-80}$$

Where [9]:

$$K = 0.187e^{-20R_w} + 0.015 \tag{B-81}$$

d. **The Length Of The Frustum**

The length of the frustum R_L can also be obtained from the geometrical relation [9]:

$$R_L = \sqrt{L^2{}_B - b^2\sin(\alpha)} - bcos(\alpha) \tag{B-82}$$

e. **The Frustum Base Width**

The Chamberlain model proposes an empirical correlation to calculate the frustum base W_1 (m) [9]:

$$W_1 = D_S(13.5e^{-6R_w} + 1.5)\left\{1 - e^{-70Ri(D_S)CR_w}\left[1 - \frac{1}{15}\sqrt{\frac{\rho_{air}}{\rho_j}}\right]\right\} \tag{B-83}$$

Where:

$$C = 1000e^{-100R_w} + 0.8 \tag{B-84}$$

$$Ri(D_S) = D_S(\frac{g}{u_j^2 D_S^2})^{1/3} \tag{B-85}$$

f. **The Frustum's Tip Width**

There is an empirical correlation to calculate the tip width developed by Chamberlain [9]:

$$W_2 = L(0.18e^{-1.5R_w} + 0.31)(1 - 0.47e^{-25R_w}) \tag{B-86}$$

g. The Surface Area Of the Frustum Including End Discs

The surface area can be calculated using the expression:

$$A = \frac{\pi}{4}(W_1^2 + W_2^2) + \frac{\pi}{2}(W_1 + W_2)\sqrt{R_L^2 + \left(\frac{W_2 - W_1}{2}\right)^2} \quad \text{(B-87)}$$

B.2.2.5 The View Factor

When it comes to jet flames, the flame is typically depicted as a cylinder that is slanted and whose diameter is equal to the average of the two end discs of the frustum. Equations (B-43) and (B-44) can then be used to calculate the maximum view factor for a jet flame, though the distance, tilt angle, and radius will be different since the configuration is changed (Figure B-10) [9]:

$$d' = \sqrt{(b \sin \Theta_{jv})^2 + (d - b \cos\Theta_{jv})^2} \quad \text{(B-88)}$$

$$\theta' = 90° - \Theta_{jv} + \alpha - \arctan\left(\frac{a \sin \Theta_{jv}}{d - a \cos \Theta_{jv}}\right) \quad \text{(B-89)}$$

$$R' = \frac{W_1 + W_2}{4} \quad \text{(B-90)}$$

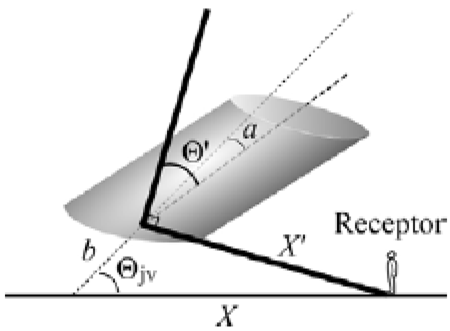


Figure B-10 Flame Configuration for View Factor [9]

B.2.2.6 Surface Emissive Power

For jet flames, the surface emissive power SEP (kW.m^{-2}) can be expressed as [19]:

$$SEP = X_r \frac{\dot{m}}{A} \Delta H_c \quad \text{(B-91)}$$

Where ΔH_c (KJ/Kg) is the combustion heat for the fuel studied, A (m^2) is the frustum area calculated with equation (B-87) while X_r denotes the fraction of the heat radiated from the surface of the flame that depends on the gas post-expansion velocity u_j and it can be estimated using [9]:

$$X_r = 0.21e^{-0.00323u_j} + 0.11 \tag{B-92}$$

Although, modifications were applied to the fraction X_r by the JFSH-Cook model when it was observed that it varies additionally on the fuel molecular weight from $W_g = 21$ (g/mol) [19]:

$$X_r = 0.21e^{-0.00323u_j} + 0.11 \quad for\ W_g \leq 21 \tag{B-93}$$

$$X_r = \sqrt{\frac{W_g}{21}}(0.21e^{-0.00323u_j} + 0.11) \quad for\ 21 \leq W_g \leq 60 \tag{B-94}$$

$$X_r = 1.69(0.21e^{-0.00323u_j} + 0.11) \quad for\ W_g > 60 \tag{B-95}$$

B.2.2.7 Thermal Radiation intensity:

The thermal radiation intensity can be calculated similarly with pool fires:

$$q" = SEP.F.\tau \tag{B-96}$$

With τ is the atmospheric transmissivity discussed in the pool fire section and can be estimated using the equations (B-56), (B-57), or (B-58).

B.3 Vapor Cloud Explosions

In the subsequent section, our primary focus will be directed towards Vapor Cloud Explosions, as they demonstrate a comparatively higher occurrence frequency in comparison to other explosion types.

Vapor Cloud Explosions (VCEs) have undergone comprehensive research over the years, leading to the development of numerous models aimed at providing accurate descriptions of their characteristics:

- **The TNT Equivalent Method:** It is the simplest model that analysis VCEs. The method is based on evaluating how effective the chemical energy transformation into mechanical energy [10].

- **The TNO Multi-Energy Model:** The model was developed after it was observed that only potions of the vapor cloud trigger a blast wave. The general approach of the TNO is that those portions are the ones partially or fully congested. The TNO vapor cloud explosion is therefore considered a collection of smaller explosions from multiple cloud sources [10].
- **The Baker-Strehlow-Tang:** In this model, multiple parameters were combined to estimate the blast overpressure: Confinement effect, fuel reactivity, and congestion. They are then used to obtain the flame speed according to a table of 27 combinations [20].

When comparing the three analytical models, it is noteworthy that the TNT equivalent method does not incorporate any obstacles within its calculations, thus assuming an idealistic environment. In contrast, both the TNO and BST models account for the presence of obstacles. However, based on the depicted Figure B-11, it can be observed that all three models yield comparable outcomes when evaluating blast effects at greater distances [6].

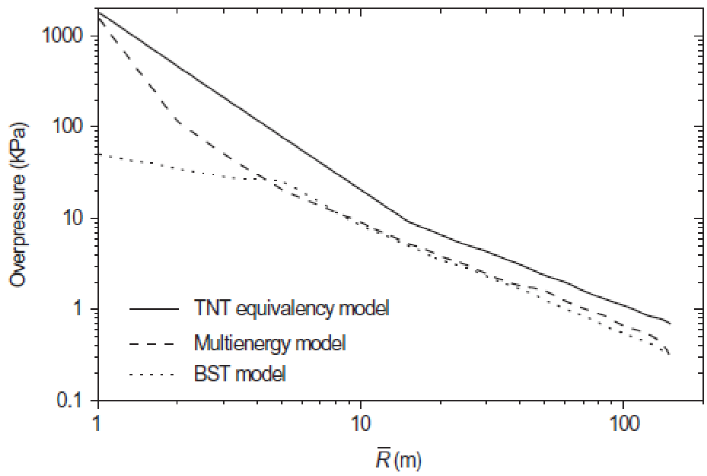


Figure B-11 Comparison Between the three VCE models [6]

Based on that, the TNO Multi-Energy model was adopted and will be discussed in detail in the following section.

B.3.1 The TNO Multi-Energy Model

In the TNO Multi-Energy Model, the blast overpressure and duration can be obtained directly from the abacus or curves, as depicted in the figures. These figures illustrate 10 blast classes, with the scaled distance represented on the x-axis, the scaled peaked overpressure on the y-axis

(Figure B-12), and the scaled duration on the y-axis (Figure B-13). The values for the scaled peaked overpressure and duration are calculated using the following correlations [21]:

$$r' = x\left(\frac{E}{P_a}\right)^{-\frac{1}{3}} \quad \text{(B-97)}$$

$$P_s' = \frac{P_s}{P_a} \quad \text{(B-98)}$$

$$t_p = \frac{t_p'}{c_0}\left(\frac{E}{P_a}\right)^{\frac{1}{3}} \quad \text{(B-99)}$$

With E (J) being the explosion energy, x (m), the target distance from the center of the explosion, P_a (Pa) is the atmospheric pressure, and c_0 (m.s^{-2}), the sound velocity of atmospheric air.

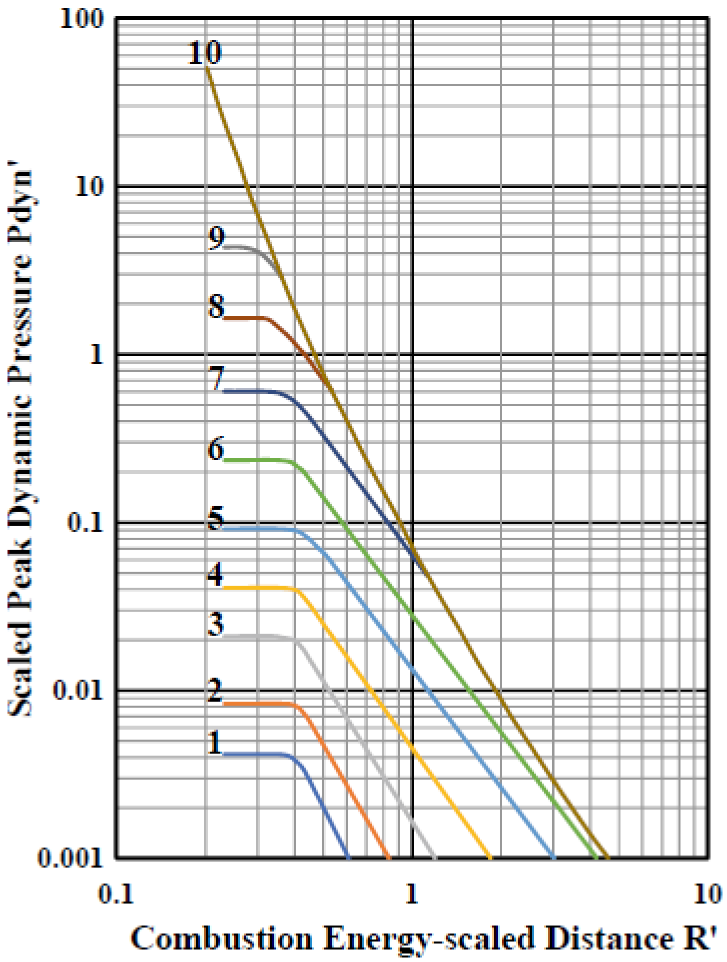


Figure B-12 Scaled dynamic pressure versus scaled distance [18]

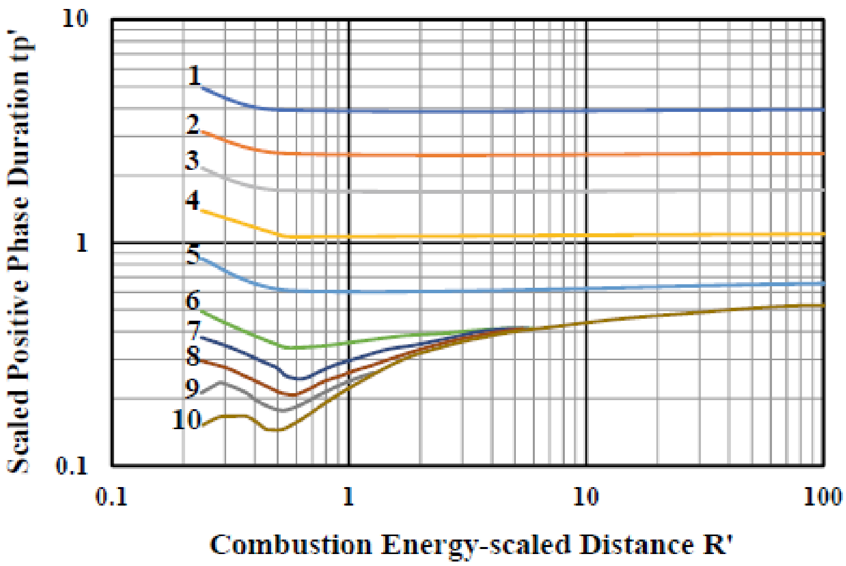


Figure B-13 Scaled positive phase duration versus scaled distance [18]

As depicted in Figure B-12, the curves in the graph are labeled with numbers corresponding to different blast strengths, ranging from 1 (representing a weak blast) to 10 (representing a detonation). It can be observed that for blast classes 7 and above, the curves tend to converge towards the 10th class curve, which represents the detonation limit, as the energy-scaled distances increase [10].

The selection of the appropriate blast strength is of utmost importance in evaluating the overpressure. As the determination of blast strength can be subjective in certain scenarios, a table was introduced as a reference guide Table B-5 to aid in the decision-making process. This table assists in making informed judgments regarding the appropriate blast strength to be used for accurate overpressure assessment.

Table B-5 Blast strength selection guide [10]

Ignition Energy	Obstruction	Confinement	Blast class
High	High	Parallel plane	7-10
High	High	Unconfined	7-10
Low	High	Parallel plane	5-7
High	Low	Parallel plane	5-7
High	Low	Unconfined	4-6
High	None	Parallel plane	4-6
Low	High	Unconfined	4-5
High	None	Unconfined	4-5
Low	Low	Parallel plane	3-5
Low	Low	Unconfined	2-3
Low	None	Parallel plane	1-2
Low	None	Unconfined	1

The selection criteria can be explained further as follows:

a. <u>Ignition Energy</u>

Ignition energy refers to the supply of energy required to initiate the combustion of fuel. A high-level ignition energy source can be exemplified by a confined vented explosion, whereas low-level sources encompass sparks, hot surfaces, and flames [10].

b. <u>Obstruction</u>

In an unobstructed location, the explosion blast strength is significantly low due to the absence of obstacles, which facilitates a uniform distribution of the cloud. Conversely, in an obstructed zone characterized by numerous obstructions such as machinery, the flow transitions from laminar to turbulent, leading to an increased spreading velocity of the cloud. Consequently, the intensity of the explosion blast is heightened in such cases.

c. <u>Confinement</u>

A vapor cloud is considered contained if it is enclosed on two or three sides by walls or barriers. On the other hand, if a gas vapor is only confined by the ground, it is classified as unconfined[10].

After determining the appropriate blast strength, the estimation of overpressure at various distances from a target can be accomplished by following a specific procedure, which can be outlined in the following steps:

2- Cloud Size determination.
3- Identification of possible blast sources.
4- Defining congested zones.
5- Finding the cloud congested volume.
6- Calculating blast parameters.

B.3.2 Cloud Size

In order to assess the size of a cloud resulting from an unintended release and utilize that information in explosion calculations, it is customary to conduct a dispersion study. In cases where a dispersion calculation is unavailable, the mass quantity is often approximated [21]. The estimation of the quantity is accomplished by employing the previously discussed source term modeling. However, the approach may vary depending on the nature of the released fluid.

a. <u>Liquid Releases</u>

As elaborated in the section pertaining to pool evaporation source term modeling, the process of liquid vaporization plays a significant role in the generation of a potentially flammable vapor cloud. By quantifying the rate of evaporation using equation (B-93), we can subsequently utilize this information to estimate the amount of liquid that has evaporated, employing the following methodology:

$$M_{ev} = Ev.t_{ex} \tag{B-100}$$

Where M_{ev} (Kg) is the evaporated amount, Ev (Kg.s^{-1}) is the evaporation rate and t_{ex} (s) is the explosion time ranging from 5 to 10 minutes [9].

b. <u>Gas Release</u>

The utilization of gas release modeling enables us to determine the mass discharge rate, which serves as a direct measure for evaluating the quantity of gas that has been released into the surrounding atmosphere:

$$M_{gas} = \dot{m}.t \tag{B-101}$$

With t (s) being the duration of the leak.

Upon quantifying the fuel quantity that contributes to the formation of a vapor cloud explosion, our objective is to determine the total volume of the cloud. This can be achieved through the following procedure:

1. Establishing the combustion reaction of the fuel:

This step enables us to determine the gas-to-air ratio by considering the stoichiometric coefficient derived from the combustion reaction. For instance, alkanes can be represented by the following general reaction equation:

$$C_nH_{2n+2} + \frac{3n+1}{2}O_2 \rightarrow nCO_2 + (n+1)H_2O$$

The ratio of gas/oxygen is then: $^2/_{3n+1}$

And since the oxygen percentage in the air is 21% the ratio above should be multiplied by $^1/_5$ to obtain the ratio gas/air, in other words:

$$GAR = \frac{2}{5(3n+1)} \tag{B-102}$$

GAR (-) is the ratio of gas/air and *n* (-) is the number of carbon atoms in the compound.

2. Calculating the cloud total volume:

The total volume of the cloud can then be obtained simply by:

$$V = \frac{1}{GAR}\frac{M}{\rho} \tag{B-103}$$

Where M (Kg) is the amount of gas released after a leak or the evaporated amount in case of a liquid release forming a pool and ρ (Kg.m^{-3}) is the density of the gas or the liquid in a vapor phase.

3. Determining the cloud radius:

The cloud radius comes in handy in representing the cloud on a facility layout plan, it can be derived from the cloud volume considering it as a hemisphere:

$$R = \left(\frac{3}{2}\frac{V}{\pi}\right)^{\frac{1}{3}} \tag{B-104}$$

B.3.3 Identification of Blast Sources

To accurately determine the most likely blast source, it is essential to apply engineering judgment. Several common locations can serve as potential blast sources, including process equipment within chemical plants or refineries, confined spaces between parallel walls or barriers, enclosed areas such as tunnels, corridors, or covered conveyor belts, and areas where highly turbulent fuel-air mixtures may occur due to high-pressure releases. These locations are known to present conditions conducive to initiating a blast event [10].

B.3.4 Defining Congested Areas

To define the congested area, two empirical conditions were proposed to identify which equipment to include in the obstructed zone [9]:

$$X < 25\ m$$

$$X < 10D_1 \qquad or \qquad X < 1.5D_2$$

Where D_1 (m) is the object's smallest dimension measured on a plane perpendicular to the flame's direction and D_2 (m) is the object's dimension perpendicular to the flame's propagation direction.

B.3.5 Calculating the cloud congested volume

Once the congested area and the vapor cloud have been depicted on the facility layout plan, the relevant volume for subsequent calculations is determined by considering the intersection between the cloud and the obstructed zone. This intersection volume represents the portion where the vapor cloud and the congested area overlap, and it is the specific volume taken into account for further analysis and computations.

B.3.6 Calculating Blast Parameters

B.3.6.1 <u>Explosion Energy</u>

The energy released from an explosion can be calculated using [9]:

$$E = V_c(\Delta H_c \times \rho \times GAR) \tag{B-105}$$

Where V_c (m^3) is the volume of the intersection between the vapor cloud and the congested zone.

B.3.6.2 The Blast Overpressure

After calculating the energy-scaled distance with equation (B-97) we can find the scaled peaked pressure using the abacus (See Figure B-12).

However, if we want to compute the TNO multi-energy model, the curves corresponding to the blast classes (1-10) should be interpolated.

A correlation was proposed for two classes 3 and 10 [9]:

$$P_s' = 10^{-b\log_{10} r' - c} \quad \text{(B-106)}$$

Where the constants b (-) and c (-) are obtained from Table B-8 [9]:

Table B-6 Coefficient b and c for equation (B-106) [9]

Blast Class	Ranges of r'	B	C
10	$0.15 < r' < 1.0$ $1.0 \leq r' \leq 2.5$ $r' > 2.5$	2.3721 1.5236 1.1188	0.3372 0.3372 0.5120
3	$r' \leq 0.6$ $r' > 0.6$	0 0.9621	1.3010 1.5145

As for the other blast classes, we tried to interpolate the curve of class 7 since it's the class we chose for the blast.

After observing the blast pressure abacus (See Figure B-12), it becomes apparent that all curves can be divided into three segments, the 7th class curve for instance can be split like below:

1- For $r' \in [0.25,\ 0.4]$ $P_s' = 1$.
2- For $r' \in]0.4, 1]$ a best-fit function for the data gathered (Table B-7) was obtained using the curve fitting toolbox in MATLAB:

Table B-7 Data for energy-scaled distance and scaled pressure

r'	0.5	0.54	0.58	0.6	0.68	0.7	0.79	0.8	0.89	0.9
P'_s	0.95	0.9	0.85	0.8	0.75	0.7	0.66	0.62	0.59	0.52

An exponential function with a squared determination factor of R^2=0.98 was thus obtained:

$$P_s' = 1.897e^{-1.39r'} \quad \text{(B-107)}$$

3- For $r' > 1$ the 7th curve is fitted on top of the 10th class curve which means they basically have the same evolution in that interval, as a result, the scaled overpressure in this range can be calculated using equation (B-106).

Appendix C. Frequency Analysis Results

C.1 Failure frequencies:

Table C-1 Inlet line failure frequencies [2], [13]

FZ 01 : Inlet line 16''						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	Piping 16”	30	4,10E-06	3,30E-06	1,24E-06	1,80E-06
Flanges	16”	8	2,50E-05	7,30E-06	9,00E-07	8,10E-06
Manual Valve	6”	2	3,60E-05	1,50E-05	7,10E-06	9,00E-06
Actuated valve	16”	1	5,70E-05	1,90E-05	3,20E-06	1,30E-06
Instrument connections	1/2”	6	5,00E-05	N/A	0,00E+00	0,00E+00
Total			7,52E-04	2,06E-04	6,18E-05	1,38E-04

FZ 01 : Inlet line 12''						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	Piping 12”	23,56	4,10E-06	3,30E-06	1,24E-06	1,80E-06
Flanges	12”	2	1,50E-05	5,90E-06	1,10E-06	3,90E-06
Manual Valve	1”	1	1,30E-05	7,40E-06	0,00E+00	N/A
	12”	1	2,40E-05	1,30E-05	3,50E-06	3,50E-06
Actuated valve	12”	1	5,50E-05	2,50E-05	5,60E-06	4,30E-06
Instrument connections	1/2”	1	5,00E-05	N/A	0,00E+00	0,00E+00
Total			2,69E-04	1,35E-04	4,05E-05	5,80E-05

Table C-2 Separator failure frequencies [2], [13]

FZ 02: Separator TX1H-046 'Gas part'						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Flanges	½''	6	6,00E-06	2,80E-06	N/A	N/A
	2''	1	6,00E-06	2,80E-06	N/A	N/A
	3''	5	6,90E-06	3,18E-06	N/A	N/A
	4''	1	7,80E-06	3,55E-06	1,10E-06	N/A
	6''	6	9,60E-06	4,30E-06	9,90E-07	1,70E-06
	8''	2	1,23E-05	5,10E-06	1,05E-06	2,80E-06
Manual Valve	½''	4	1,30E-05	7,40E-06	0,00E+00	N/A
	3''	1	1,30E-05	7,00E-06	0,00E+00	N/A
	6''	2	1,30E-05	6,20E-06	1,50E-06	1,20E-06
	8''	2	1,85E-05	9,60E-06	2,50E-06	2,35E-06
Actuated valve	6''	2	6,20E-05	3,00E-05	7,20E-06	6,10E-06
Process vessels	Inlets >150 mm	1	2,60E-04	1,40E-04	3,80E-05	3,60E-05
Instrument connections	1''	3	5,00E-05	2,70E-05	0,00E+00	0,00E+00
	2''	2	5,00E-05	2,00E-05	6,60E-06	0,00E+00
Total			1,13E-03	5,72E-04	8,27E-05	7,11E-05
FZ 02: THE GAS LINE 10"-PV-03B3-1800 FROM SEPERATOR TX1H-046 TO KOV(L=26,2)						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	10"	17,2	5,10E-06	2,50E-06	6,40E-07	5,60E-07
	12"	9	5,10E-06	2,50E-06	6,40E-07	5,60E-07

Flanges	10"	10	1,50E-05	5,90E-06	1,10E-06	3,90E-06
	12"	4	1,50E-05	5,90E-06	1,10E-06	3,90E-06
Manual Valve	10’’	5	2,40E-05	1,30E-05	3,65E-06	3,50E-06
	12’’	1	2,40E-05	1,30E-05	3,50E-06	3,50E-06
Actuated valve	10’’	1	5,50E-05	2,50E-05	5,60E-06	4,30E-06
	12’’	1	5,50E-05	2,50E-05	5,60E-06	4,30E-06
Instrument connections	1	4	5,00E-05	2,70E-05	0,00E+00	0,00E+00
Total			3,82E-04	1,80E-04	4,38E-05	6,96E-05
FZ 02 : Separator TX1H-046 ‘Oil part’						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Flanges	½’’	20	6,00E-06	0,00E+00	N/A	N/A
	3’’	6	6,90E-06	3,18E-06	N/A	N/A
	4’’	2	7,80E-06	3,55E-06	1,10E-06	N/A
	6’’	28	9,60E-06	4,30E-06	9,90E-07	1,70E-06
Manual Valve	½’’	6	1,30E-05	0,00E+00	0,00E+00	N/A
	3’’	3	1,30E-05	7,00E-06	0,00E+00	N/A
Process vessels	Inlets >150 mm	1	2,60E-04	1,40E-04	3,80E-05	3,60E-05
Instrument connections	2’’	5	5,00E-05	2,00E-05	6,60E-06	0,00E+00
Total			1,07E-03	4,08E-04	1,01E-04	8,36E-05
FZ 02: Pipe between separator and Surge tank						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	6’’	91	6,70E-06	2,70E-06	5,60E-07	3,50E-07

Flanges	6’’	28	9,60E-06	4,30E-06	9,90E-07	1,70E-06
Manual Valve	6’’	11	1,30E-05	6,20E-06	1,50E-06	1,20E-06
	1/2"	6	1,30E-05	0,00E+00	0,00E+00	N/A
Actuated valve	4’’	1	6,20E-05	3,00E-05	9,60E-06	N/A
	6’’	1	6,20E-05	3,00E-05	7,20E-06	6,10E-06
Instrument connections	2"	9	5,00E-05	2,00E-05	6,60E-06	0,00E+00
Total			1,22E-03	4,94E-04	1,12E-04	9,88E-05

Table C-3 Surge tank failure frequencies [2], [13]

FZ 03 : Surge Tank (GAS)						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Flanges	½’’	1	6,00E-06	N/A	N/A	N/A
	2’’	2	6,00E-06	2,80E-06	N/A	N/A
	4’’	4	7,80E-06	3,55E-06	1,10E-06	N/A
	6’’	4	9,60E-06	4,30E-06	9,90E-07	1,70E-06
Manual valve	½’’	1	1,30E-05	N/A	0,00E+00	N/A
	2’’	1	1,30E-05	7,40E-06	0,00E+00	N/A
	4’’	3	1,30E-05	6,80E-06	7,50E-07	N/A
	6’’	5	1,30E-05	6,20E-06	1,50E-06	1,20E-06
Actuated valve	4’’	1	6,20E-05	3,00E-05	9,60E-06	N/A
	6’’	2	6,20E-05	3,00E-05	7,20E-06	6,10E-06
Process vessels	Inlets >150 mm	1	2,60E-04	1,40E-04	3,80E-05	3,60E-05
Instrument connections	1’’	6	5,00E-05	2,70E-05	0,00E+00	0,00E+00
	2’’	2	5,00E-05	2,00E-05	6,60E-06	0,00E+00
TOTAL			1,06E-03	5,28E-04	9,33E-05	6,10E-05
FZ 03 : Surge Tank (Oil)						
Release sources			Leak frequencies			

		Part Count	5 mm	25 mm	100 mm	>150 mm
Flanges	½’’	1	6,00E-06	2,80E-06	N/A	N/A
	4’’	6	1,09E-05	4,65E-06	1,48E-06	N/A
	6’’	2	9,60E-06	4,30E-06	9,90E-07	1,70E-06
	8’’	6	1,23E-05	5,10E-06	1,05E-06	2,80E-06
Manual valve	4’’	3	1,30E-05	6,80E-06	7,50E-07	N/A
	6’’	4	1,30E-05	6,20E-06	1,50E-06	1,20E-06
	8’’	2	1,85E-05	9,60E-06	2,50E-06	2,35E-06
Actuated valve	8’’	1	5,85E-05	2,50E-05	6,40E-06	5,20E-06
Process vessels	Inlets >150 mm	1	2,60E-04	1,40E-04	3,80E-05	3,60E-05
Instrument connections	1’’	9	5,00E-05	2,70E-05	0,00E+00	0,00E+00
	2’’	1	5,00E-05	2,00E-05	6,60E-06	0,00E+00
TOTAL			1,23E-03	6,17E-04	9,36E-05	9,36E-05
FZ 03: Pipe between surge tank and export pumps						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Pipe	8’’	43,2	5,90E-06	2,60E-06	6,00E-07	4,55E-07
Flanges	6"	3	9,60E-06	4,30E-06	9,90E-07	1,70E-06
	8"	5	1,23E-05	5,10E-06	1,05E-06	2,80E-06
Manual valve	6"	1	1,30E-05	6,20E-06	1,50E-06	1,20E-06
	8"	1	1,85E-05	9,60E-06	2,50E-06	2,35E-06
Actuated valve	8’’	1	5,85E-05	2,50E-05	6,40E-06	5,20E-06
Instrument connections	1/2"	2	5,00E-05	2,70E-05	0,00E+00	0,00E+00
TOTAL			3,74E-04	1,66E-04	3,93E-05	3,35E-05

Table C-4 Knock out Vessel failure frequencies [13], [22]

FZ 04 : KOV 01-XRZ-009 (Gas Part)						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Flanges	1’’	5	6,00E-06	2,80E-06	N/A	N/A
	2’’	1	6,00E-06	2,80E-06	N/A	N/A
	3’’	1	6,90E-06	3,18E-06	N/A	N/A
	4’’	4	7,80E-06	3,55E-06	1,10E-06	N/A
	8’’	11	1,23E-05	5,10E-06	1,05E-06	2,80E-06
	10’’	3	1,50E-05	5,90E-06	1,10E-06	3,90E-06
	12’’	2	1,50E-05	5,90E-06	1,10E-06	3,90E-06
Manual valve	1/2’’	3	1,30E-05	7,40E-06	0,00E+00	N/A
	4’’	2	1,30E-05	6,80E-06	7,50E-07	N/A
	6’’	2	1,30E-05	6,20E-06	1,50E-06	1,20E-06
	8’’	2	1,85E-05	9,60E-06	2,50E-06	2,35E-06
	12’’	1	2,40E-05	1,30E-05	3,50E-06	3,50E-06
Actuated valve	6’’	2	6,20E-05	3,00E-05	7,20E-06	6,10E-06
	10’’	1	5,50E-05	2,50E-05	5,60E-06	4,30E-06
Process vessels	Inlets >150 mm	1	2,60E-04	1,40E-04	3,80E-05	3,60E-05
Instrument connections	1’’	6	5,00E-05	2,70E-05	0,00E+00	0,00E+00
	2’’	3	5,00E-05	2,00E-05	6,60E-06	0,00E+00
TOTAL			1,33E-03	6,47E-04	1,12E-04	1,13E-04
FZ 04 : KOV 01-XRZ-009 (Liquid part)						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Flanges	1’’	3	6,00E-06	2,80E-06	N/A	N/A
	2’’	10	6,00E-06	2,80E-06	N/A	N/A
	3’’	14	6,90E-06	3,18E-06	N/A	N/A
	4’’	1	7,80E-06	3,55E-06	1,10E-06	N/A

Manual valve	2’’	5	1,30E-05	7,40E-06	0,00E+00	N/A
	3’’	6	1,30E-05	7,00E-06	0,00E+00	N/A
Actuated valve	3’’	1	6,20E-05	3,00E-05	7,20E-06	6,10E-06
Process vessels	Inlets >150 mm	1	2,60E-04	1,40E-04	3,80E-05	3,60E-05
TOTAL			6,47E-04	3,33E-04	4,63E-05	4,21E-05

Table C-5 Centrifugal pumps failure frequencies [13], [23]

FZ 05 : Booster Pumps						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	6’’	17,86	6,70E-06	2,70E-06	5,60E-07	3,50E-07
	10’’	9,1	5,10E-06	2,50E-06	6,40E-07	5,60E-07
flanges	1’’	6	6,00E-06	2,80E-06	N/A	N/A
	6’’	17	9,60E-06	4,30E-06	9,90E-07	1,70E-06
Manual valve	1/2’’	6	1,30E-05	N/A	0,00E+00	N/A
	6’’	6	1,30E-05	6,20E-06	1,50E-06	1,20E-06
Pumps: Centrifugal	Inlets 50 to 150 mm diameter	3	1,40E-03	3,00E-04	3,90E-05	N/A
Instrument connections	1’’	3	5,00E-05	2,70E-05	0,00E+00	0,00E+00
	2’’	16	5,00E-05	2,00E-05	6,60E-06	0,00E+00
TOTAL			5,67E-03	1,50E-03	2,64E-04	4,74E-05
FZ 05 : Export Pumps						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	6’’	17,86	6,70E-06	2,70E-06	5,60E-07	3,50E-07
	10’’	9	5,10E-06	2,50E-06	6,40E-07	5,60E-07
flanges	1’’	6	6,00E-06	2,80E-06	N/A	N/A
	6’’	16	9,60E-06	4,30E-06	9,90E-07	1,70E-06
Manual valve	1/2’’	6	1,30E-05	N/A	0,00E+00	N/A

	6''	6	1,30E-05	6,20E-06	1,50E-06	1,20E-06
Manual valve	1/2''	6	1,30E-05	N/A	0,00E+00	N/A
	6''	6	1,30E-05	6,20E-06	1,50E-06	1,20E-06
Pumps: Centrifugal	Inlets 50 to 150 mm diameter	3	1,40E-03	3,00E-04	3,90E-05	N/A
Instrument connections	1''	3	5,00E-05	2,70E-05	0,00E+00	0,00E+00
	2''	16	5,00E-05	2,00E-05	6,60E-06	0,00E+00
TOTAL			5,67E-03	1,50E-03	2,64E-04	4,74E-05

Table C-6 Oil expedition line failure frequencies [13], [24]

FZ 06 : Oil Expedition line						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	12''	191m	5,10E-06	2,50E-06	6,40E-07	5,60E-07
Flanges	8''	4	1,23E-05	5,10E-06	1,05E-06	2,80E-06
	10''	8	1,50E-05	5,90E-06	1,10E-06	3,90E-06
	12''	13	1,50E-05	5,90E-06	1,10E-06	3,90E-06
	14''	4	2,50E-05	7,30E-06	9,00E-07	8,10E-06
Manual valve	1/2''	1	1,30E-05	7,40E-06	N/A	N/A
	8''	2	1,85E-05	9,60E-06	2,50E-06	2,35E-06
	10''	4	2,40E-05	1,30E-05	3,65E-06	3,50E-06
	12''	5	2,40E-05	1,30E-05	3,50E-06	3,50E-06
	14''	2	3,00E-05	1,80E-05	5,30E-06	6,25E-06
Actuated valve	12''	1	5,50E-05	2,50E-05	5,60E-06	4,30E-06
Instrument connections	½''	6	5,00E-05	2,70E-05	N/A	N/A
TOTAL			2,12E-03	1,02E-03	2,06E-04	2,85E-04

Table C-7 Gas expedition line failure frequencies [13], [24]

FZ 07 : Gas Expedition line						
Release sources		Part Count	Leak frequencies			
			5 mm	25 mm	100 mm	>150 mm
Piping	10’’	170,32m	5,10E-06	2,50E-06	6,40E-07	5,60E-07
Flanges	2’’	12	6,00E-06	2,80E-06	N/A	N/A
	8’’	2	1,23E-05	5,10E-06	1,05E-06	2,80E-06
	10’’	18	1,50E-05	5,90E-06	1,10E-06	3,90E-06
	12’’	2	1,50E-05	5,90E-06	1,10E-06	3,90E-06
Manual valve	2’’	5	1,30E-05	7,40E-06	0,00E+00	N/A
	10’’	5	2,40E-05	1,30E-05	3,65E-06	3,50E-06
Actuated valve	8’’	1	5,85E-05	2,50E-05	6,40E-06	5,20E-06
	10’’	2	5,50E-05	2,50E-05	5,60E-06	4,30E-06
Instrument connections	½’’	11	5,00E-05	2,70E-05	0,00E+00	0,00E+00
TOTAL			2,18E-03	1,07E-03	1,70E-04	2,11E-04

C.2 Probability of ignition:

Table C-8 Ignition probabilities [8]

Fire zone		Breach diameter	Release rate (Kg/s)	Immediate ignition	Delayed ignition
FZ01	Inlet Pipe 16”-PF-06B3-1400 (30m)	5 mm	0.816	0,001	0,001
		25 mm	20.407	0,001	0,019
		100 mm	277.07	0,001	0,099
		150 mm	623.407	0,001	0,099
	Inlet pipe 12”-PF 03B3-1401 (l23.56m)	5 mm	0.692	0,001	0,001
		25 mm	17.316	0,001	0,019
		100 mm	226.524	0,001	0,099

		150 mm	558.580	0,001	0,099
FZ02	Separator TX1H-046 'Liquid part'	5 mm	0,460	0,001	0,001
		25 mm	11.60	0,001	0,014
		100 mm	185.62	0,001	0,099
		150 mm	673.64	0,001	0,099
	Separator TX1H-046 'Gas part'	5 mm	0,023	0,001	0
		25 mm	0,553	0,001	0,001
		100 mm	8,850	0,001	0,029
		150 mm	32,105	0,001	0,079
	The Gas Line 10" From Separator To KOV	5 mm	0.0213	0,001	0
		25 mm	0.532	0,001	0,001
		100 mm	8.835	0,001	0,029
		150 mm	30.893	0,001	0,079
	Pipe between separator and Surge tank (91m)	5 mm	0.255	0,001	0
		25 mm	6.378	0,001	0,019
		100 mm	102.048	0,001	0,099
		150 mm	229.609	0,001	0,099
FZ03	Surge Tank TX6961-014	5 mm	0.270	0,001	0
		25 mm	6.760	0,001	0.014
		100 mm	108	0,001	0,099
		150 mm	392.85	0,001	0,099
	Pipe between surge tank and export pumps (43,2m)	5 mm	0.295	0,001	0
		25 mm	7.377	0,001	0,019
		100 mm	118.041	0,001	0,099
		150 mm	265.593	0,001	0,099
FZ04	Knock-Out Vessel 01-XRZ009 IS 02	5 mm	0.017	0,001	0
		25 mm	0.42	0,001	0.001
		100 mm	7.077	0,001	0.029
		150 mm	25.68	0,001	0.059

FZ 05	Booster pumps (20.8m)	5 mm	0.571	0,001	0
		25 mm	14.292	0,001	0,019
		100 mm	228.679	0,001	0,099
		150 mm	514.528	0,001	0,099
	Export pumps	5 mm	1.161	0,001	0,0005
		25 mm	29.394	0,001	0.029
		100 mm	464.526	0,001	0,099
		150 mm	868.617	0,001	0,099
FZ 06	Oil Expedition line	5 mm	0.62	0,001	0
		25 mm	15.52	0,001	0,019
		100 mm	248.456	0,001	0,099
		150 mm	559.027	0,001	0,099
	Gas Expedition line	5 mm	0.017	0,001	0
		25 mm	0.429	0,001	0
		100 mm	6.861	0,001	0,019
		150 mm	15.445	0,001	0,039

Appendix D. Consequences analysis modeling results

D.1 Scenario N°1.1: Loss of Containment in the Admission Line 16”

Table D-1 Scenario FZ-1.1-005 modeling results

<table>
<tr><th colspan="5">SMALL BREACH</th></tr>
<tr><td colspan="5">Description: The initiating event is the loss of containment of hydrocarbon liquid due to a small breach (5 mm) in the admission line 16”-PF-06B3-1400.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="4">0.816</td></tr>
<tr><td colspan="5">Early Pool Fire with a 4.161 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame Height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td colspan="2">4.6158</td><td>7.480</td><td>6.5</td></tr>
<tr><td>Winter</td><td colspan="2">4.470</td><td>7.482</td><td>6.6</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">1590.0</td></tr>
<tr><td colspan="5">Late Pool Fire with a 8.78 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame Height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td colspan="2">7.895</td><td>13.869</td><td>10.258</td></tr>
<tr><td>Winter</td><td colspan="2">7.7098</td><td>14.000</td><td>11.570</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">134.72</td></tr>
<tr><td colspan="5">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="4">979.2</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>0.888</td><td rowspan="2">Evaporated amount (Kg)</td><td>265.67</td></tr>
<tr><td>Winter</td><td>0.188</td><td>56.521</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>3605.5</td><td rowspan="2">Congested cloud volume (m^3)</td><td>676</td></tr>
<tr><td>Winter</td><td>767.07</td><td>241</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="3">11.985</td></tr>
<tr><td>Winter</td><td colspan="3">7.154</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td>Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">50</td><td>35</td><td>21</td></tr>
<tr><td>Winter</td><td colspan="2">36</td><td>25</td><td>16</td></tr>
</table>

Table D-2 Scenario FZ-1.1-025 modeling results

<table>
<tr><th colspan="5">MEDIUM BREACH</th></tr>
<tr><td colspan="5">Description: The initiating event is the loss of containment of hydrocarbon liquid due to an medium breach (25 mm) in the admission line 16”-PF-06B3-1400.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="4">20.407</td></tr>
<tr><td colspan="5">Early Pool Fire with 21.634 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td colspan="2">14.593</td><td>26.505</td><td>0.9</td></tr>
<tr><td>Winter</td><td colspan="2">14.178</td><td>26.502</td><td>3.3</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">824.49</td></tr>
<tr><td colspan="5">Late Pool Fire with a 31.059 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">19.235</td><td>37.270</td><td>0.4</td></tr>
<tr><td>Winter</td><td colspan="2">19.588</td><td>37.270</td><td>2.4</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">134.67 (2 min 14 s)</td></tr>
<tr><td colspan="5">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="4">12244.2</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>9.636</td><td rowspan="2">Evaporated amount (Kg)</td><td>2890.9</td></tr>
<tr><td>Winter</td><td>2.0502</td><td>766.32</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>39234</td><td rowspan="2">Congested cloud volume (m^3)</td><td>2143</td></tr>
<tr><td>Winter</td><td>10400</td><td>1438.38</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="3">26.558</td></tr>
<tr><td>Winter</td><td colspan="3">17.061</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td>Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">59</td><td>41</td><td>25</td></tr>
<tr><td>Winter</td><td colspan="2">51</td><td>36</td><td>22</td></tr>
</table>

Table D-3 Scenario FZ-1.1-100 modeling results

<table>
<tr><th colspan="5">LARGE BREACH</th></tr>
<tr><td colspan="5">Description: The central event is the loss of containment of hydrocarbon liquid due to a large breach (100 mm) in the admission line 16”-PF-06B3-1400.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="4">277.07</td></tr>
<tr><td colspan="5">Pool Fire with a 38.271 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td>Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td>23.579</td><td colspan="2">44.300</td><td>0.5</td></tr>
<tr><td>Winter</td><td>32.202</td><td colspan="2">45.600</td><td>3.500</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">134.66 (2 min 13 s)</td></tr>
<tr><td colspan="5">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="4">41560,5</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>21.962</td><td rowspan="2">Evaporated amount(Kg)</td><td>6588.6</td></tr>
<tr><td>Winter</td><td>4.672</td><td>1401.8</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>89417</td><td rowspan="2">Congested cloud volume (m^3)</td><td>2656.08</td></tr>
<tr><td>Winter</td><td>19024</td><td>1766.23</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="3">34.951</td></tr>
<tr><td>Winter</td><td colspan="3">20.865</td></tr>
<tr><td>Atmospheric condition</td><td>Distance at 200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td>63</td><td colspan="2">43</td><td>27</td></tr>
<tr><td>Winter</td><td>55</td><td colspan="2">38</td><td>24</td></tr>
</table>

Table D-4 Scenario FZ-1.1-150 modeling results

<table>
<tr><th colspan="4">CATASTROPHIC BREACH</th></tr>
<tr><td colspan="4">Description: The central event is the loss of containment of hydrocarbon liquid due to a catastrophic breach (>150 mm) in the admission line 16”-PF-06B3-1400.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="3">623.407</td></tr>
<tr><td colspan="4">Pool Fire with a 54.28 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td>Flame height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td>22.520</td><td>79.700</td><td>N/A</td></tr>
<tr><td>Winter</td><td>22.184</td><td>80.100</td><td>N/A</td></tr>
</table>

<table>
<tr><td>Burning duration (s)</td><td colspan="5">134.67</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of Liquid released (Kg)</td><td colspan="5">37404.5</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>27.684</td><td colspan="2" rowspan="2">Evaporated amount(Kg)</td><td>8305.2</td></tr>
<tr><td>Winter</td><td>5.890</td><td>1767.0</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>112720</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>2836.268</td></tr>
<tr><td>Winter</td><td>23981</td><td>1895.824</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">37.755</td></tr>
<tr><td>Winter</td><td colspan="4">22.539</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">65</td><td colspan="2">45</td><td>28</td></tr>
<tr><td>Winter</td><td colspan="2">57</td><td colspan="2">39</td><td>24</td></tr>
</table>

Appendix D. Consequences analysis modeling results

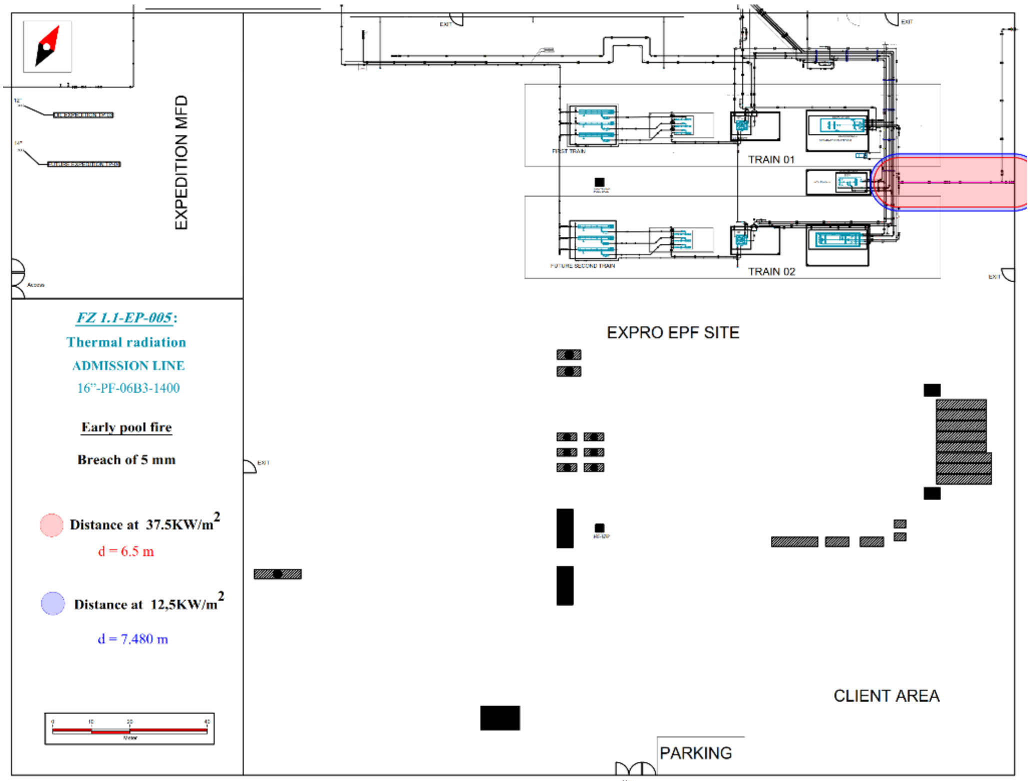


Figure D-1 Scenario FZ-1.1-EP-005 modeling contours

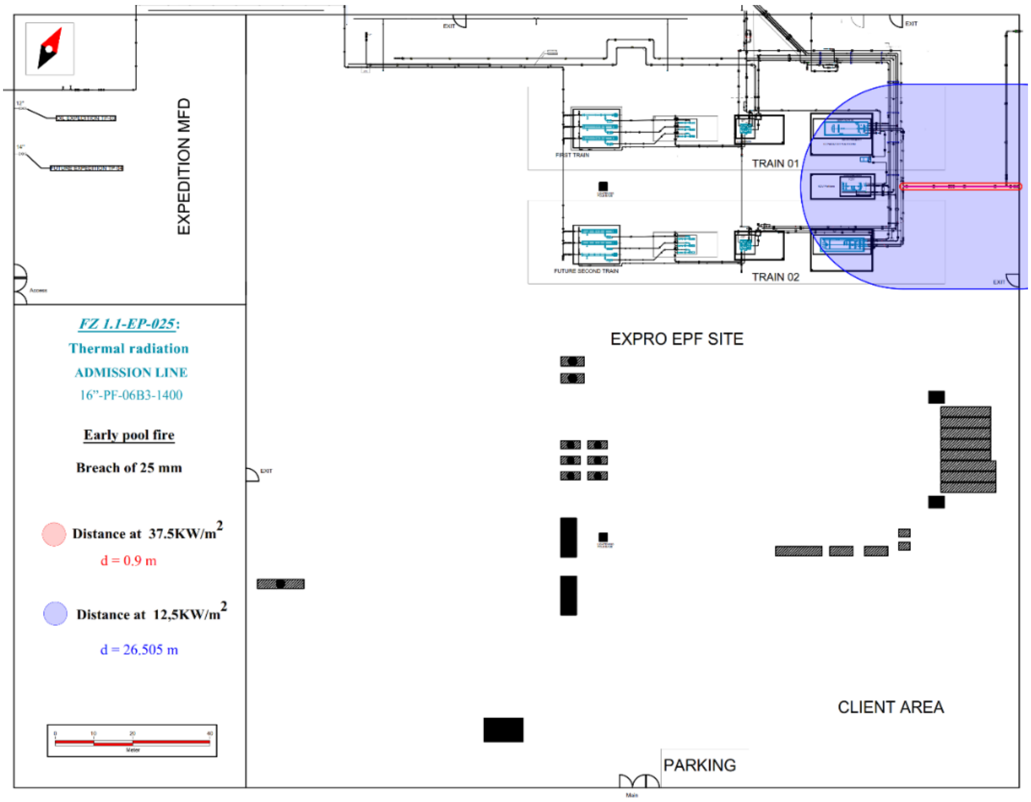


Figure D-2 Scenario FZ-1.1-EP-025 modeling contours

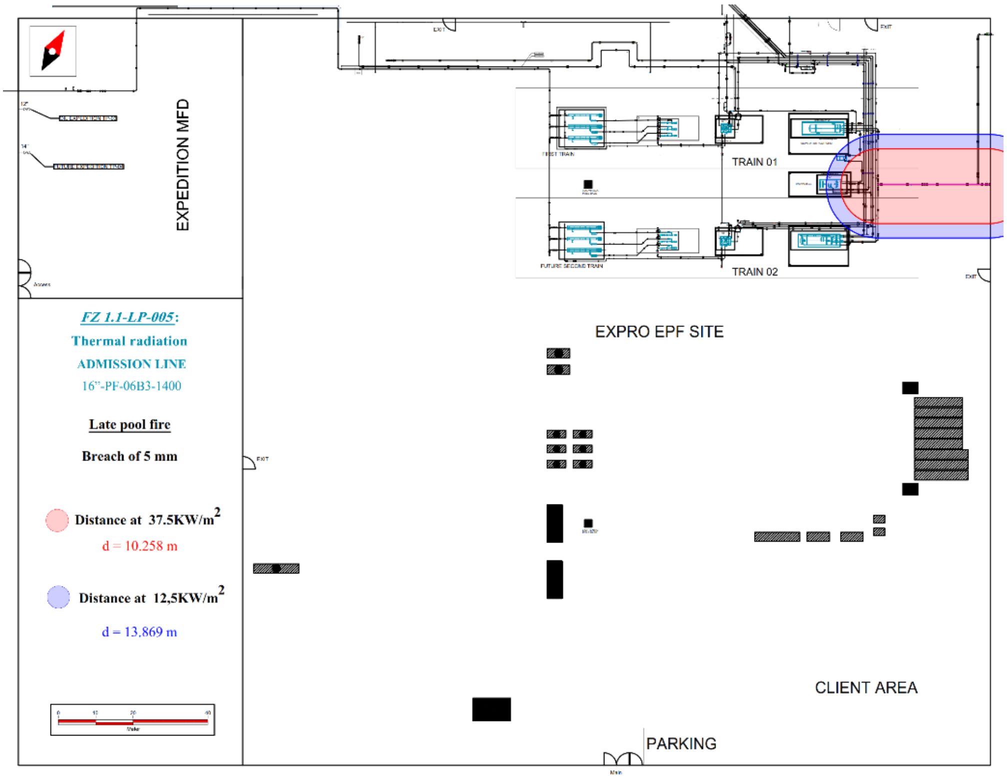


Figure D-3 Scenario FZ-1.1-LP-005 modeling contours

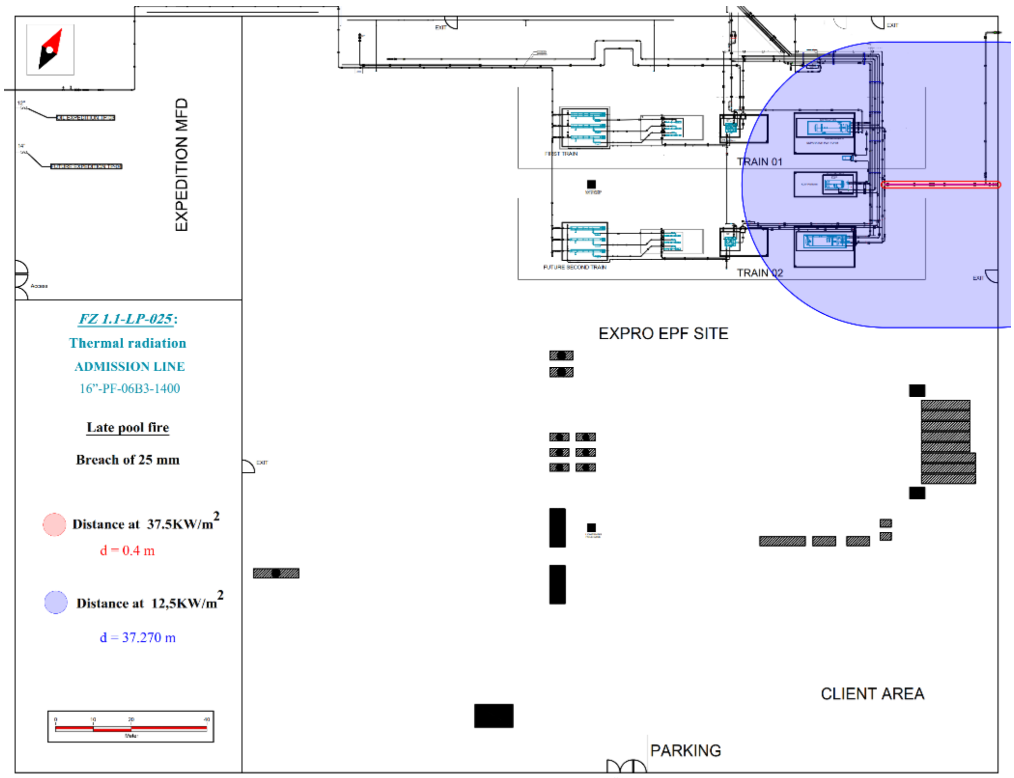


Figure D-4 Scenario FZ-1.1-LP-025 modeling contours

Appendix D. Consequences analysis modeling results

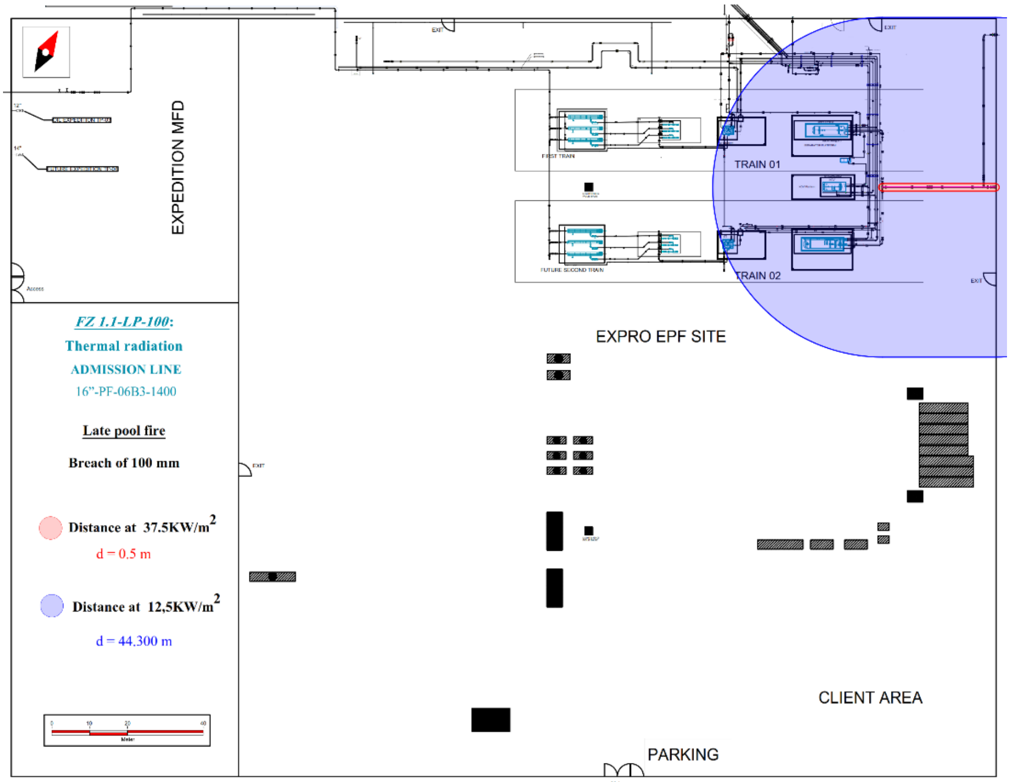


Figure D-5 Scenario FZ-1.1-LP-100 modeling contours

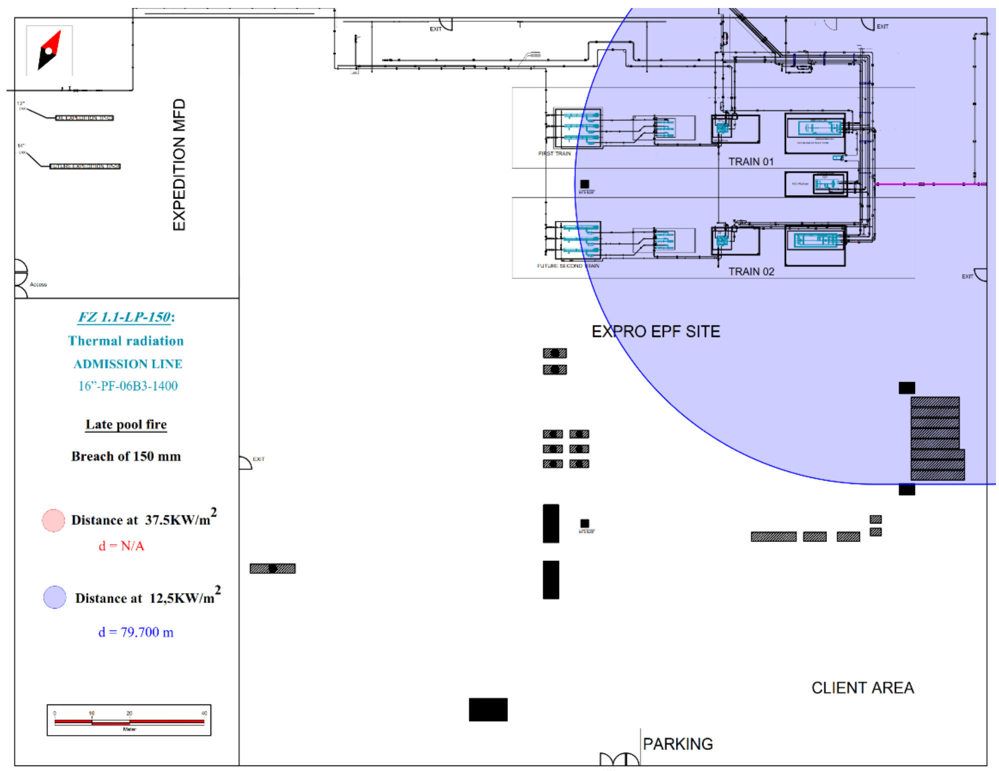


Figure D-6 Scenario FZ-1.1-LP-150 modeling contours

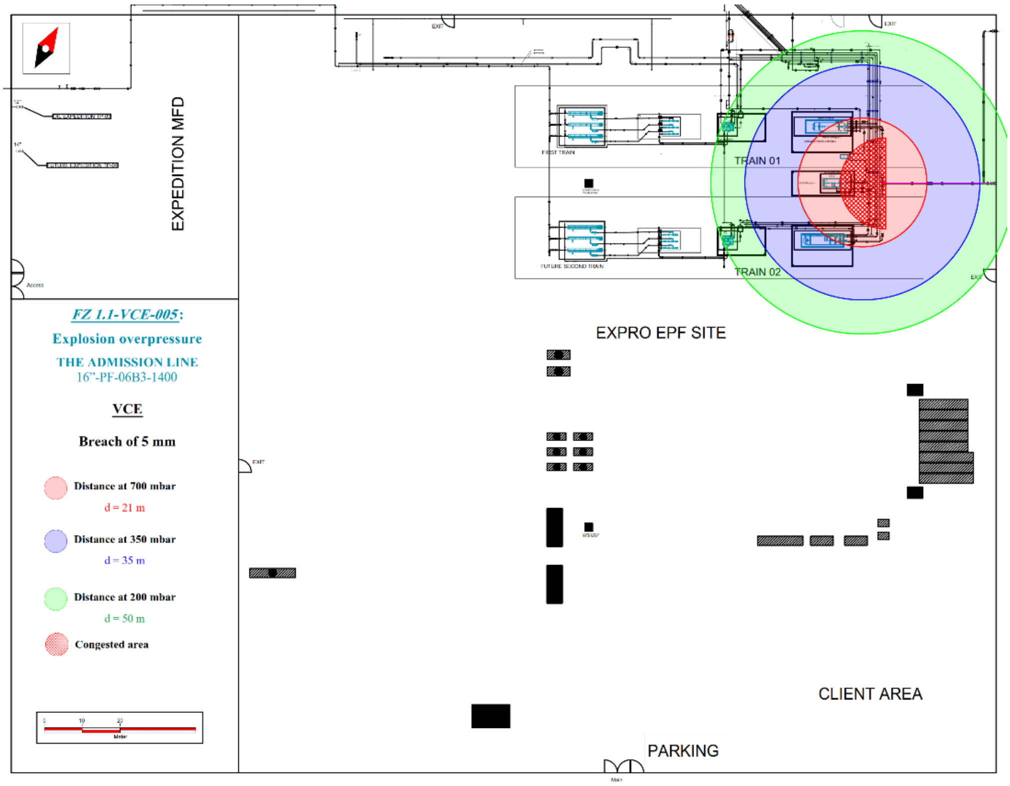


Figure D-7 Scenario FZ-1.1-VCE-005 modeling contours

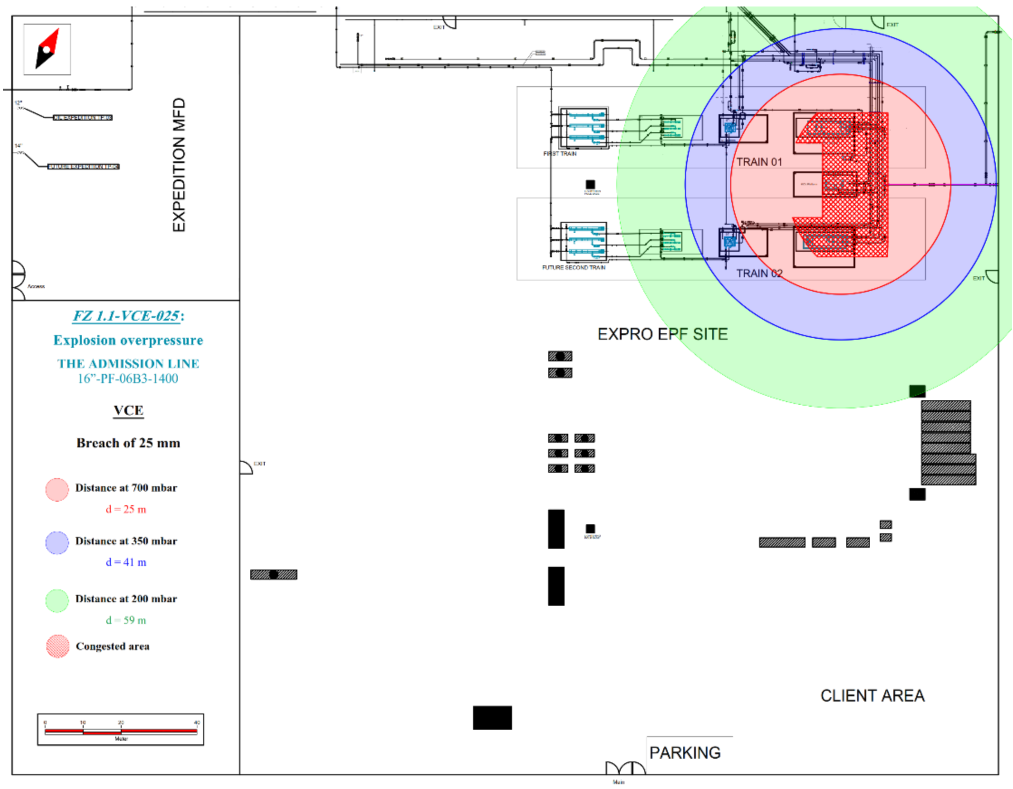


Figure D-8 Scenario FZ-1.1-VCE-025 modeling contours

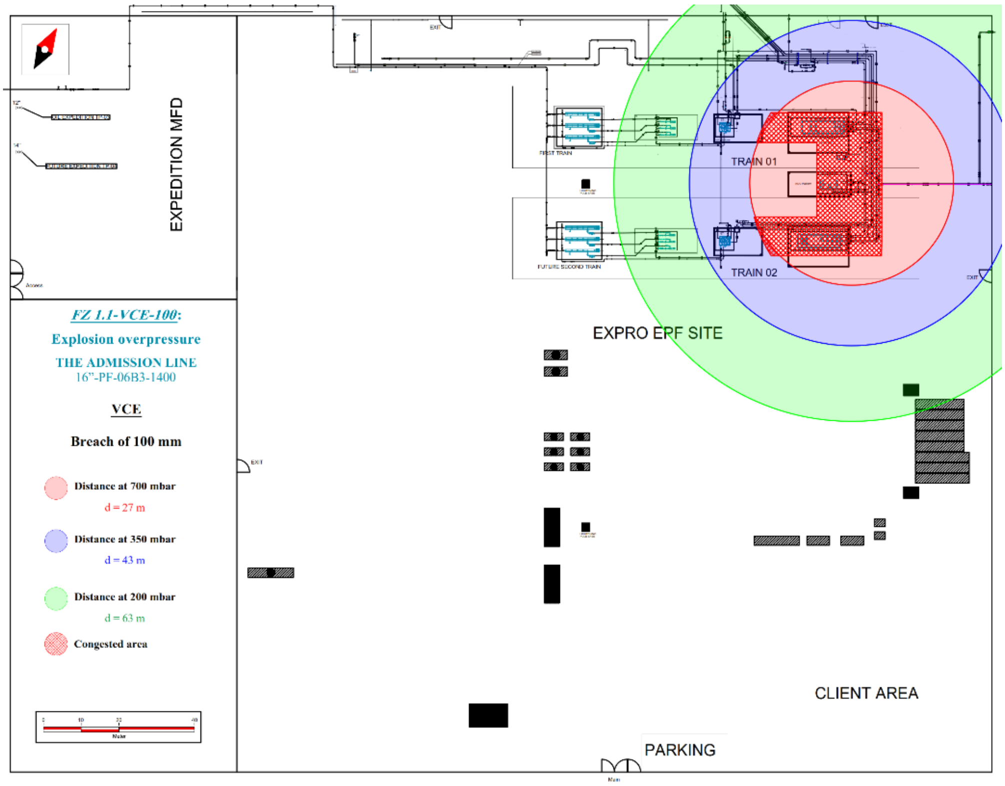


Figure D-9 Scenario FZ-1.1-VCE-100 modeling contours

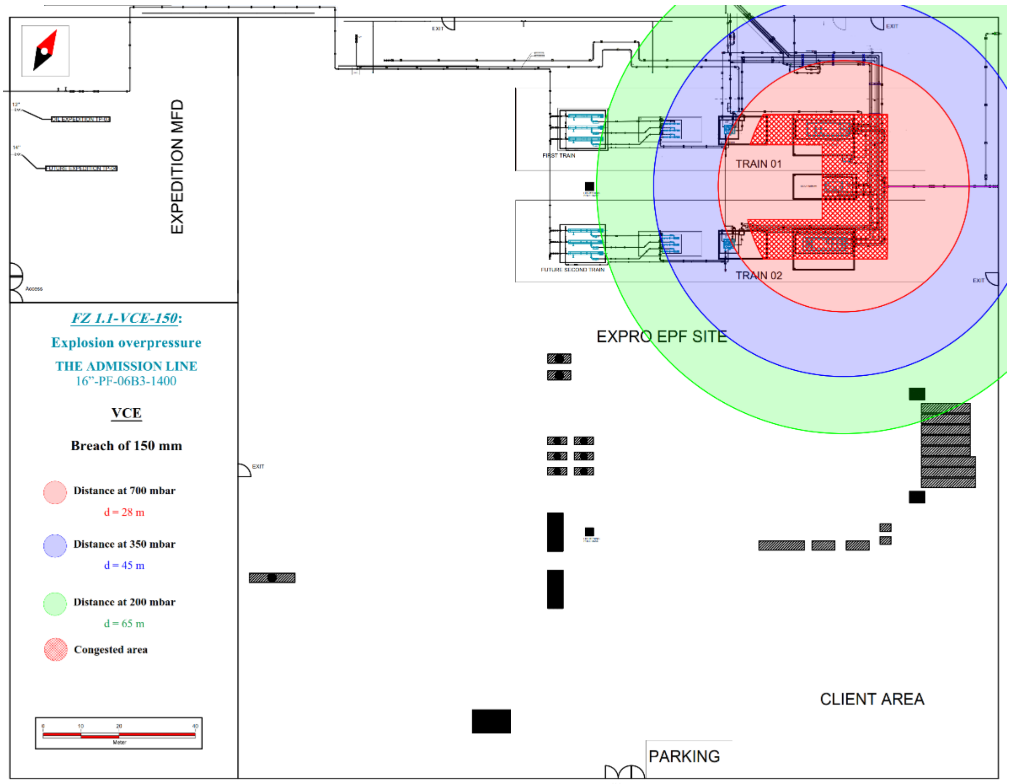


Figure D-10 Scenario FZ-1.1-VCE-150 modeling contours

D.2 Scenario N°1.2: Loss of Containment in the Admission Line 12”

Table D-5 Scenario FZ-1.2-005 modeling results

SMALL BREACH				
Description: The initiating event is the loss of containment of hydrocarbon liquid due to a small breach (5 mm) in the admission line 12”-PF-03B3-1401.				
Leak flow(Kg/s)	0.692			
Early Pool Fire with a 3.832 m diameter				
Atmospheric condition	Flame Height (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m	
Summer	4.3445	7.016	6.3	
Winter	4.2078	7.025	6.4	
Burning duration (s)	1619.9 (27 min)			
Late Pool Fire with a 8.088 m diameter				
Atmospheric condition	Flame Height (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m	
Summer	7.356	13.050	10.580	
Winter	7.244	13.110	10.900	
Burning duration (s)	134.78 (2 min 16 s)			
Vapor Cloud Explosion				
Amount of liquid released (Kg)	830.4			
Vaporization rate (Kg/s)	Summer	0.7578	Evaporated amount	227.34
	Winter	0.1612		48.3
Total volume of the cloud (m^3)	Summer	3085.3	Congested cloud volume (m^3)	757.444
	Winter	656.40		351.222
Cloud radius (m)	Summer	11.378		
	Winter	6.7926		
Atmospheric condition	Distance at200 mbar in (m)	Distance at 350 mbar in (m)	Distance at 700 mbar in (m)	
Summer	42	29	18	
Winter	33	22	14	

Table D-6 Scenario FZ-1.2-025 modeling results

MEDIUM BREACH					
Description: The central event is the loss of containment of hydrocarbon liquid due to an medium breach (25 mm) in the admission line 12”-PF-03B3-1401.					
Leak flow(Kg/s)	17.316				
Early Pool Fire with a 20.094 m diameter					
Atmospheric condition	Flame height (m)		Distance at 12.5 KW/m^2 in (m)		Distance at 37.5 KW/m^2 in (m)
Summer	13.696		25.485		9.9
Winter	13.265		25.562		15.5
Burning duration (s)	815.38 (13 min 35 s)				
Late Pool Fire with a 28.598 m diameter					
Atmospheric condition	Flame height (m)		Distance at 12.5 KW/m^2 in (m)		Distance at 37.5 KW/m^2 in (m)
Summer	20.266		34.530		0.5
Winter	19.629		34.760		3.940
Burning duration (s)	134.78 (2 min 15 s)				
Vapor Cloud Explosion					
Amount of liquid released (Kg)	10389				
Vaporization rate (Kg/s)	Summer	8.2445	Evaporated amount (Kg)		2473.4
	Winter	1.7541			526.2
Total volume of the cloud (m^3)	Summer	33567	Congested cloud volume (m^3)		1821.824
	Winter	7141.5			1071.237
Cloud radius (m)	Summer	25.213			
	Winter	15.051			
Atmospheric condition	Distance at 200 mbar in (m)		Distance at 350 mbar in (m)		Distance at 700 mbar in (m)
Summer	56		39		24
Winter	47		32		20

Table D-7 Scenario FZ-1.2-100 modeling results

<table>
<tr><th colspan="5">LARGE BREACH</th></tr>
<tr><td colspan="5">Description: The central event is the loss of containment of hydrocarbon liquid due to a large breach (100 mm) in the admission line 12”-PF-03B3-1401.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="4">226.524</td></tr>
<tr><td colspan="5">Pool Fire with a 35.487 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">22.025</td><td>40.860</td><td>0.600</td></tr>
<tr><td>Winter</td><td colspan="2">21.604</td><td>41.700</td><td>3.600</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">135.82 (2 min 17 s)</td></tr>
<tr><td colspan="5">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="4">33 9786</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>19.041</td><td rowspan="2">Evaporated amount (Kg)</td><td>5712.2</td></tr>
<tr><td>Winter</td><td>4.051</td><td>1215.3</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>77523</td><td rowspan="2">Congested cloud volume (m^3)</td><td>2498.66</td></tr>
<tr><td>Winter</td><td>16493</td><td>1438.82</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="3">33.327</td></tr>
<tr><td>Winter</td><td colspan="3">19.895</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td>Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">62</td><td>43</td><td>27</td></tr>
<tr><td>Winter</td><td colspan="2">51</td><td>36</td><td>22</td></tr>
</table>

Table D-8 Scenario FZ-1.2-150 modeling results

<table>
<tr><th colspan="4">CATASTROPHIC BREACH</th></tr>
<tr><td colspan="4">Description: The initiating event is the loss of containment of hydrocarbon liquid due to a catastrophic breach (>150 mm) in the admission line 12”-PF-03B3-1401.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="3">558.58</td></tr>
<tr><td colspan="4">Pool Fire with a 51.386 m diameter</td></tr>
<tr><td>Atmospheric condition</td><td>Flame height (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td>22.182</td><td>76.100</td><td>N/A</td></tr>
<tr><td>Winter</td><td>21.522</td><td>76.350</td><td>N/A</td></tr>
</table>

<table>
<tr><td>Burning duration (s)</td><td colspan="5">134.67 (2 min 14 s)</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of Liquid released (Kg)</td><td colspan="5">33 514,8</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>24.956</td><td colspan="2" rowspan="2">Evaporated amount (Kg)</td><td>7 486,8</td></tr>
<tr><td>Winter</td><td>5.309</td><td>1 592,7</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>101610</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>2913.668</td></tr>
<tr><td>Winter</td><td>21617</td><td>1558.824</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">36.472</td></tr>
<tr><td>Winter</td><td colspan="4">21.773</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">65</td><td colspan="2">45</td><td>28</td></tr>
<tr><td>Winter</td><td colspan="2">53</td><td colspan="2">37</td><td>23</td></tr>
</table>

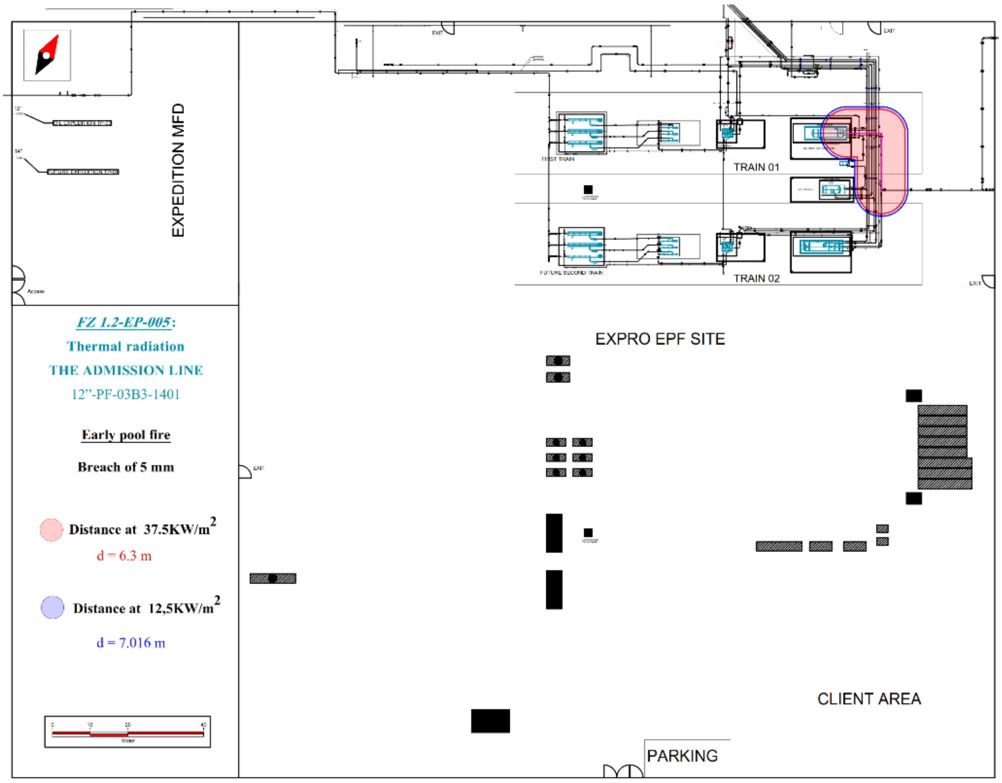


Figure D-11 Scenario FZ-1.2-EP-005 modeling contours

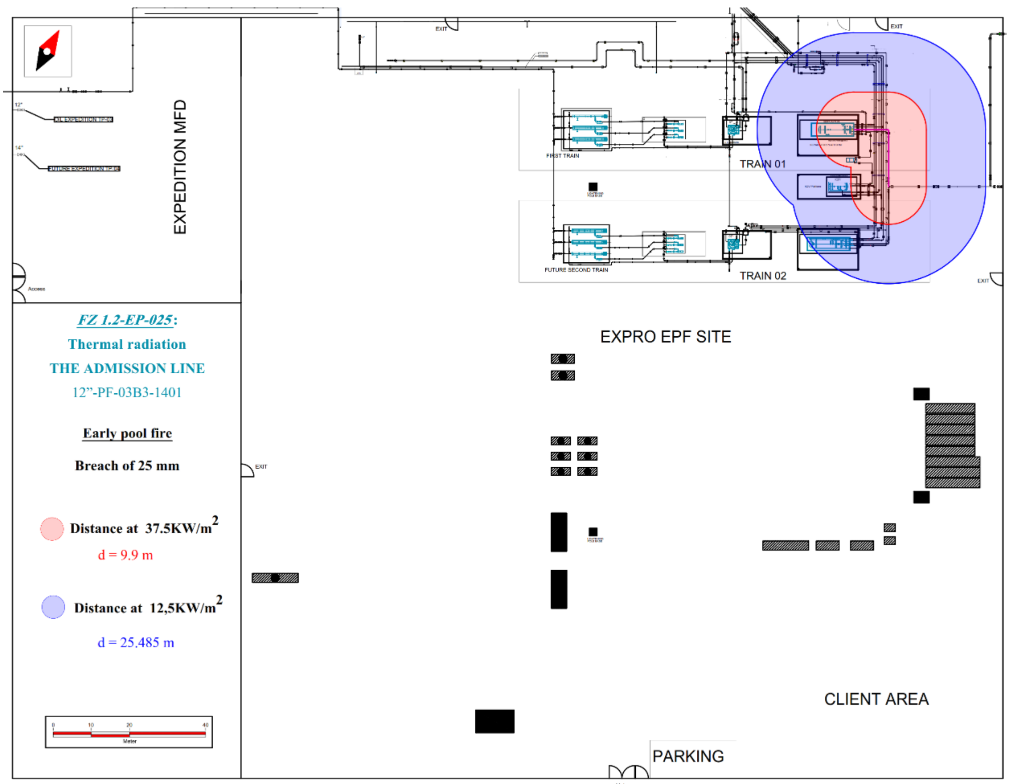


Figure D-12 Scenario FZ-1.2-EP-025 modeling contours

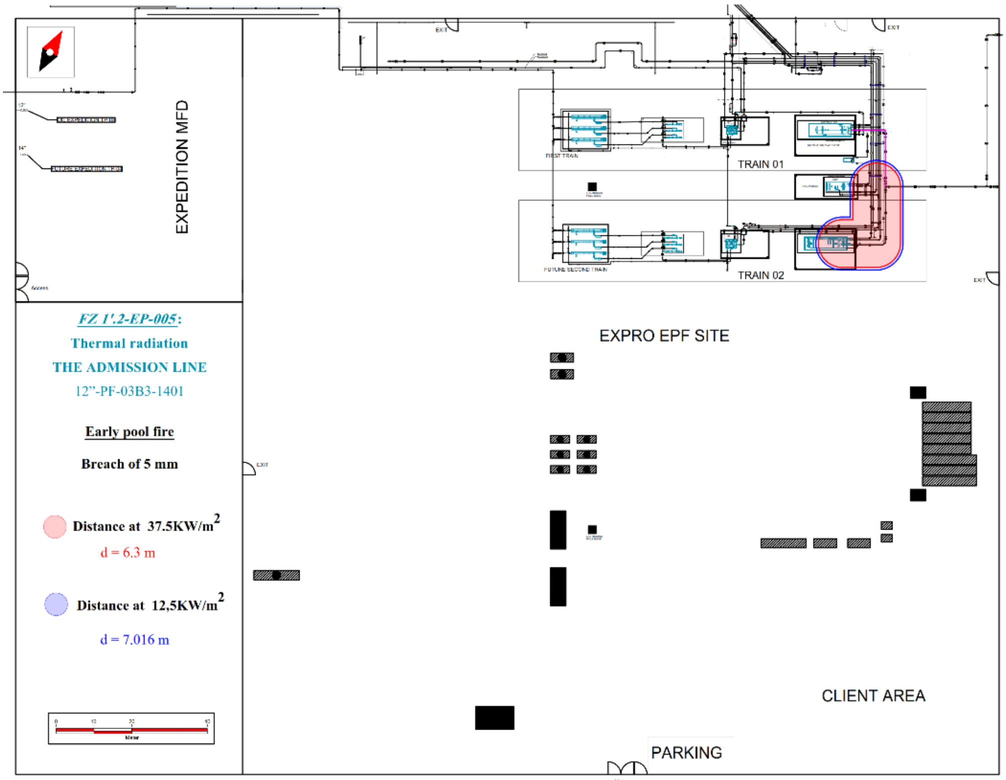


Figure D-13 Scenario FZ-1.2'-EP-005 modeling contours

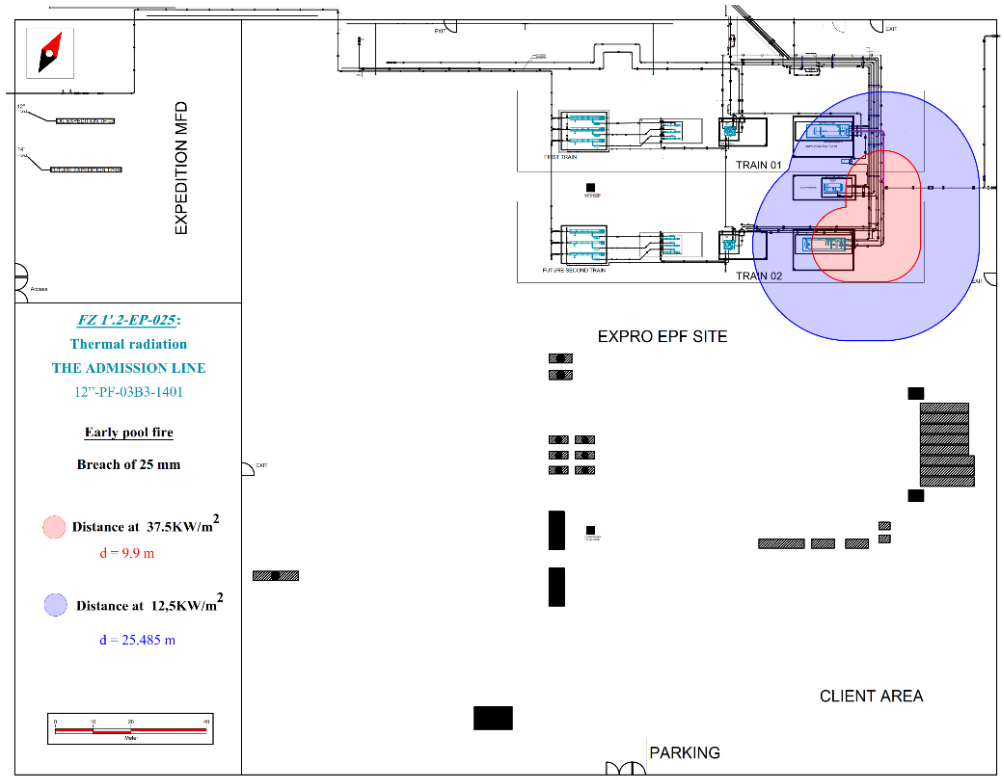


Figure D-14 Scenario FZ-1.2'-EP-025 modeling contours

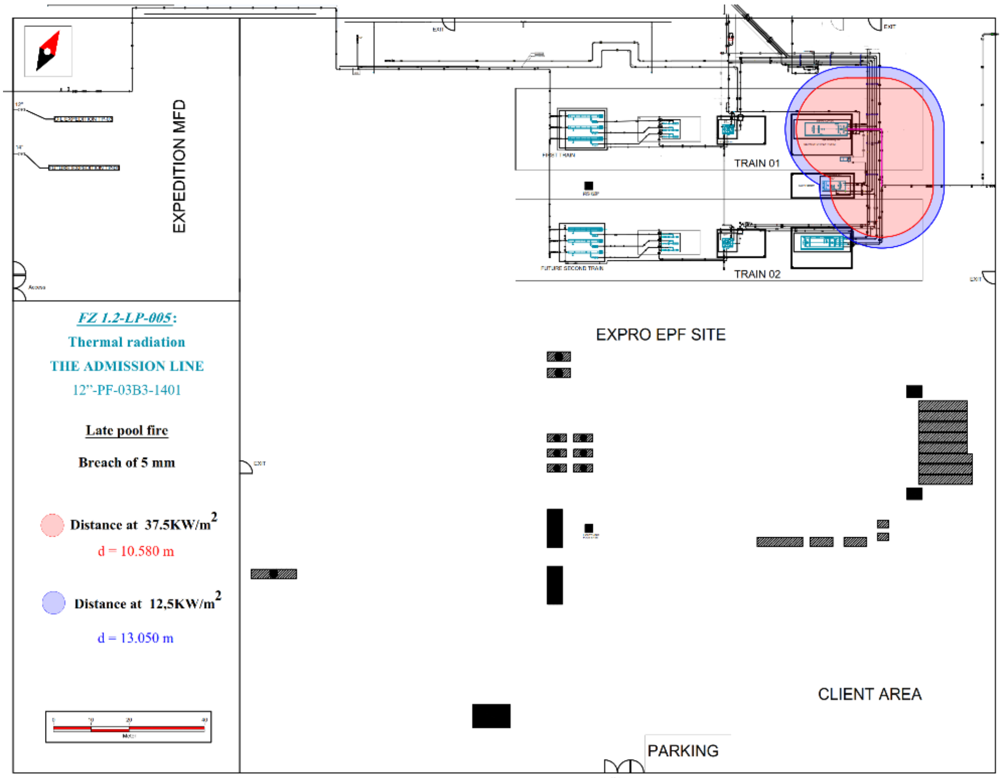


Figure D-15 Scenario FZ-1.2-LP-005 modeling contours

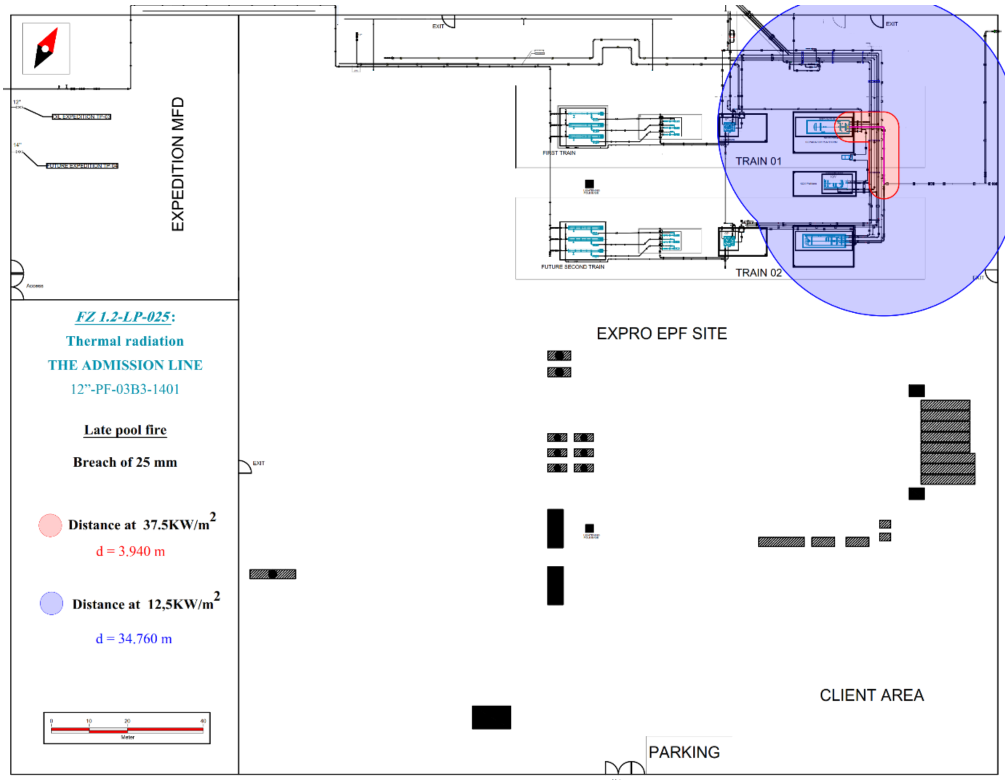


Figure D-16 Scenario FZ-1.2-LP-025 modeling contours

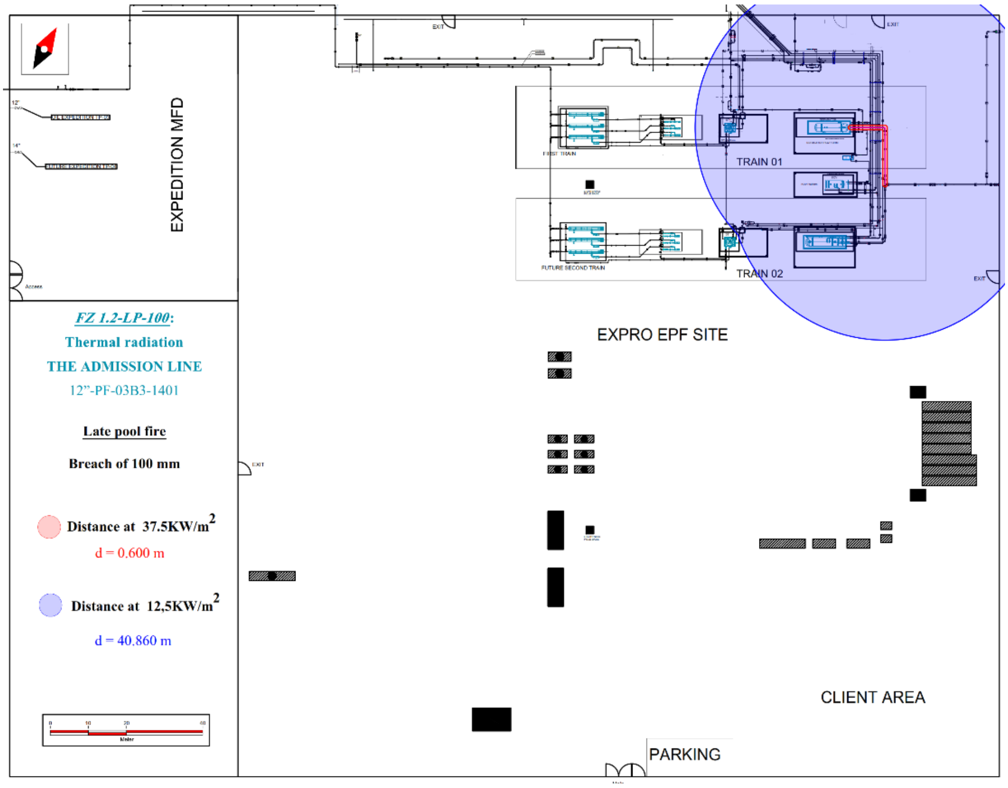


Figure D-17 Scenario FZ-1.2-LP-100 modeling contours

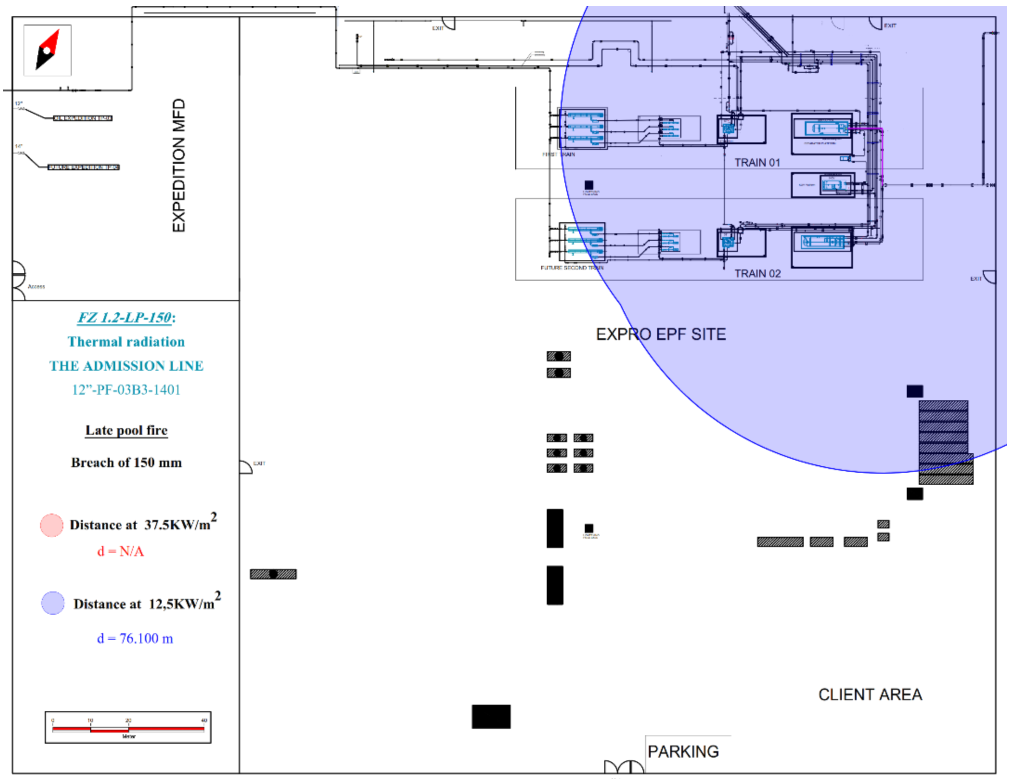


Figure D-18 Scenario FZ-1.2-LP-150 modeling contours

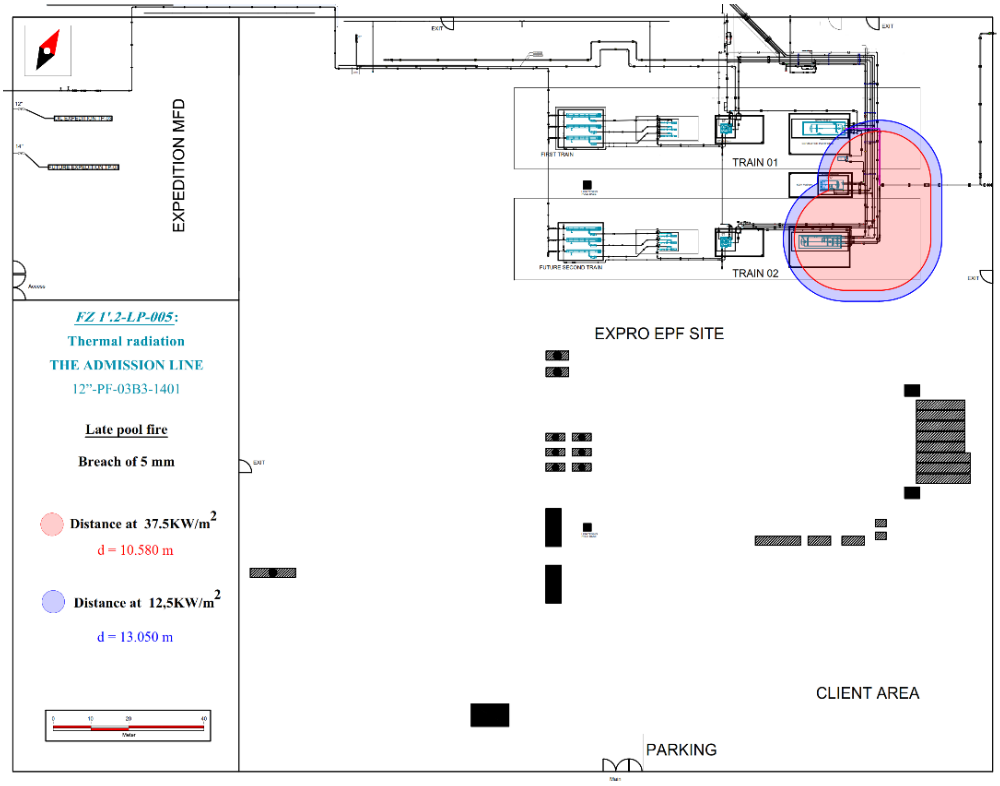
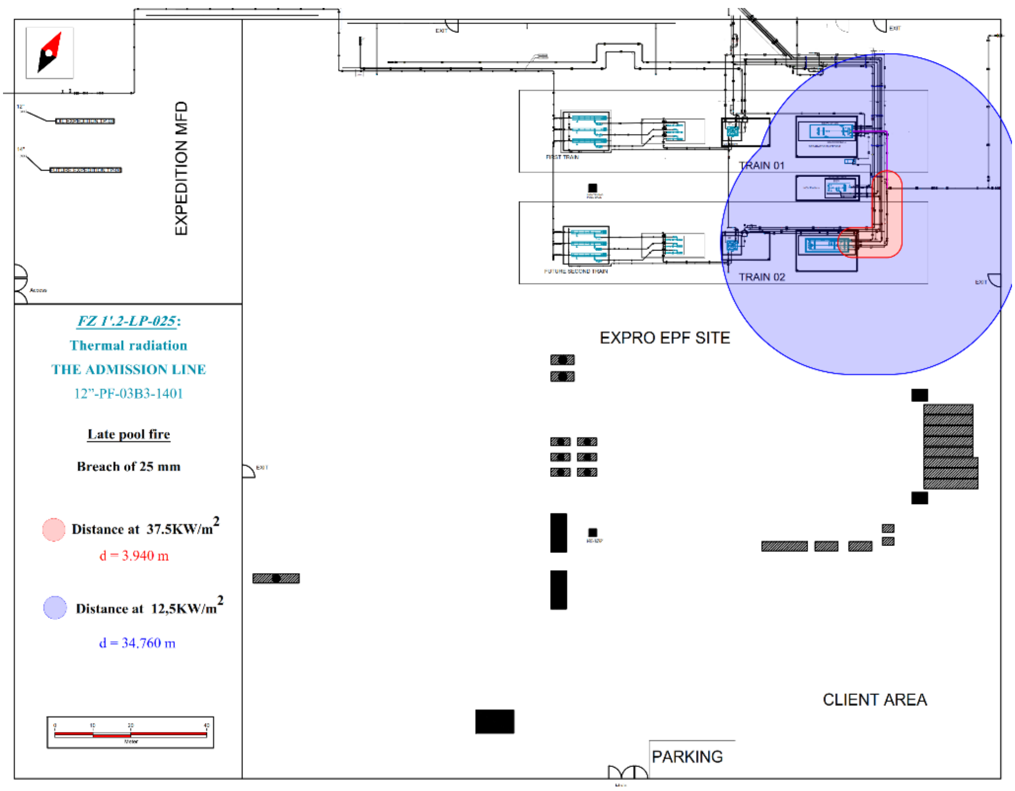


Figure D-19 Scenario FZ-1.2'-LP-005 modeling contours



Appendix Figure D-20 Scenario FZ-1.2'-LP-025 modeling contours

Appendix D. Consequences analysis modeling results

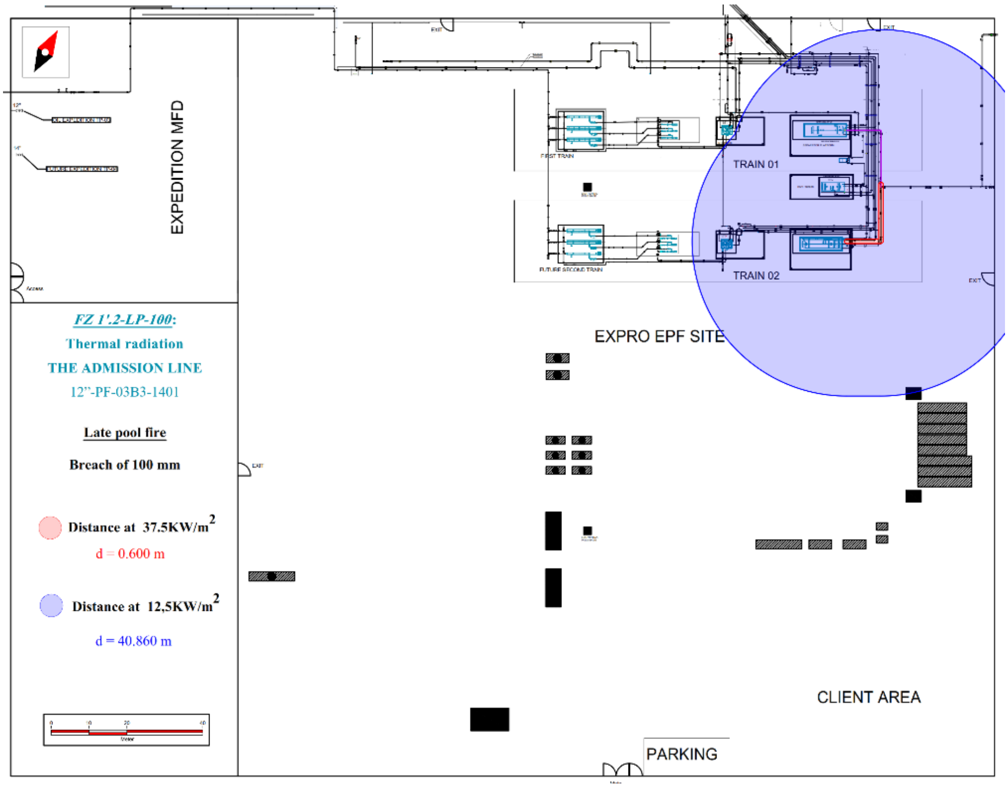


Figure D-21 Scenario FZ-1.2'-LP-100 modeling contours

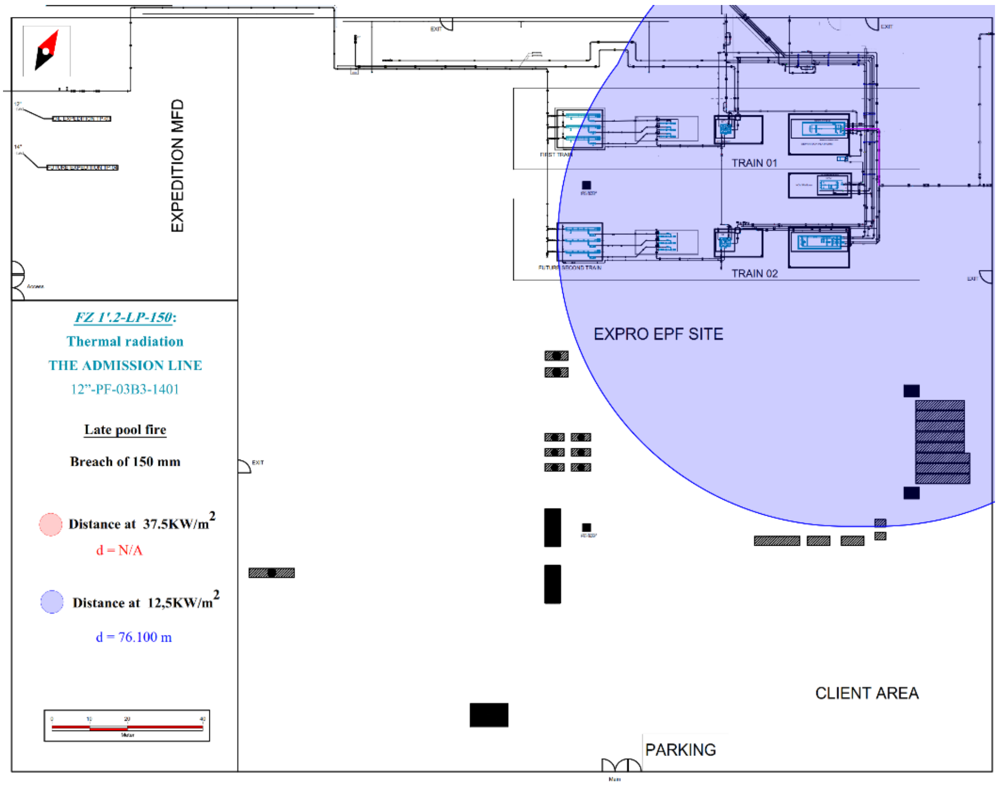


Figure D-22 Scenario FZ-1.2'-LP-150 modeling contours

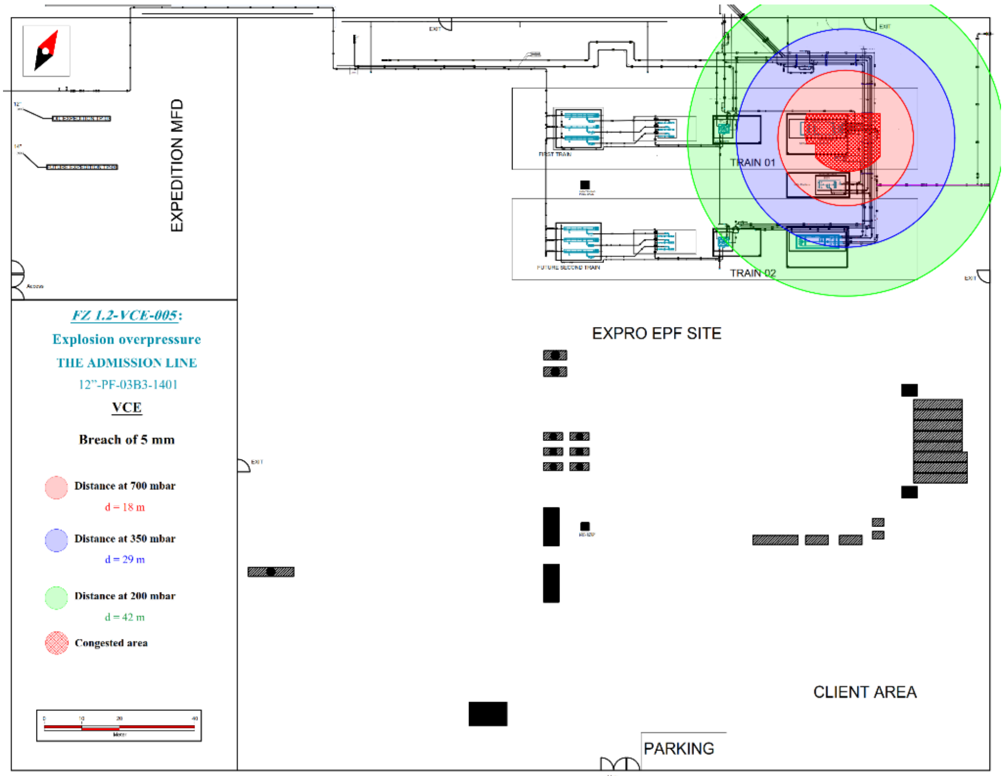


Figure D-23 Scenario FZ-1.2-VCE-005 modeling contours

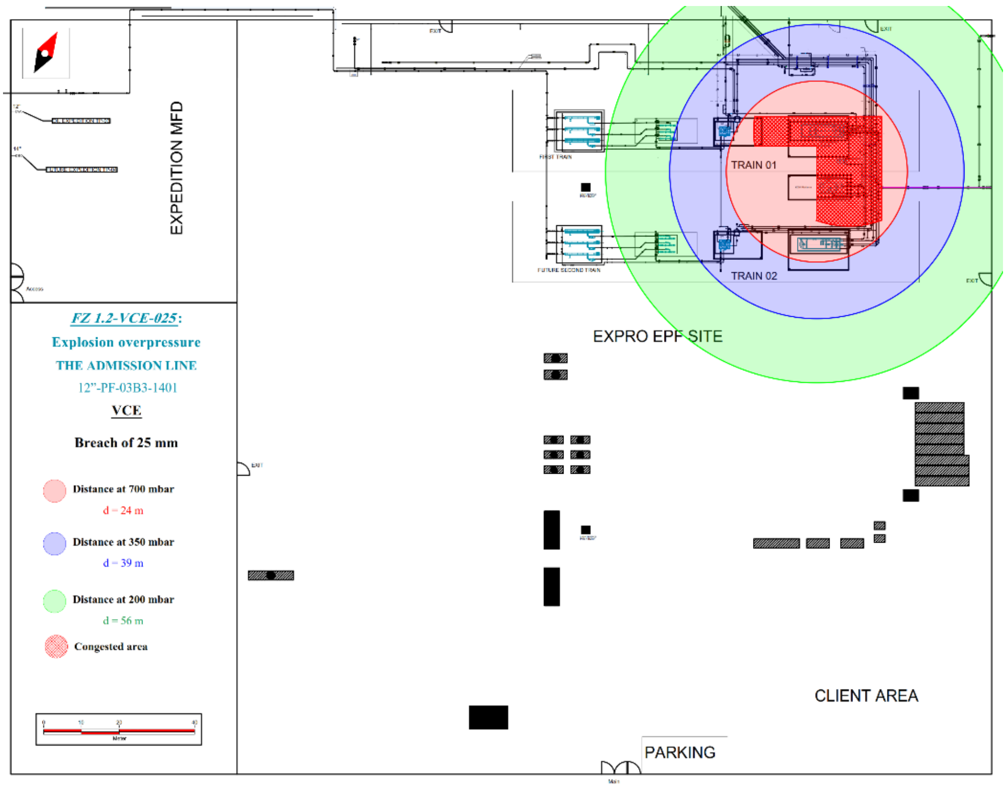


Figure D-24 Scenario FZ-1.2-VCE-025 modeling contours

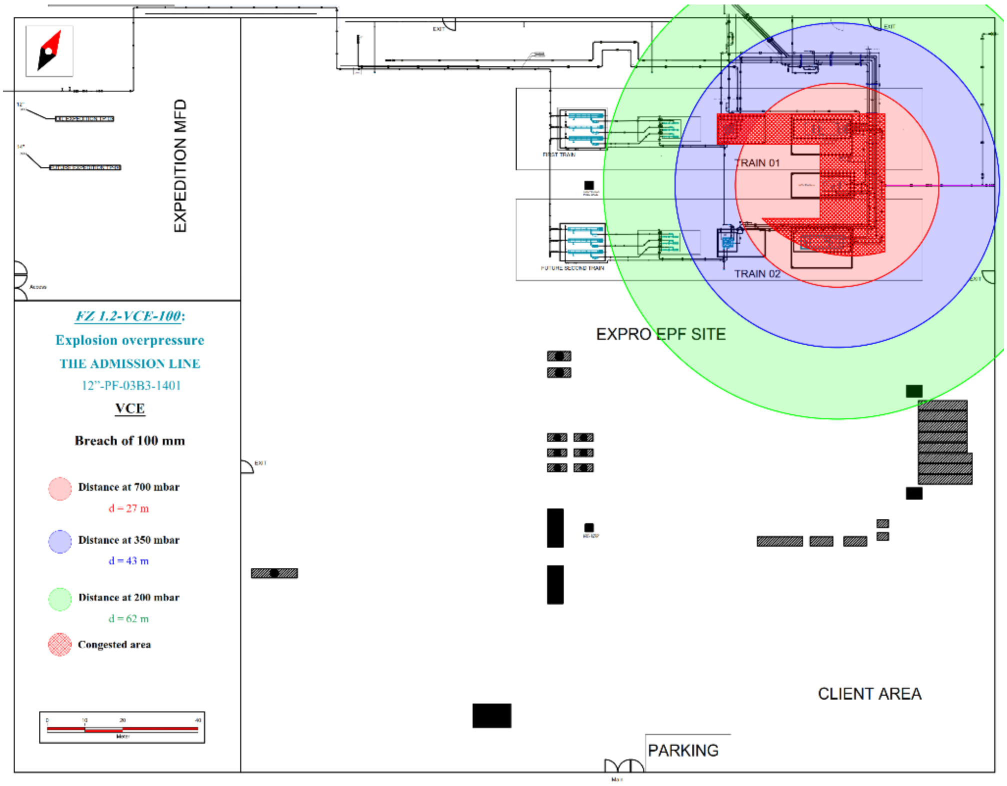


Figure D-25 Scenario FZ-1.2-VCE-100 modeling contours

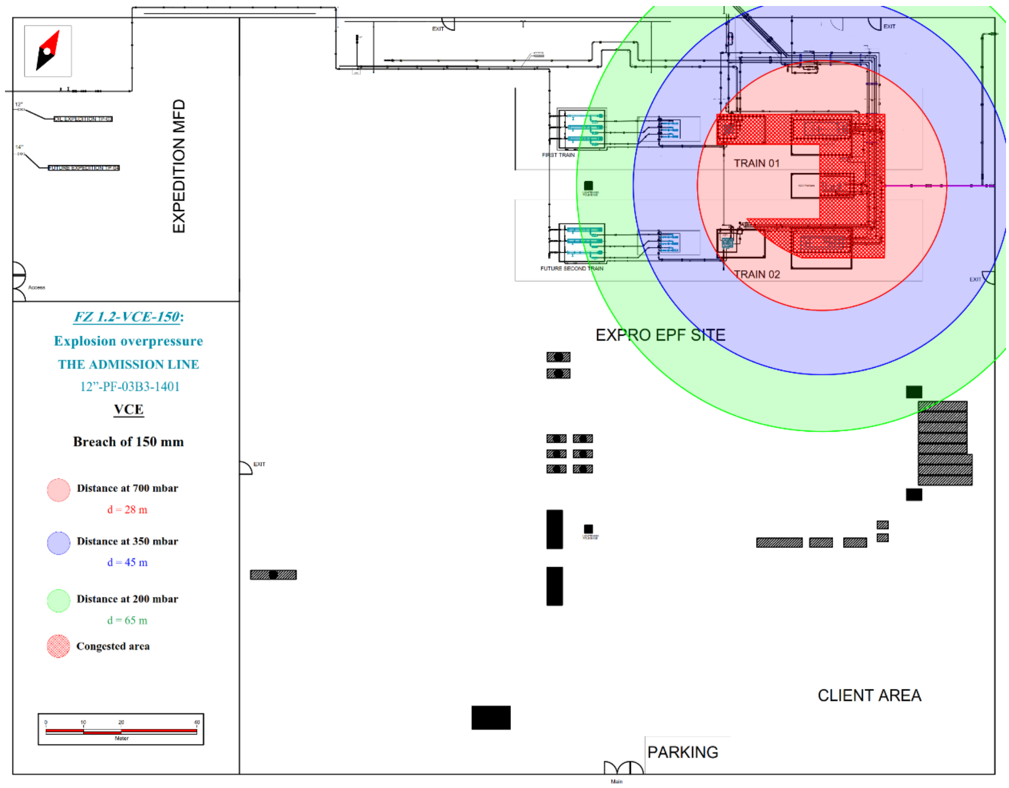


Figure D-26 Scenario FZ-1.2-VCE-150 modeling contours

Appendix D. Consequences analysis modeling results

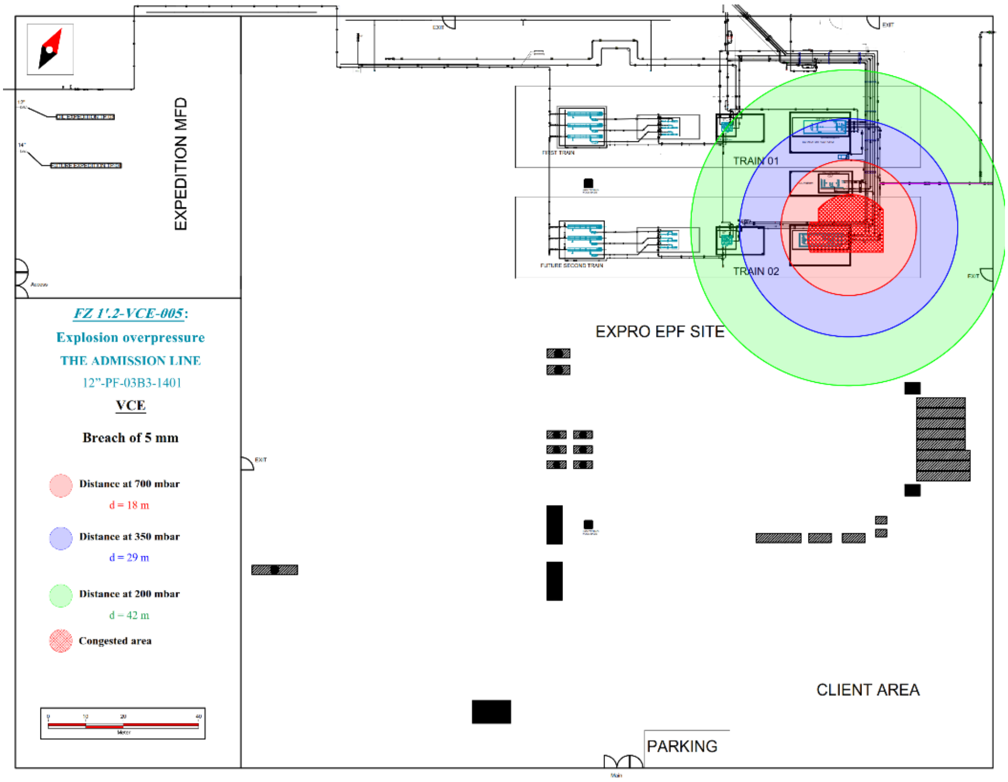


Figure D-27 Scenario FZ-1.2'-VCE-005 modeling contours

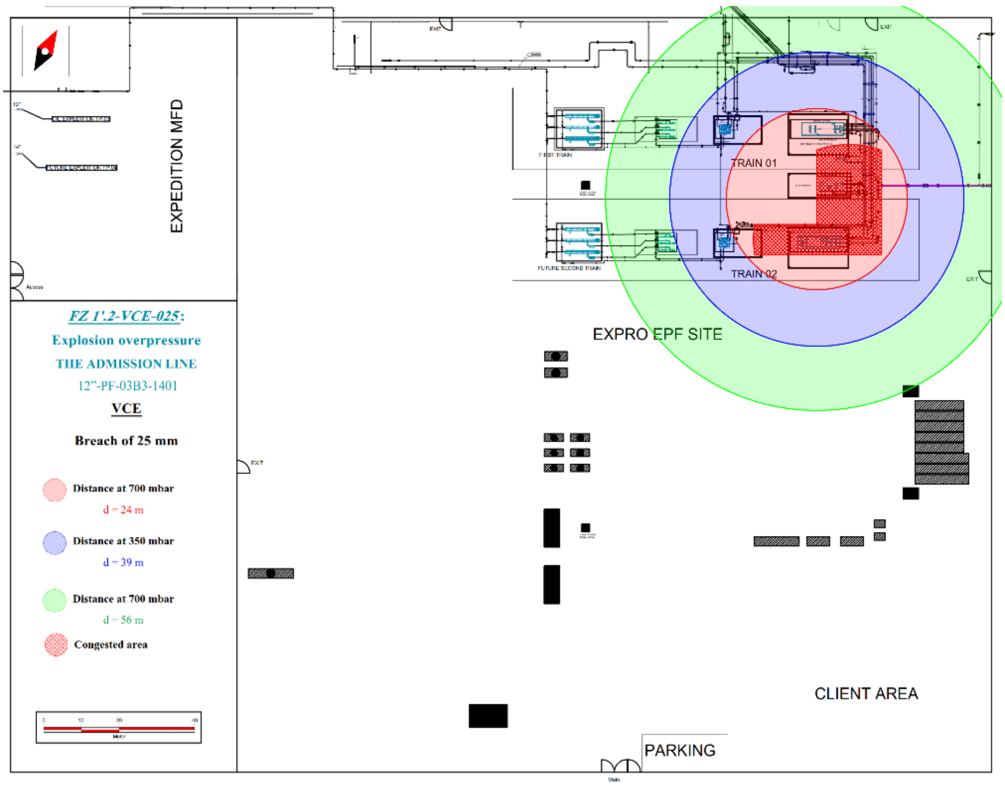


Figure D-28 Scenario FZ-1.2'-VCE-025 modeling contours

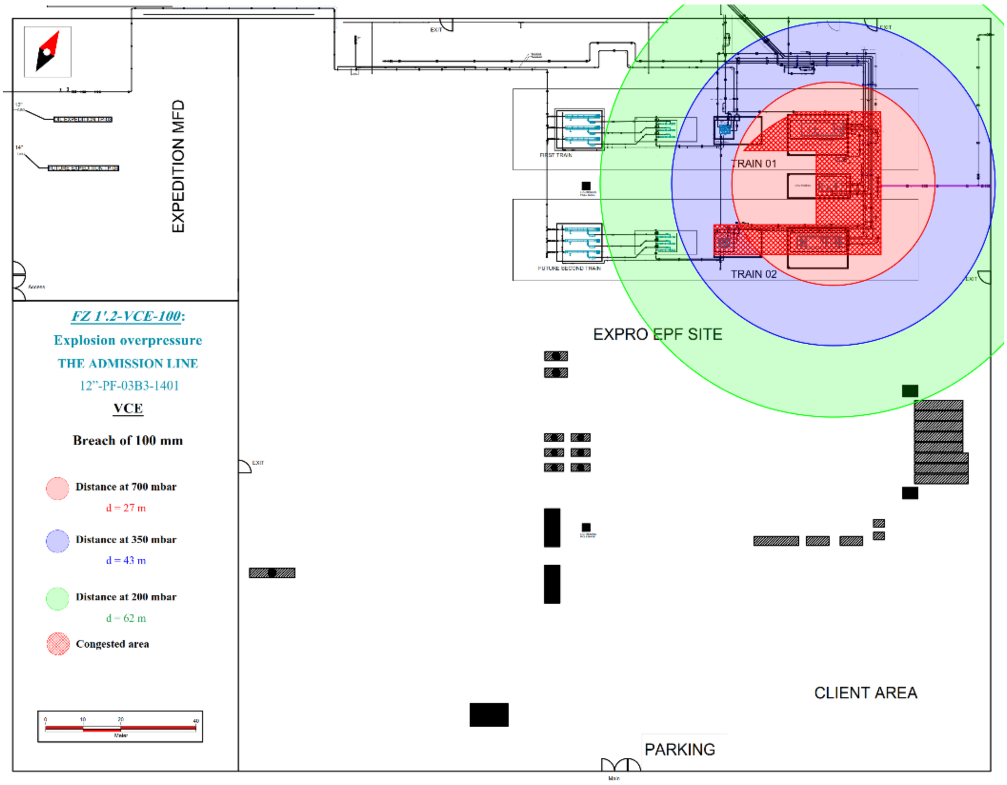


Figure D-29 Scenario FZ-1.2'-VCE-100 modeling contours

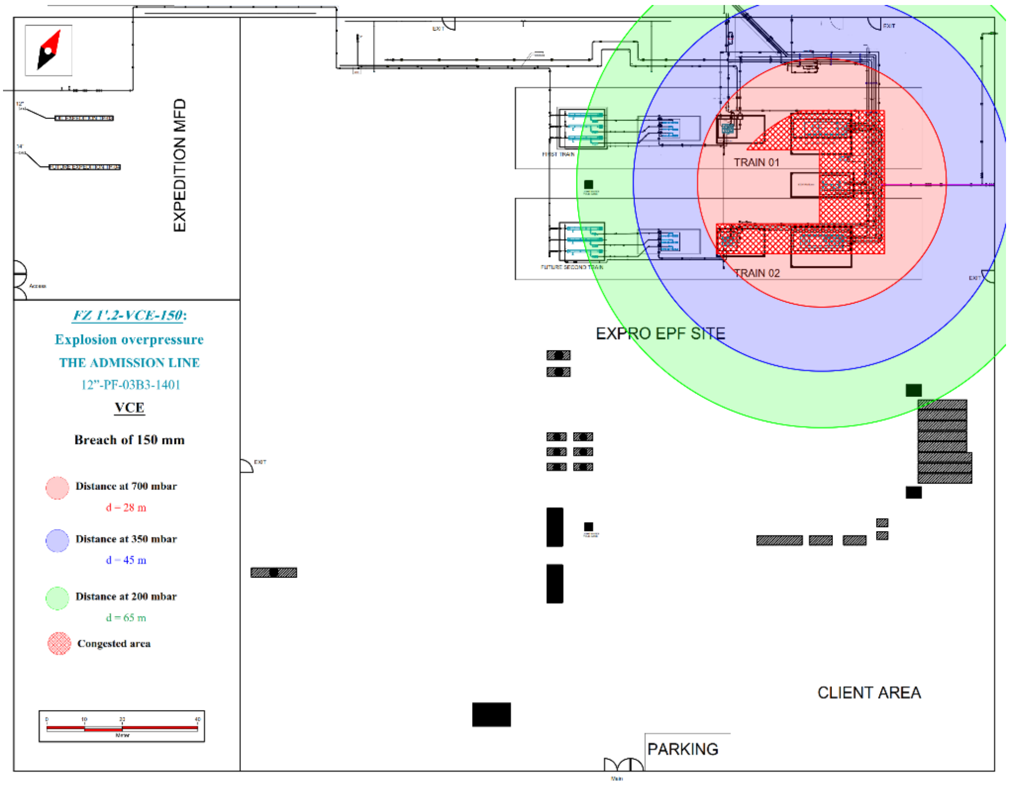


Figure D-30 Scenario FZ-1.2'-VCE-150 modeling contours

D.3 Scenario N 2.1: Loss of Containment in the Separator TX1H-046 Part Liquid

Equipment : Separator TX1H-046		
Description	The TX1H-046 three-phase separator ensures the separation of the received crude oil into three phases: gas, oil and water	
Design parameter	Dimension	2.134 m/8.8 m
Operating parameter	Pressure	150 psia (10,3421 bar)
	Temperature	100 °F
Substance	Gas / Oil / Water	

For the modeling of the effects, we first consider that the TX1H-046 separator filled with oil in a conservative way and then filled with gas.

Table D-9 Scenario FZ-2.1-005 modeling results

SMALL BREACH			
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a small breach (5mm) in the TX1H-046 separator.			
Leak flow(Kg/s)	0.4641		
Early Pool Fire with a 3.137 m diameter			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m)
Summer	3.751	5.763	5.4
Winter	3.63	5.763	5.3
Burning duration (s)	1706.2 (28 min 26 s)		
Late Pool fire with a 6.61 m diameter			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m
Summer	7.651	14.600	12.483
Winter	7.410	14.502	12.467
Burning duration (s)	134.65 (2 min 14 s)		
Vapor cloud explosion			
Amount of liquid released (Kg)	556.92		

	Summer	0.518		311.21

Vaporization rate (Kg/s)	Winter	0.110	Evaporated amount(Kg)	33.106
Total volume of the cloud (m^3)	Summer	4223.6	Congested cloud volume (m^3)	598.444
	Winter	449.29		264.444
Cloud radius (m)	Summer	10		
	Winter	5.986		

Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m
Summer	39	27	17
Winter	31	21	13

Table D-10 Scenario FZ-2.1-025/100/150 modeling results

MEDIUM/LARGE/CATASTROPHIC BREACHES				
Description: The central feared event is the loss of containment of liquid hydrocarbon due to a breach (25/100/150mm) in the TX1H-046 separator in presence of retention dike (Rectangular flame shape).				
Breach sizes	Leak flow (Kg/s)			
25mm	11.602			
100mm	185.62			
150mm	673.64			
Pool fire with a 14.602 m equivalent diameter				
Atmospheric condition	Dike width (m)	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m
Summer	10.59	11.612	4.800	N/A
	15.3		5.400	N/A
Winter	10.59	11.247	5.600	N/A
	15.3		6.300	N/A
Early pool fire				
Breach sizes	Burning duration (s)			
25mm	962.26 (16 min)			
100mm	5812.2 (96 min 50s)			
Late Pool fire				
Breach sizes	Burning duration (s)			
25mm	692.90 (11 min 31 s)			
100mm	5542.8 (92 min 21 s)			

<table>
<tr><td>150mm</td><td colspan="5">4020.2 (67 min)</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td rowspan="3">Amount of liquid released (Kg)</td><td>25mm</td><td colspan="4">6960</td></tr>
<tr><td>100mm</td><td colspan="4">27 843</td></tr>
<tr><td>150mm</td><td colspan="4">40598.4</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>1.202</td><td rowspan="2" colspan="2">Evaporated amount (Kg)</td><td>360.62</td></tr>
<tr><td>Winter</td><td>0.255</td><td>76.724</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>4894.2</td><td rowspan="2" colspan="2">Congested cloud volume (m^3)</td><td>918.444</td></tr>
<tr><td>Winter</td><td>1041.2</td><td>413.237</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">13.27</td></tr>
<tr><td>Winter</td><td colspan="4">7.922</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in m</td><td colspan="2">Distance at 350 mbar in m</td><td>Distance at 700 mbar in m</td></tr>
<tr><td>Summer</td><td colspan="2">45</td><td colspan="2">31</td><td>19</td></tr>
<tr><td>Winter</td><td colspan="2">35</td><td colspan="2">24</td><td>15</td></tr>
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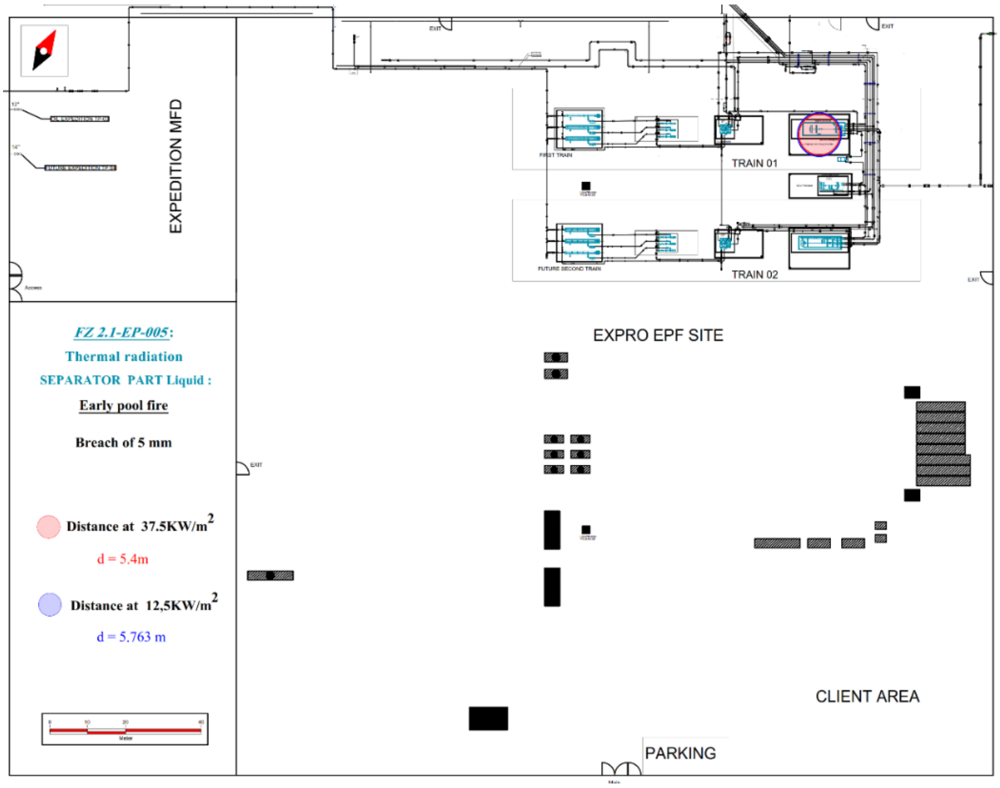

Figure D-31 Scenario FZ-2.1-EP-005 modeling contours

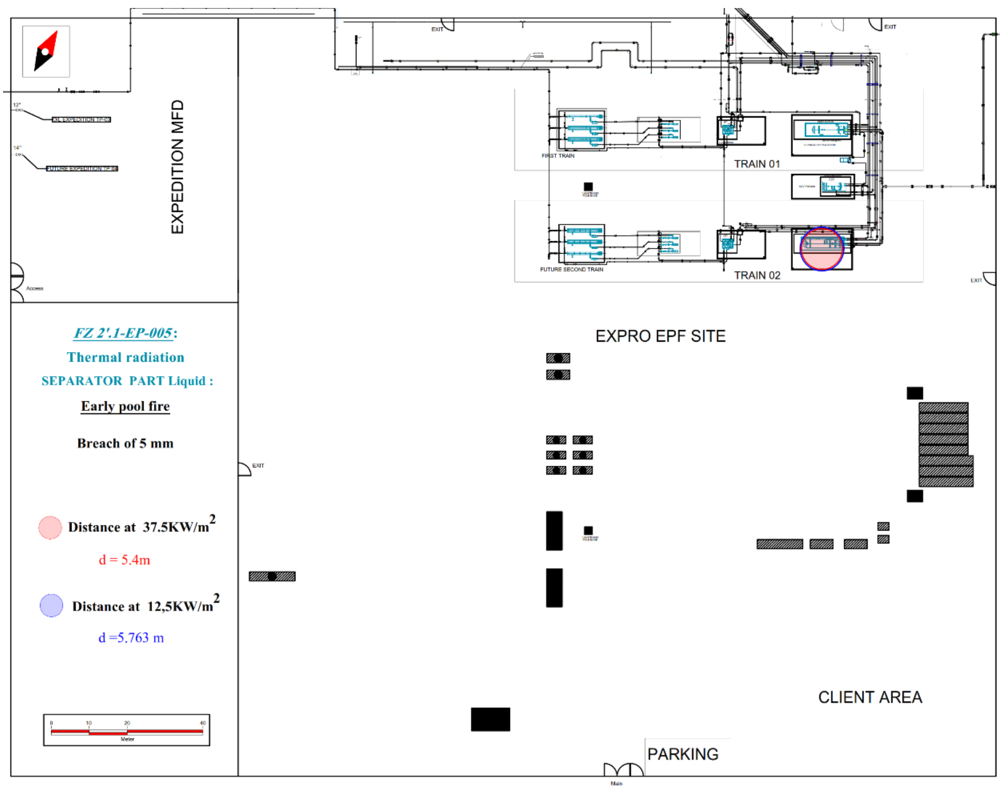

Figure D-32 Scenario FZ-2.1’-EP-005 modeling contours

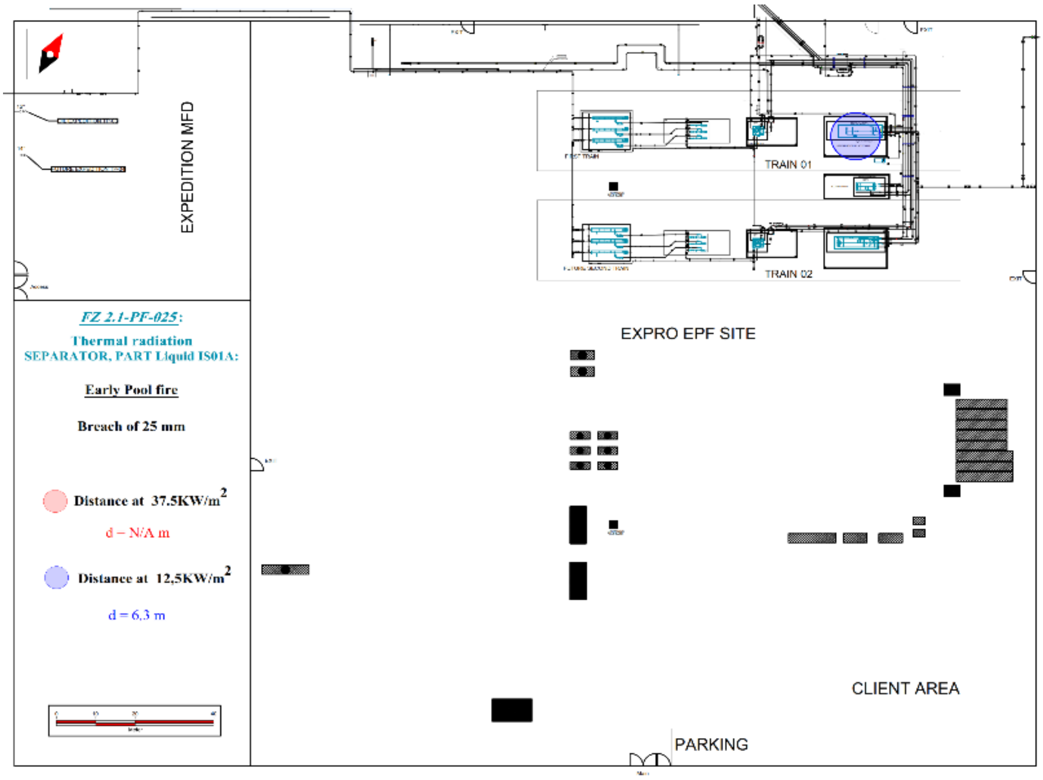

Figure D-33 Scenario FZ-2.1-EP-025 modeling contours

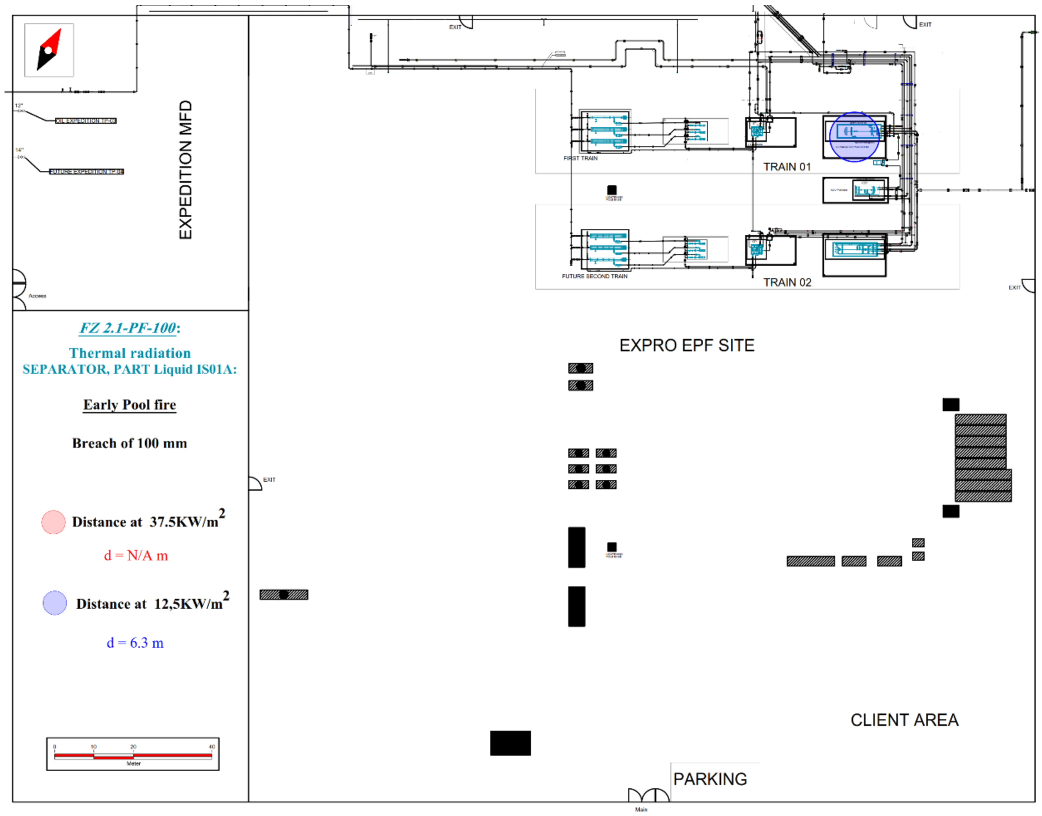

Figure D-34 Scenario FZ-2.1-EP-100 modeling contours

Appendix D. Consequences analysis modeling results

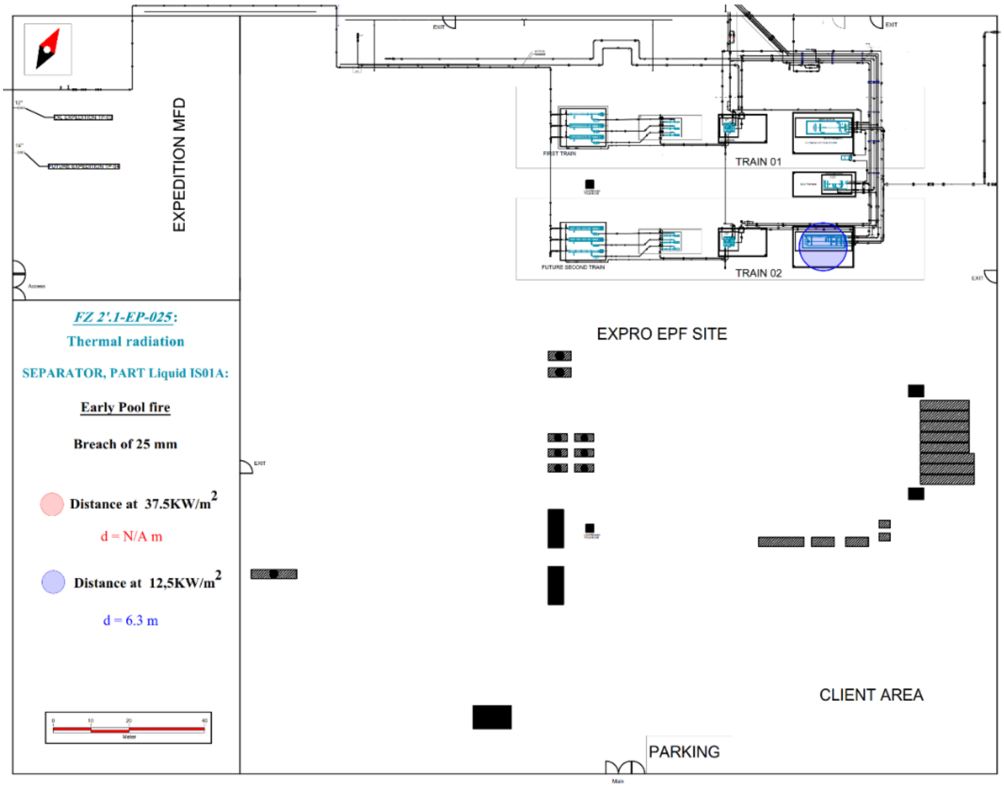

Figure D-35Scenario FZ-2'.1-EP-025 modeling contours

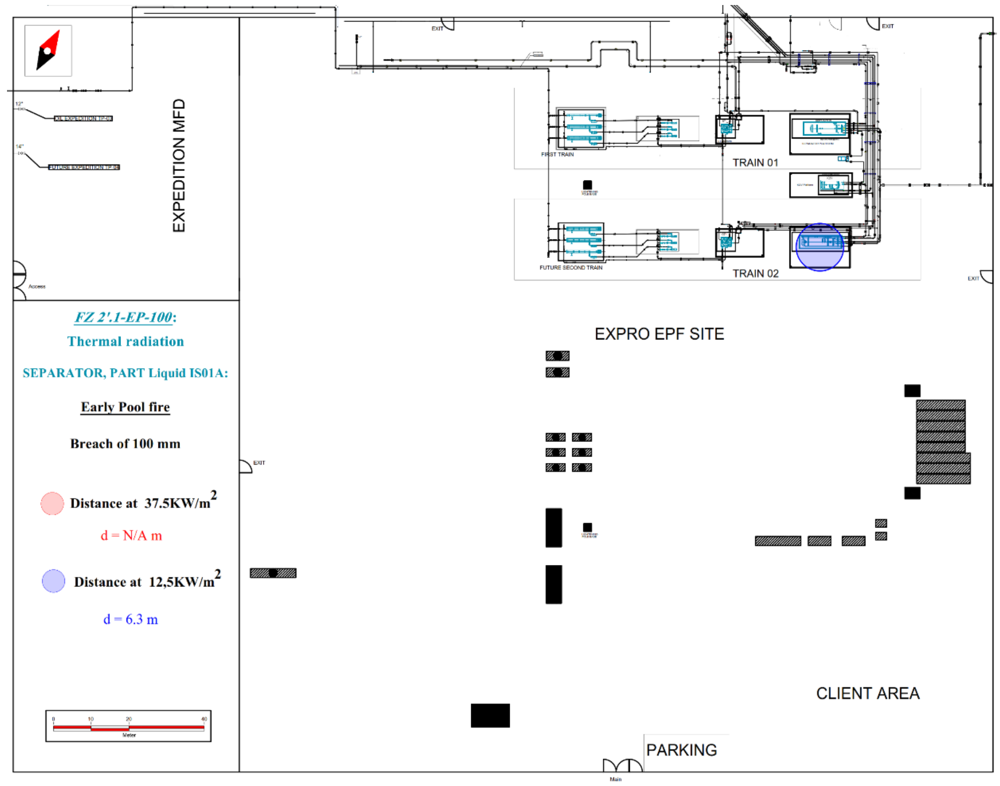

Figure D-36 Scenario FZ-2'.1-EP-100 modeling contours

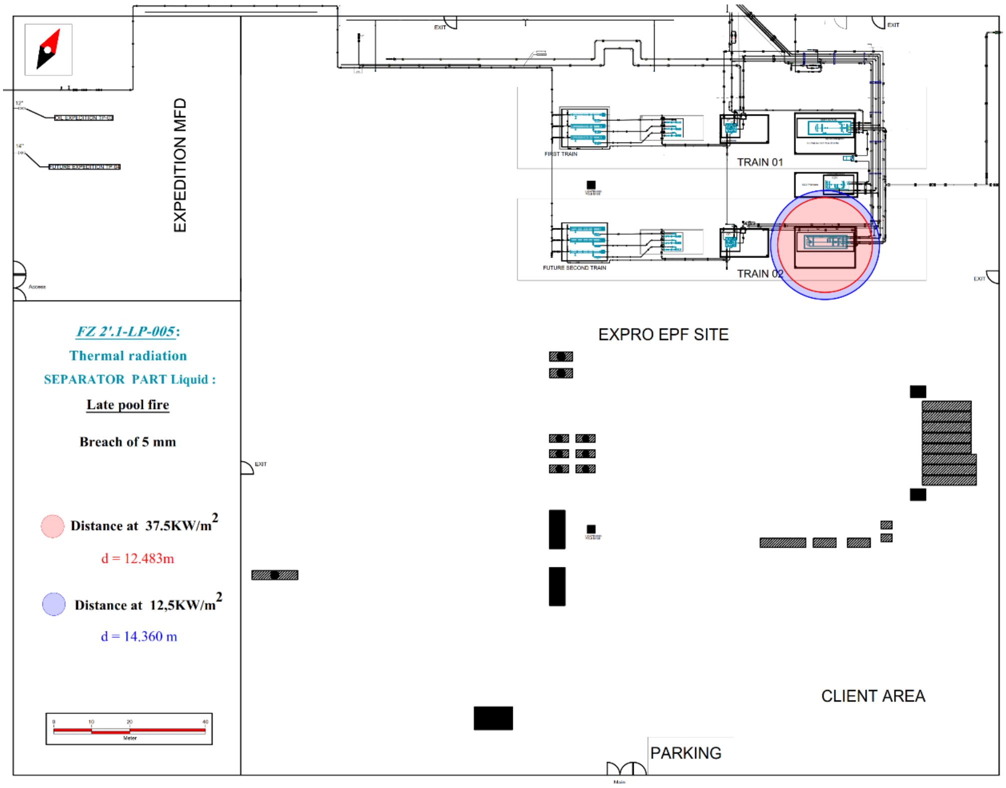

Figure D-37 Scenario FZ-2'.1-LP-005 modeling contours

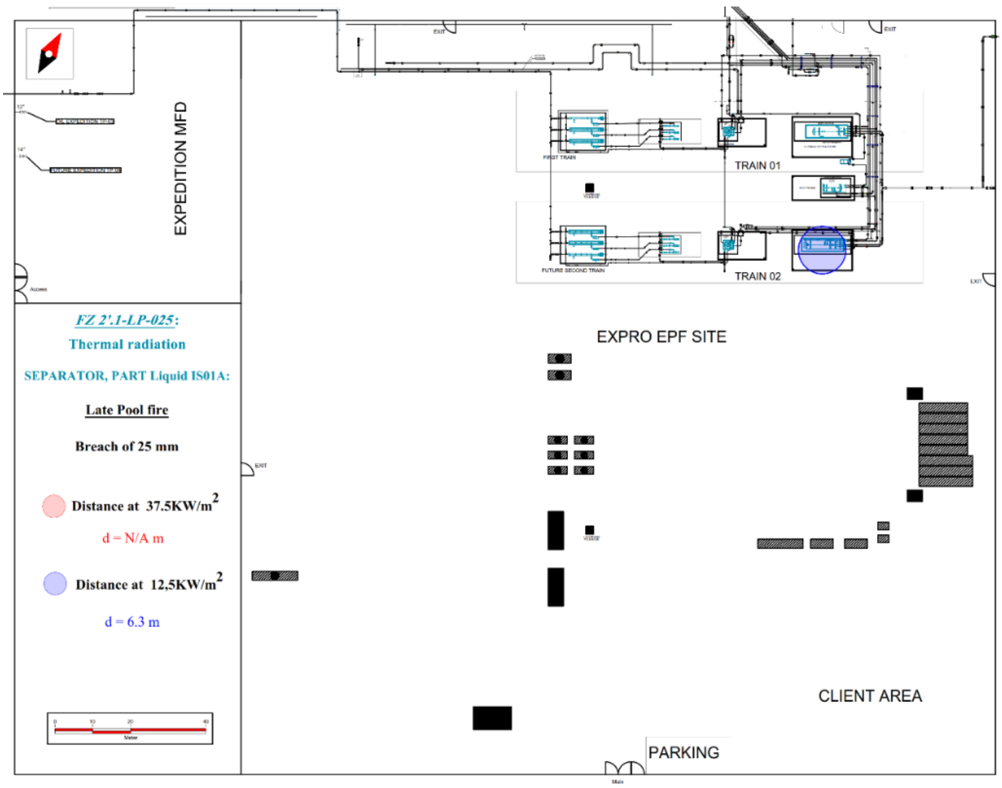

Figure D-38 Scenario FZ-2’.1-LP-025 modeling contours

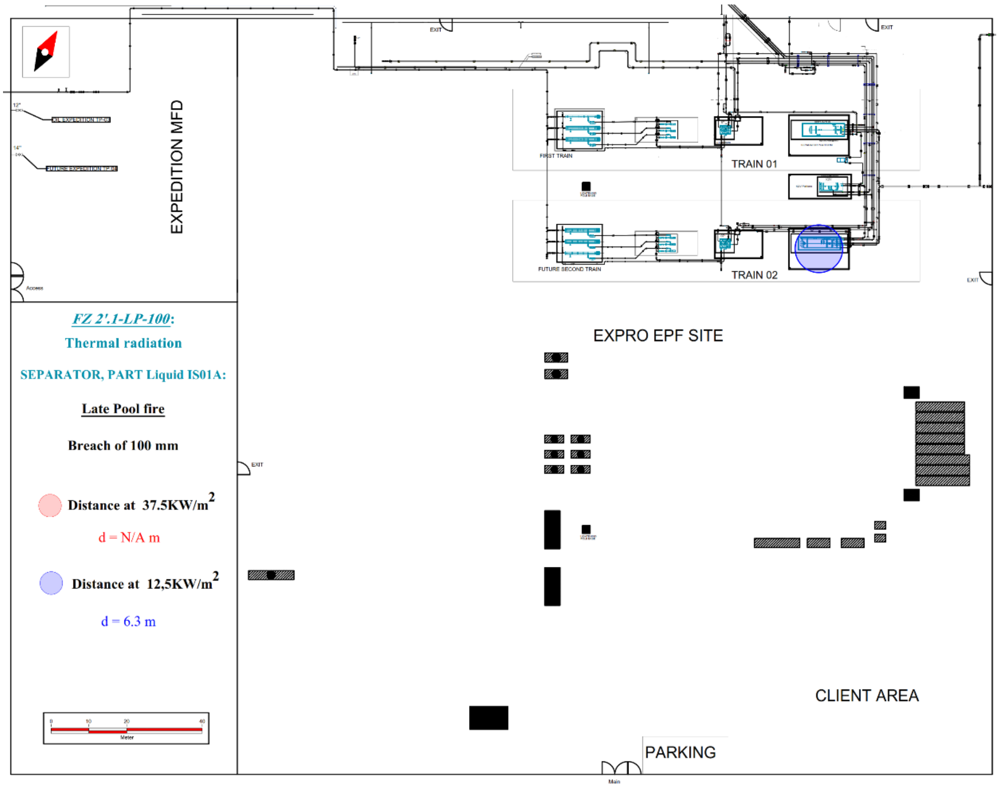

Figure D-39 Scenario FZ-2'.1-LP-100 modeling contours

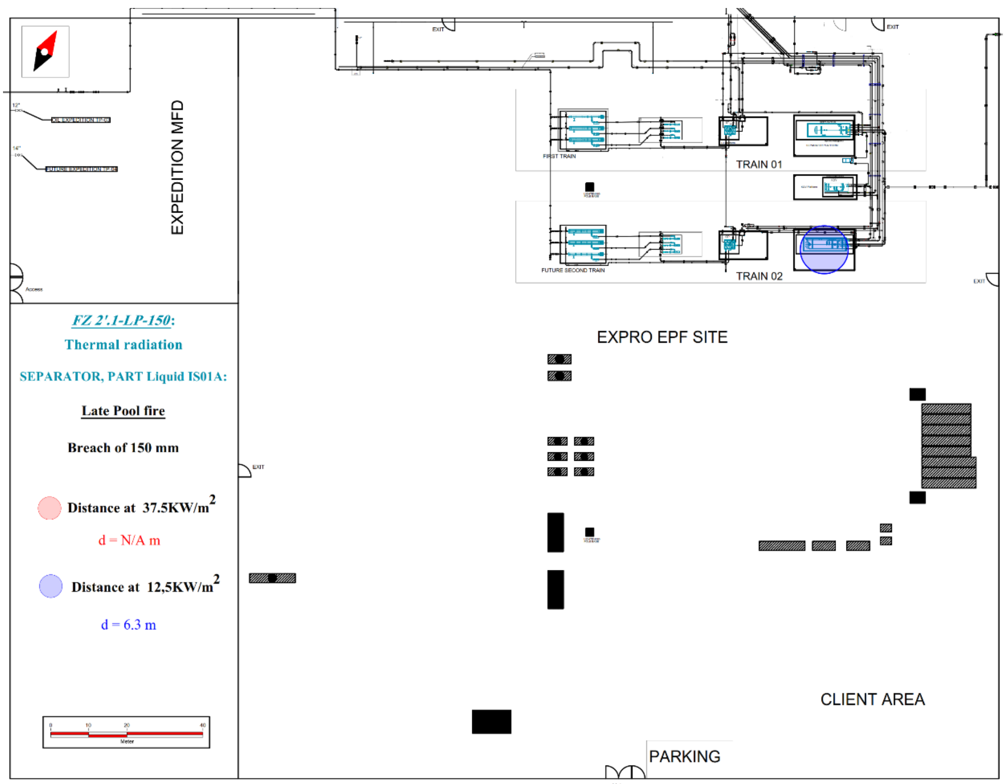

Figure D-40 Scenario FZ-2'.1-LP-150 modeling contours

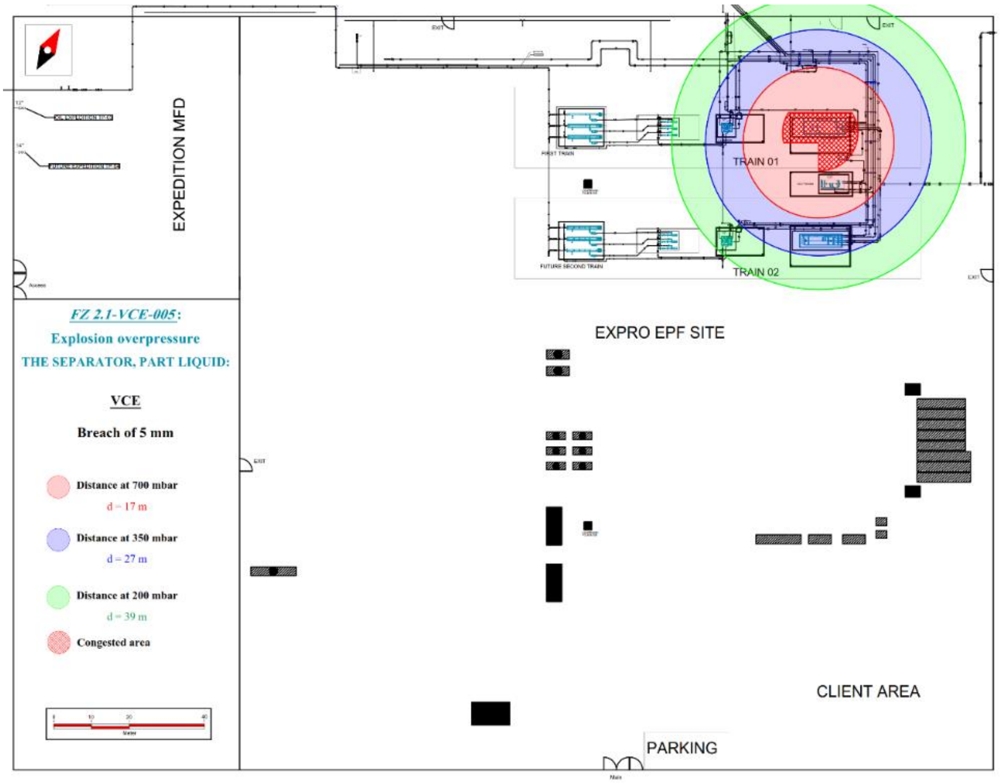

Figure D-41 Scenario FZ-2.1-VCE-005 modeling contours

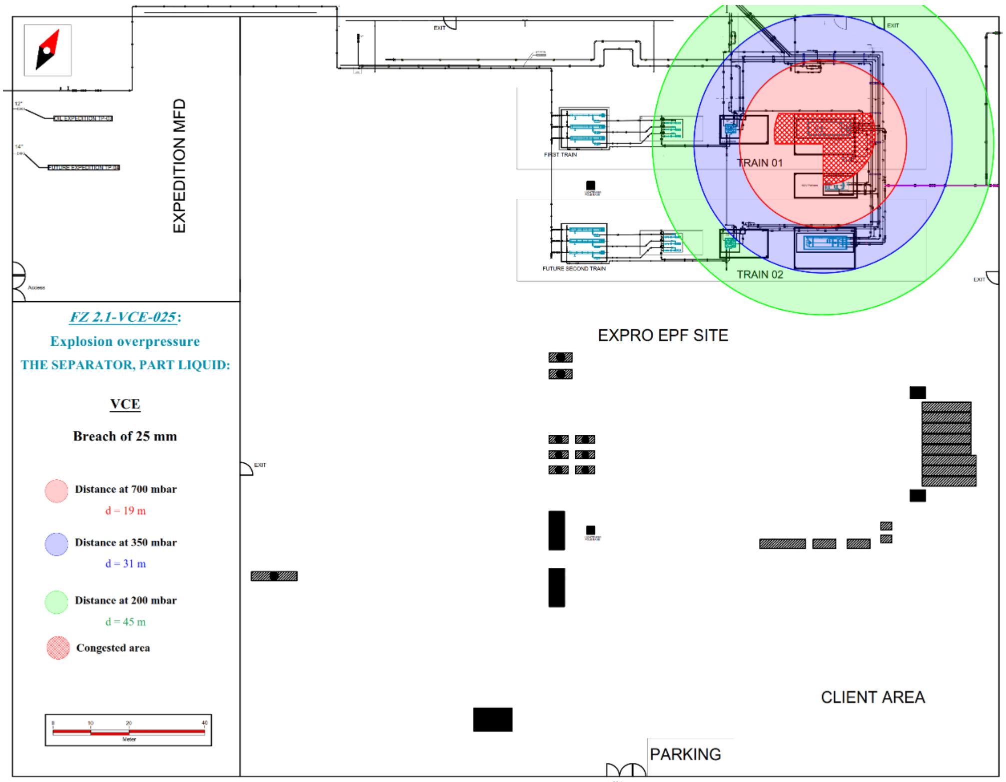

Figure D-42 Scenario FZ-2.1-VCE-025 modeling contours

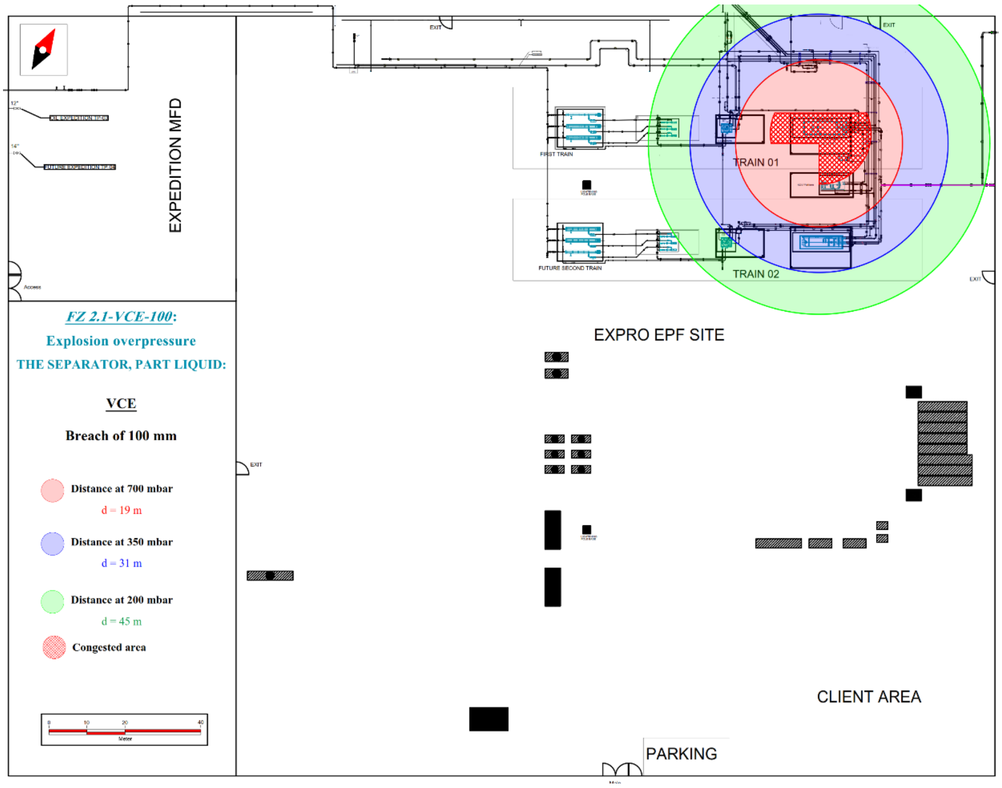

Figure D-43 Scenario FZ-2.1-VCE-100 modeling contours

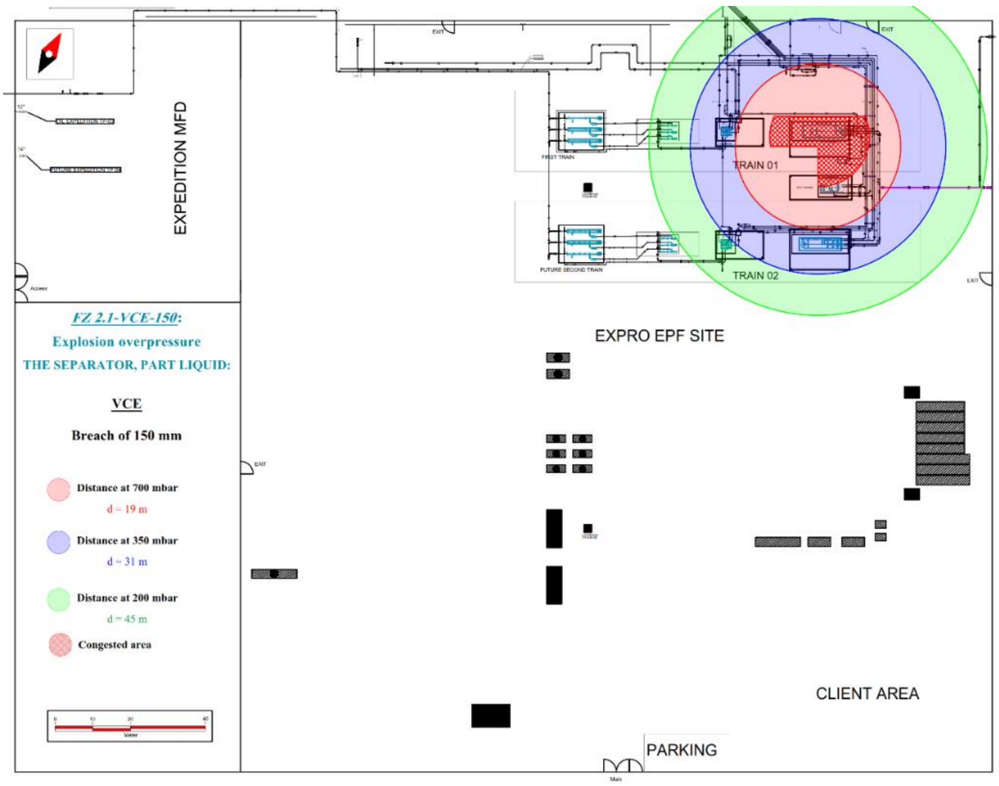

Figure D-44 Scenario FZ-2.1-VCE-150 modeling contours

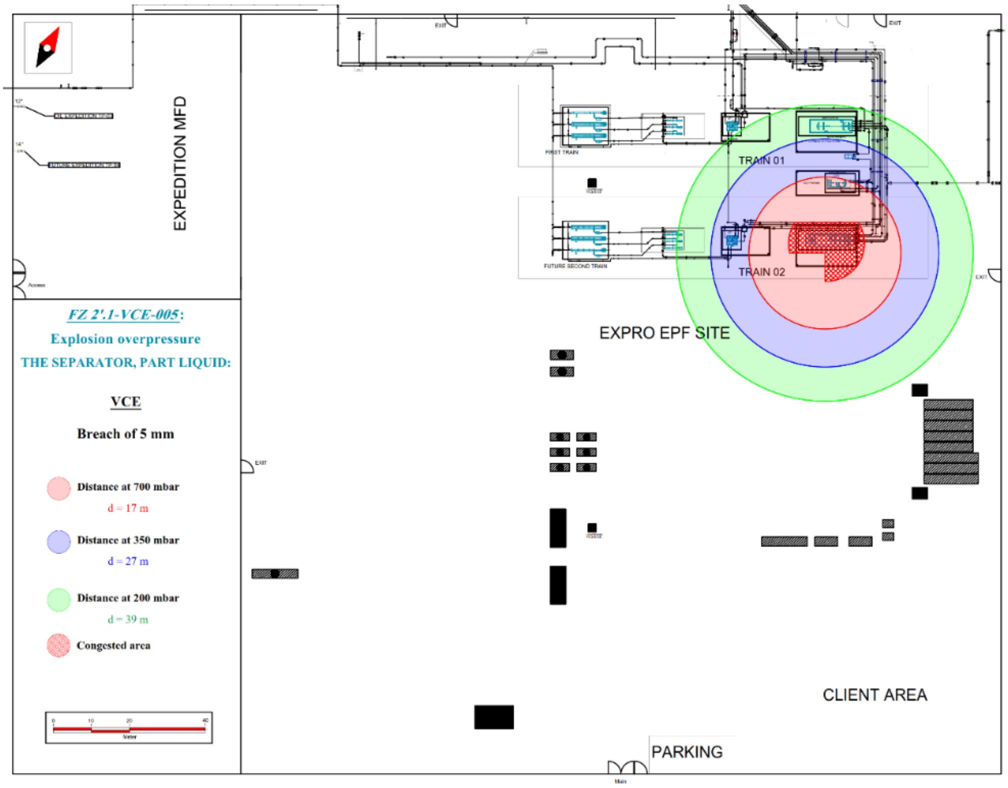

Figure D-45 Scenario FZ-2'.1-VCE-005 modeling contours

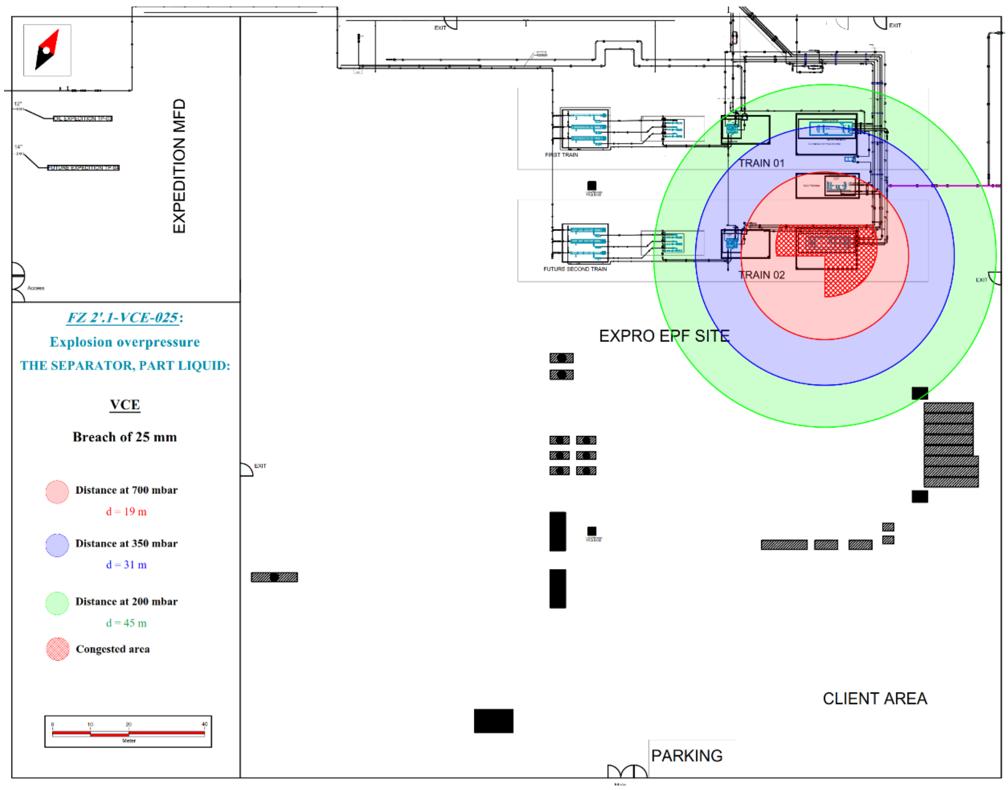

Figure D-46 Scenario FZ-2'.1-VCE-025 modeling contours

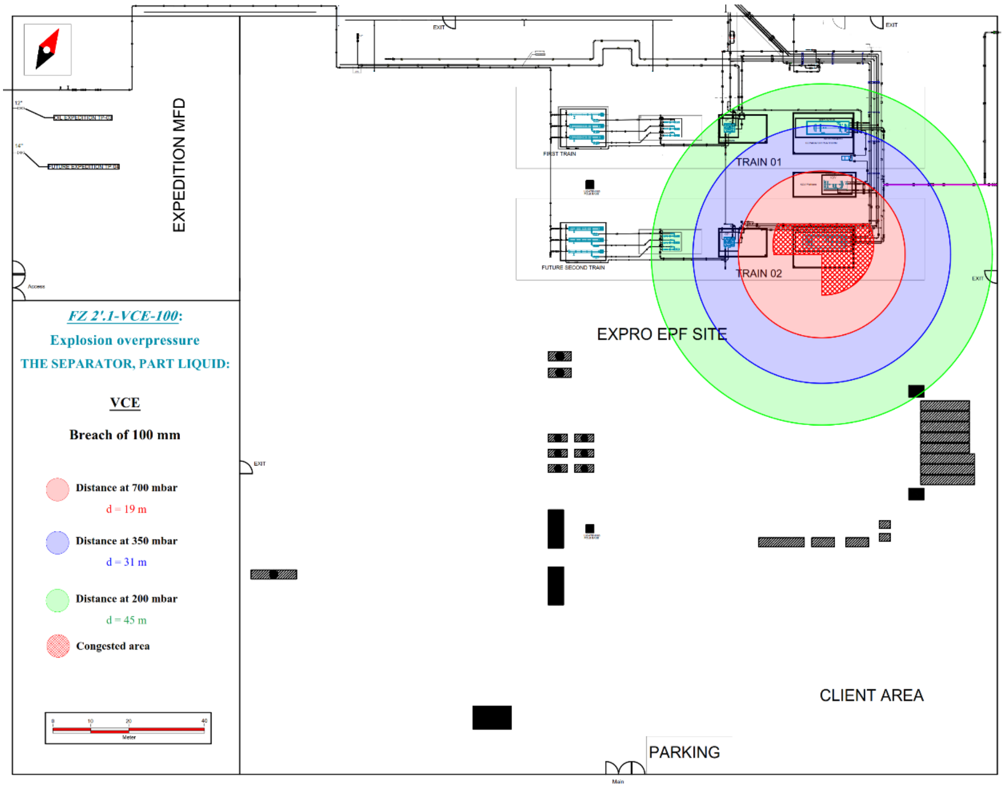

Figure D-47 Scenario FZ-2'.1-VCE-100 modeling contours

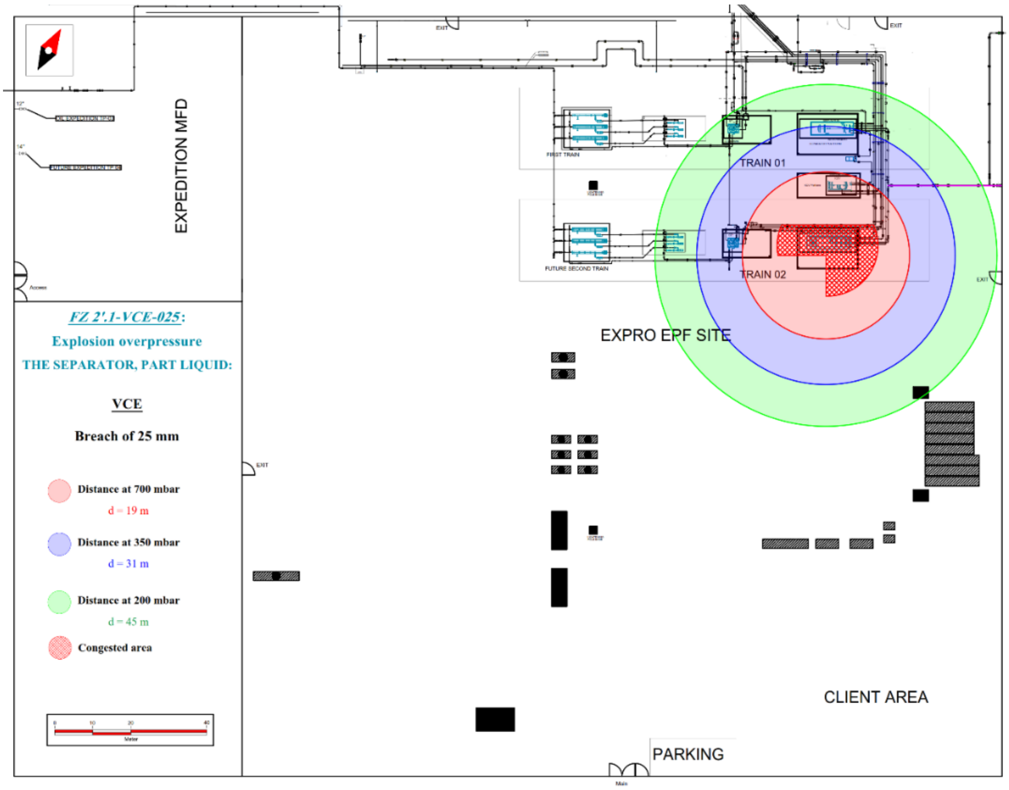

Figure D-48 Scenario FZ-2'.1-VCE-150 modeling contours

D.4 Scenario N°2.2: Loss of Containment in the Separator TX1H-046 Part Gas

Table D-11 Scenario FZ-2.2-005 modeling results

<table>
<tr><th colspan="8">SMALL BREACH</th></tr>
<tr><td colspan="8">Description: The initiating event is the loss of containment of hydrocarbon gas due to a small breach (5mm) in the TX1H-046 separator.</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="7">0.023</td></tr>
<tr><td colspan="8">Jet fire with a velocity of 709.30 m/s in summer and 666.29m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="3">Flame length (m)</td><td colspan="2">Distance at 12.5 KW/m^2 in (m)</td><td colspan="2">Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td colspan="3">1.841</td><td colspan="2">1.945</td><td colspan="2">N/A</td></tr>
<tr><td>Winter</td><td colspan="3">1.905</td><td colspan="2">1.907</td><td colspan="2">N/A</td></tr>
<tr><td colspan="8">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of gas released (Kg)</td><td colspan="7">27.6</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="3">456.20</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>263.444</td></tr>
<tr><td>Winter</td><td colspan="3">406.48</td><td>246.444</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="6">6.016</td></tr>
<tr><td>Winter</td><td colspan="6">5.789</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td colspan="3">Distance at 350 mbar in (m)</td><td colspan="2">Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">17</td><td colspan="3">12</td><td colspan="2">8</td></tr>
<tr><td>Winter</td><td colspan="2">16</td><td colspan="3">11</td><td colspan="2">7</td></tr>
</table>

Table D-12 Scenario FZ-2.2-025 modeling results

<table>
<tr><th colspan="4">MEDIUM BREACH</th></tr>
<tr><td colspan="4">Description: The central feared event is the loss of containment of hydrocarbon gas due to an medium breach (25mm) in the TX1H-046 separator.</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="3">0.553</td></tr>
<tr><td colspan="4">Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td>Flame length (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td>7.882</td><td>7.844</td><td>3.513</td></tr>
<tr><td>Winter</td><td>8.145</td><td>8.109</td><td>3.609</td></tr>
</table>

Vapor Cloud Explosion				
Amount of gas released (kg)	331.74			
Total volume of the cloud (m^3)	Summer	5484.3	Congested cloud volume (m^3)	963.444
	Winter	4886.6		902.444
Cloud radius (m)	Summer	13.783		
	Winter	13.263		
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m	
Summer	26	18	12	
Winter	25	17	11	

Table D-13 Scenario FZ-2.2-100 modeling results

LARGE BREACH				
Description: The initiating event is the loss of containment of hydrocarbon gas hydrocarbon due to a large breach (100mm) in the TX1H-046 separator.				
Leak flow (Kg/s)	8.85			
Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter				
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m	
Summer	27.344	27.84	12.861	
Winter	28.215	29.49	13.935	
Vapor Cloud Explosion				
Amount of gas released	2655			
Total volume of the cloud (m^3)	Summer	43884	Congested cloud volume	2177.224
	Winter	39102		1993.178
Cloud radius (m)	Summer	27.569		
	Winter	26.528		
Atmospheric condition	Distance at 200 mbar in m	Distance at 300 mbar in m	Distance at 700 mbar in m	
Summer	34	24	15	
Winter	34	23	14	

Table D-14 Scenario FZ-2.2-150 modeling results

<table>
<tr><th colspan="6">CATASTROPHIC BREACH</th></tr>
<tr><td colspan="6">Description: The initiating event is the loss of containment of hydrocarbon gas due to a catastrophic breach (>150mm) in the TX1H-046 separator.</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="5">32.105</td></tr>
<tr><td colspan="6">Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame length (m)</td><td colspan="2">Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td colspan="2">48.388</td><td colspan="2">50.290</td><td>23.893</td></tr>
<tr><td>Winter</td><td colspan="2">49.899</td><td colspan="2">53.88</td><td>26.043</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of gas released (Kg)</td><td colspan="5">1926.3</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>31840</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>1898.82</td></tr>
<tr><td>Winter</td><td>26528</td><td>1672.02</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">24.773</td></tr>
<tr><td>Winter</td><td colspan="4">23.838</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at200 mbar in m</td><td colspan="2">Distance at 350 mbar in m</td><td>Distance at 700 mbar in m</td></tr>
<tr><td>Summer</td><td colspan="2">33</td><td colspan="2">23</td><td>14</td></tr>
<tr><td>Winter</td><td colspan="2">32</td><td colspan="2">22</td><td>13</td></tr>
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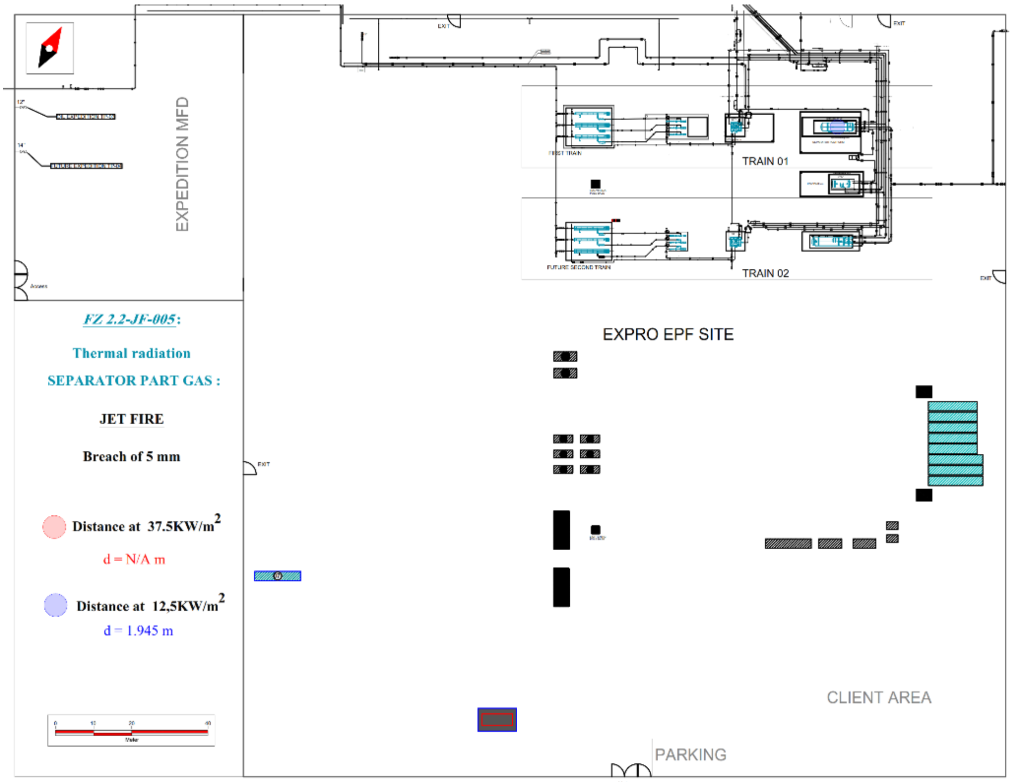


Figure D-49 Scenario FZ-2.2-JF-005 modeling contours

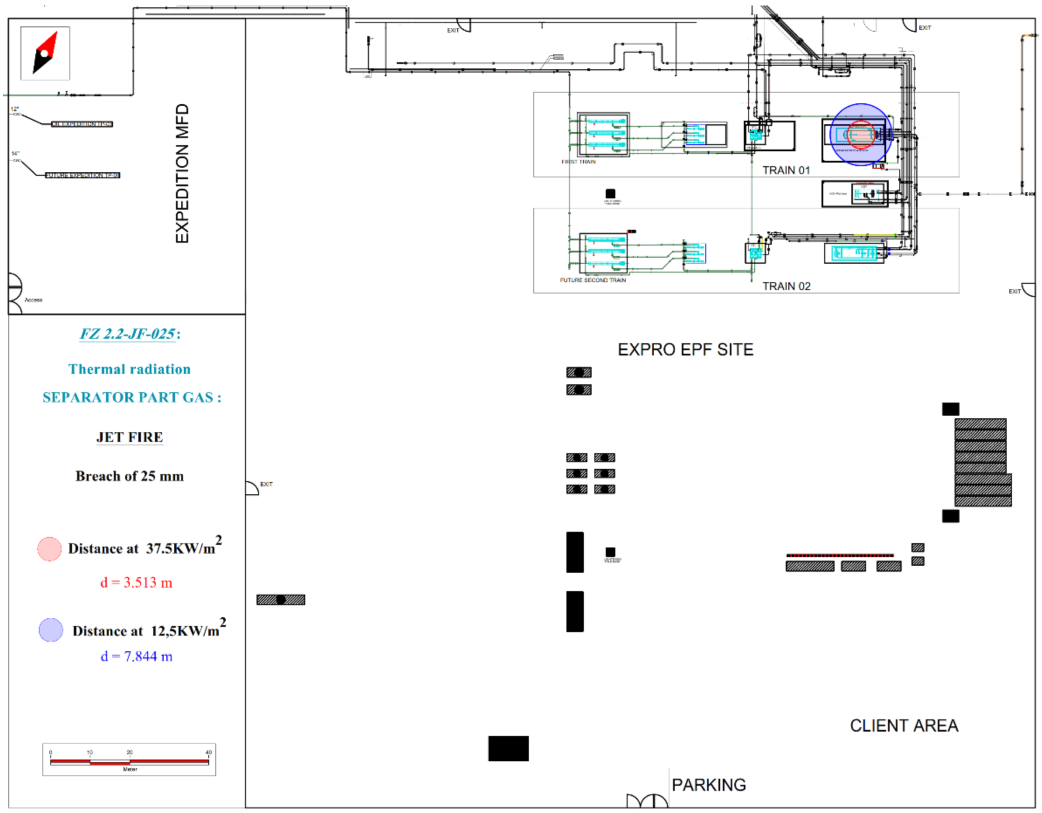


Figure D-50 Scenario FZ-2.2-JF-025 modeling contours

Appendix D. Consequences analysis modeling results

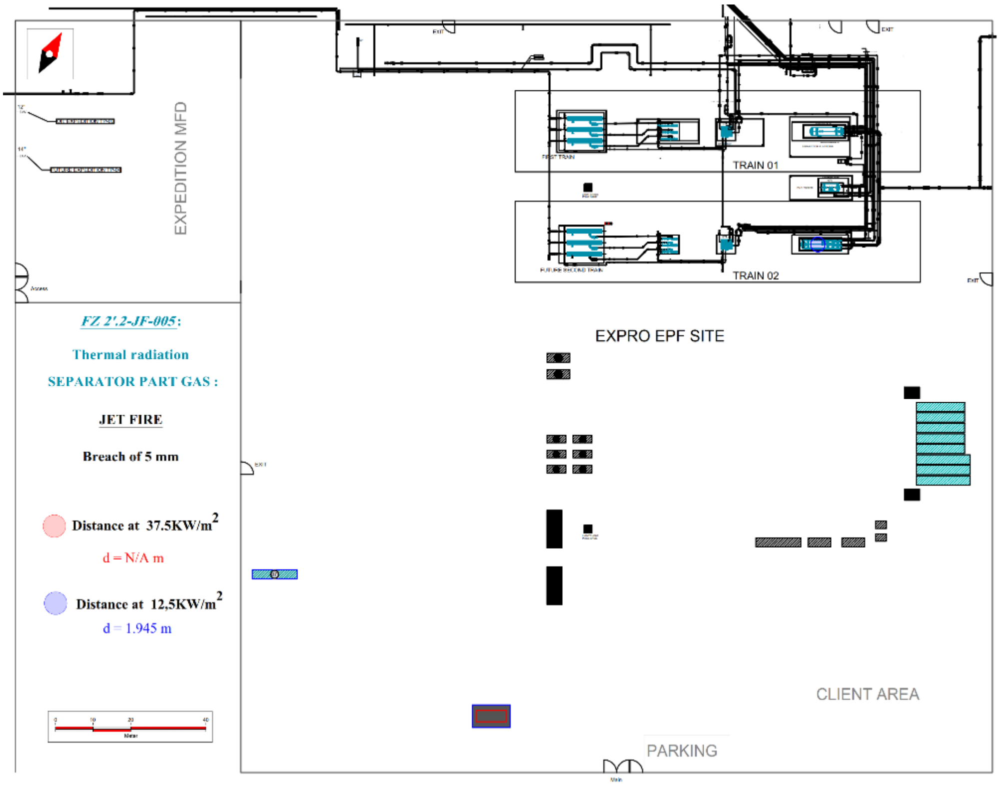


Figure D-51 Scenario FZ-2'.2-JF-005 modeling contours

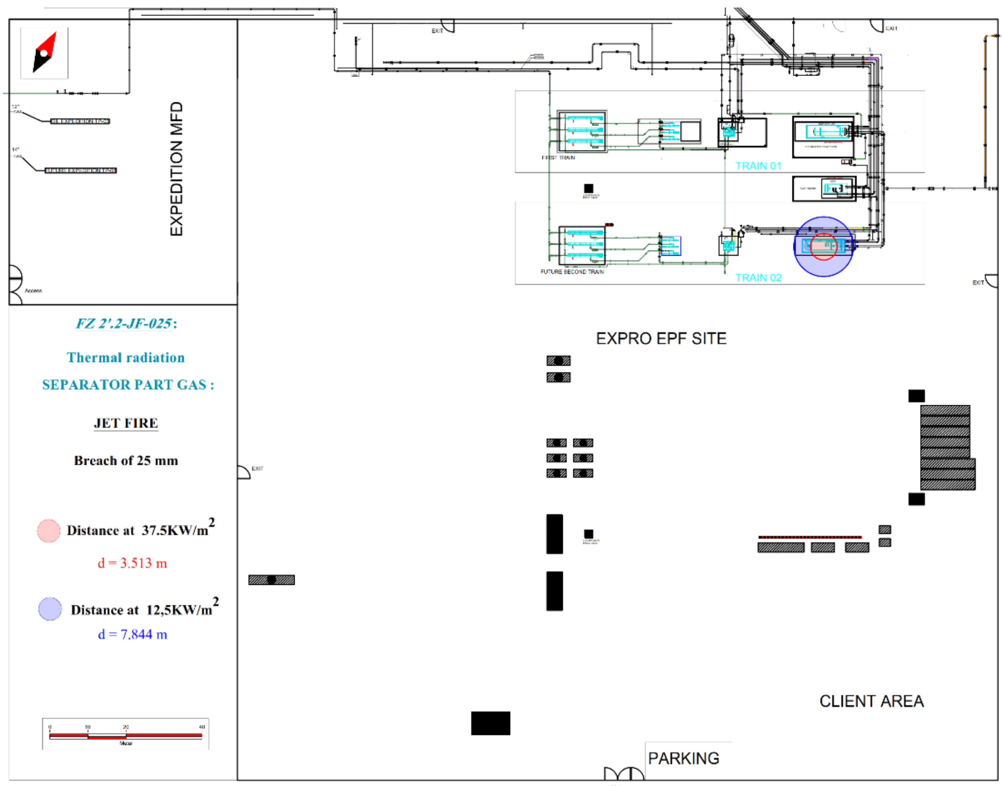


Figure D-52 Scenario FZ-2'.2-JF-025 modeling contours

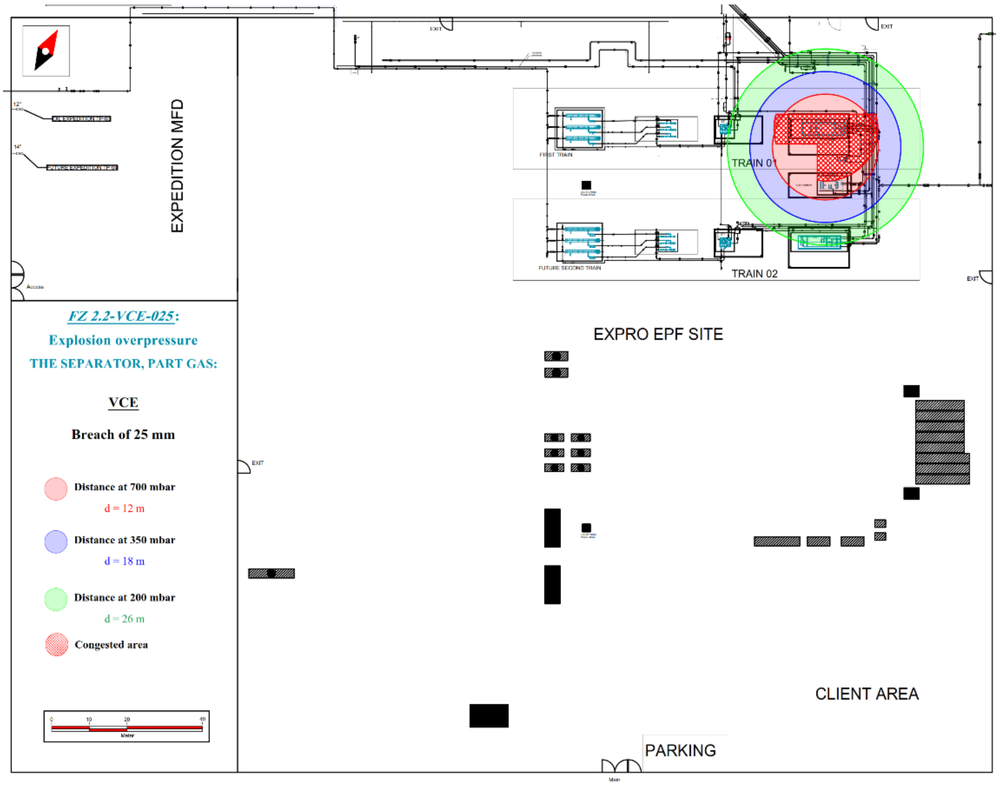


Figure D-53 Scenario FZ-2.2-VCE-025 modeling contours

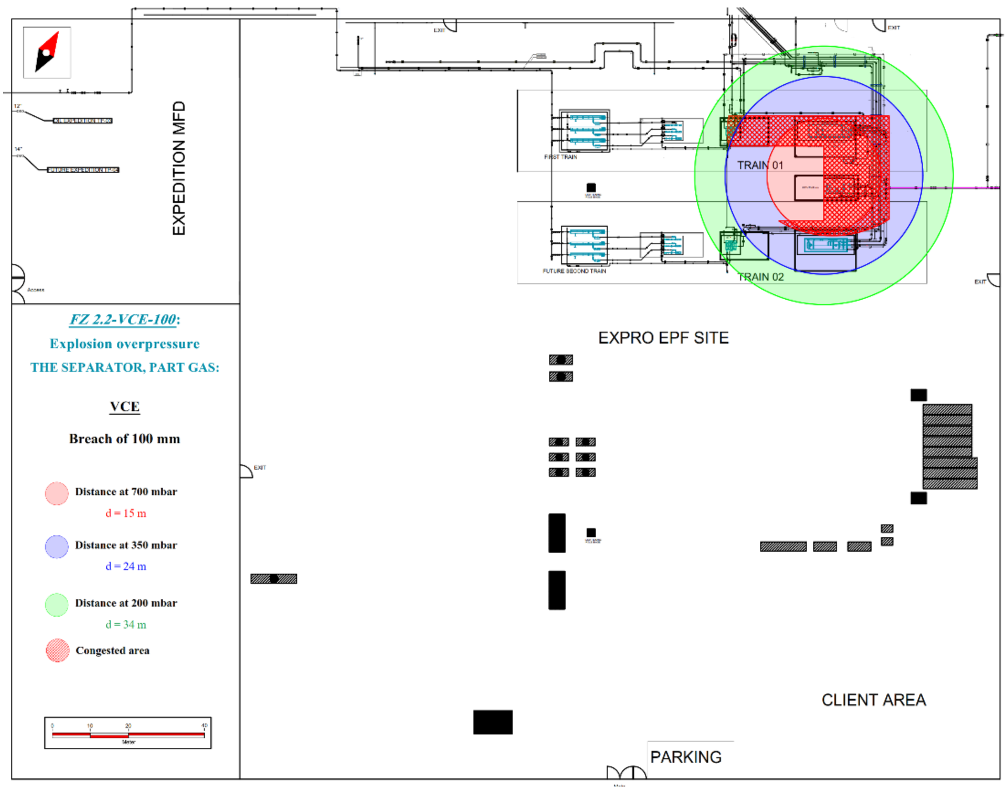


Figure D-54 Scenario FZ-2.2-VCE-100 modeling contours

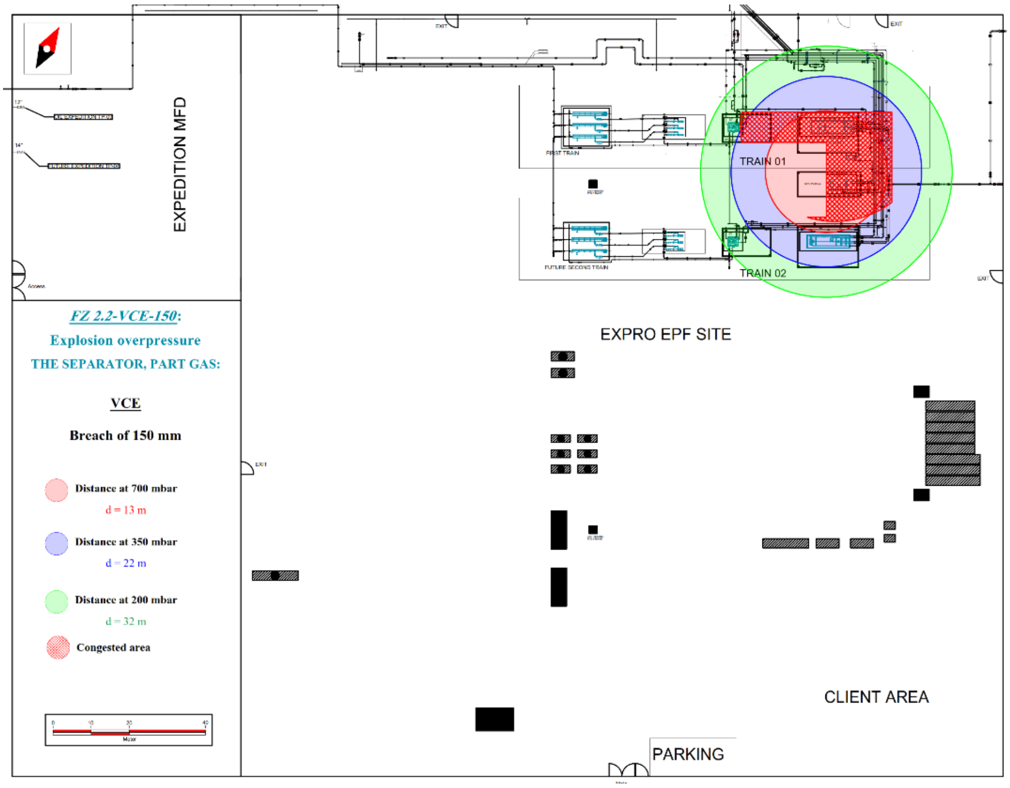
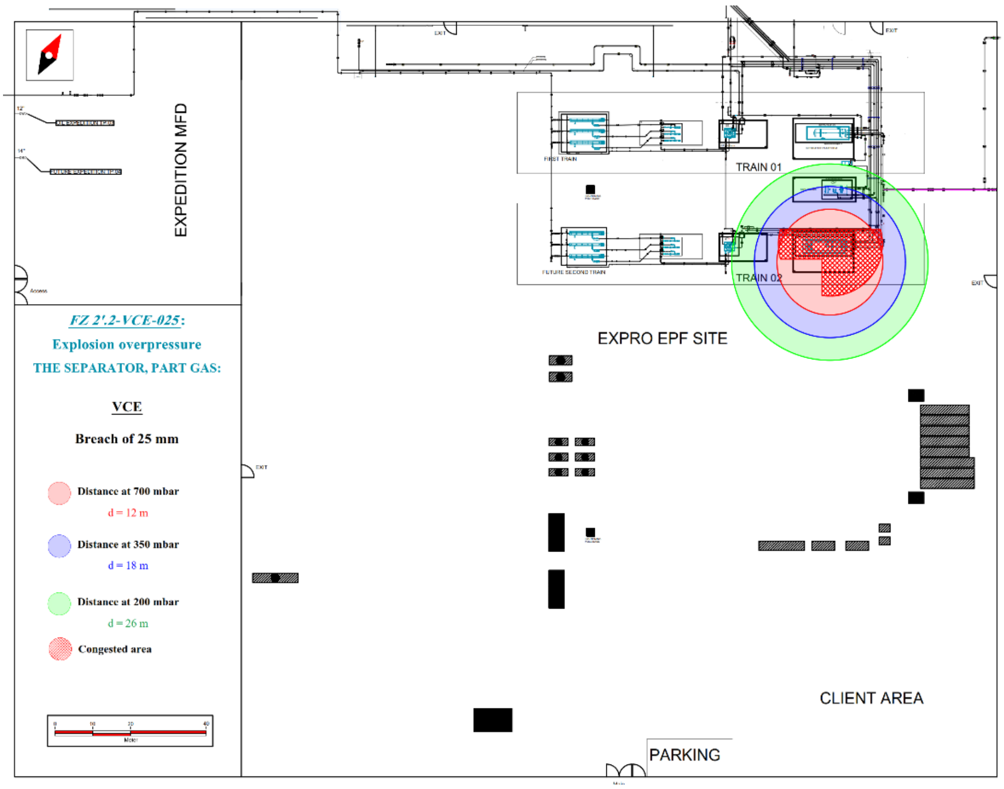


Figure D-55 Scenario FZ-2.2-VCE-150 modeling contours



Appendix Figure D-56 Scenario FZ-2'.2-VCE-025 modeling contours

Appendix D. Consequences analysis modeling results

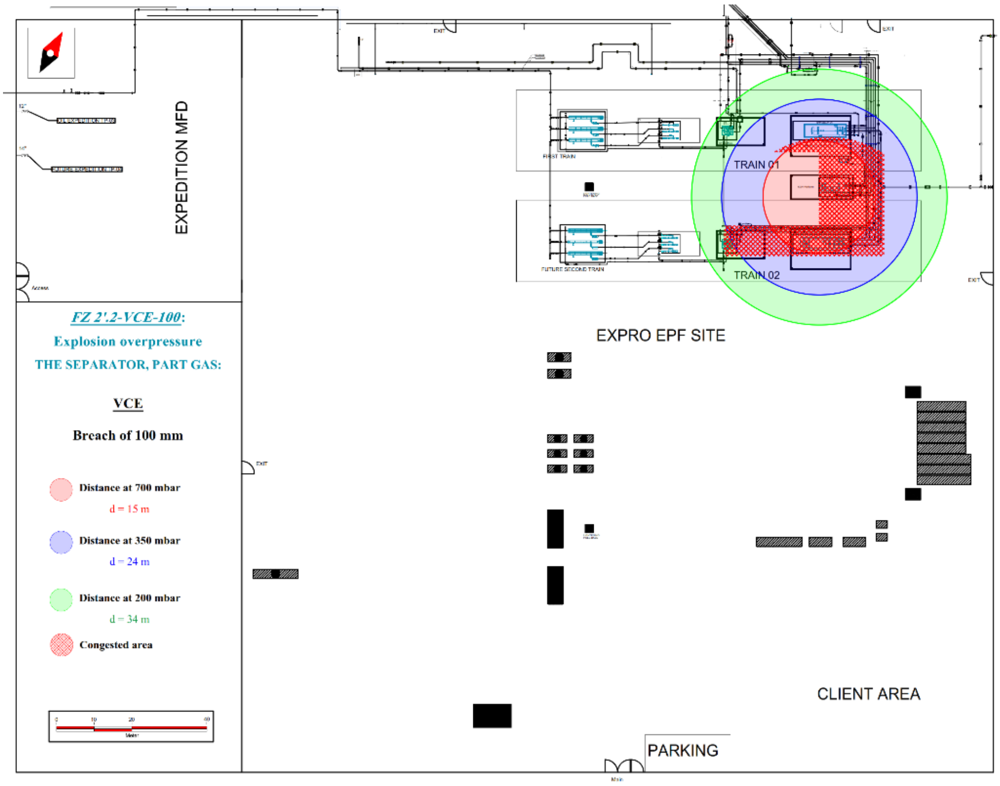


Figure D-57 Scenario FZ-2'.2-VCE-100 modeling contours

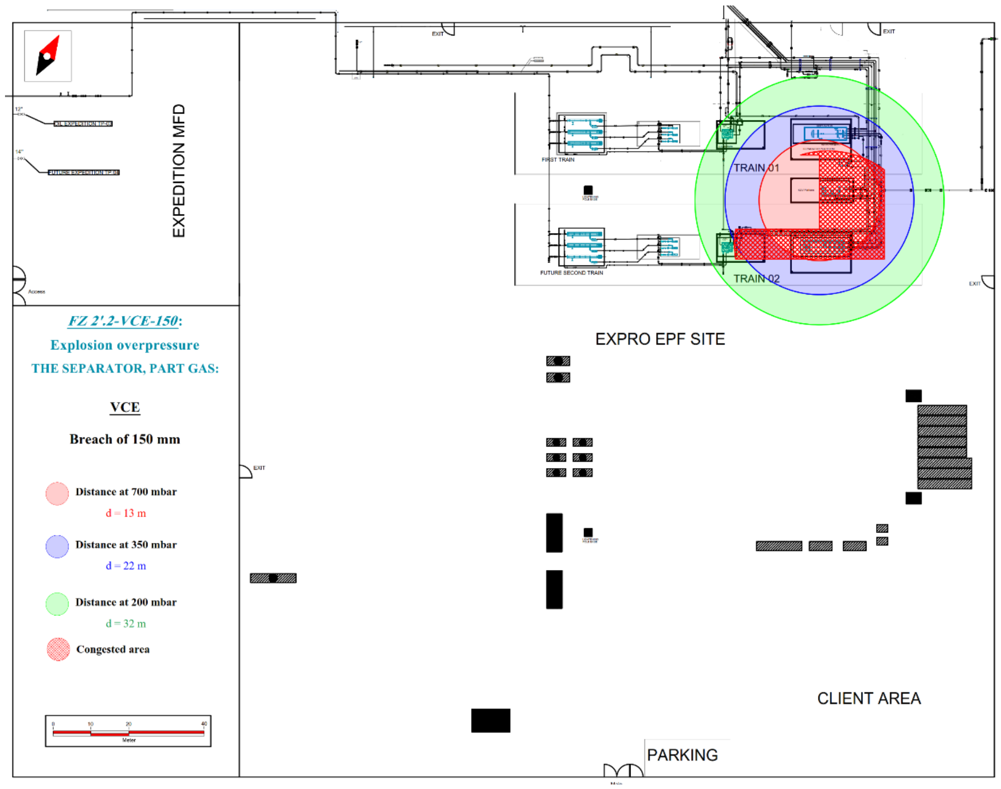


Figure D-58 Scenario FZ-2'.2-VCE-150 modeling contours

D.5 Scenario N°2.3: Loss of Containment in the Gas LINE 10”-PV-03B3-1800 from Separator TX1H-046 TO KOV

Table D-15 FZ-2.3-005-modeling results

<table>
<tr><th colspan="6">SMALL BREACH</th></tr>
<tr><td colspan="6">Description: The initiating event is the loss of containment of gaseous hydrocarbon due to a small breach (5mm) in the gas line 10”-PV-03B3-1800</td></tr>
<tr><td>Leak flow(Kg/s)</td><td colspan="5">0.021</td></tr>
<tr><td colspan="6">Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame length (m)</td><td colspan="2">Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">1.799</td><td colspan="2">1.880</td><td>N/A</td></tr>
<tr><td>Winter</td><td colspan="2">1.863</td><td colspan="2">1.840</td><td>N/A</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of gas released (Kg)</td><td colspan="5">26.4</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>416.53</td><td rowspan="2" colspan="2">Congested cloud volume (m^3)</td><td>315.38</td></tr>
<tr><td>Winter</td><td>371.13</td><td>298.25</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">5.837</td></tr>
<tr><td>Winter</td><td colspan="4">5.616</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">18</td><td colspan="2">13</td><td>8</td></tr>
<tr><td>Winter</td><td colspan="2">17</td><td colspan="2">12</td><td>7</td></tr>
</table>

Table D-16 FZ-2.3-025-modeling results

<table>
<tr><th colspan="4">MEDIUM BREACH</th></tr>
<tr><td colspan="4">Description: The initiating event is the loss of containment of gaseous hydrocarbon due to a medium breach (25mm) in the gas line 10”-PV-03B3-1800</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="3">0.532</td></tr>
<tr><td colspan="4">Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td>Flame length (m)</td><td>Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td>7.771</td><td>7.730</td><td>3.452</td></tr>
<tr><td>Winter</td><td>8.029</td><td>7.990</td><td>3.544</td></tr>
</table>

Vapor Cloud Explosion				
Amount of gas released (Kg)	331.8			
Total volume of the cloud (m^3)	Summer	5276	Congested cloud volume	1288.38
	Winter	4701		1102.25
Cloud radius (m)	Summer	13.607		
	Winter	13.093		
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m	
Summer	29	20	13	
Winter	28	19	12	

Table D-17 FZ-2.3-100-modeling results

LARGE BREACH				
Description : The initiating event is the loss of containment of gaseous hydrocarbon due to a large breach (100mm) in the gas line 10”-PV-03B3-1800				
Leak flow (Kg/s)	8.835			
Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter				
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m)	
Summer	27.581	27.820	12.851	
Winter	28.456	29.460	13.924	
Vapor Cloud Explosion				
Amount of gas released (Kg)	2650.5			
Total volume of the cloud (m^3)	Summer	43785	Congested cloud volume (m^3)	2770.268
	Winter	39013		2300.98
Cloud radius (m)	Summer	27.548		
	Winter	26.508		
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m	
Summer	37	26	16	
Winter	36	25	15	

Table D-18 FZ-2.3-150-modeling results

<table>
<tr><th colspan="8">CATASTROPHIC BREACH</th></tr>
<tr><td colspan="8">Description: The initiating event is the loss of containment of gaseous hydrocarbon due to a catastrophic breach (>150mm) in the gas line 10”-PV-03B3-1800</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="7">30.893</td></tr>
<tr><td colspan="8">Jet fire with a velocity of 696.01m/s in summer and 676.72 m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="3">Flame length (m)</td><td colspan="2">Distance at 12.5 KW/m^2 in (m)</td><td colspan="2">Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td>Summer</td><td colspan="3">47.987</td><td colspan="2">49.410</td><td colspan="2">23.453</td></tr>
<tr><td>Winter</td><td colspan="3">49.482</td><td colspan="2">52.920</td><td colspan="2">25.559</td></tr>
<tr><td colspan="8">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of gas released (Kg)</td><td colspan="7">1854.6</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="3">30638</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>2563.28</td></tr>
<tr><td>Winter</td><td colspan="3">27299</td><td>2117.55</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="6">24.457</td></tr>
<tr><td>Winter</td><td colspan="6">23.534</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in m</td><td colspan="3">Distance at 350 mbar in m</td><td colspan="2">Distance at 700 mbar in m</td></tr>
<tr><td>Summer</td><td colspan="2">36</td><td colspan="3">25</td><td colspan="2">16</td></tr>
<tr><td>Winter</td><td colspan="2">35</td><td colspan="3">24</td><td colspan="2">15</td></tr>
</table>

Appendix D. Consequences analysis modeling results

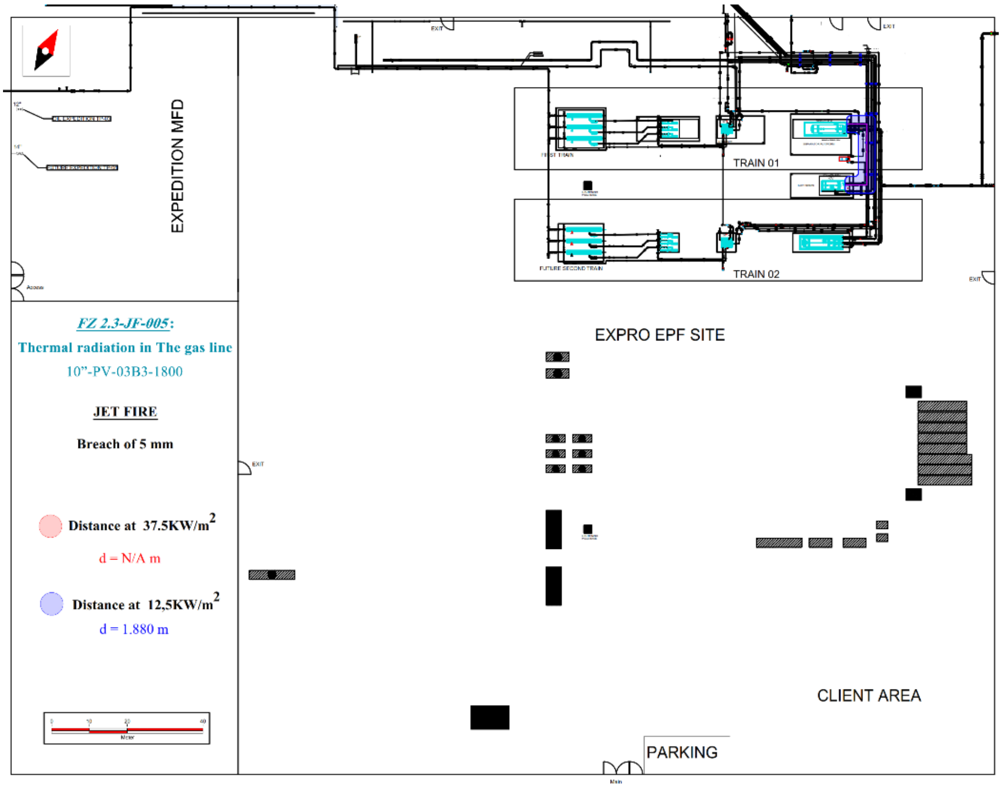


Figure D-59 Scenario FZ-2.3-JF-005 contours

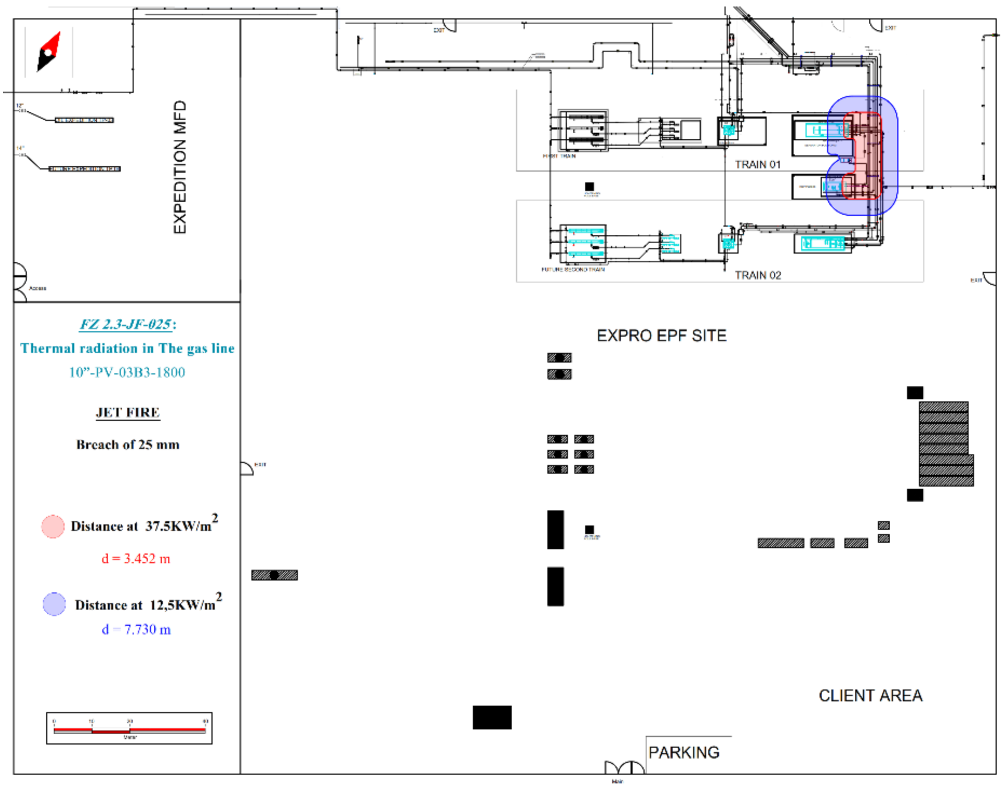


Figure D-60 Scenario FZ-2.3-JF-025 contours

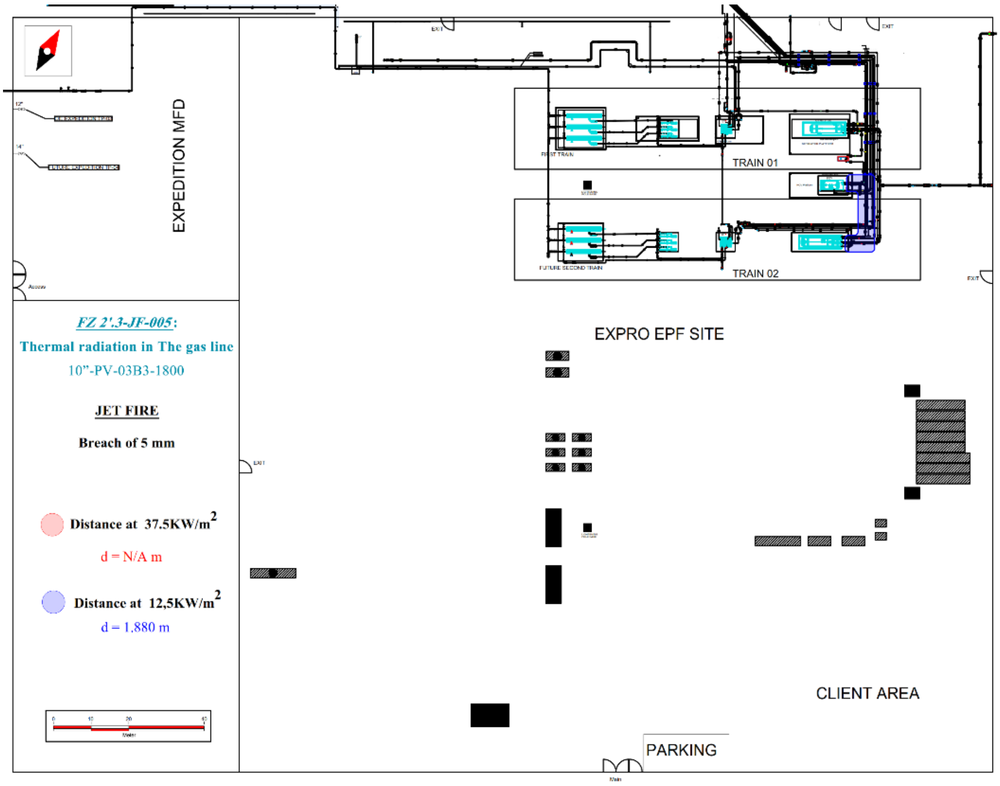


Figure D-61 Scenario FZ-2'.3-JF-005 contours

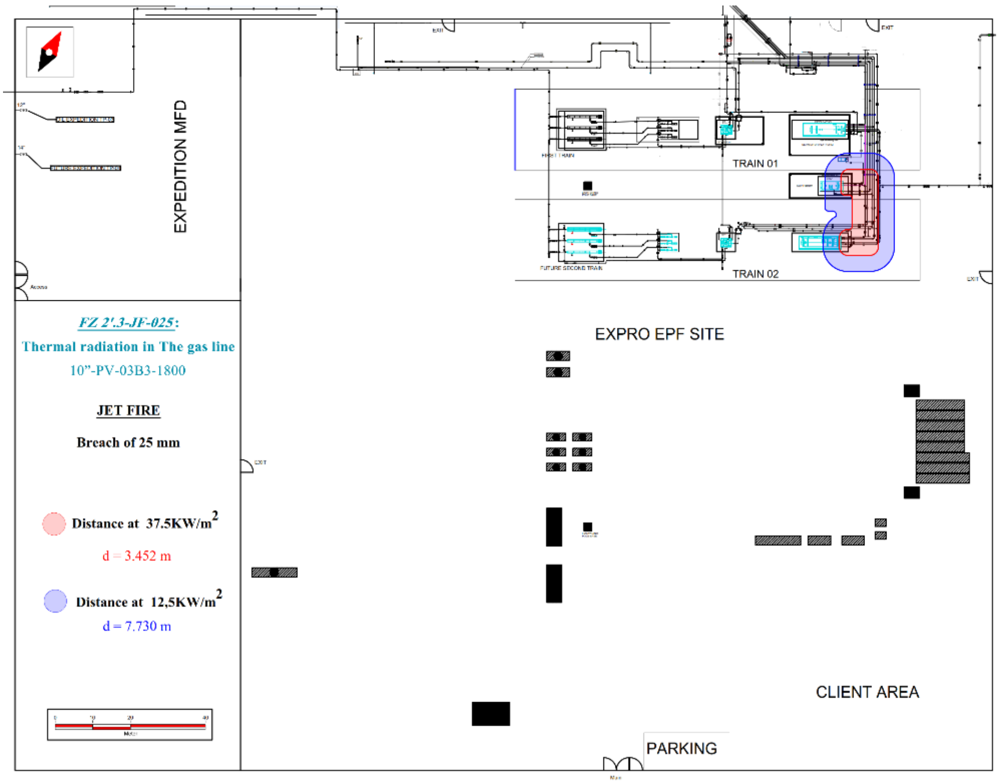


Figure D-62 Scenario FZ-2'.3-JF-025 contours

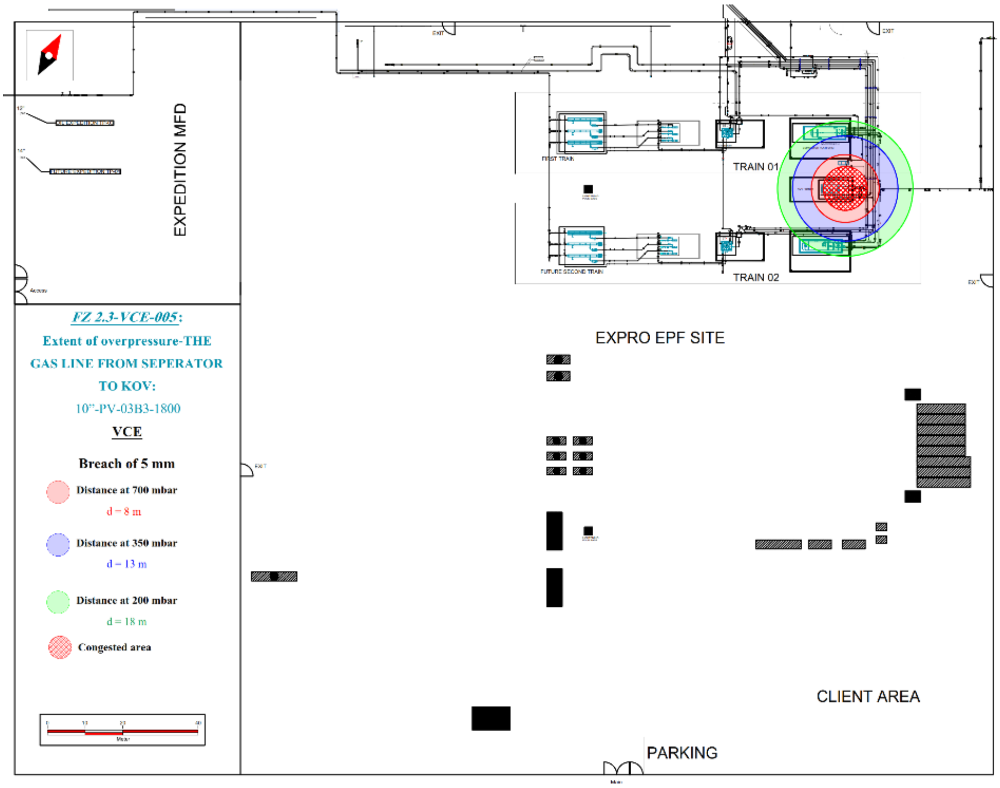


Figure D-63 Scenario FZ-2.3-VCE-005 contours

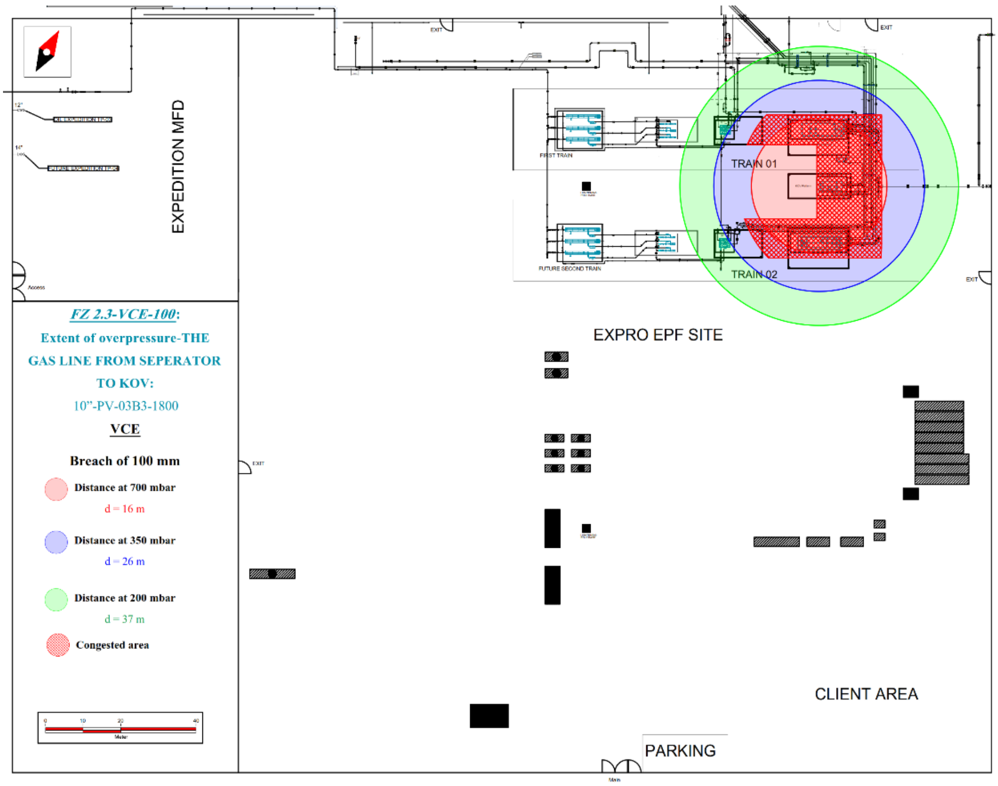


Figure D-64 Scenario FZ-2.3-VCE-100 contours

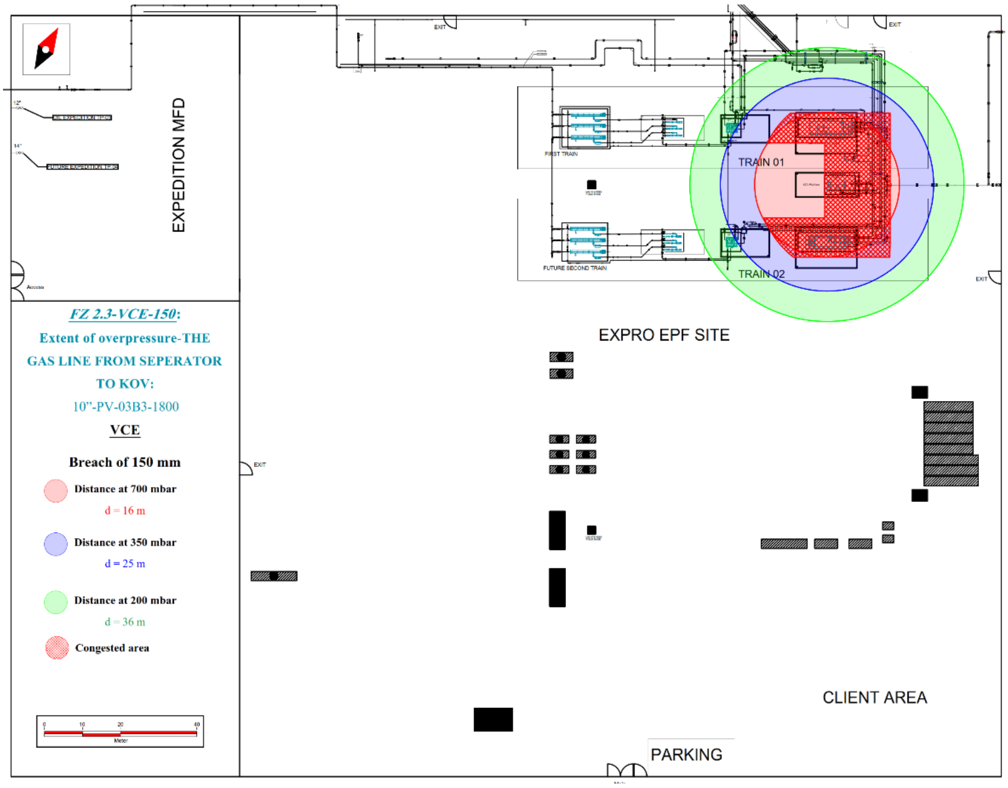


Figure D-65 Scenario FZ-2.3-VCE-150 contours

D.6 Scenario N°2.4: Loss of Containment in the Pipe between Separator & Surge Tank 6”-PL-03B3-1200

Table D-19 Scenario FZ-2.4-005 modeling results

SCENARIO N°2.4.1 : SMALL BREACH			
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a small breach (5mm) in the pipe between separator and surge tank 6”-PL-03B3-1200			
Leak flow(Kg/s)	0.255		
Early Pool fire with a diameter of 2.326m			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)
Summer	3.0103	4.263	4.2
Winter	2.6822	4.158	4.2
Burning duration (s)	1924.6 (32 min)		
Late Pool fire with a diameter of 6.522 m			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)
Summer	6.327	11.600	9.32

Winter	6.438		11.786		9.695
Burning duration (s)	155.38 (2 min 35 s)				
Vapor Cloud Explosion					
Amount of liquid released (Kg)	306				
Vaporization rate (Kg/s)	Summer	0.262	Evaporated amount (Kg)		78.6
	Winter	0.055			16.4
Total volume of the cloud (m^3)	Summer	1066.9	Congested cloud volume (m^3)		243.4
	Winter	226.98			127.4
Cloud radius (m)	Summer	7.986			
	Winter	4.767			
Atmospheric condition	Distance at 200 mbar in (m)		Distance at 350 mbar in (m)		Distance at 700 mbar in (m)
Summer	29		20		13
Winter	23		16		N/A

Table D-20 Scenario FZ-2.4-025 modeling results

SCENARIO N°2.4.2 : MEDIUM BREACH			
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a medium breach (25 mm) in the pipe between separator and surge tank 6”-PL-03B3-1200			
Leak flow (Kg/s)	6.378		
Early Pool fire with a diameter of 13.089 m			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)
Summer	9.001	17.317	13.700
Winter	8.7244	17.315	13.800
Burning duration (s)	743.56 (12 min 24 s)		
Late Pool fire with a diameter of 17.364 m			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)
Summer	14.544	30.600	0.775
Winter	14.086	31.150	3.239
Burning duration (s)	134.66 (2 min 15s)		
Vapor Cloud Explosion			

Amount of liquid released (Kg)	3 826,8			
Vaporization rate (Kg/s)	Summer	3.210	Evaporated amount (Kg)	963
	Winter	0.683		204.9
Total volume of the cloud (m^3)	Summer	13073	Congested cloud volume (m^3)	503.4
	Winter	2781.3		322.4
Cloud radius (m)	Summer	18.412		
	Winter	10.992		
Atmospheric condition	Distance at 200 mbar in (m)	Distance at 350 mbar in (m)	Distance at 700 mbar in (m)	
Summer	36	25	16	
Winter	31	22	14	

Table D-21 Scenario FZ-2.4-100 modeling results

SCENARIO N°2.4 : LARGE BREACH				
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a large breach (100 mm) in the pipe between separator and surge tank 6"-PL-03B3-1200				
Leak flow (Kg/s)	102.048			
Early Pool fire with a diameter of 46.557 m				
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)	
Summer	27.214	52.268	0.4	
Winter	26.357	52.262	2.300	
Burning duration (s)	569.05 (9 min 30s)			
Late Pool fire with a diameter of 49.112 m				
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)	
Summer	29.037	73.200	N/A	
Winter	28.123	73.350	N/A	
Burning duration (s)	134.67 (2 min 15s)			
Vapor Cloud Explosion				
Amount of liquid released (Kg)	15 305.2			
Vaporization rate (Kg/s)	Summer	22.910	Evaporated amount(Kg)	6 873
	Winter	4.874		1 462,2
	Summer	93276		1869.624

Total volume of the cloud (m^3)	Winter	19845	Congested cloud volume (m^3)	569.4
Cloud radius (m)	Summer	35.446		
	Winter	21.161		
Atmospheric condition	Distance at 200 mbar in (m)		Distance at 350 mbar in (m)	Distance at 700 mbar in (m)
Summer	56		39	24
Winter	38		26	17

Table D-22 Scenario FZ-2.4-150 modeling results

SCENARIO N°2.4.4 : CATASTROPHIC BREACH				
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a large breach (>150 mm) in the pipe between separator and surge tank 6"-PL-03B3-1200				
Leak flow (Kg/s)	229.609			
Pool fire with a diameter of 32.946 m				
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2	
Summer	22.267	52.000	0.426	
Winter	21.789	52.105	2.448	
Burning duration (s)	134.84 (2 min 17s)			
Vapor Cloud Explosion				
Amount of Liquid released (Kg)	13 776,54			
Vaporization rate (Kg/s)	Summer	12.121	Evaporated amount(Kg)	3 636,3
	Winter	2.578		773,4
Total volume of the cloud (m^3)	Summer	43860	Congested cloud volume (m^3)	750.362
	Winter	9331.3		456.4
Cloud radius (m)	Summer	27.564		
	Winter	16.455		
Atmospheric condition	Distance at 200 mbar in (m)	Distance at 350 mbar in (m)	Distance at 350 mbar in (m)	
Summer	41	29	18	
Winter	35	25	15	

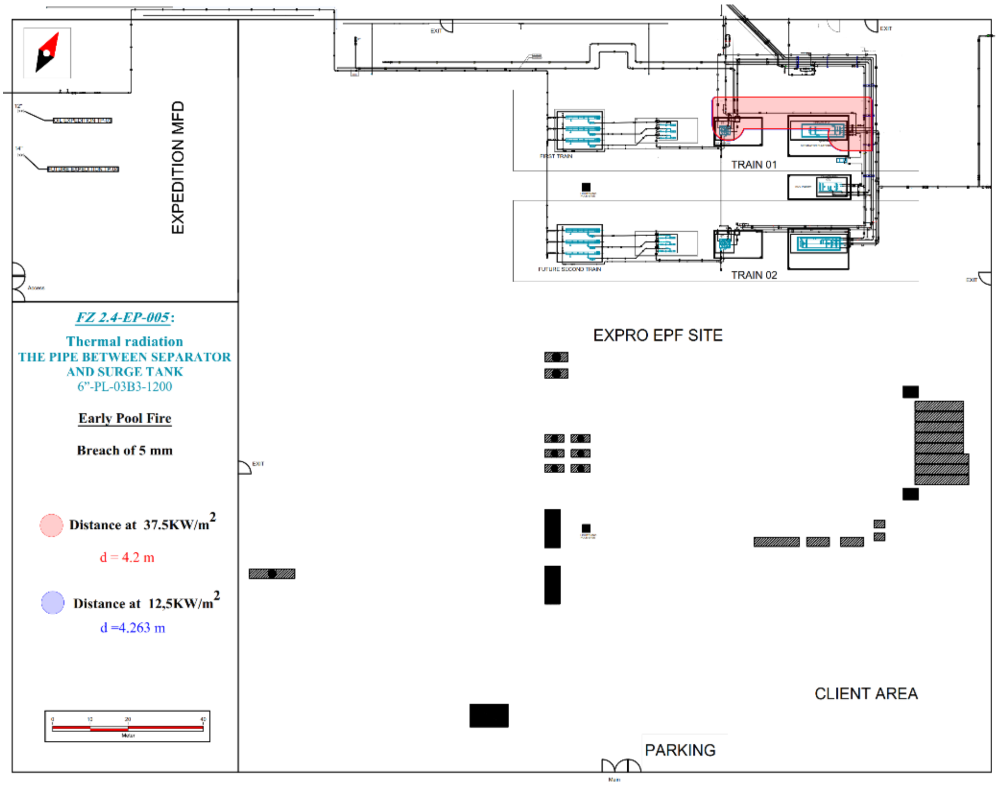


Figure D-66 Scenario FZ-2.4-EP-005 contours

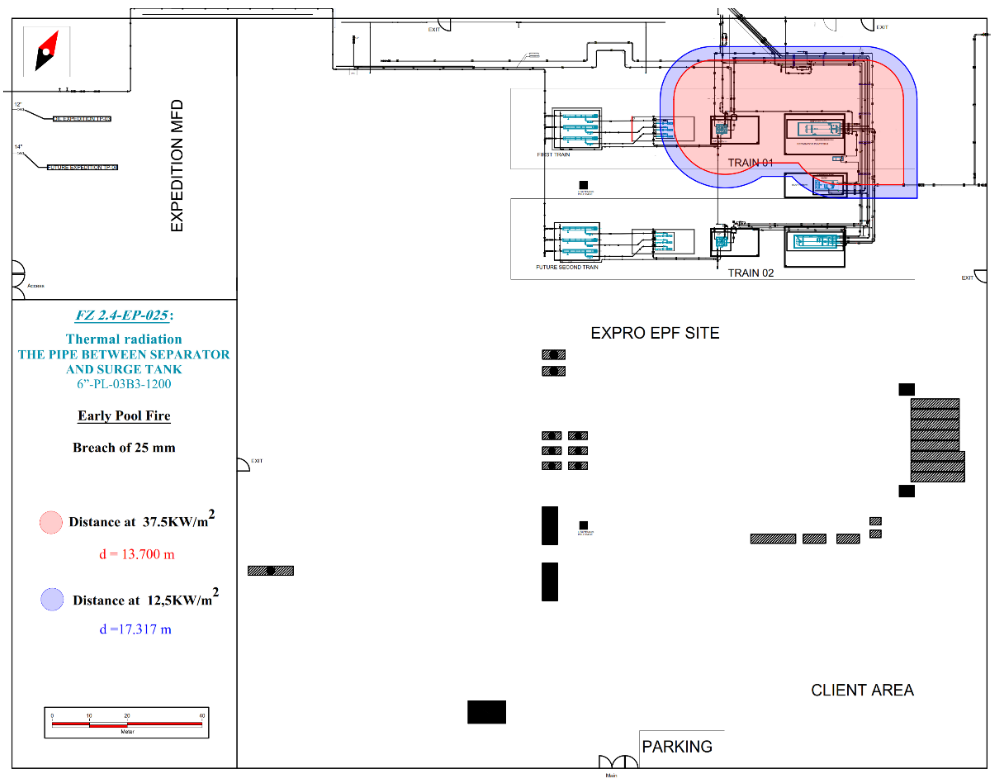


Figure D-67 Scenario FZ-2.4-EP-025 contours

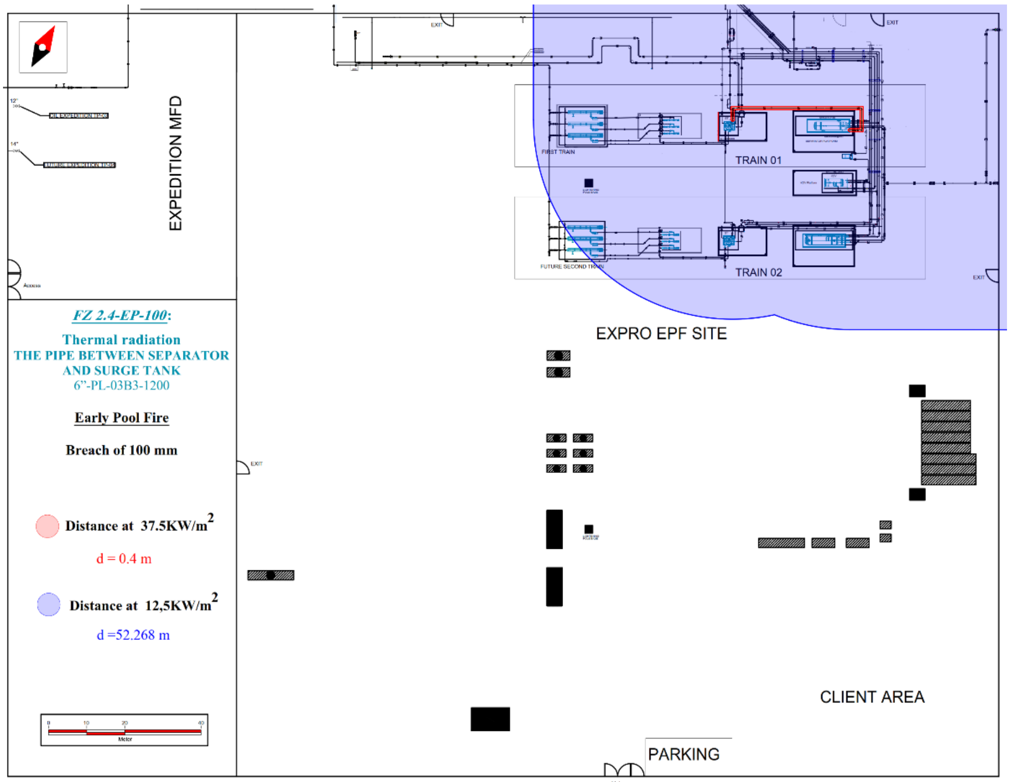


Figure D-68 Scenario FZ-2.4-EP-100 contours

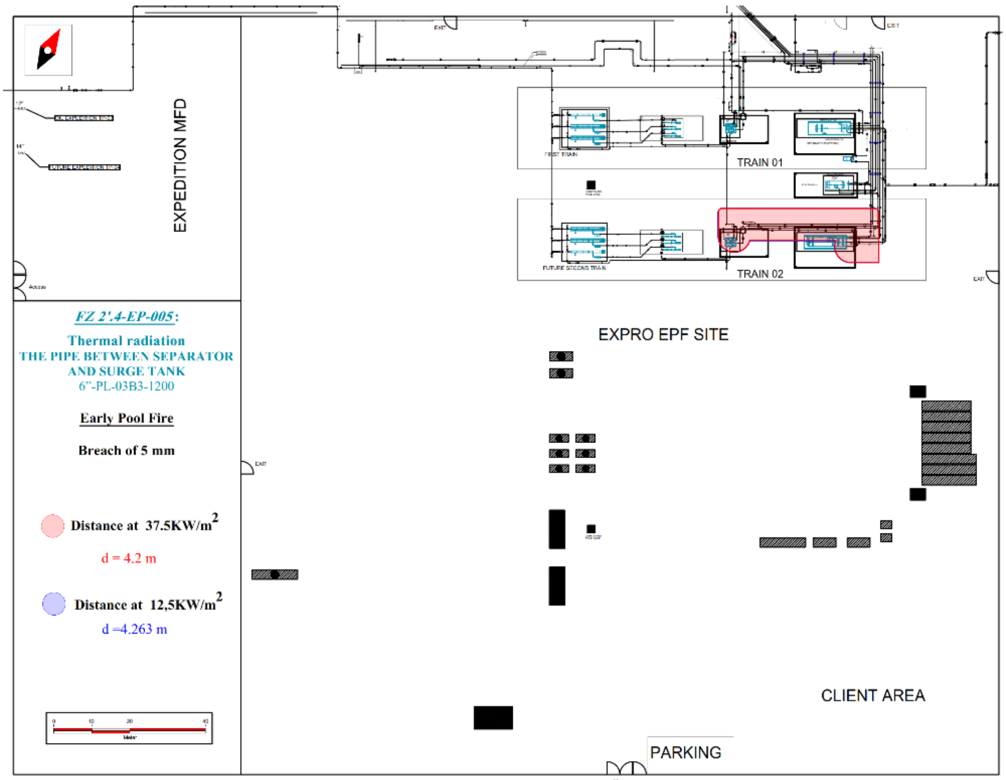


Figure D-69 Scenario FZ-2'.4-EP-005 contours

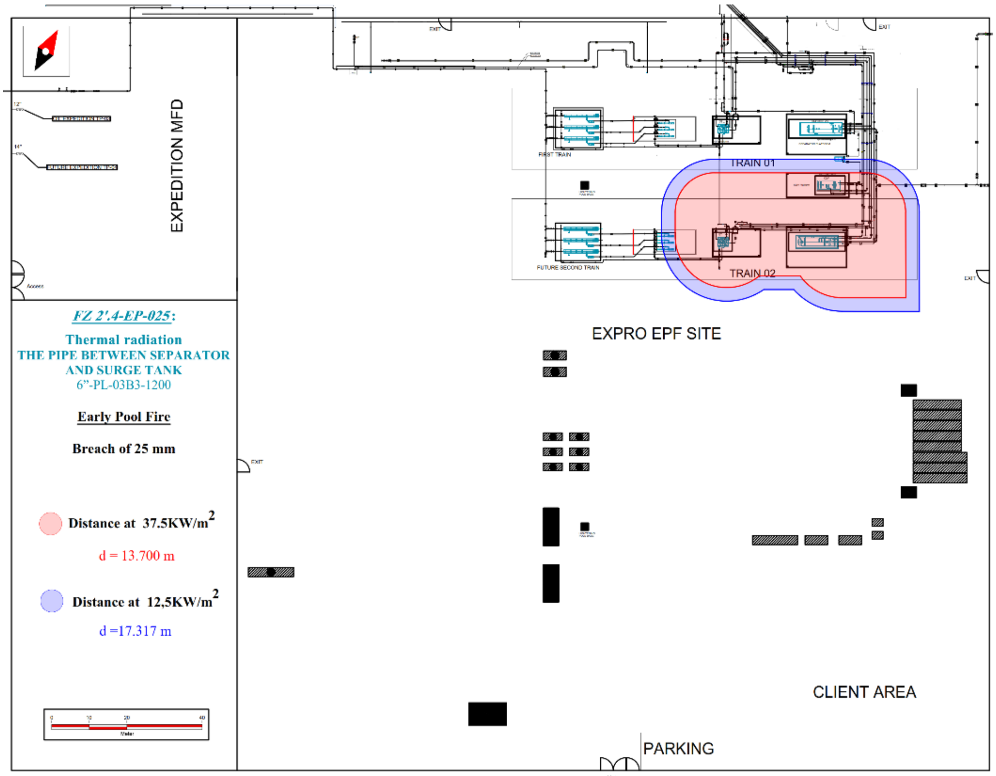


Figure D-70 Scenario FZ-2'.4-EP-025 contours

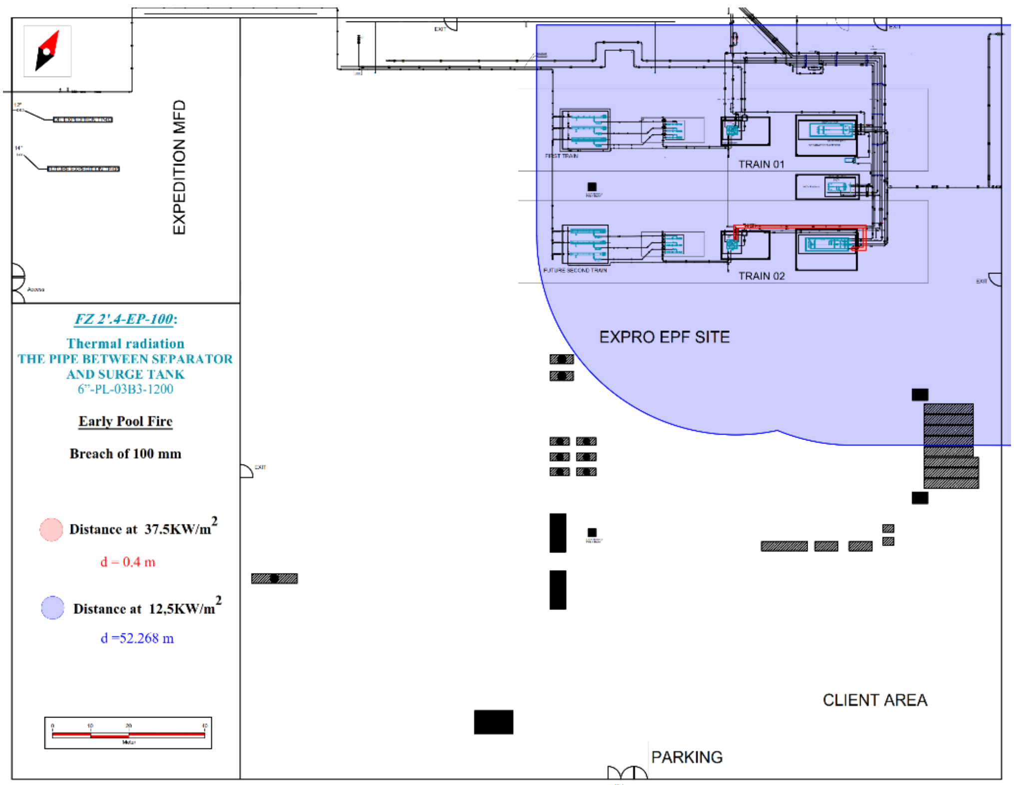


Figure D-71 Scenario FZ-2'.4-EP-100 contours

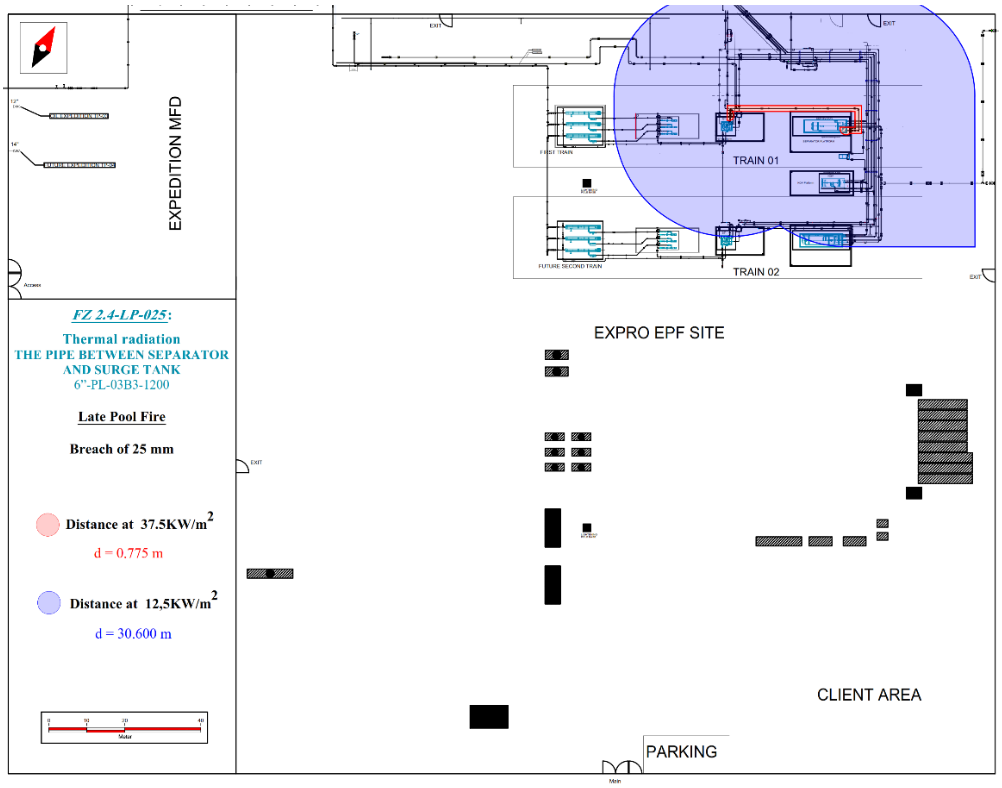


Figure D-72 Scenario FZ-2.4-LP-025 contours

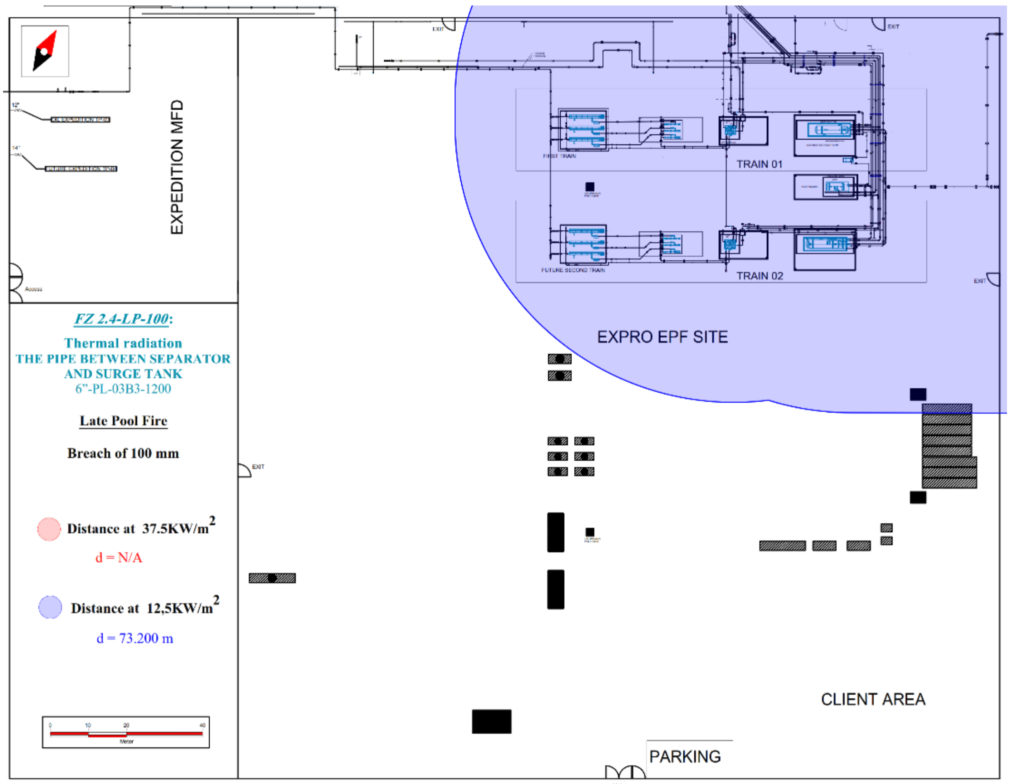


Figure D-73 Scenario FZ-2.4-LP-100 contours

Appendix D. Consequences analysis modeling results

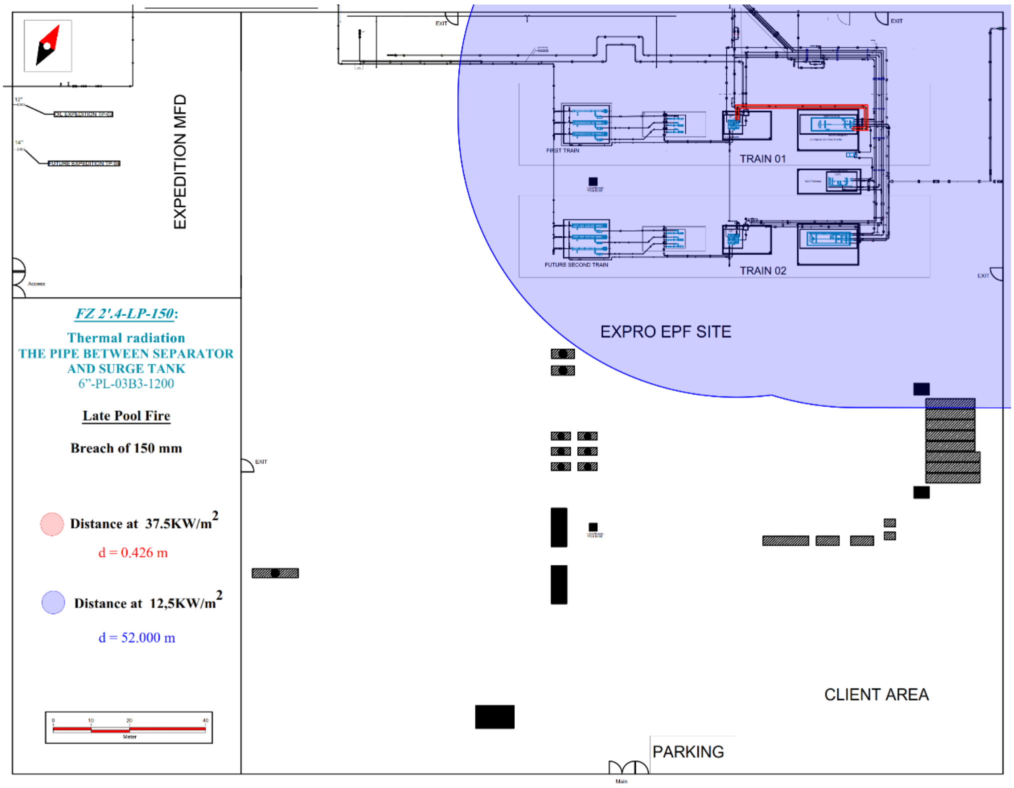


Figure D-74 Scenario FZ-2.4-LP-150 contours

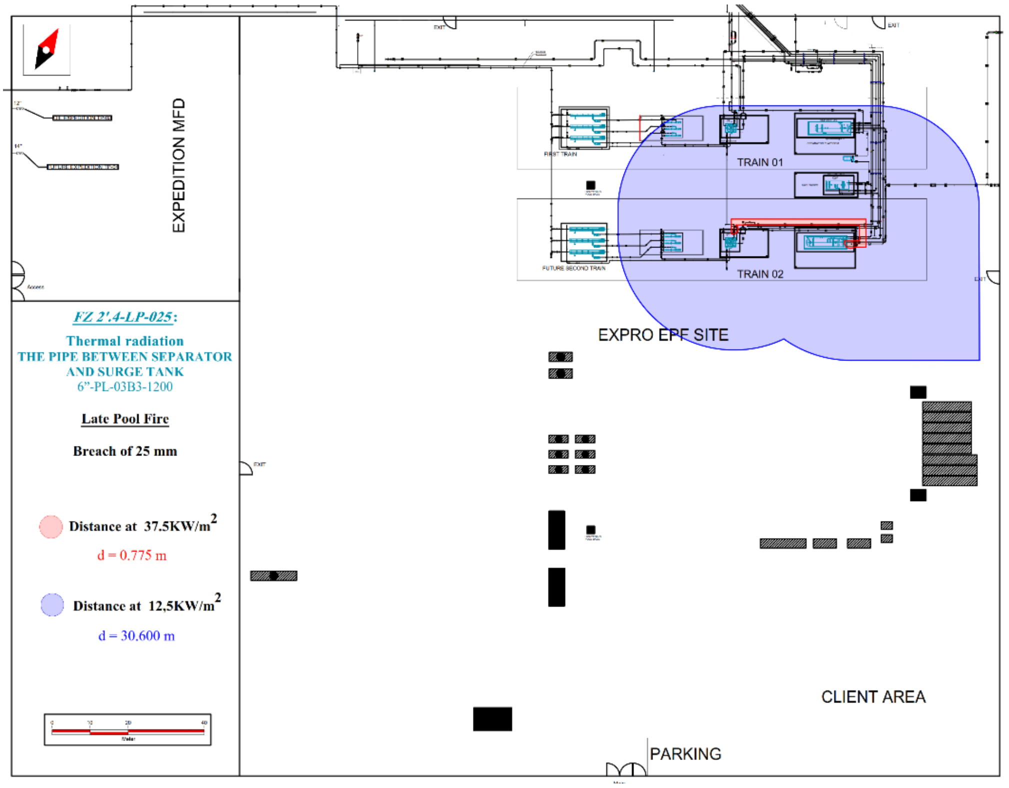


Figure D-75 Scenario FZ-2'.4-LP-025 contours

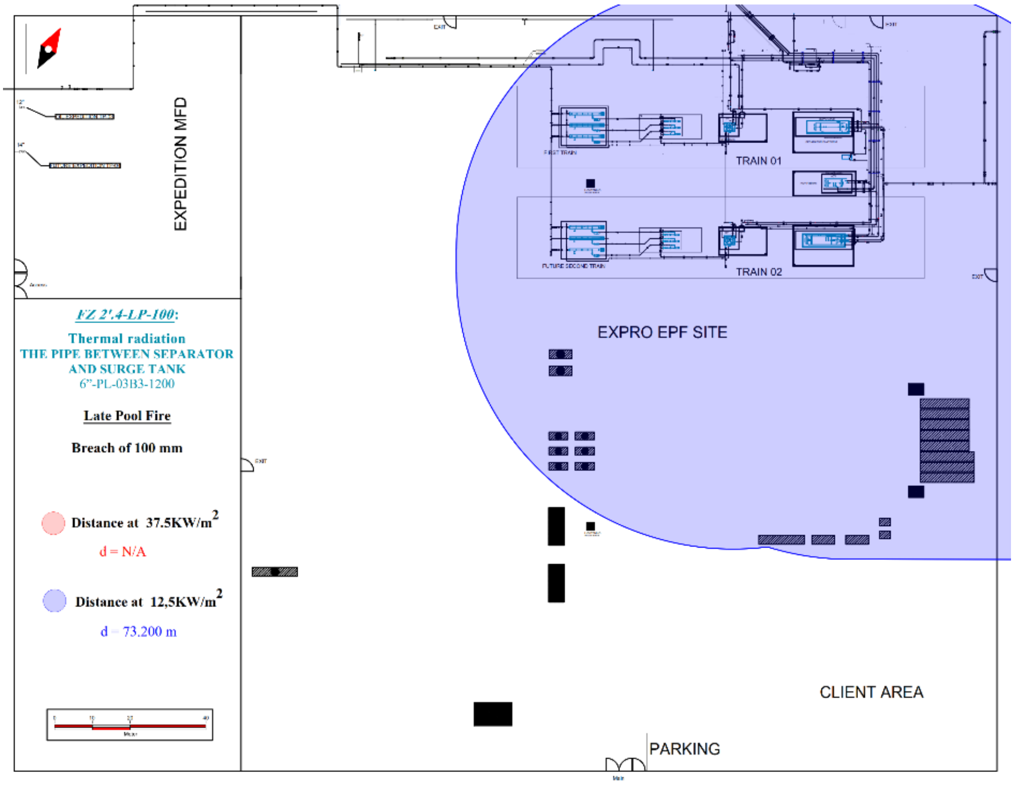


Figure D-76 Scenario FZ-2'.4-LP-100 contours

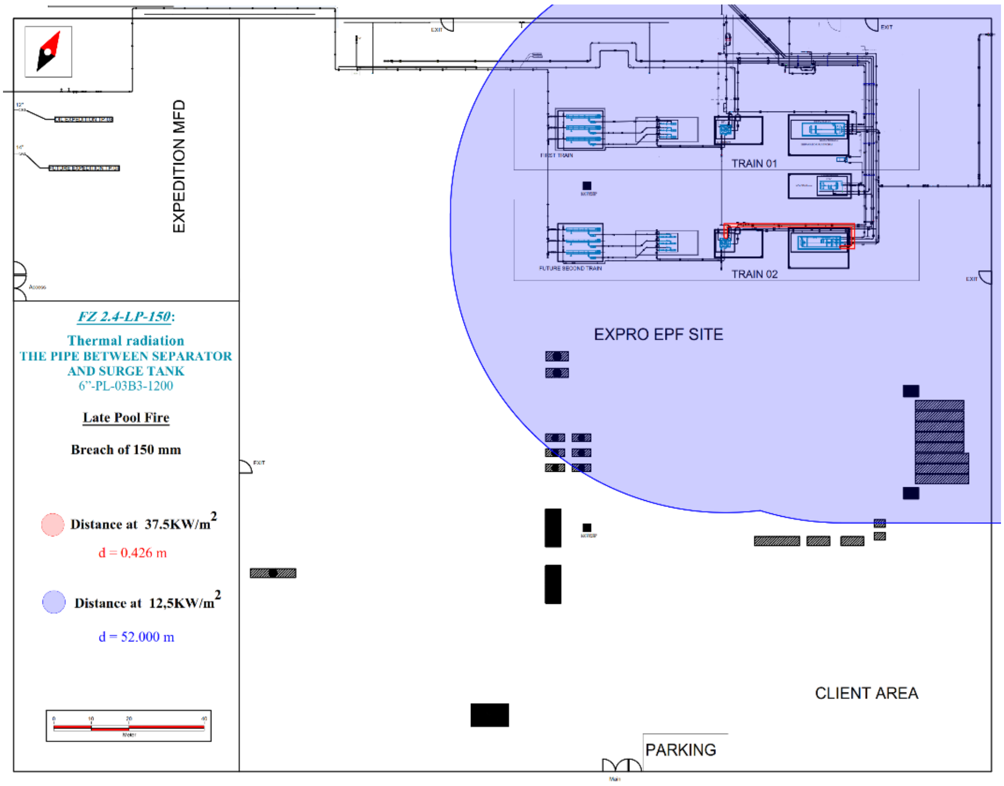


Figure D-77 Scenario FZ-2'.4-LP-150 contours

Appendix D. Consequences analysis modeling results

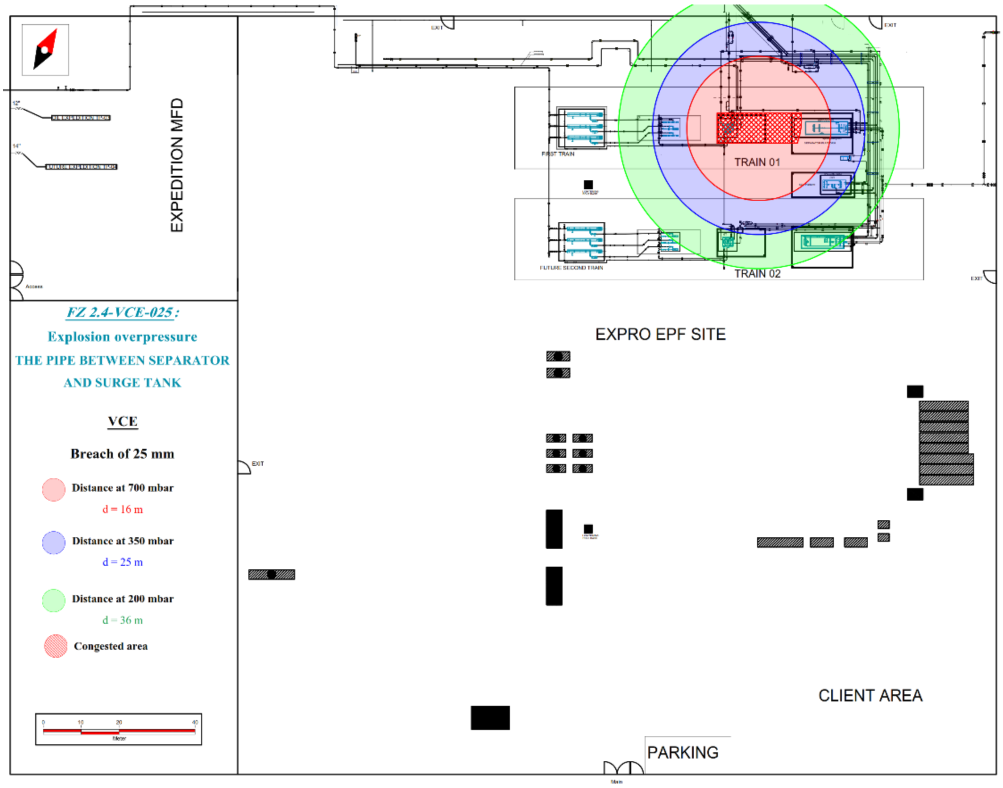


Figure D-78 Scenario FZ-2.4-VCE-025 contours

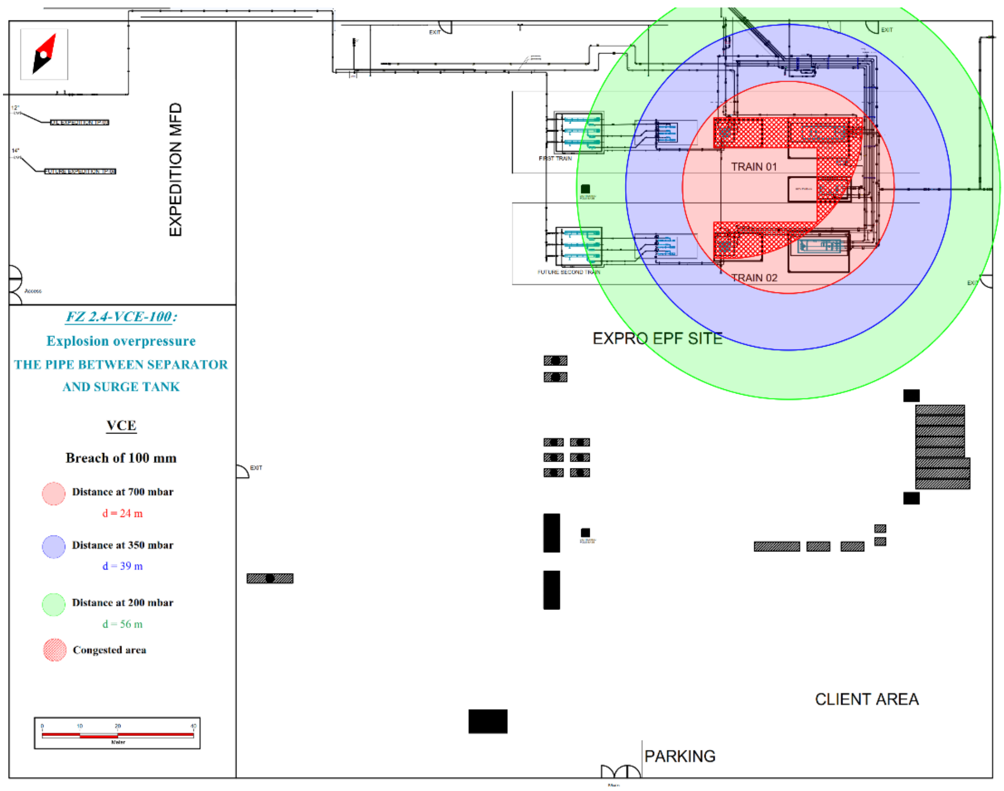


Figure D-79 Scenario FZ-2.4-VCE-100 contours

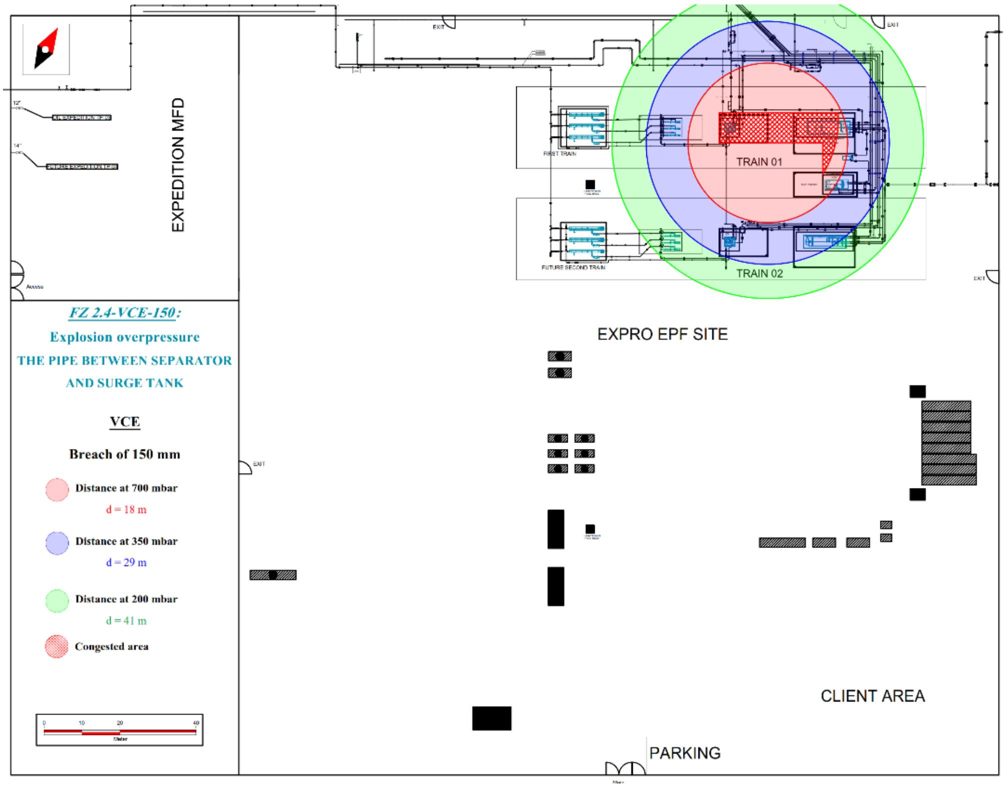


Figure D-80 Scenario FZ-2.4-VCE-150 contours

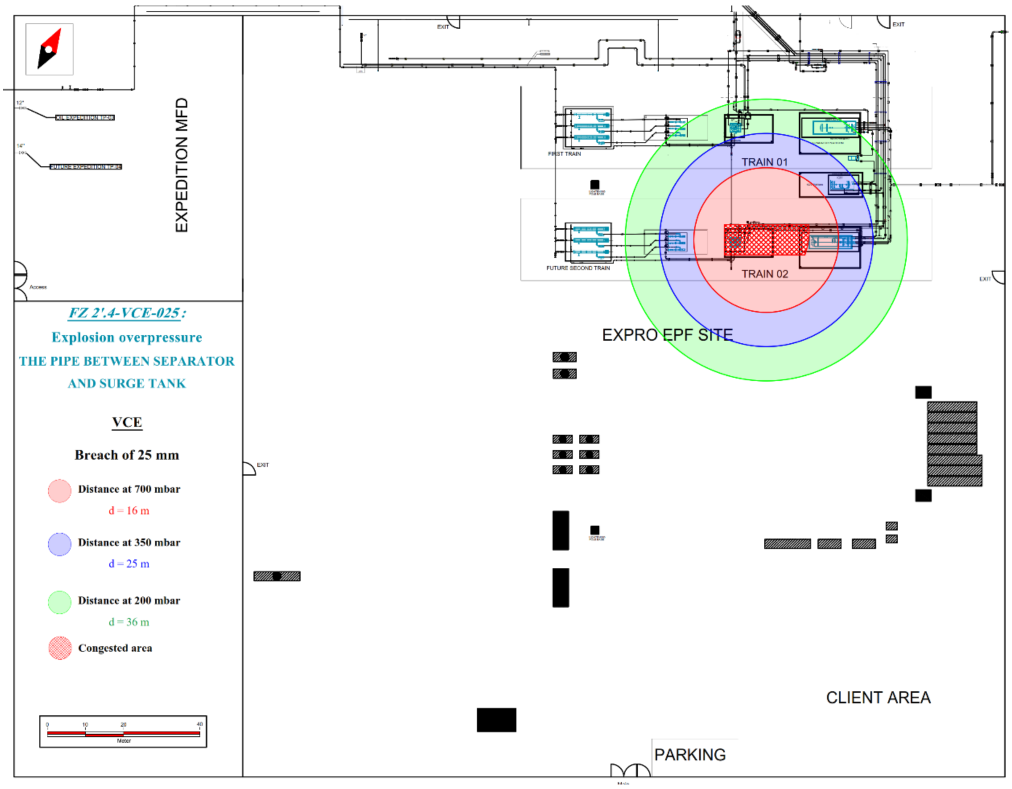


Figure D-81Scenario FZ-2'.4-LP-025 contours

Appendix D. Consequences analysis modeling results

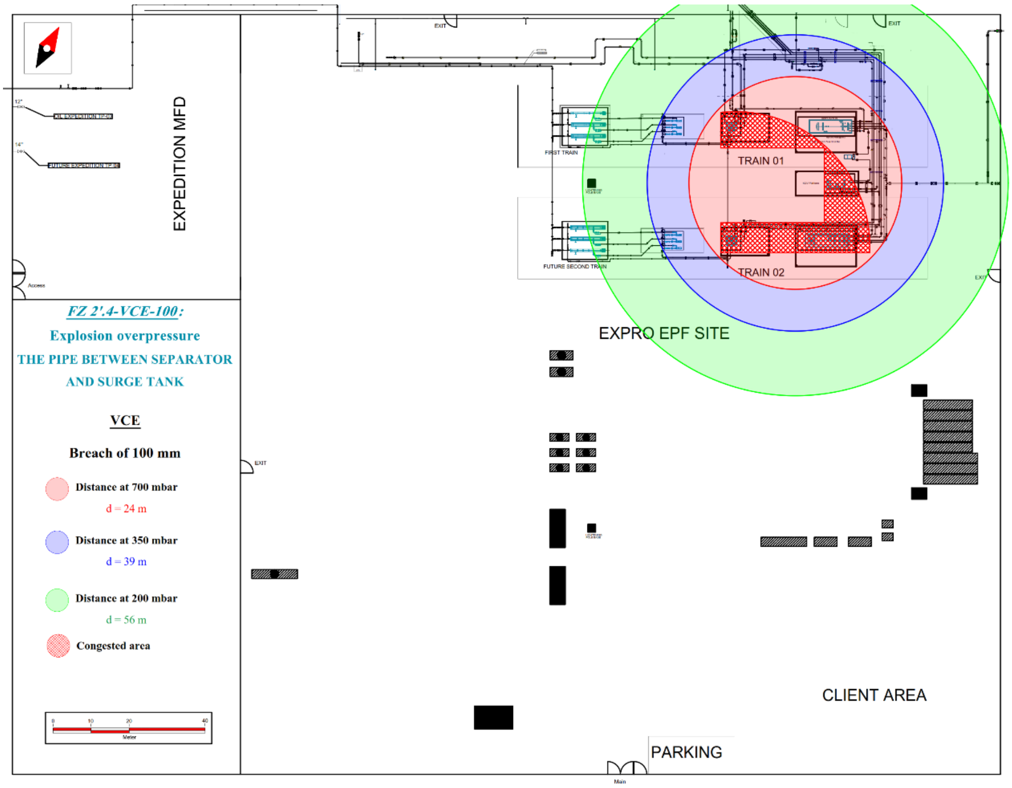


Figure D-82 Scenario FZ-2'.4-LP-100 contours

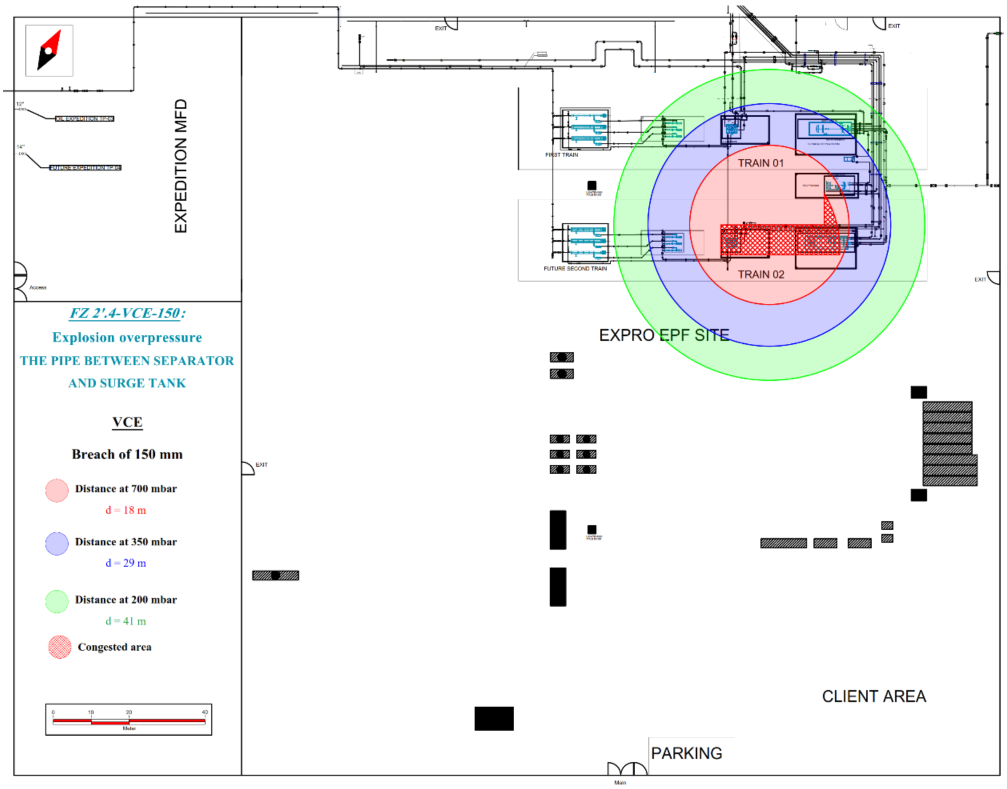


Figure D-83 Scenario FZ-2'.4-LP-150 contours

D.7 Scenario N°3.1: Loss of Containment in the Surge Tank TX6961-014

Equipment : SURGE TANK TX6961-014		
Description	Oil surge tank is a vessel designed to store liquid hydrocarbons after separation	
Design parameter	Dimension	1.192 m/ 4.8 m
Operating parameter	Pressure	4 bar
	Temperature	100 °F
Substance	Oil	

Table D-23 Scenario FZ-3.1-005 modeling results

SCENARIO N°3.1.1 : SMALL BREACH					
Description : The initiating event is the loss of containment of liquid hydrocarbon due to a small breach (5mm) in surge tank TX6961-014					
Leak flow(Kg/s)	0.272				
Early Pool Fire with a 2.402 m diameter					
Atmospheric condition	Flame height (m)		Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m	
Summer	3.082		4.401	4.3	
Winter	2.827		4.450	4.300	
Burning duration (s)	1897.9 (31 min 38 s)				
Late Pool fire with a 7.176 m diameter					
Atmospheric condition	Flame height (m)		Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m)	
Summer	6.830		11.900	10.298	
Winter	6.615		11.998	10.242	
Burning duration (s)	136.10 (2 min 16 s)				
Vapor Cloud Explosion					
Amount of liquid released (Kg)	326.4				
Vaporization rate (Kg/s)	Summer	0.313	Evaporated amount	94.174	
	Winter	0.066		19.8	
Total volume of the cloud (m^3)	Summer	1278.1	Congested cloud volume (m^3)	331.4	
	Winter	271.92		196.4	

Cloud radius (m)	Summer	8.482	
	Winter	5.0636	
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m
Summer	35	22	14
Winter	27	19	12

Table D-24 Scenario FZ-3.1-025 modeling results

SCENARIO N°3.1.2 : MEDIUM/LARGE/CATASTROPHIC BREACH				
Description: The initiating event is the loss of containment of liquid hydrocarbon due to breach (25/100/150mm) in surge tank TX6961-014 in the presence of a retention dike (Rectangular flame shape).				
Breach sizes	Leak flow (Kg/s)			
25mm	6.809			
100mm	108. 953			
150mm	245.145			
Pool fire with a 10.668 m equivalent diameter				
Atmospheric condition	Dike width (m)	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m
Summer	7.15	9.211	5.020	N/A
	12.5		6.120	N/A
Winter	7.15	8.921	5.770	N/A
	12.5		7.230	N/A
Early Pool fire				
Breach sizes	Burning duration (s)			
25mm	1032.5 (17 min 13 s)			
100mm	6372.6 (106 min 13 s)			
Late Pool fire				
Breach sizes	Burning duration (s)			
25mm	762.80 (12 min 43 s)			
100mm	6082.7 (101 min 23 s)			
150mm	2746.0 (48 min)			
Vapor Cloud Explosion				
	25	4056		

Appendix D. Consequences analysis modeling results

<table>
<tr><td rowspan="2">Amount of liquid released (Kg)</td><td>100</td><td colspan="4">16342.95</td></tr>
<tr><td>150</td><td colspan="4">23571</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>0.664</td><td rowspan="2" colspan="2">Evaporated amount (Kg)</td><td>199.25</td></tr>
<tr><td>Winter</td><td>0.141</td><td>44.065</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>2704.1</td><td rowspan="2" colspan="2">Congested cloud volume (m^3)</td><td>388.19</td></tr>
<tr><td>Winter</td><td>598.03</td><td>274.4</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">10.889</td></tr>
<tr><td>Winter</td><td colspan="4">6.585</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in m</td><td colspan="2">Distance at 350 mbar in m</td><td>Distance at 700 mbar in m</td></tr>
<tr><td>Summer</td><td colspan="2">34</td><td colspan="2">23</td><td>15</td></tr>
<tr><td>Winter</td><td colspan="2">30</td><td colspan="2">21</td><td>13</td></tr>
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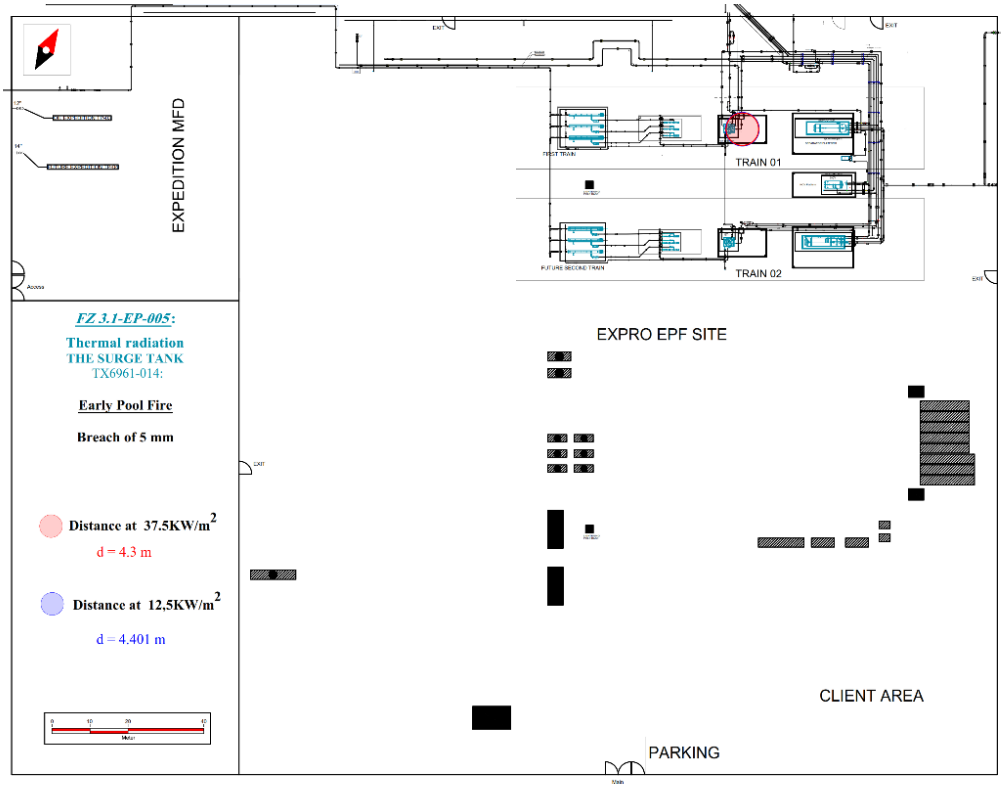


Figure D-84 Scenario FZ-3.1-EP-005 contours

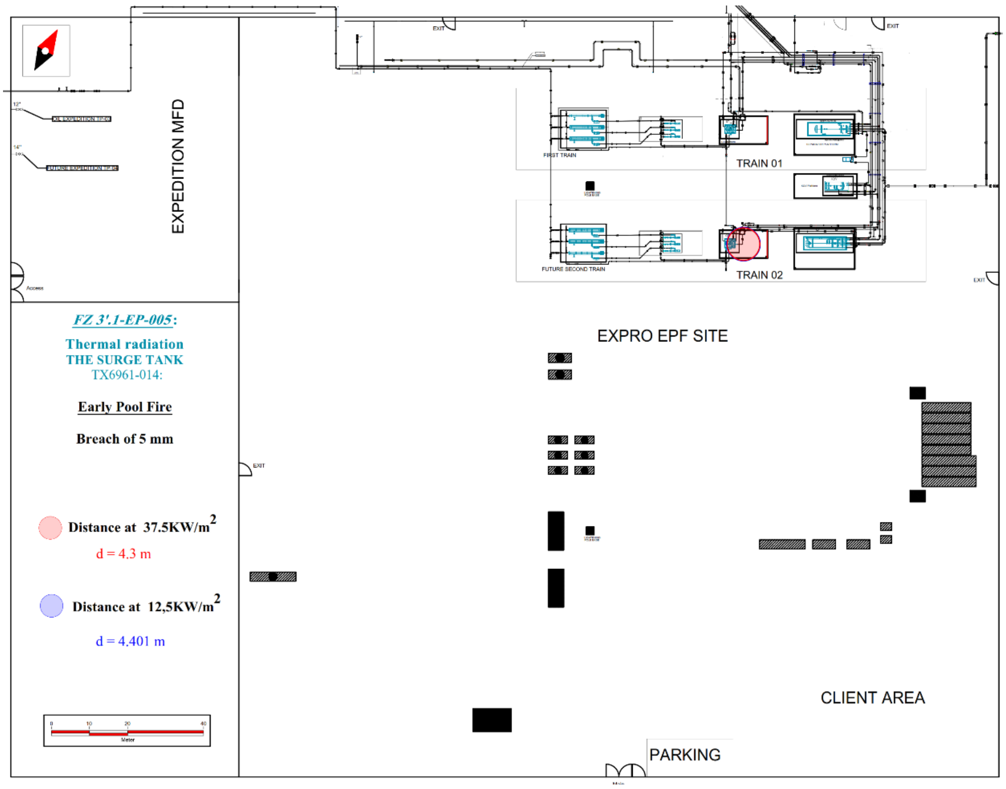


Figure D-85 Scenario FZ-3'.1-EP-005 contours

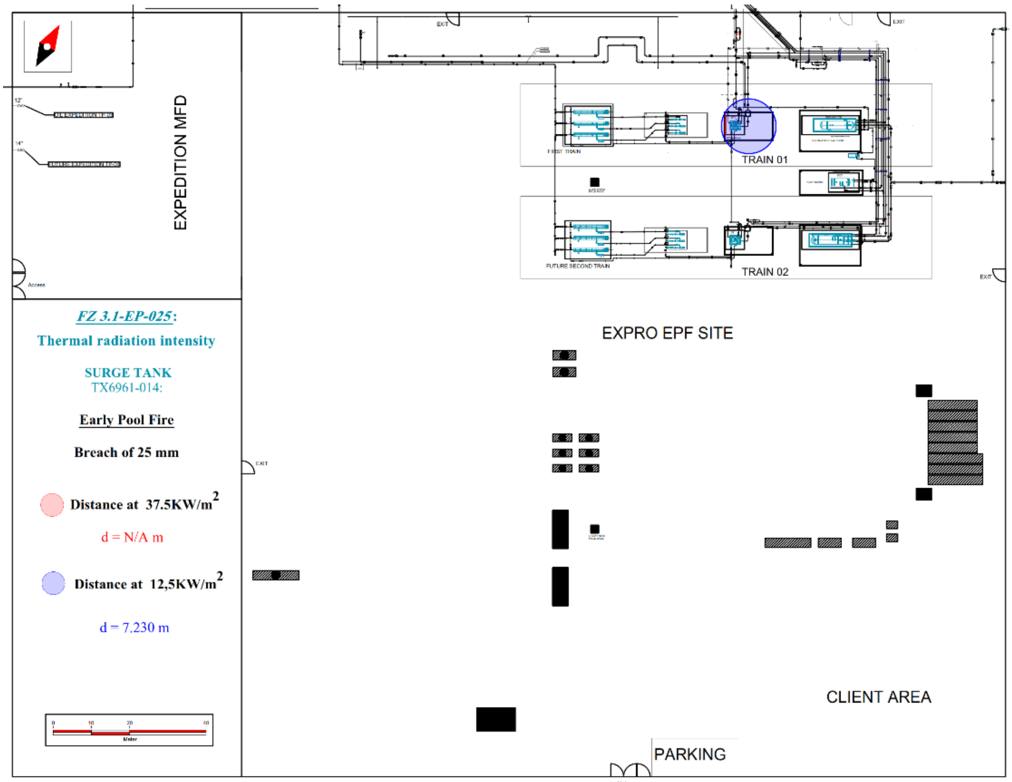


Figure D-86 Scenario FZ-3.1-EP-025 contours

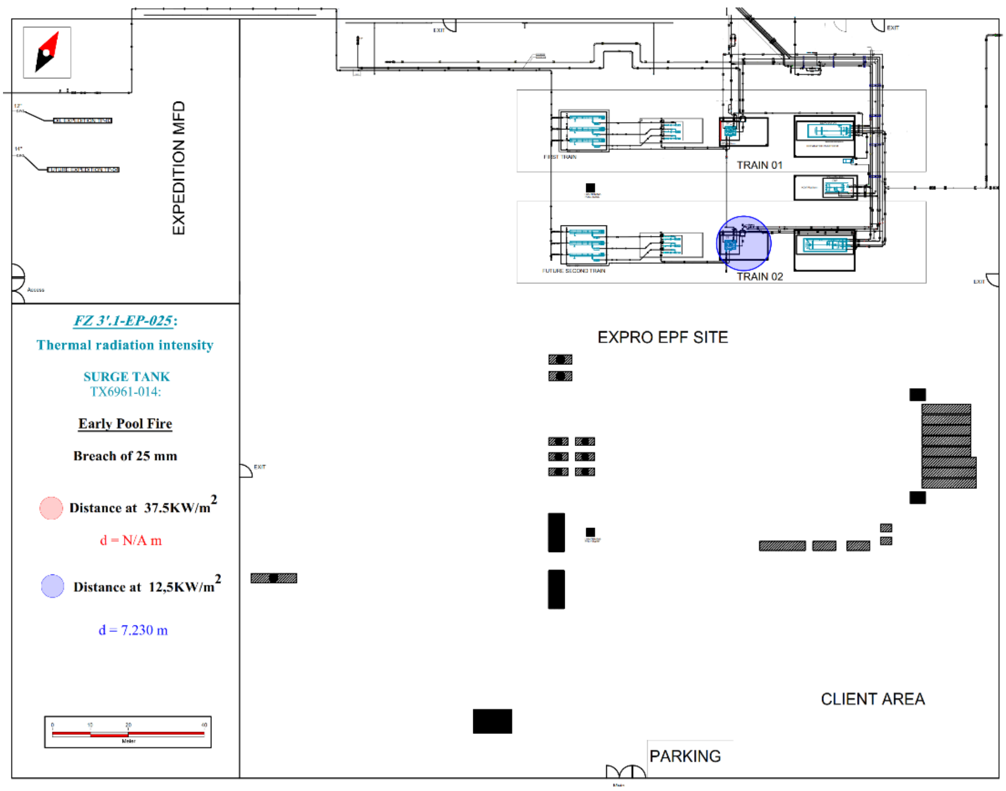


Figure D-87 Scenario FZ-3’.1-EP-025 contours

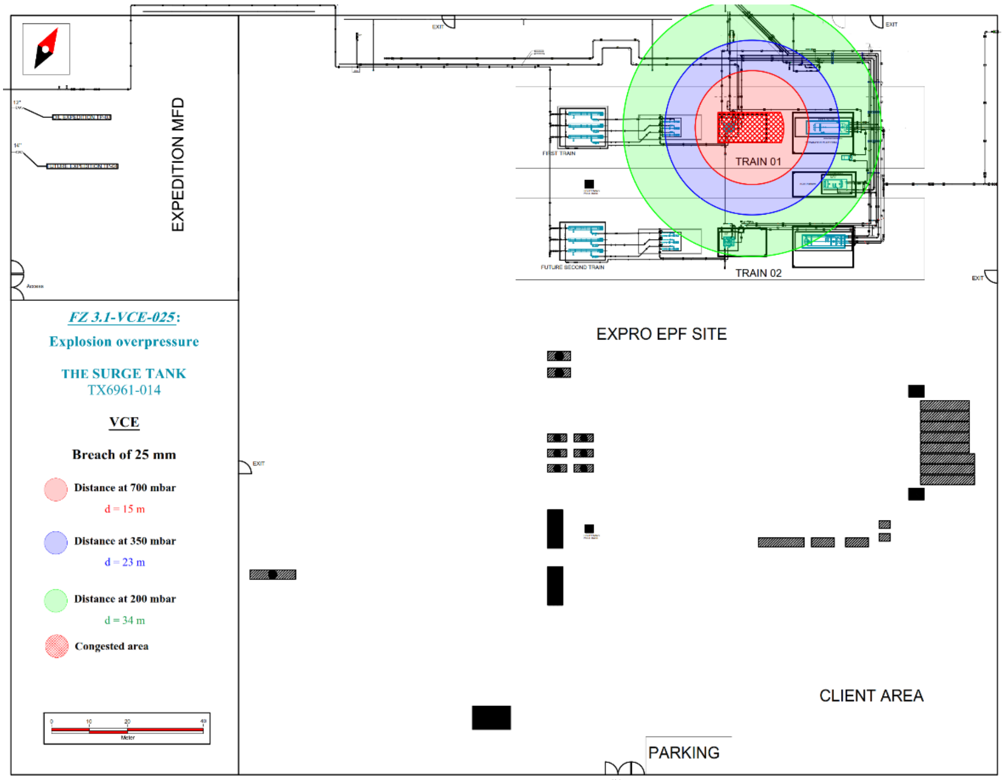


Figure D-88 Scenario FZ-3.1-VCE-025 contours

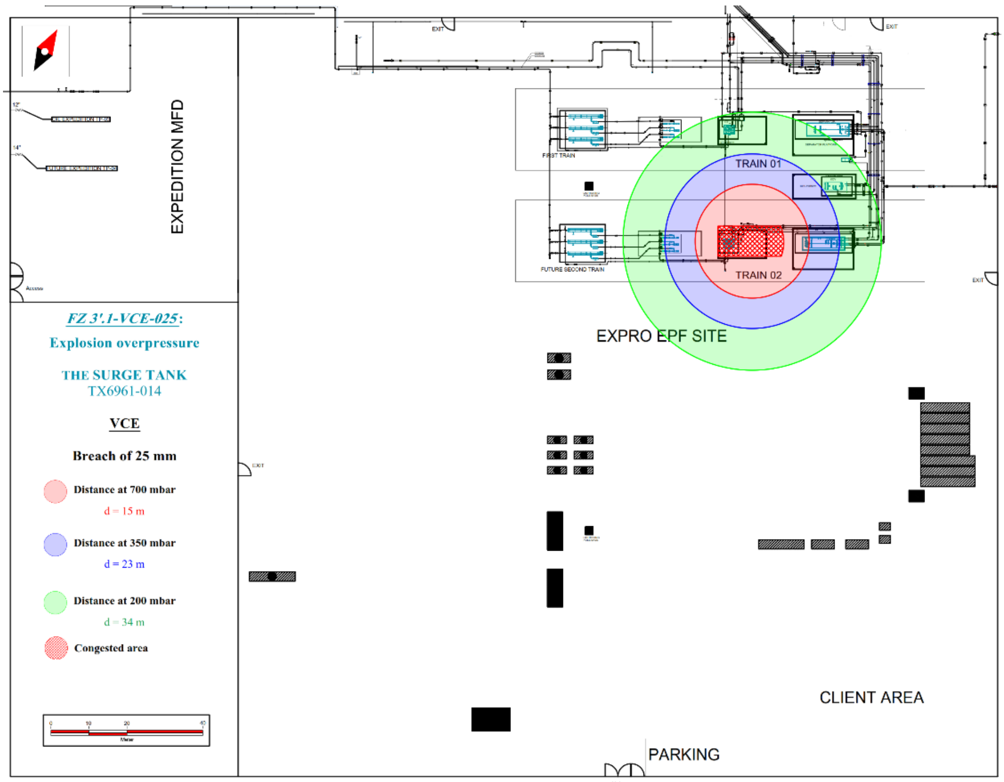


Figure D-89 Scenario FZ-3'.1-VCE-025 contours

D.8 Scenario N°3.2: Loss of Containment in the Pipe between the Surge Tank & Pumps

Table D-25 Scenario FZ-3.2-005 modeling results

SMALL BREACH					
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a small breach (5 mm) in the pipe between surge tank and pumps 10”-PL-03B3-1218					
Leak flow (Kg/s)	0.295				
Early Pool fire with a diameter of 2.502					
Atmospheric condition	Flame height (m)		Distance at 12.5 KW/m2 (m)		Distance at 37.5 KW/m2 (m)
Summer	3.1759		4.651		4.500
Winter	3.0759		4.651		4.600
Burning duration (s)	1864.6 (31 min)				
Late Pool fire with a diameter of 7.468 m					
Atmospheric condition	Flame height (m)		Distance at 12.5 KW/m2 (m)		Distance at 37.5 KW/m2 (m)
Summer	7.0356		12.300		10.314
Winter	6.814		12.700		10.245
Burning duration (s)	136.02 (2 min 12 s)				
Vapor Cloud Explosion					
Amount of liquid released (Kg)	354				
Vaporization rate (Kg/s)	Summer	0.3385	Evaporated amount (Kg)		101.55
	Winter	0.0720			21.605
Total volume of the cloud (m^3)	Summer	1378.1	Congested cloud volume (m^3)		/
	Winter	293.21			/
Cloud radius (m)	Summer	8.697			
	Winter	5.192			
Atmospheric condition	Distance at 200 mbar in (m)		Distance at 350 mbar in (m)		Distance at 700 mbar in (m)
Summer	N/A		N/A		N/A
Winter	N/A		N/A		N/A

Table D-26 Scenario FZ-3.2 -025 modeling results

<table>
<tr><th colspan="6">MEDIUM BREACH</th></tr>
<tr><td colspan="6">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a medium breach (25 mm) in the pipe between surge tank and pumps 10”-PL-03B3-1218</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="5">7.377</td></tr>
<tr><td colspan="6">Early Pool fire with a diameter of 13.903 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">9.5837</td><td colspan="2">18.356</td><td>14.100</td></tr>
<tr><td>Winter</td><td colspan="2">9.1406</td><td colspan="2">18.356</td><td>14.200</td></tr>
<tr><td>Burning duration (s)</td><td colspan="5">755.40 (12 min 36 s)</td></tr>
<tr><td colspan="6">Late Pool fire with a diameter of 26.41 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">17.952</td><td colspan="2">32.500</td><td>0.753</td></tr>
<tr><td>Winter</td><td colspan="2">17.387</td><td colspan="2">33.156</td><td>3.203</td></tr>
<tr><td>Burning duration (s)</td><td colspan="5">134.66 (2 min 15s)</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="5">4 426,2</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>3.6841</td><td colspan="2" rowspan="2">Evaporated amount (Kg)</td><td>1105.2</td></tr>
<tr><td>Winter</td><td>0.783</td><td>235.14</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>15000</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>70.3</td></tr>
<tr><td>Winter</td><td>3191.2</td><td>/</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">19.276</td></tr>
<tr><td>Winter</td><td colspan="4">11.507</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">19</td><td colspan="2">13</td><td>N/A</td></tr>
<tr><td>Winter</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Table D-27 Scenario FZ-3.2 -100 modeling results

<table>
<tr><th colspan="5">LARGE BREACH</th></tr>
<tr><td colspan="5">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a large breach (100 mm) in the pipe between surge tank and pumps 10”-PL-03B3-1218</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="4">118.041</td></tr>
<tr><td colspan="5">Pool fire with a diameter of 27.792 m</td></tr>
<tr><td>Atmospheric condition</td><td>Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td>18.786</td><td colspan="2">32.986</td><td>0.782</td></tr>
<tr><td>Winter</td><td>18.051</td><td colspan="2">33.900</td><td>3.800</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">135.75 (2 min 16 s)</td></tr>
<tr><td colspan="5">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="4">17 706,15</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>11.997</td><td rowspan="2">Evaporated amount(Kg)</td><td>3599.0</td></tr>
<tr><td>Winter</td><td>2.552</td><td>765.70</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>48843</td><td rowspan="2">Congested cloud volume (m^3)</td><td>148.4</td></tr>
<tr><td>Winter</td><td>10392</td><td>33</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="3">28.570</td></tr>
<tr><td>Winter</td><td colspan="3">17.056</td></tr>
<tr><td>Atmospheric condition</td><td>Distance at 200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td>24</td><td colspan="2">17</td><td>11</td></tr>
<tr><td>Winter</td><td>15</td><td colspan="2">11</td><td>7</td></tr>
</table>

Table D-28 Scenario FZ-3.2 -150 modeling results

<table>
<tr><th colspan="4">CATASTROPHIC BREACH</th></tr>
<tr><td colspan="4">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a catastrophic breach (>150 mm) in the pipe between surge tank and pumps 10”-PL-03B3-1218</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="3">265.593</td></tr>
<tr><td colspan="4">Pool fire with a diameter of 35.433 m</td></tr>
<tr><td>Atmospheric condition</td><td>Flame height (m)</td><td>Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td>28.746</td><td>40.553</td><td>0.625</td></tr>
<tr><td>Winter</td><td>27.841</td><td>41.600</td><td>3.652</td></tr>
</table>

Appendix D. Consequences analysis modeling results

<table>
<tr><td>Burning duration (s)</td><td colspan="6">134.65 (2 min 13 s)</td></tr>
<tr><td colspan="7">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of Liquid released (Kg)</td><td colspan="6">15 935,58</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td colspan="2">12.361</td><td colspan="2" rowspan="2">Evaporated amount(Kg)</td><td>3708.4</td></tr>
<tr><td>Winter</td><td colspan="2">2.6299</td><td>788.98</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="2">50328</td><td colspan="2" rowspan="2">Congested cloud volume (m^3)</td><td>300.4</td></tr>
<tr><td>Winter</td><td colspan="2">10708</td><td>37.27</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="5">28.857</td></tr>
<tr><td>Winter</td><td colspan="5">17.227</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td colspan="2">Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">31</td><td colspan="2">21</td><td colspan="2">13</td></tr>
<tr><td>Winter</td><td colspan="2">16</td><td colspan="2">11</td><td colspan="2">N/A</td></tr>
</table>

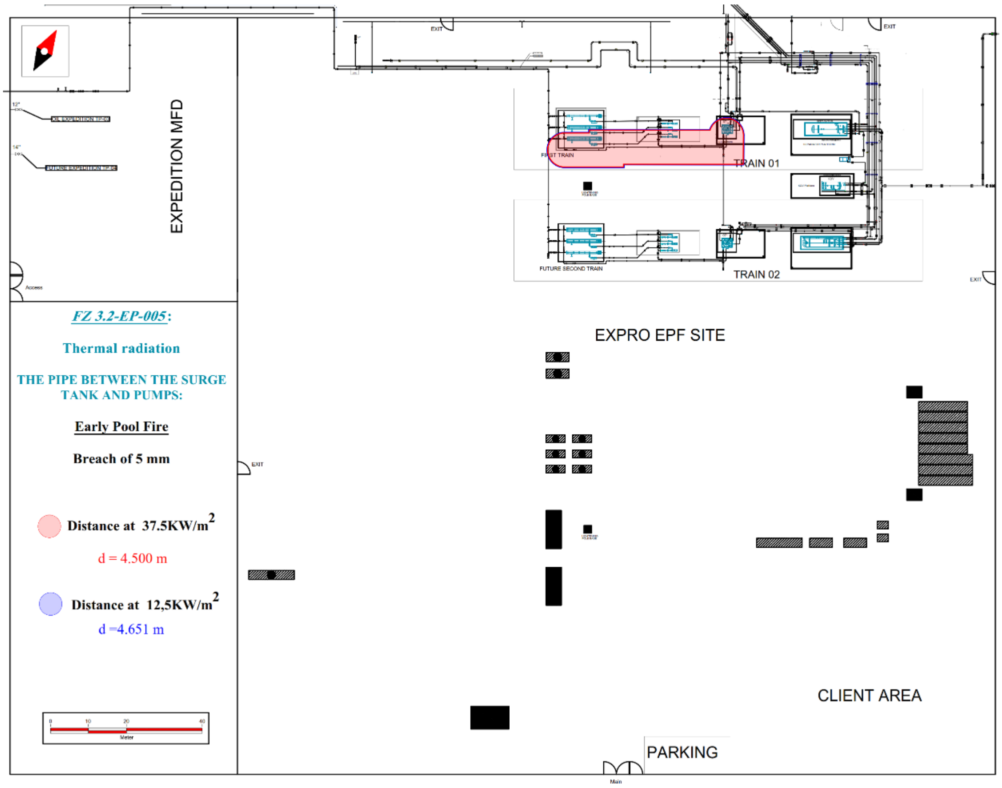


Figure D-90 Scenario FZ-3.2-EP-005 contours

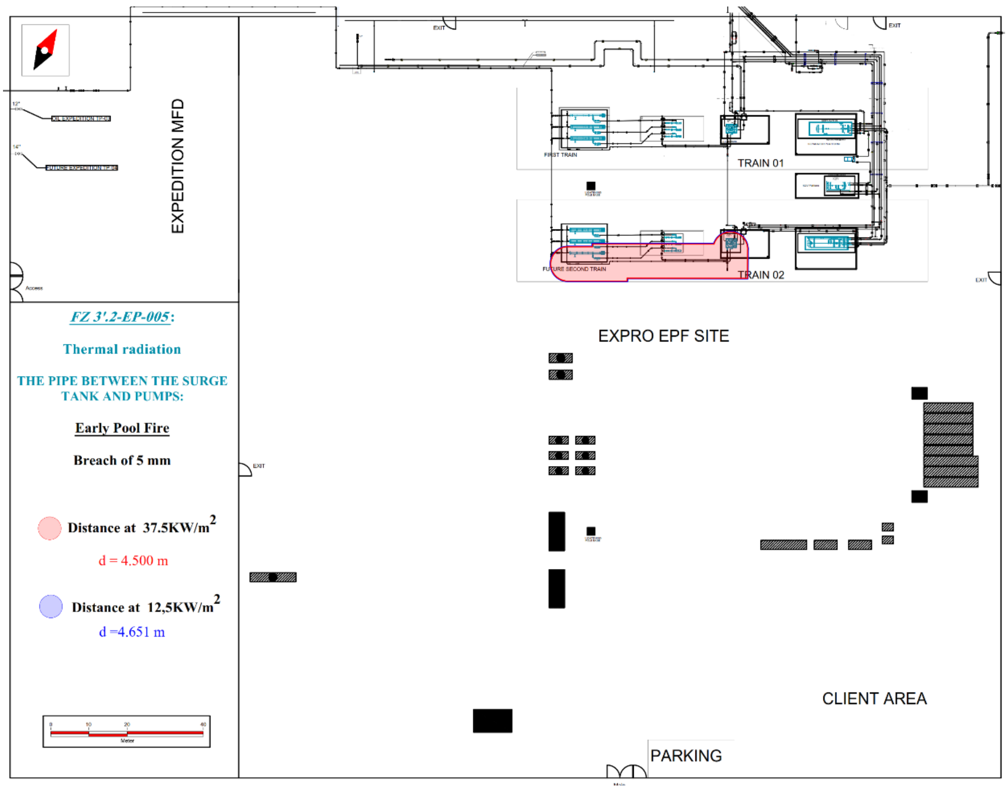


Figure D-91 Scenario FZ-3'.2-EP-005 contours

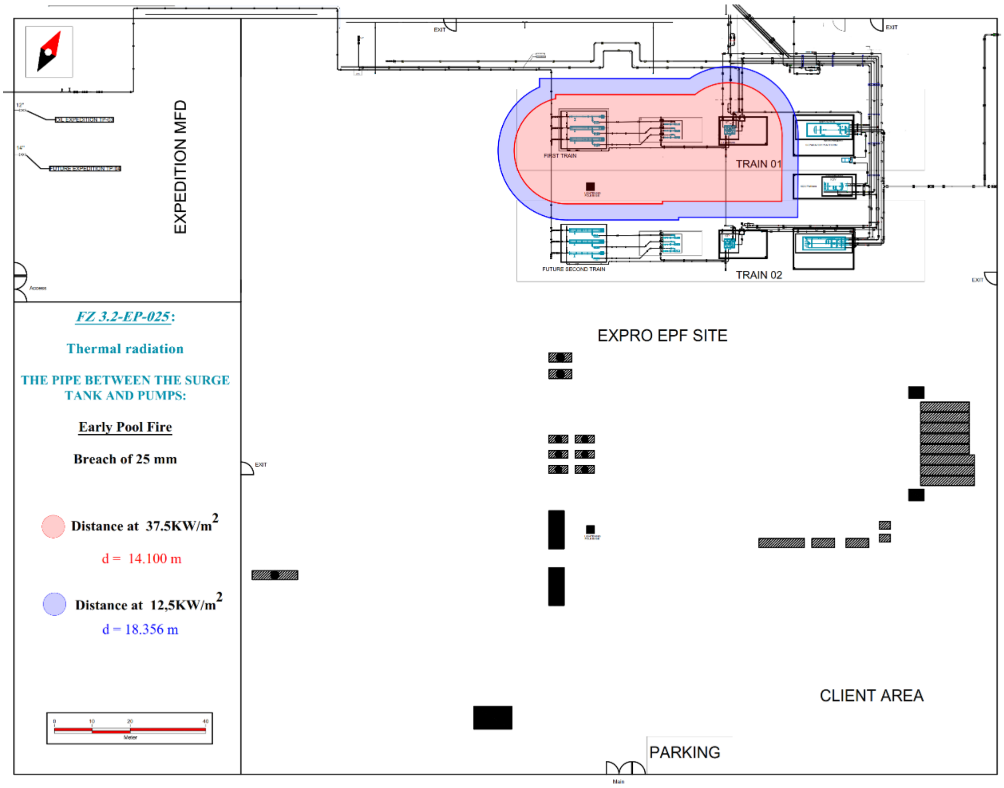


Figure D-92 Scenario FZ-3.2-EP-025 contours

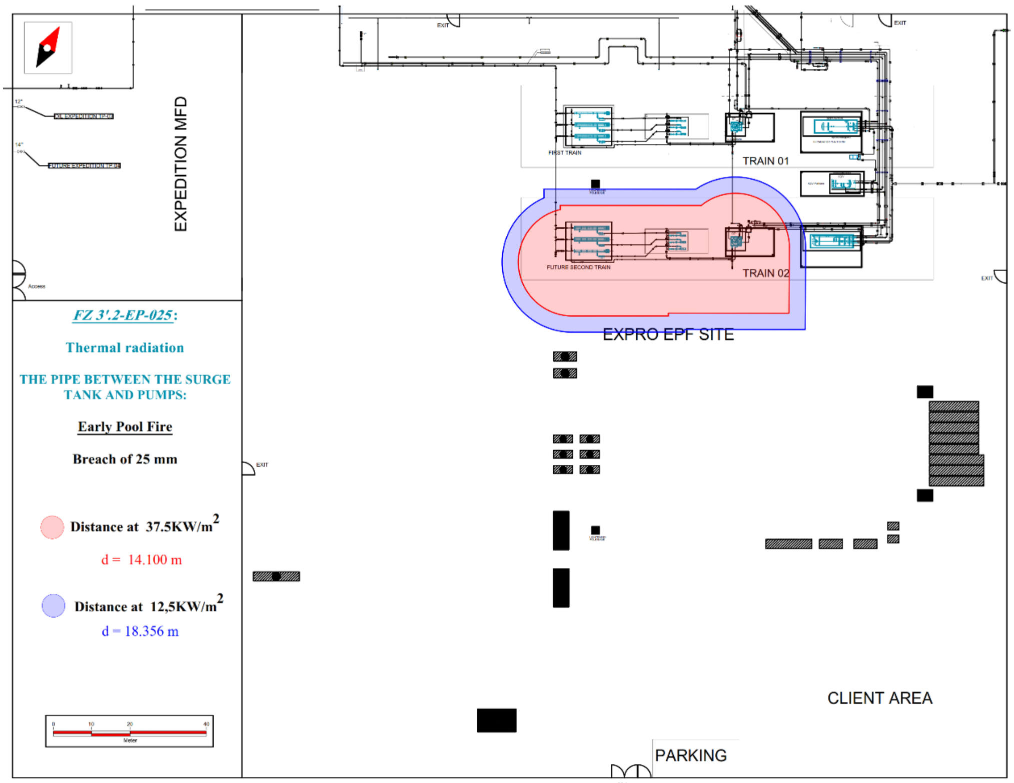


Figure D-93 Scenario FZ-3'.2-EP-025 contours

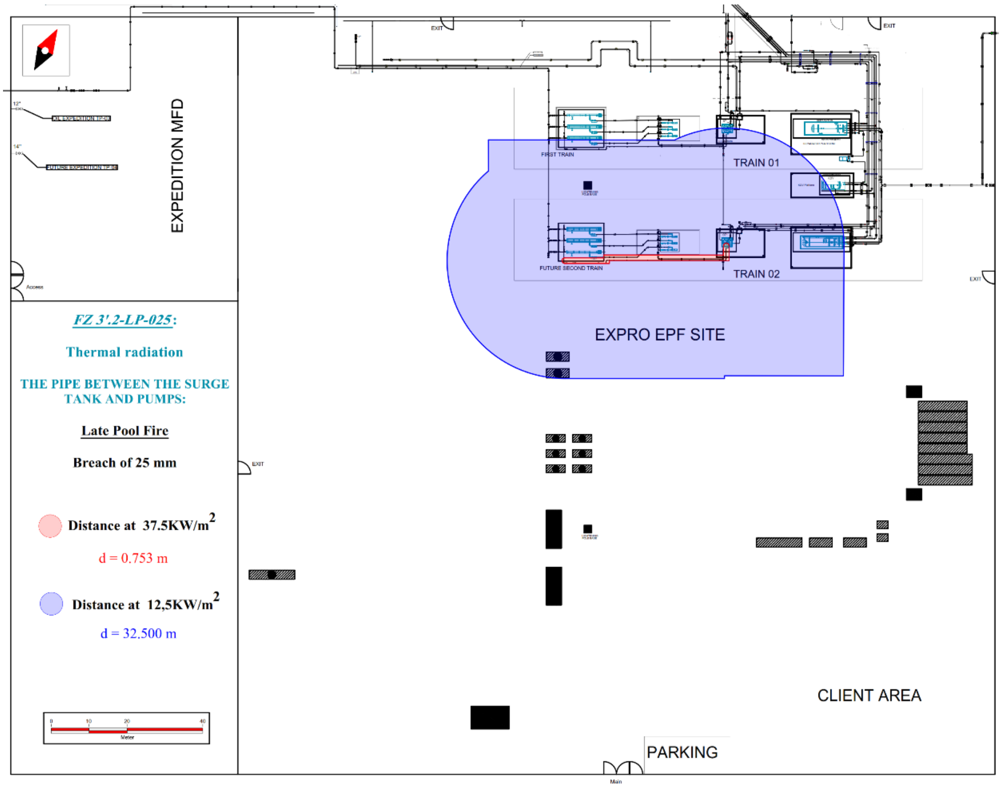


Figure D-94 Scenario FZ-3'.2-LP-025 contours

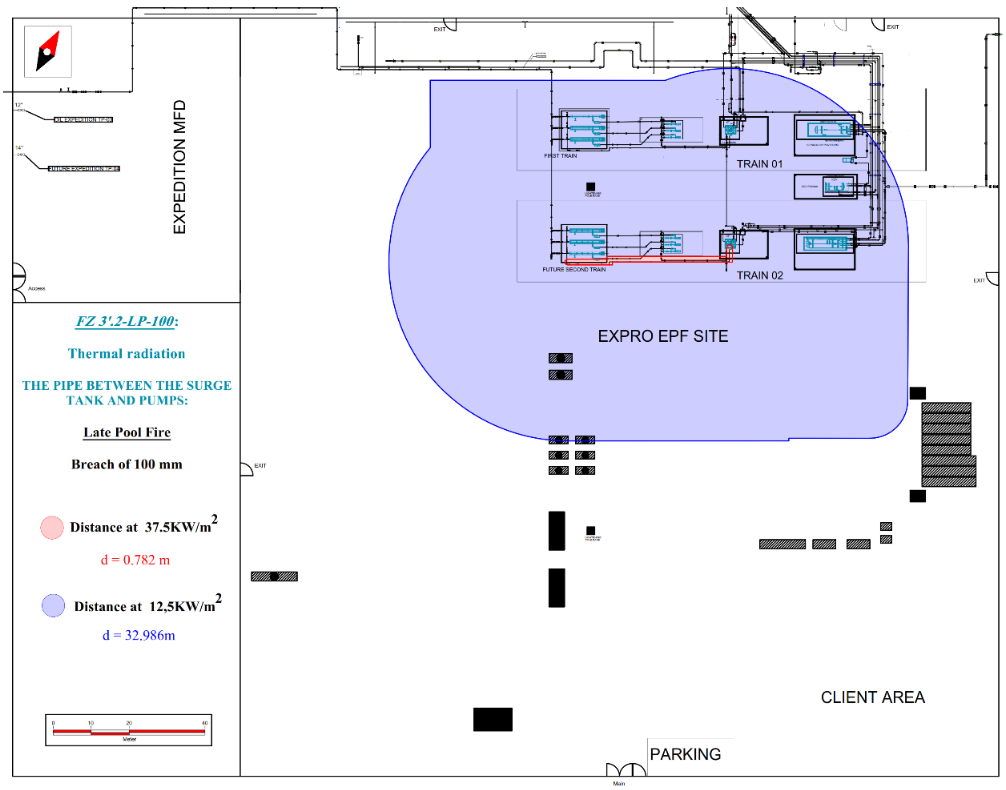


Figure D-95 Scenario FZ-3'.2-LP-100 contours

Appendix D. Consequences analysis modeling results

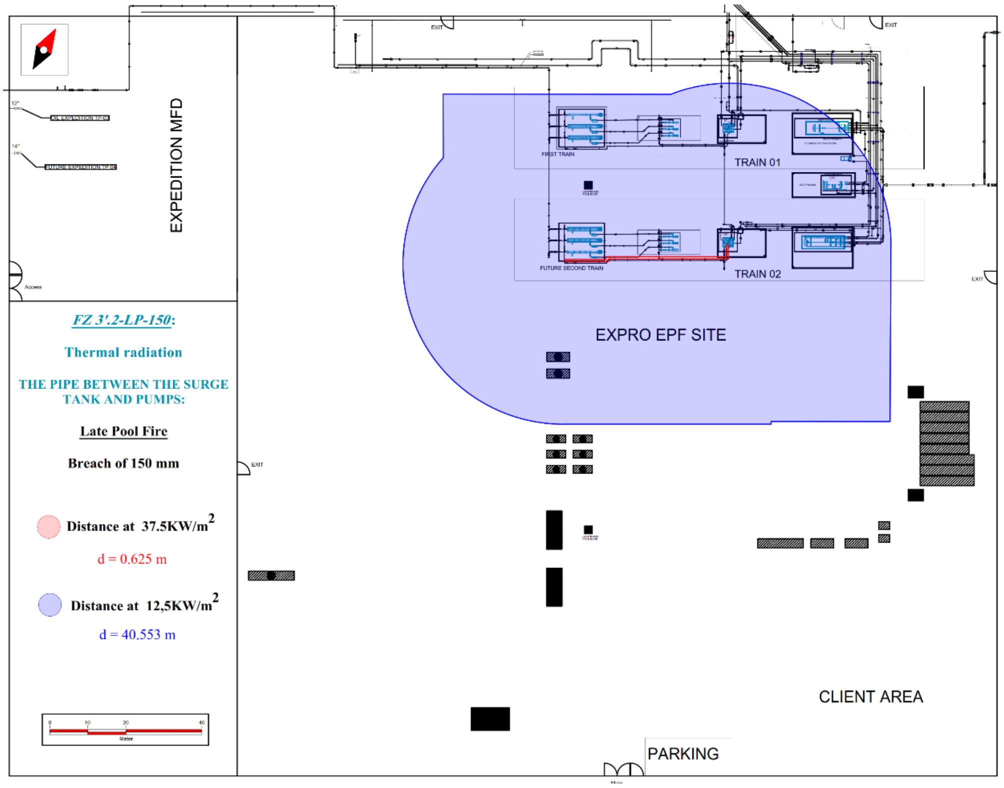


Figure D-96 Scenario FZ-3'.2-LP-150 contours

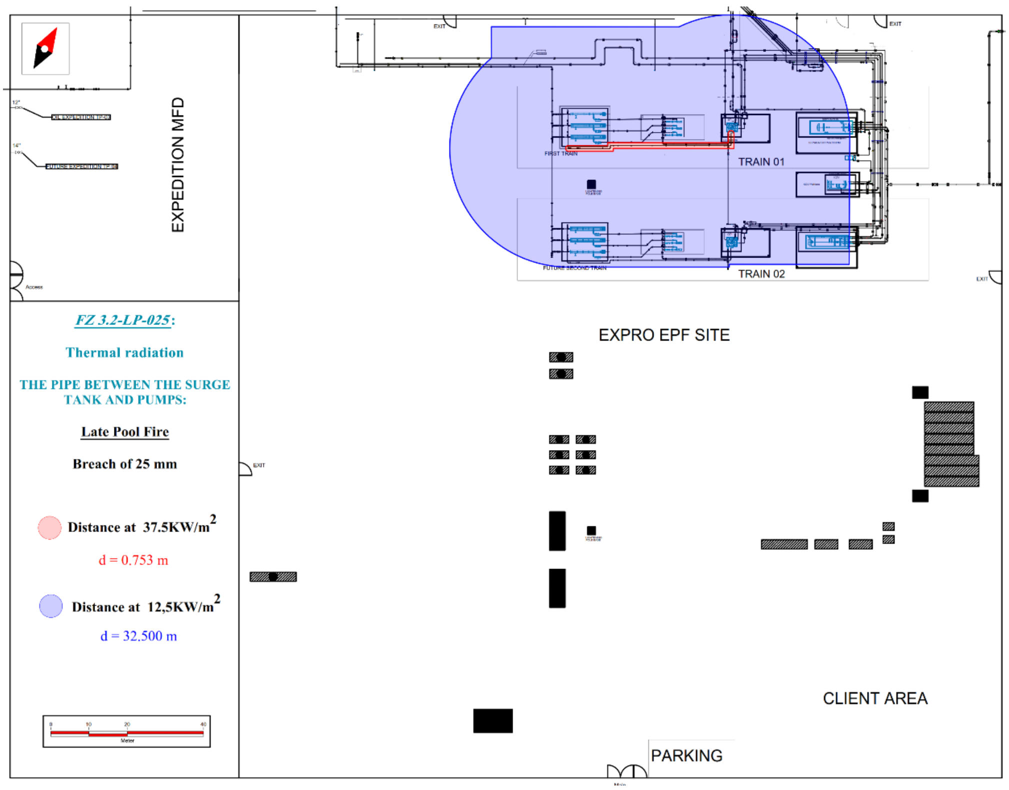


Figure D-97 Scenario FZ-3.2-LP-025 contours

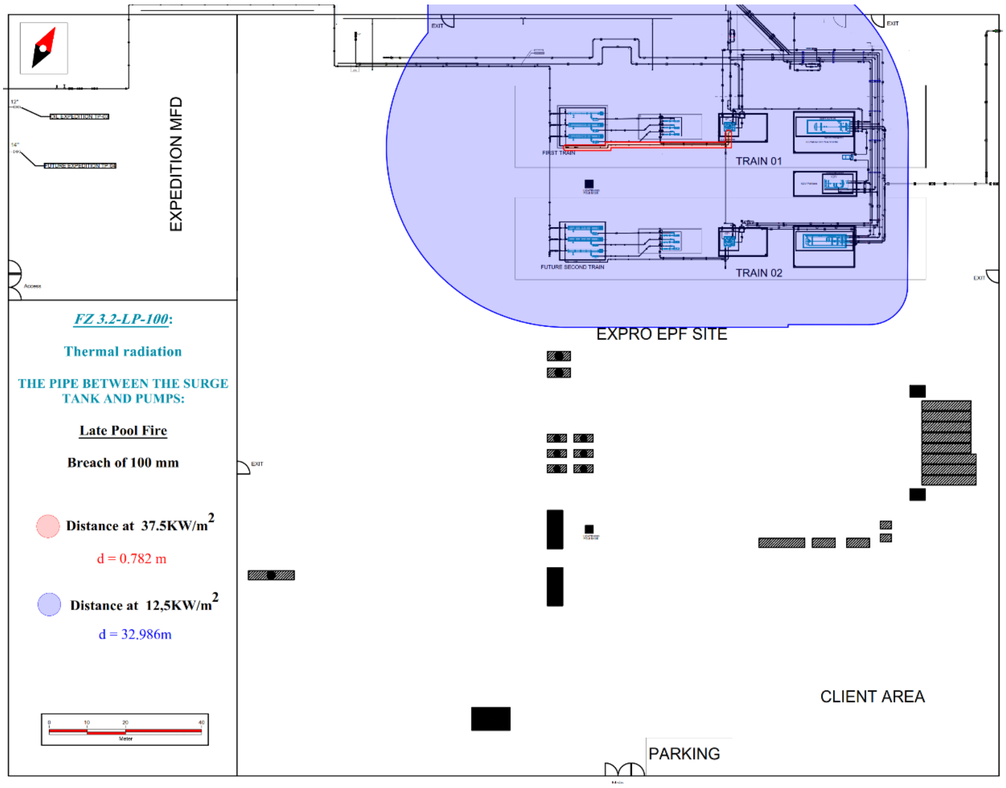


Figure D-98 Scenario FZ-3.2-LP-100 contours

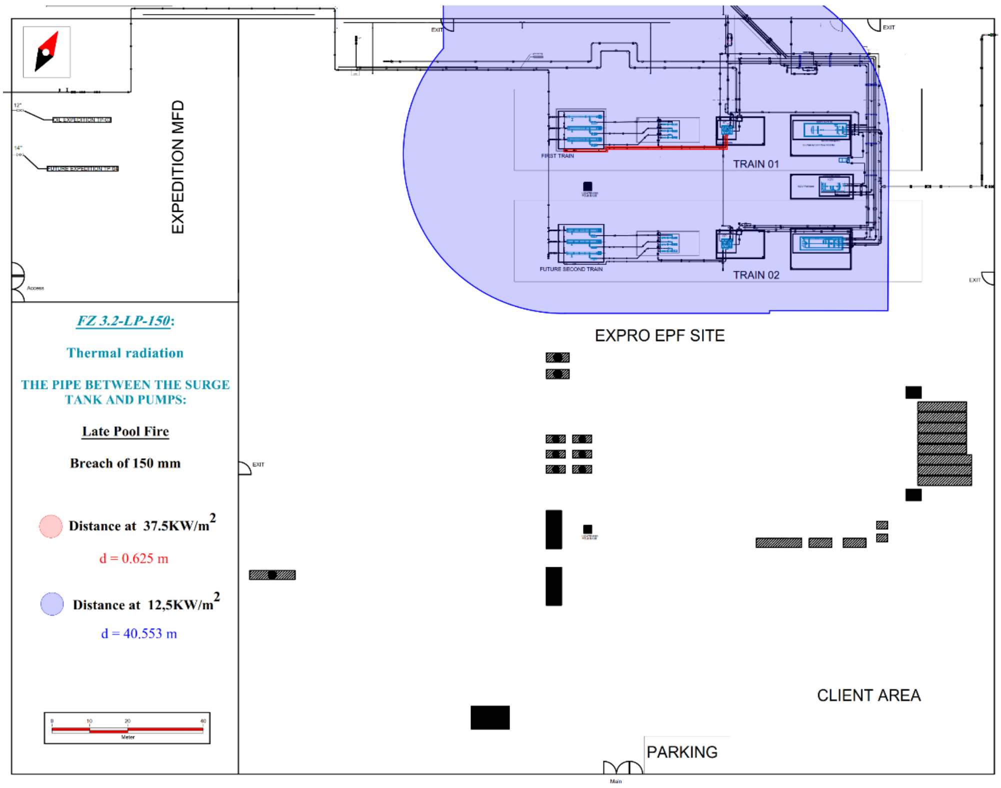


Figure D-99 Scenario FZ-3.2-LP-150 contours

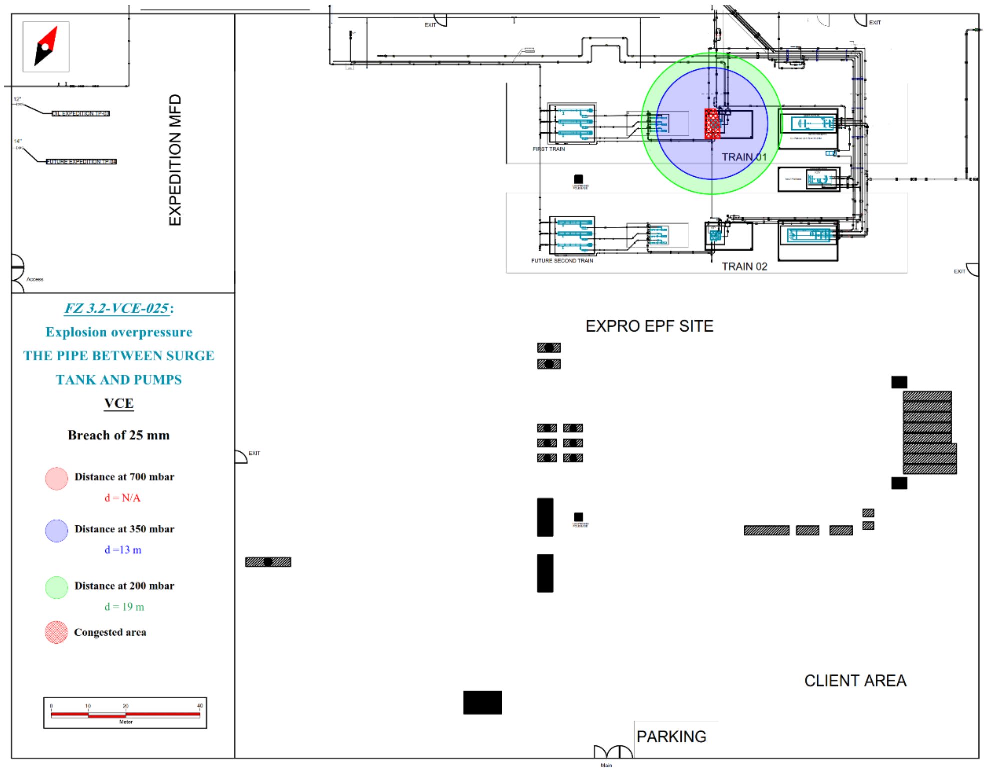


Figure D-100 Scenario FZ-3.2-VCE-025 contours

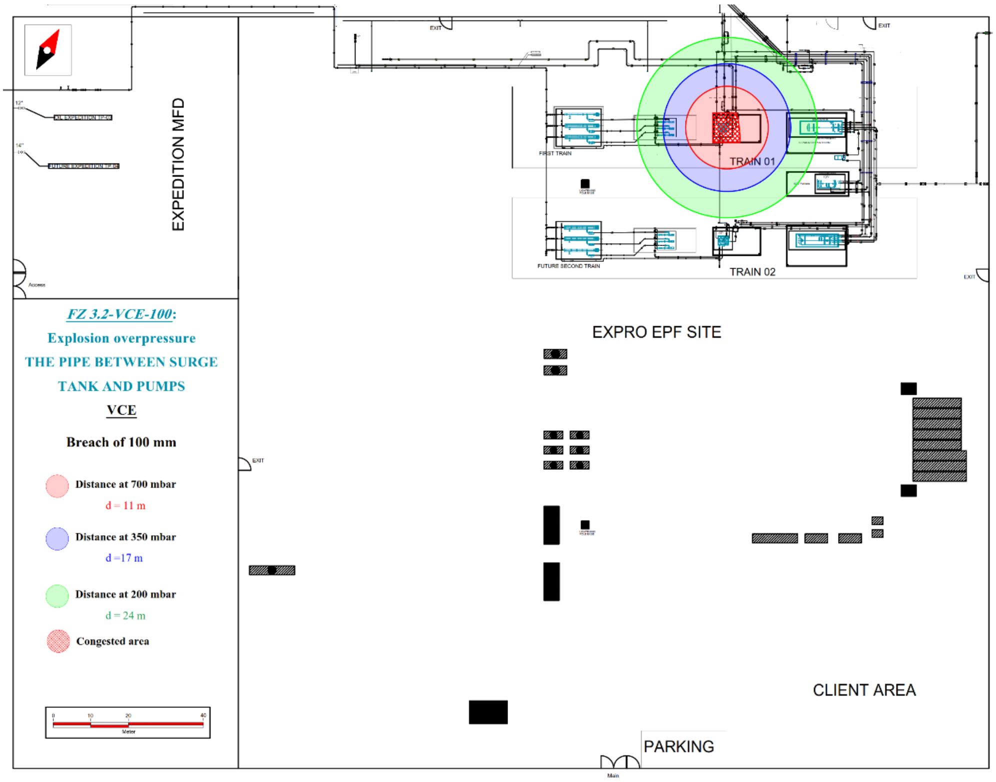
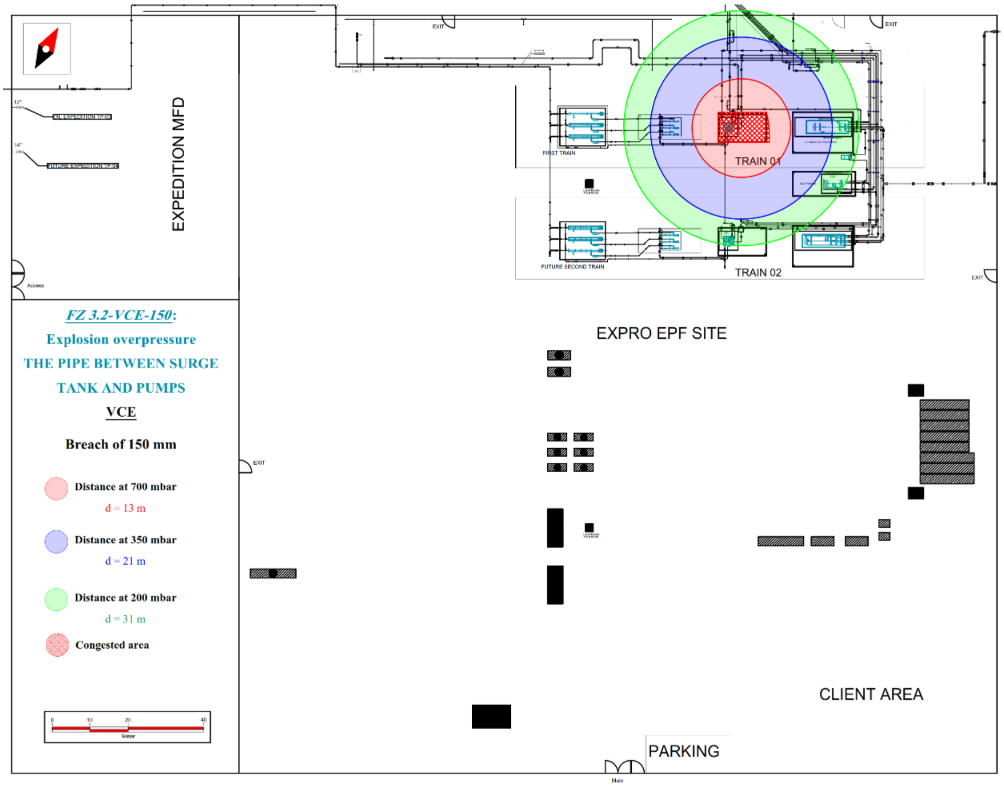


Figure D-101 Scenario FZ-3.2-VCE-100 contours



Appendix Figure D-102 Scenario FZ-3.2-VCE-150 contours

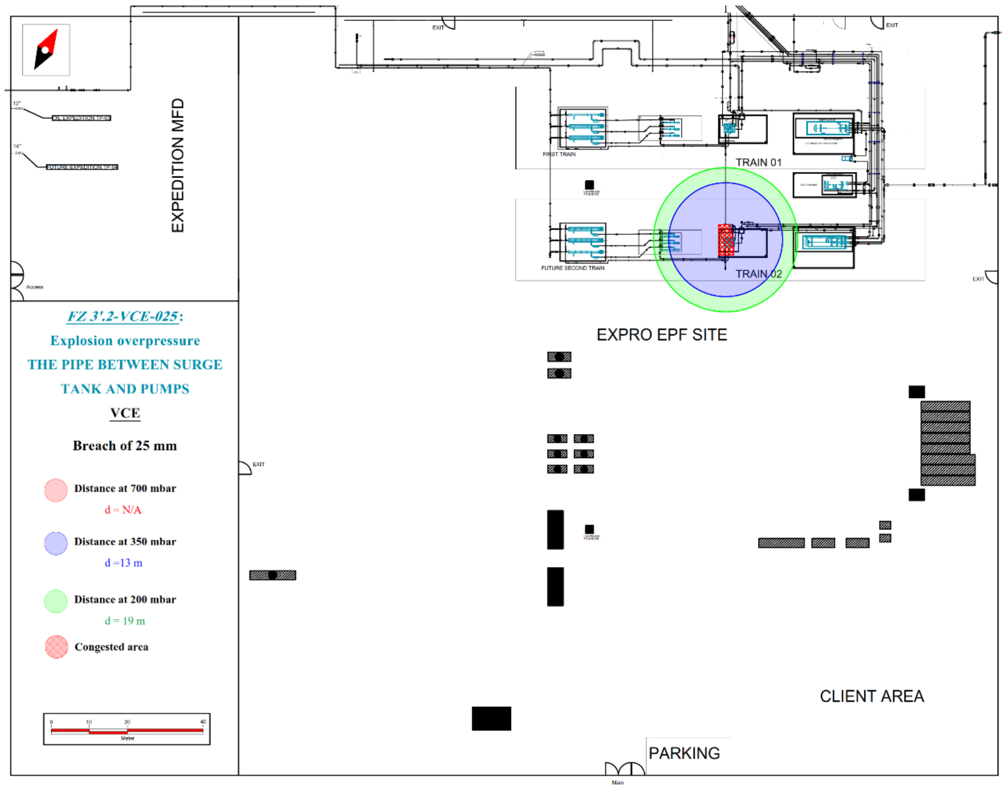


Figure D-103 Scenario FZ-3'.2-VCE-025 contours

Appendix D. Consequences analysis modeling results

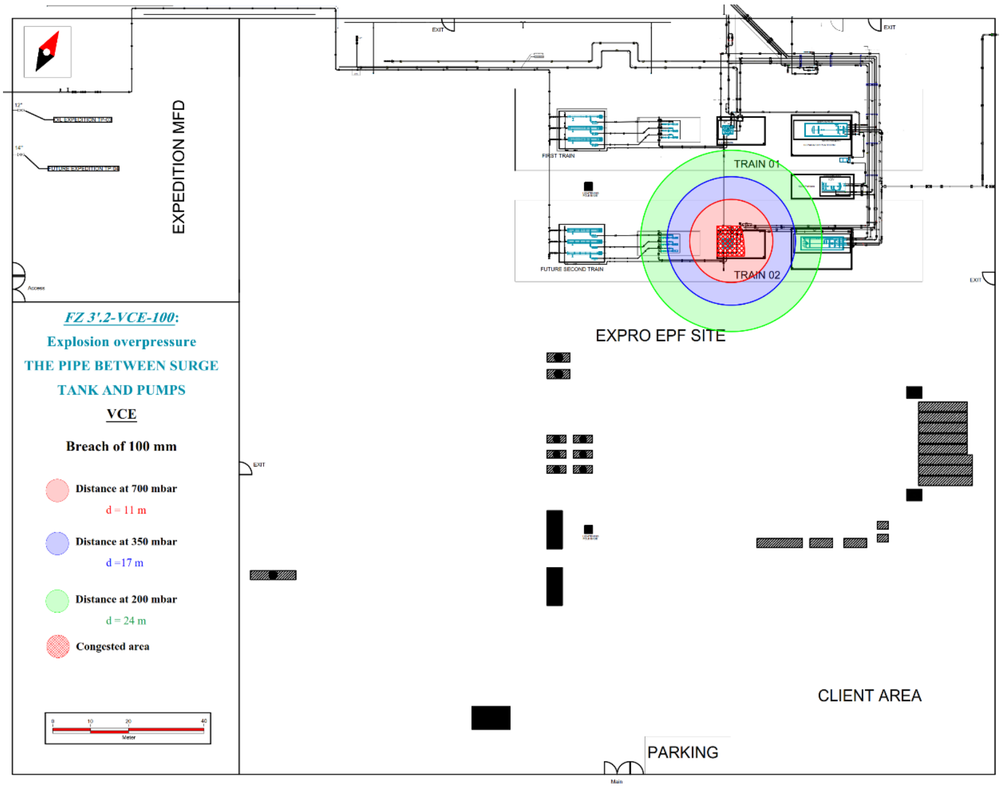


Figure D-104 Scenario FZ-3'.2-VCE-100 contours

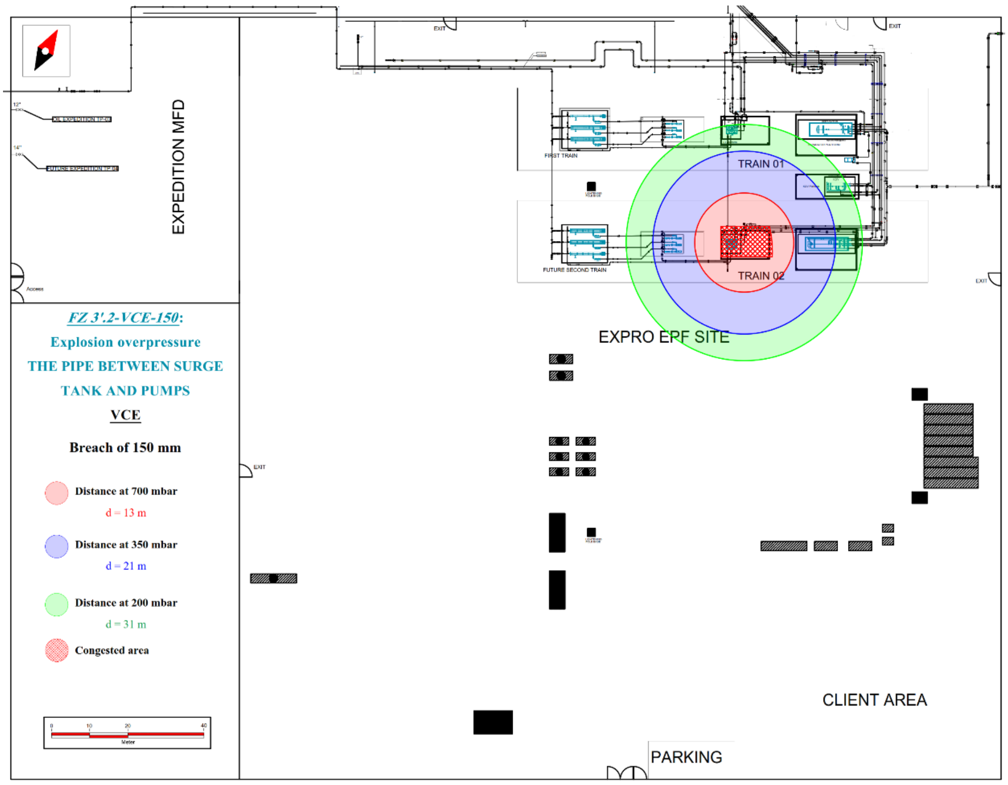


Figure D-105 Scenario FZ-3'.2-VCE-150 contours

D.9 Scenario N°4: Loss of Containment in the Knock-Out Vessel 01-XRZ009 IS 02 (GAS)

Equipment : Knock-out vessel 01-XRZ-009		
Description	Container used to remove liquid droplets from the gas. Located on the separator gas line.	
Design parameter	Dimension	1.872 m / 4.705 m
Operating parameter	Pressure	116 psia (8 bar)
	Temperature	100 °F
Substance	Gas	

Table D-29 Scenario FZ-4-005 modeling results

SMALL BREACH					
Description: the initiating event is the loss of containment of gaseous hydrocarbon due to a small breach (5mm) in the Konck-Out Vessel 01-XRZ009 IS 02					
Leak flow in Kg/s	0.017				
Jet fire with a velocity of 667.25 m/s in summer and 648.76m/s in winter					
Atmospheric condition	Flame length (m)		Distance at 12.5 KW/m^2 in (m)		Distance at 37.5 KW/m^2 in (m
Summer	1.630		1.710		N/A
Winter	1.3986		1.670		N/A
Vapor Cloud Explosion					
Amount of gas released (Kg)	21.23				
Total volume of the cloud (m^3)	Summer	337.19	Congested cloud volume (m^3)	219.38	
	Winter	300.44		187.526	
Cloud radius (m)	Summer	5.440			
	Winter	5.234			
Atmospheric condition	Distance at 200 mbar in m		Distance at 350 mbar in m		Distance at 700 mbar in m
Summer	16		11		7
Winter	15		10		6

Table D-30 Scenario FZ-4-025 modeling results

<table>
<tr><th colspan="6">MEDIUM BREACH</th></tr>
<tr><td colspan="6">Description: the initiating event is the loss of containment of gaseous hydrocarbon due to a medium breach (25mm) in the Knock-Out Vessel 01-XRZ009 IS 02</td></tr>
<tr><td>Leak flow in Kg/s</td><td colspan="5">0.442</td></tr>
<tr><td colspan="6">Jet fire with a velocity of 667.25 m/s in summer and 648.76m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame length (m)</td><td colspan="2">Distance at 12.5 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td colspan="2">7.121</td><td colspan="2">7.100</td><td>3.166</td></tr>
<tr><td>Winter</td><td colspan="2">7.441</td><td colspan="2">7.310</td><td>3.243</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of gas released (Kg)</td><td colspan="5">265.38</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td>4383.5</td><td rowspan="2" colspan="2">Congested cloud volume (m^3)</td><td>1043.38</td></tr>
<tr><td>Winter</td><td>3905.7</td><td>979.23</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">12.791</td></tr>
<tr><td>Winter</td><td colspan="4">12.309</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in m</td><td colspan="2">Distance at 350 mbar in m</td><td>Distance at 700 mbar in m</td></tr>
<tr><td>Summer</td><td colspan="2">27</td><td colspan="2">19</td><td>12</td></tr>
<tr><td>Winter</td><td colspan="2">26</td><td colspan="2">18</td><td>11</td></tr>
</table>

Table D-31 Scenario FZ-4-100 modeling results

<table>
<tr><th colspan="4">LARGE BREACH</th></tr>
<tr><td colspan="4">Description: the initiating event is the loss of containment of hydrocarbon gas due to a large breach (100mm) in the KONCK-OUT VESSEL 01-XRZ009 IS 02.</td></tr>
<tr><td>Leak flow in Kg/s</td><td colspan="3">7.077</td></tr>
<tr><td colspan="4">Jet fire with a velocity of 679.99 m/s in summer and 638.76 m/s in winter</td></tr>
<tr><td>Atmospheric condition</td><td>Flame length (m)</td><td>Distance at 16 KW/m^2 in (m)</td><td>Distance at 37.5 KW/m^2 in (m</td></tr>
<tr><td>Summer</td><td>24.991</td><td>25.110</td><td>11.561</td></tr>
<tr><td>Winter</td><td>25.787</td><td>26.570</td><td>12.511</td></tr>
<tr><td colspan="4">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of gas released (Kg)</td><td colspan="3">2123.1</td></tr>
</table>

Total volume of the cloud (m^3)	Summer	35093	Congested cloud volume (m^3)	2843.268
	Winter	31268		1536.26.8
Cloud radius (m)	Summer	25.589		
	Winter	24.623		

Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m
Summer	38	26	16
Winter	37	25	15

Table D-32 Scenario FZ-4-150 modeling results

CATASTROPHIC BREACH			
Description: the initiating event is the loss of containment of gaseous hydrocarbon due to a catastrophic breach (>150mm) in the Knock-Out Vessel 01-XRZ009 IS 02			
Leak flow in Kg/s	25.684		
Jet fire with a velocity of 667.25 m/s in summer and 648.76m/s in winter			
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m
Summer	44.233	45.400	21.451
Winter	45.615	48.530	23.360
Vapor Cloud Explosion			
Amount of gas released (Kg)	1540.8		

Total volume of the cloud (m^3)	Summer	25472	Congested cloud volume (m^3)	2660.268
	Winter	22696		2369.25
Cloud radius (m)	Summer	22.997		
	Winter	22.129		

Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m
Summer	37	25	16
Winter	37	24	15

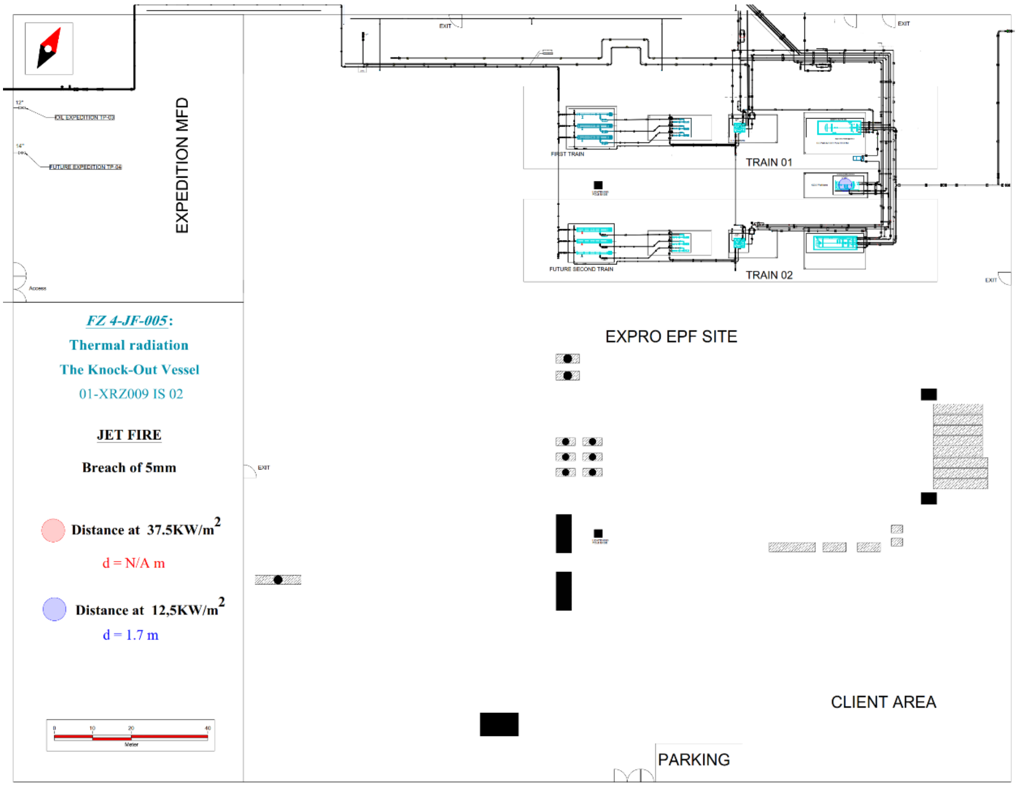


Figure D-106 Scenario FZ-4-JF-005 contours

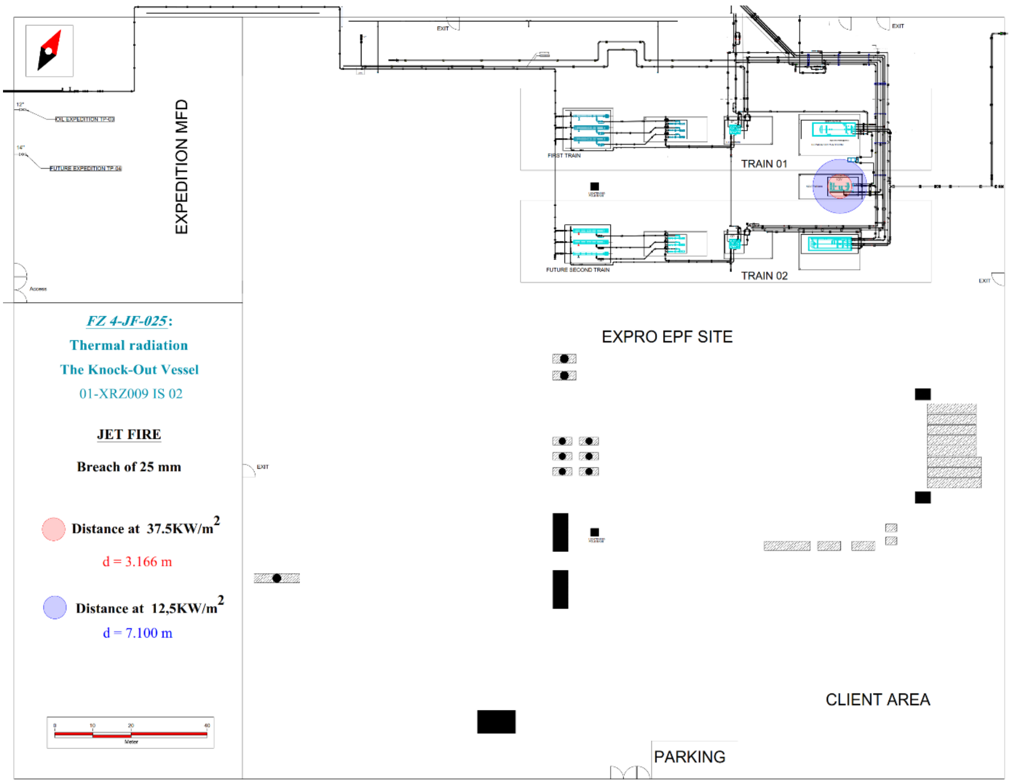


Figure D-107 Scenario FZ-4-JF-025 contours

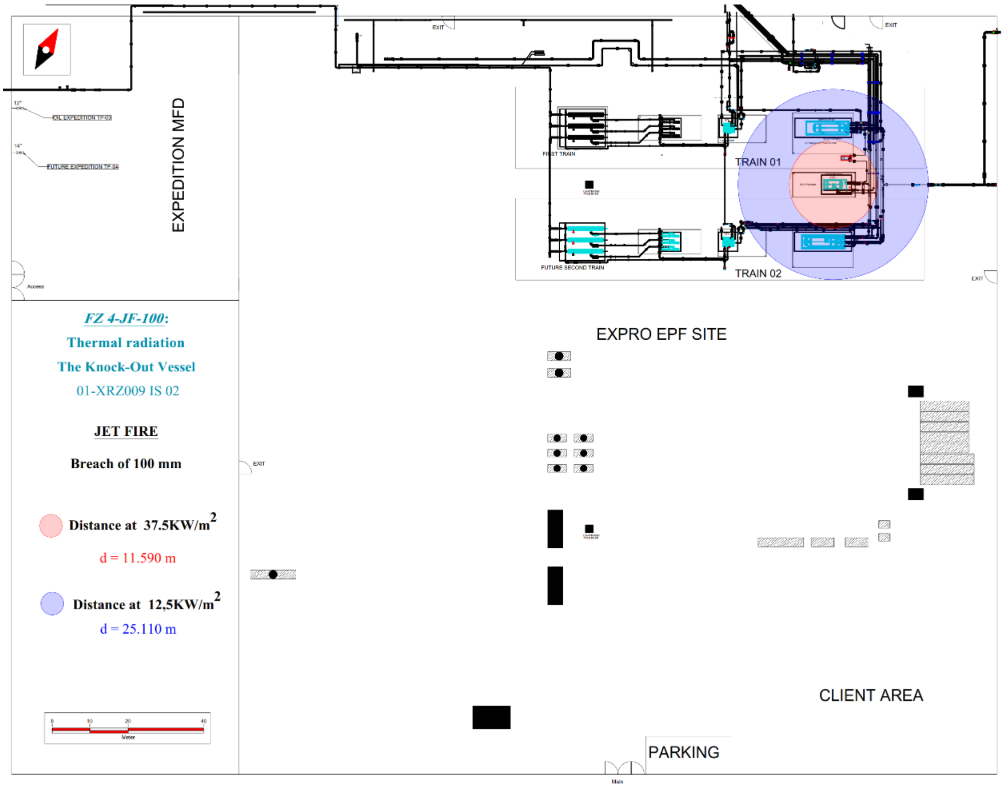


Figure D-108 Scenario FZ-4-JF-100 contours

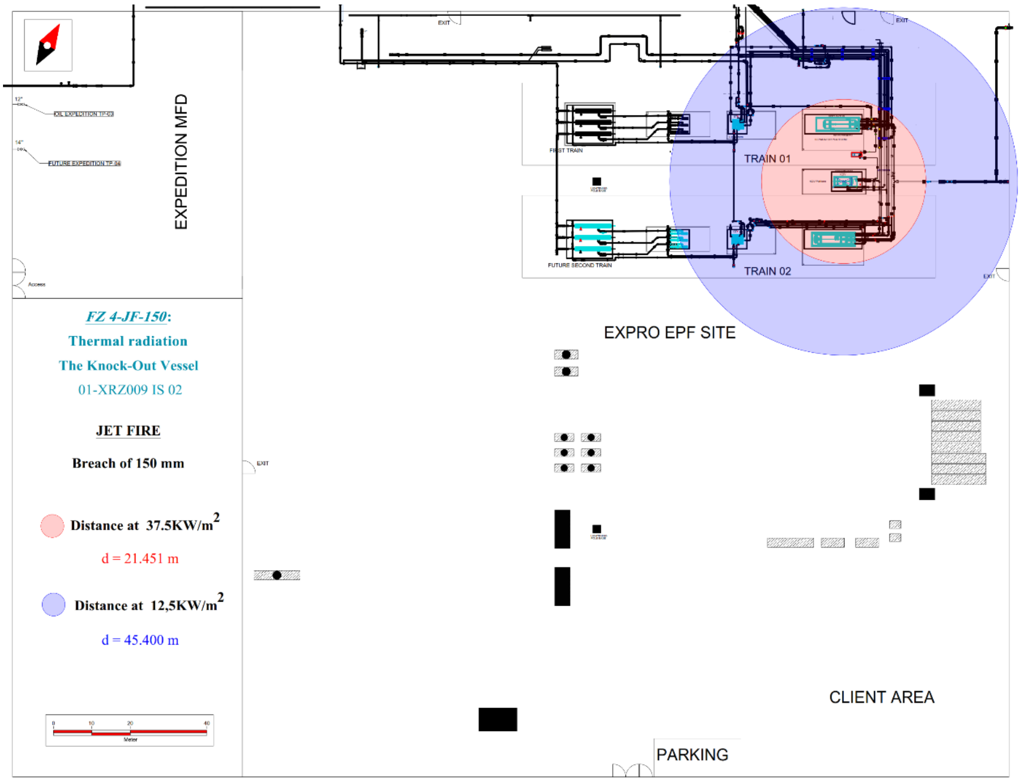


Figure D-109 Scenario FZ-4-JF-150 contours

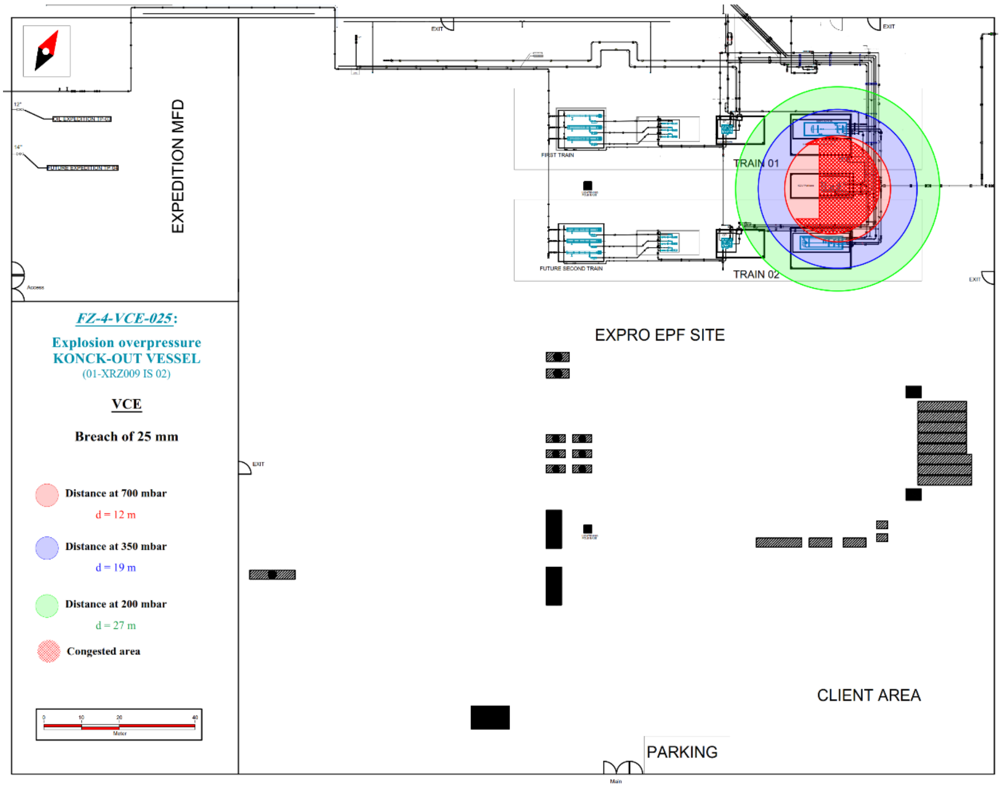


Figure D-110 Scenario FZ-4-VCE-025 contours

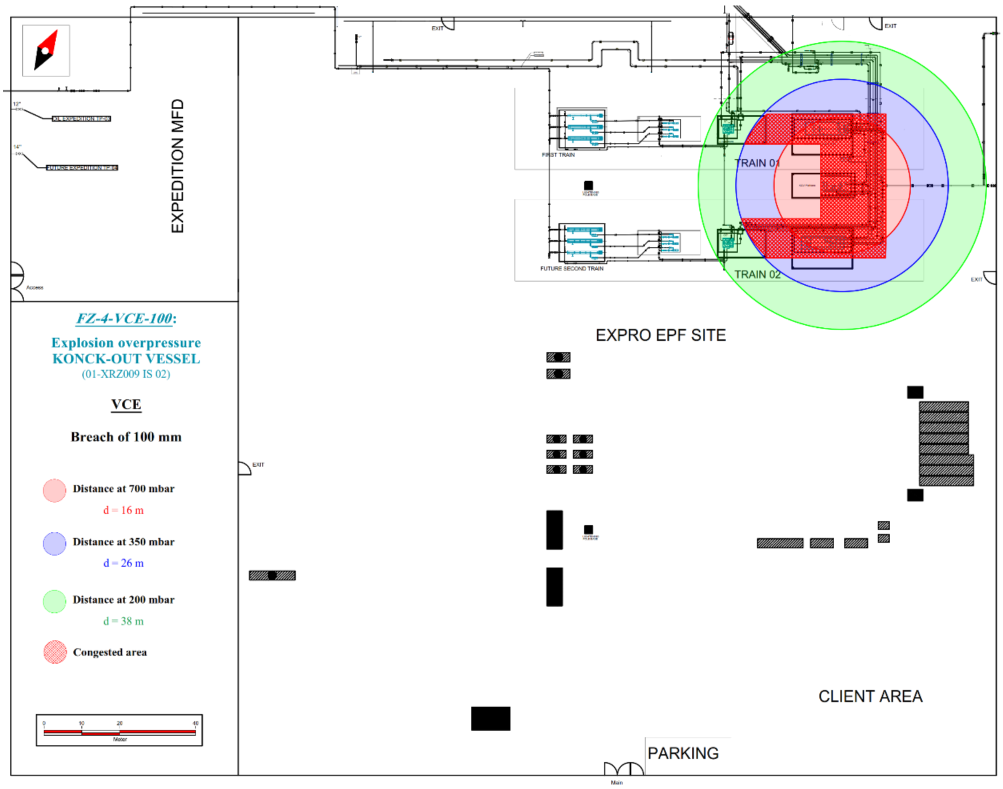


Figure D-111 Scenario FZ-4-VCE-100 contours

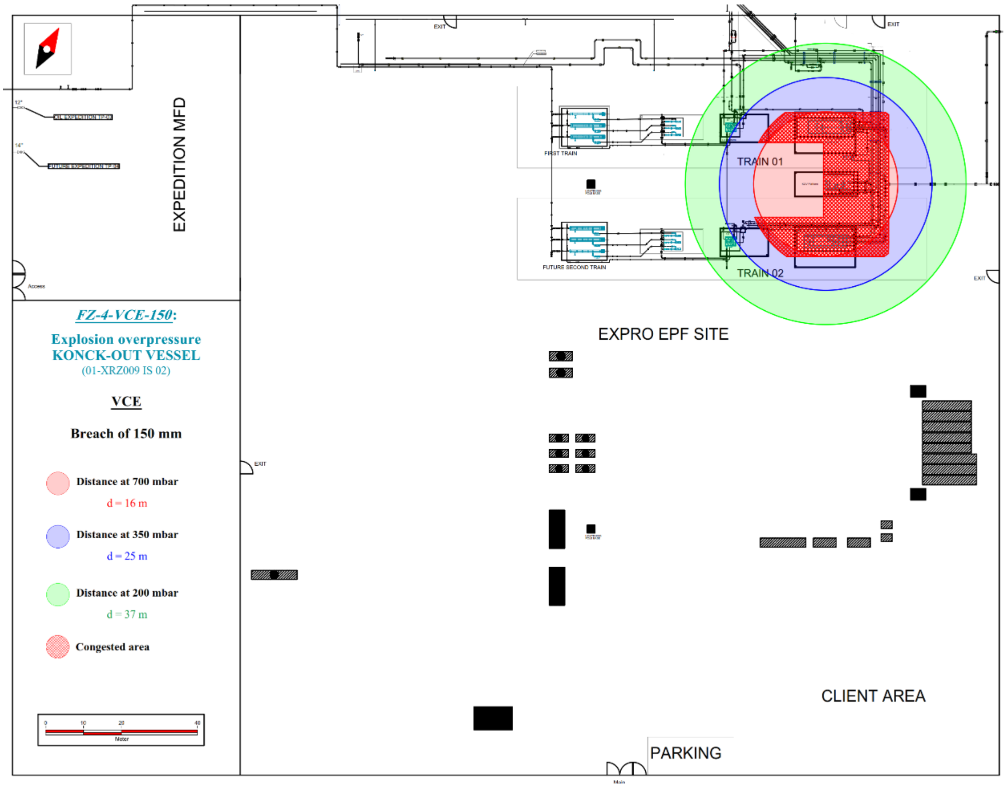


Figure D-112 Scenario FZ-4-VCE-150 contours

D.10 Scenario N°5.1: Loss of Containment in the Booster Pumps

Table D-33 Scenario FZ-5.1-005 modeing results

SMALL BREACH			
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a small breach (5 mm) in booster pumps			
Leak flow (Kg/s)	0.571		
Early Pool fire with a diameter of 3.481 m			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)
Summer	4.048	6.440	5.800
Winter	3.971	6.441	5.800
Burning duration (s)	1661.2 (27 min 36s)		
Late Pool fire with a diameter of 10.391 m			
Atmospheric condition	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m2 (m)
Summer	9.031	15.900	12.90
Winter	8.747	16.025	12.911
Burning duration (s)	134.88 (2 min 17 s)		

Vapor Cloud Explosion				
Amount of liquid released (Kg)	685,2			
Vaporization rate (Kg/s)	Summer	0.631	Evaporated amount (Kg)	189.58
	Winter	0.1344		40.334
Total volume of the cloud (m^3)	Summer	2572.9	Congested cloud volume (m^3)	/
	Winter	547.39		/
Cloud radius (m)	Summer	10.710		
	Winter	6.393		
Atmospheric condition	Distance at 200 mbar in (m)	Distance at 350 mbar in (m)	Distance at 700 mbar in (m)	
Summer	N/A	N/A	N/A	
Winter	N/A	N/A	N/A	

Table D-34 Scenario FZ-4-025 modeling results

MEDIUM/LARGE/CATASTROPHIC BREACHES				
Description: The initiating event is the loss of containment of liquid hydrocarbon due to a breach (25/100/150) in booster pumps in the presence of retention dike (Rectangular flame shape).				
Breach sizes	Leak flow (Kg/s)			
25 mm	14.292			
100 mm	228.679			
150 mm	514.528			
Pool fire with a 11.470 m equivalent diameter				
Atmospheric condition	Dike width (m)	Flame height (m)	Distance at 12.5 KW/m2 (m)	Distance at 37.5 KW/m^2 in (m
Summer	16.4	9.719	6.280	N/A
	6.3		4.550	N/A
Winter	16.4	9.4132	7.570	N/A
	6.3		5.200	N/A
Early pool fire				
Breach sizes	Burning duration (s)			
25 mm	1653.9 (27 min 30 s)			
100 mm	11344 (189 min)			
Late Pool fire				

Appendix D. Consequences analysis modeling results

Breach sizes	Burning duration (s)			
25mm	1384.3 (23 min)			
100mm	11075 (184 min 30 s)			
150mm	4983.6 (83 min)			
Vapor cloud explosion				
Amount of liquid released (Kg)	25	4056		
	100	32400		
	150	23571		
Vaporization rate (Kg/s)	Summer	0.7617	Evaporated amount (Kg)	228.50
	Winter	0.162		48.614
Total volume of the cloud (m^3)	Summer	3101.1		
	Winter	659.77		
Cloud radius (m)	Summer	11.398		
	Winter	6.8042		
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m	
Summer	N/A	N/A	N/A	
Winter	N/A	N/A	N/A	

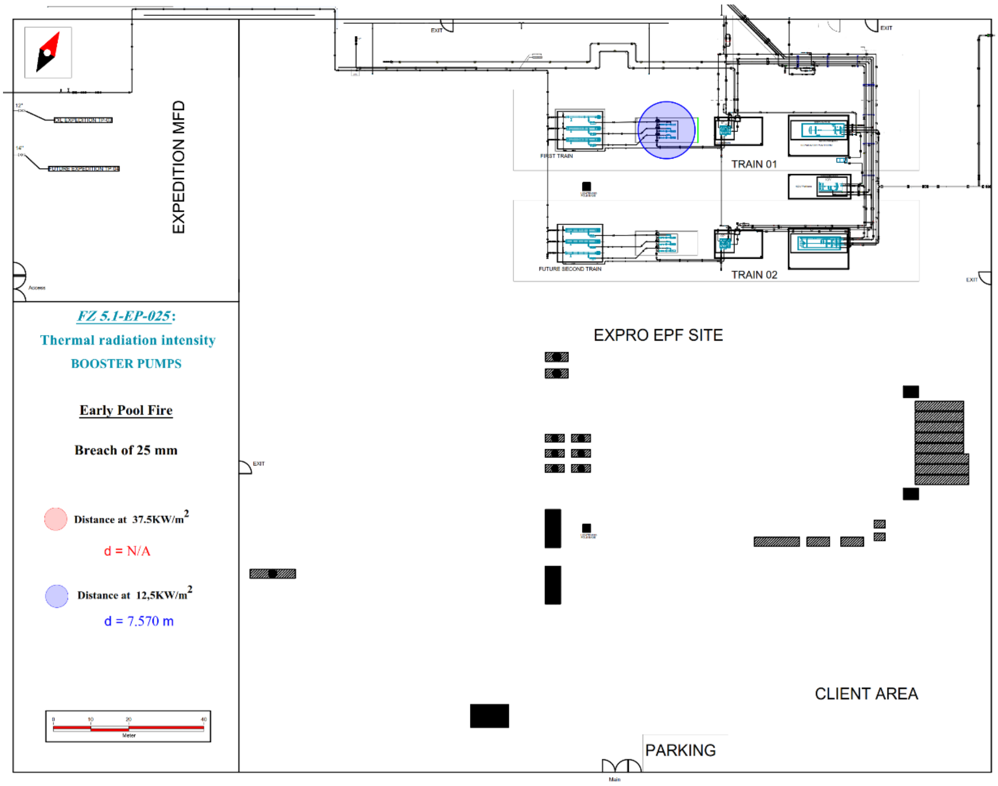


Figure D-113 Scenario FZ-5.1-EP-025 contours

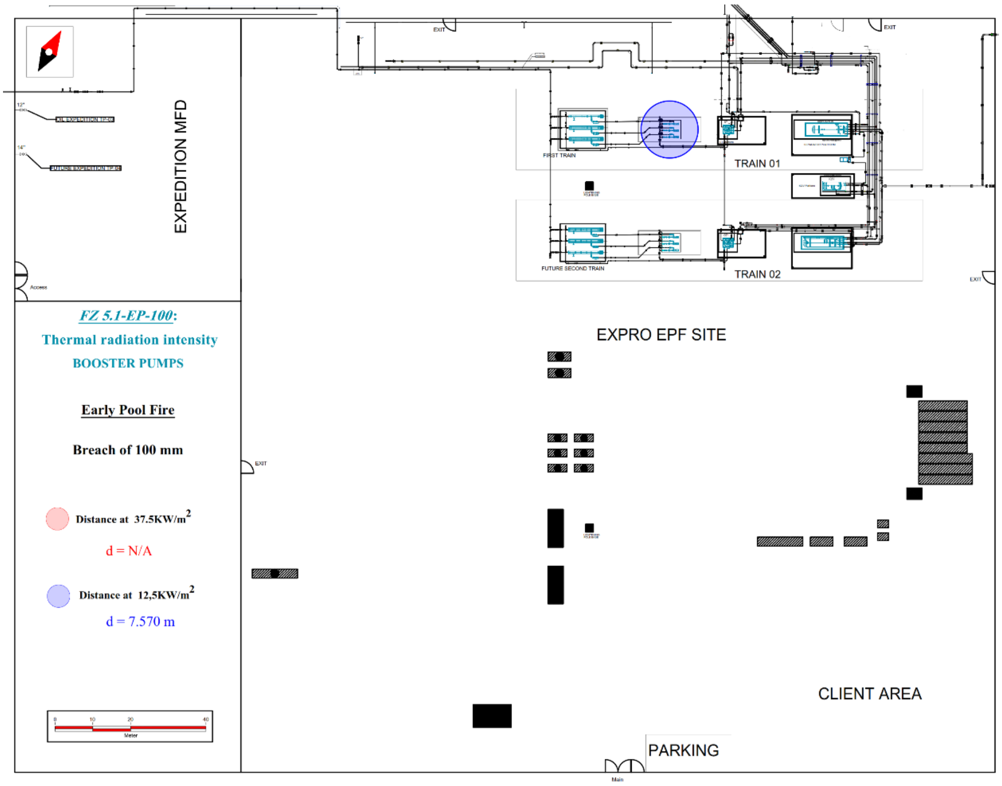
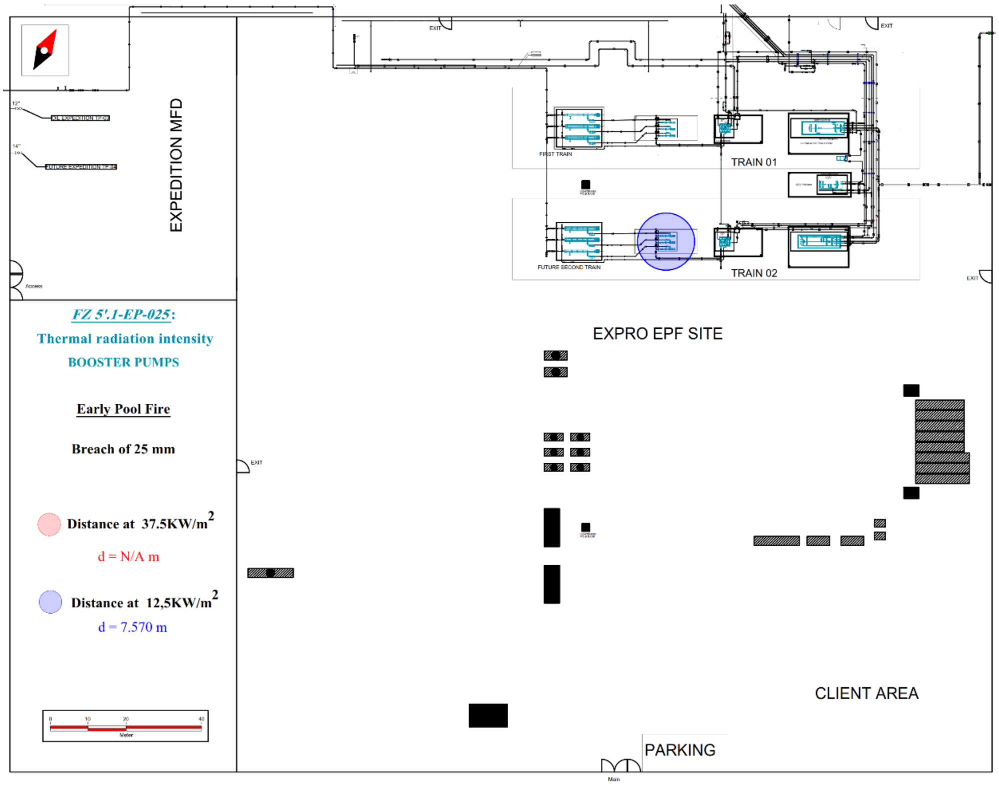


Figure D-114 Scenario FZ-5.1-EP-100 contours

Appendix D. Consequences analysis modeling results



Appendix Figure D-115 Scenario FZ-5'.1-EP-025 contours

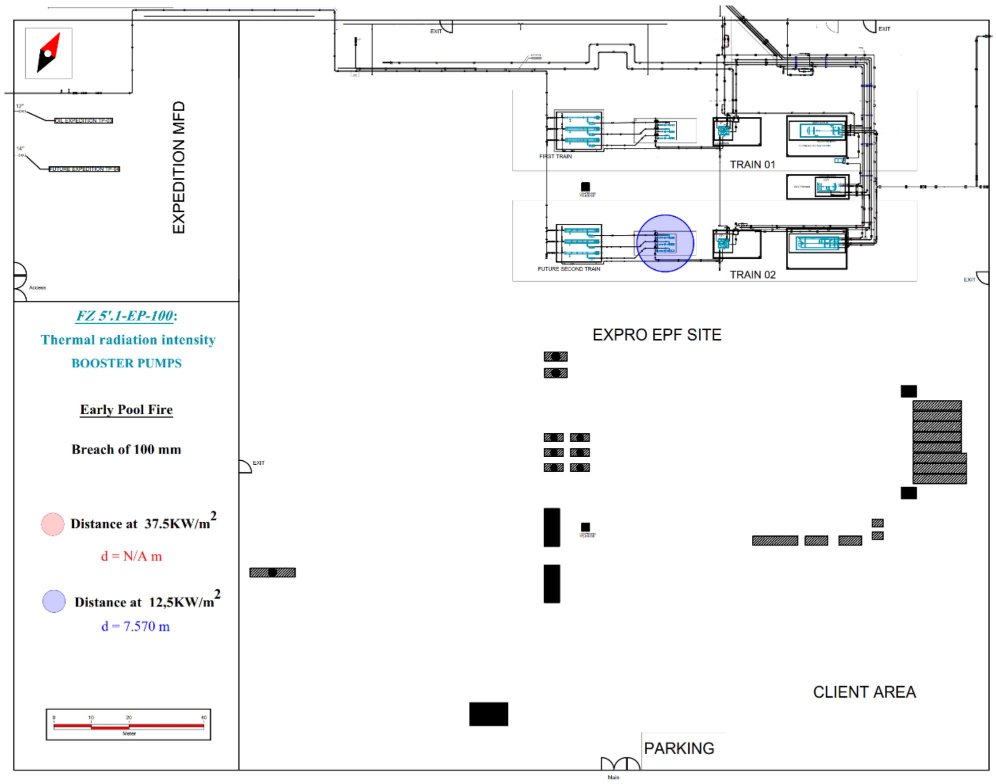


Figure D-116 Scenario FZ-5'.1-LP-100 contours

D.11 Scenario N°5.2: Loss of Containment in the Export Pumps

Table D-35 Scenario FZ-5.2-005 modeling results

<table>
<tr><th colspan="5">SMALL/MEDIUM/LARGE/CATASTROPHIC BREACHES</th></tr>
<tr><td colspan="5">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a breach (5/25/100/150) in export pumps in the presence of retention dike (Rectangular flame shape).</td></tr>
<tr><td>Breach sizes</td><td colspan="4">Leak flow (Kg/s)</td></tr>
<tr><td>5 mm</td><td colspan="4">1.161</td></tr>
<tr><td>25 mm</td><td colspan="4">29.394</td></tr>
<tr><td>100 mm</td><td colspan="4">464.526</td></tr>
<tr><td>150 mm</td><td colspan="4">868.617</td></tr>
<tr><td colspan="5">Pool fire with a 13.496 m equivalent diameter</td></tr>
<tr><td>Atmospheric condition</td><td>Dike width (m)</td><td>Flame height (m)</td><td>Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m^2 in (m)</td></tr>
<tr><td rowspan="2">Summer</td><td>13.6</td><td rowspan="2">10.959</td><td>5.550</td><td>N/A</td></tr>
<tr><td>11</td><td>5.220</td><td>N/A</td></tr>
<tr><td rowspan="2">Winter</td><td>13.6</td><td rowspan="2">10.614</td><td>6.740</td><td>N/A</td></tr>
<tr><td>11</td><td>6.260</td><td>N/A</td></tr>
<tr><td colspan="5">Early Pool fire</td></tr>
<tr><td>Breach sizes</td><td colspan="4">Burning duration (s)</td></tr>
<tr><td>5 mm</td><td colspan="4">431.75 (7 min 12 s)</td></tr>
<tr><td>25mm</td><td colspan="4">2324.6 (38 min 44 s)</td></tr>
<tr><td>100mm</td><td colspan="4">16509 (275 min)</td></tr>
<tr><td colspan="5">Late Pool fire</td></tr>
<tr><td>Breach sizes</td><td colspan="4">Burning duration (s)</td></tr>
<tr><td>5 mm</td><td colspan="4">162.35 (2 min 40s)</td></tr>
<tr><td>25 mm</td><td colspan="4">2053.5 (34 min 42 s)</td></tr>
<tr><td>100 mm</td><td colspan="4">16240 (270 min 40 s)</td></tr>
<tr><td>150 mm</td><td colspan="4">6073.4 (101 min 12 s)</td></tr>
<tr><td colspan="5">Vapor cloud explosion</td></tr>
<tr><td rowspan="3">Amount of liquid released (Kg)</td><td>25</td><td colspan="3">4056</td></tr>
<tr><td>100</td><td colspan="3">32400</td></tr>
<tr><td>150</td><td colspan="3">23571</td></tr>
<tr><td></td><td>Summer</td><td>1.035</td><td>Evaporated amount</td><td>310.74</td></tr>
</table>

<table>
<tr><td>Vaporization rate (Kg/s)</td><td>Winter</td><td colspan="2">0.220</td><td colspan="2"></td><td>66.112</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="5">4217.2</td></tr>
<tr><td>Winter</td><td colspan="5">897.23</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="5">12.628</td></tr>
<tr><td>Winter</td><td colspan="5">7.538</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in m</td><td colspan="2">Distance at 350 mbar in m</td><td colspan="2">Distance at 700 mbar in m</td></tr>
<tr><td>Summer</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
<tr><td>Winter</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td colspan="2">N/A</td></tr>
</table>

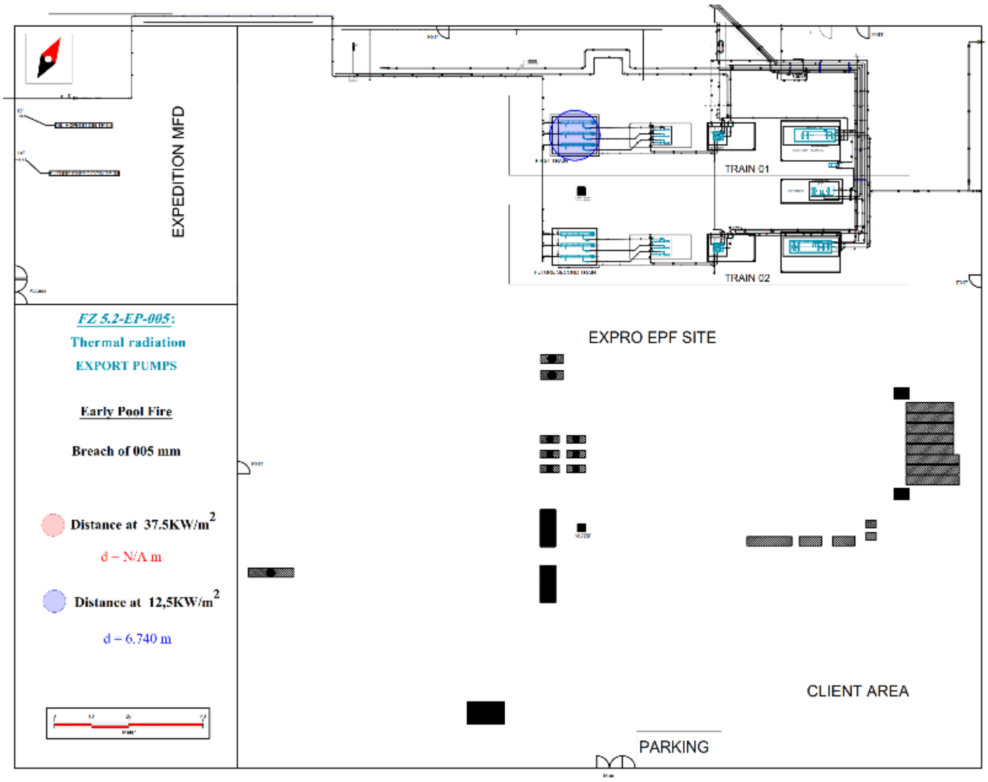


Figure D-117 Scenario FZ-5.2-EP-005 contours

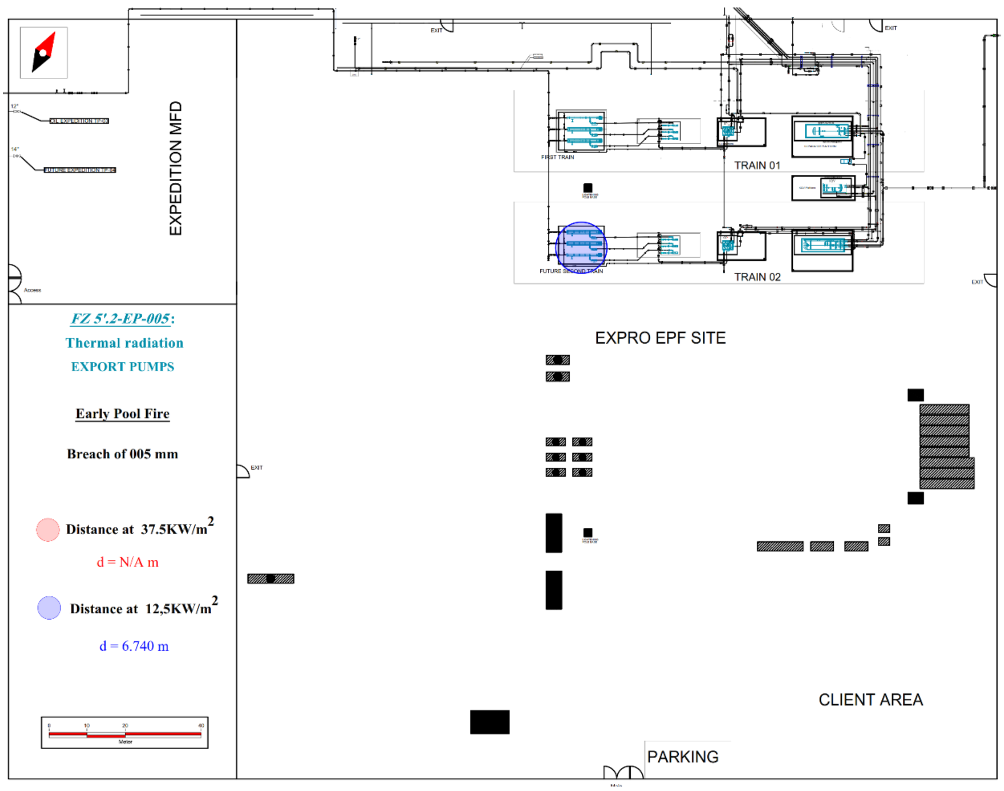


Figure D-118 Scenario FZ-5'.2-EP-005 contours

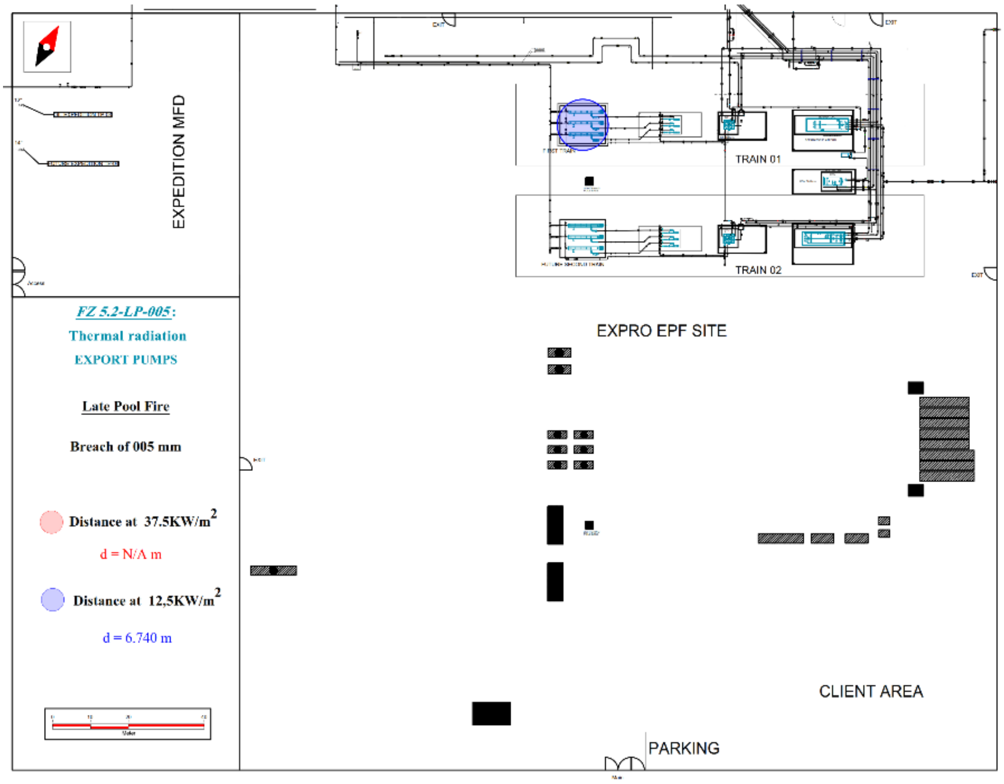


Figure D-119 Scenario FZ-5.2-LP-005 contours

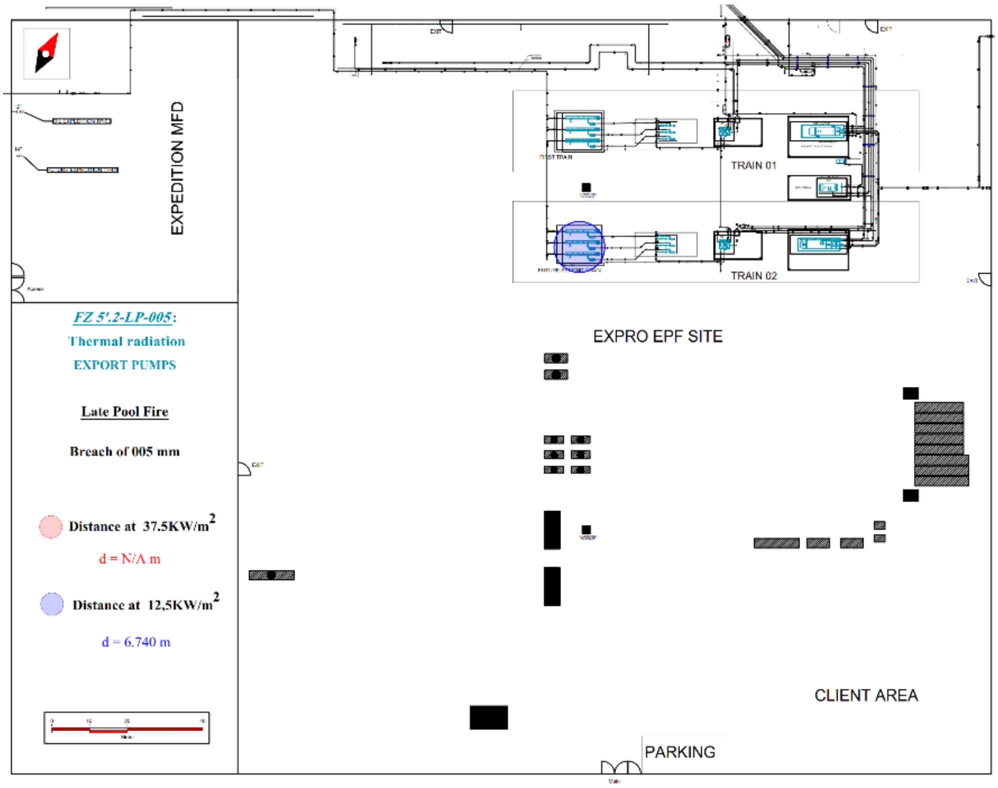


Figure D-120 Scenario FZ-5'.2-LP-005 contours

D.12 Scenario N°6: Loss of Containment in the Oil Expedition Pipe 12”-Pl-06b3-1254

Table D-36 Scenario FZ-6 -005 modeling results

<table>
<tr><th colspan="5">SMALL BREACH</th></tr>
<tr><td colspan="5">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a small breach (5 mm) in the expedition line 12”-PL-06B3-1254</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="4">0.62</td></tr>
<tr><td colspan="5">Early Pool fire with a diameter of 3.821 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td>Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">4.172</td><td>6.613</td><td>6.000</td></tr>
<tr><td>Winter</td><td colspan="2">4.0413</td><td>6.618</td><td>6.100</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">1490.1 (25 min)</td></tr>
<tr><td colspan="5">Late Pool fire with a diameter of 7.656 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td>Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">8.436</td><td>16.400</td><td>13.168</td></tr>
<tr><td>Winter</td><td colspan="2">7.989</td><td>16.582</td><td>13.257</td></tr>
<tr><td>Burning duration (s)</td><td colspan="4">134.82 (2 min 17 s)</td></tr>
<tr><td colspan="5">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="4">744</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>0.6831</td><td rowspan="2">Evaporated amount (Kg)</td><td>204,93</td></tr>
<tr><td>Winter</td><td>0.145</td><td>43,5</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="3">2781.2</td></tr>
<tr><td>Winter</td><td colspan="3">591.71</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="3">10.992</td></tr>
<tr><td>Winter</td><td colspan="3">6.561</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td>Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
<tr><td>Winter</td><td colspan="2">N/A</td><td>N/A</td><td>N/A</td></tr>
</table>

Table D-37 Scenario FZ-6-025 modeling results

<table>
<tr><th colspan="6">MEDIUM BREACH</th></tr>
<tr><td colspan="6">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a medium breach (25 mm) in the expedition line 12”-PL-06B3-1254</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="5">15.52</td></tr>
<tr><td colspan="6">Early Pool fire with a diameter of 19.160 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">13.106</td><td colspan="2">24.474</td><td>11.000</td></tr>
<tr><td>Winter</td><td colspan="2">12.618</td><td colspan="2">24.583</td><td>11.100</td></tr>
<tr><td>Burning duration (s)</td><td colspan="5">807.62 (13 min 30s)</td></tr>
<tr><td colspan="6">Late Pool fire with a diameter of 27.086 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">19.547</td><td colspan="2">44.300</td><td>0.5340</td></tr>
<tr><td>Winter</td><td colspan="2">18.799</td><td colspan="2">45.058</td><td>2.788</td></tr>
<tr><td>Burning duration (s)</td><td colspan="5">134.67 (2 min 15 s)</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="5">9 312</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>7.439</td><td colspan="2" rowspan="2">Evaporated amount (Kg)</td><td>2 231,7</td></tr>
<tr><td>Winter</td><td>1.5618</td><td>468,6</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="4">30291</td></tr>
<tr><td>Winter</td><td colspan="4">6444.5</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">24.364</td></tr>
<tr><td>Winter</td><td colspan="4">14.545</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
<tr><td>Winter</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Table D-38 Scenario FZ-6 -100 modeling results

<table>
<tr><th colspan="6">LARGE BREACH</th></tr>
<tr><td colspan="6">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a large breach (100 mm) in the expedition line 12”-PL-06B3-1254</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="5">248.456</td></tr>
<tr><td colspan="6">Pool fire with a diameter of 36.738 m</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Flame height (m)</td><td colspan="2">Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2 (m)</td></tr>
<tr><td>Summer</td><td colspan="2">22.380</td><td colspan="2">42.650</td><td>0.465</td></tr>
<tr><td>Winter</td><td colspan="2">22.161</td><td colspan="2">42.900</td><td>3.612</td></tr>
<tr><td>Burning duration (s)</td><td colspan="5">134.66 (2 min 15s)</td></tr>
<tr><td colspan="6">Vapor Cloud Explosion</td></tr>
<tr><td>Amount of liquid released (Kg)</td><td colspan="5">74 536,8</td></tr>
<tr><td rowspan="2">Vaporization rate (Kg/s)</td><td>Summer</td><td>20.329</td><td rowspan="2" colspan="2">Evaporated amount(Kg)</td><td>6098.7</td></tr>
<tr><td>Winter</td><td>4.325</td><td>1297.5</td></tr>
<tr><td rowspan="2">Total volume of the cloud (m^3)</td><td>Summer</td><td colspan="4">82769</td></tr>
<tr><td>Winter</td><td colspan="4">17609</td></tr>
<tr><td rowspan="2">Cloud radius (m)</td><td>Summer</td><td colspan="4">34.062</td></tr>
<tr><td>Winter</td><td colspan="4">20.334</td></tr>
<tr><td>Atmospheric condition</td><td colspan="2">Distance at 200 mbar in (m)</td><td colspan="2">Distance at 350 mbar in (m)</td><td>Distance at 700 mbar in (m)</td></tr>
<tr><td>Summer</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
<tr><td>Winter</td><td colspan="2">N/A</td><td colspan="2">N/A</td><td>N/A</td></tr>
</table>

Table D-39 Scenario FZ-6 -150 modeling results

<table>
<tr><th colspan="4">CATASTROPHIC BREACH</th></tr>
<tr><td colspan="4">Description: The initiating event is the loss of containment of liquid hydrocarbon due to a catastrophic breach (>150 mm) in the expedition line 12”-PL-06B3-1254</td></tr>
<tr><td>Leak flow (Kg/s)</td><td colspan="3">559.027</td></tr>
<tr><td colspan="4">Pool fire with a diameter of 51.407 m</td></tr>
<tr><td>Atmospheric condition</td><td>Flame height (m)</td><td>Distance at 12.5 KW/m2 (m)</td><td>Distance at 37.5 KW/m2</td></tr>
<tr><td>Summer</td><td>22.458</td><td>76.100</td><td>N/A</td></tr>
<tr><td>Winter</td><td>21.527</td><td>76.150</td><td>N/A</td></tr>
</table>

Burning duration (s)	134.66 (2 min 15 s)			
Vapor Cloud Explosion				
Amount of Liquid released (Kg)	33 541,62			
Vaporization rate (Kg/s)	Summer	24.975	Evaporated amount(Kg)	7492.5
	Winter	5.3135		1594.0
Total volume of the cloud (m^3)	Summer	101680		
	Winter	21634		
Cloud radius (m)	Summer	36.481		
	Winter	21.778		
Atmospheric condition	Distance at 200 mbar in (m)	Distance at 350 mbar in (m)	Distance at 700 mbar in (m)	
Summer	N/A	N/A	N/A	
Winter	N/A	N/A	N/A	

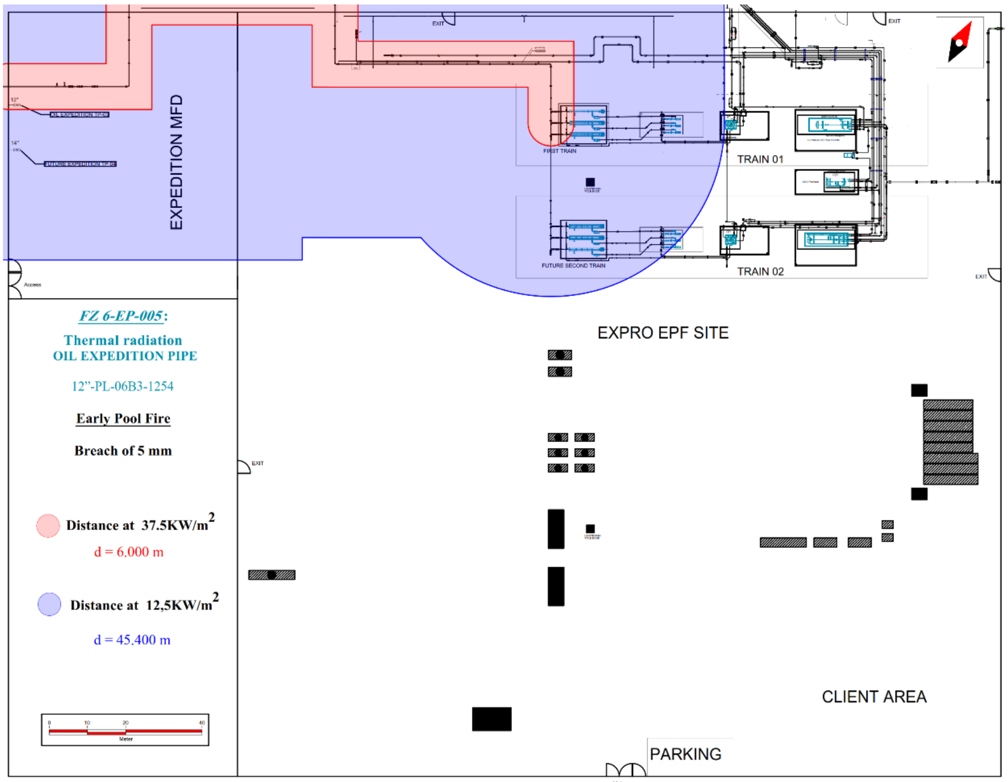


Figure D-121 Scenario FZ-6-EP-005 contours

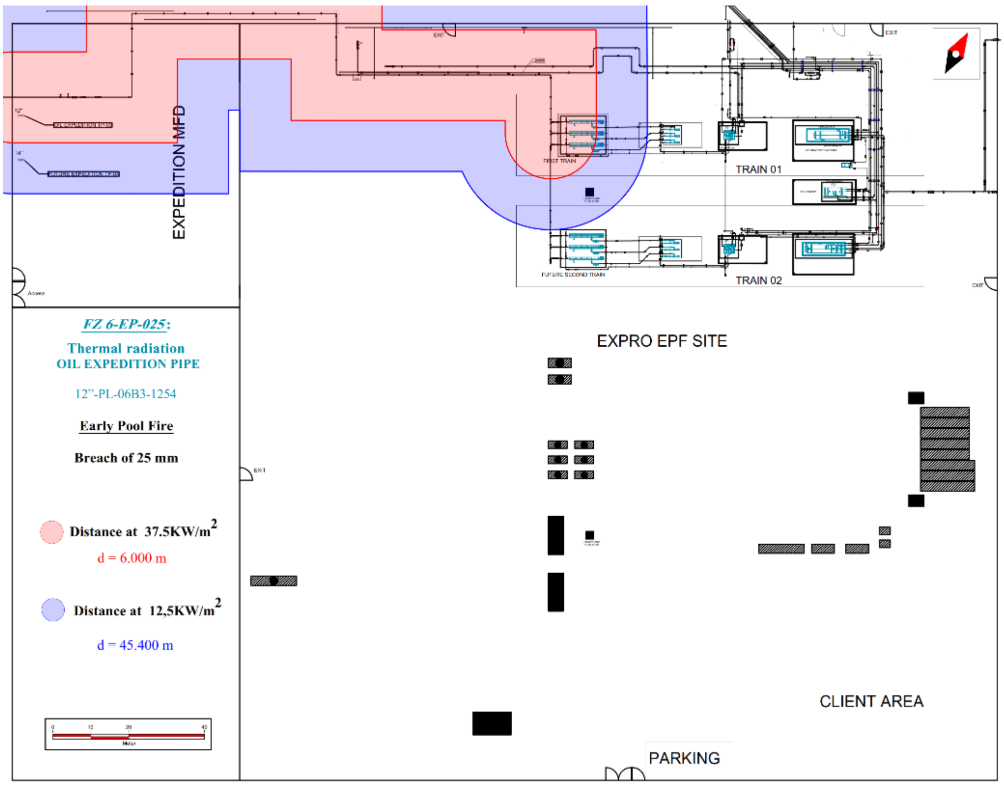


Figure D-122 Scenario FZ-6-EP-005 contours

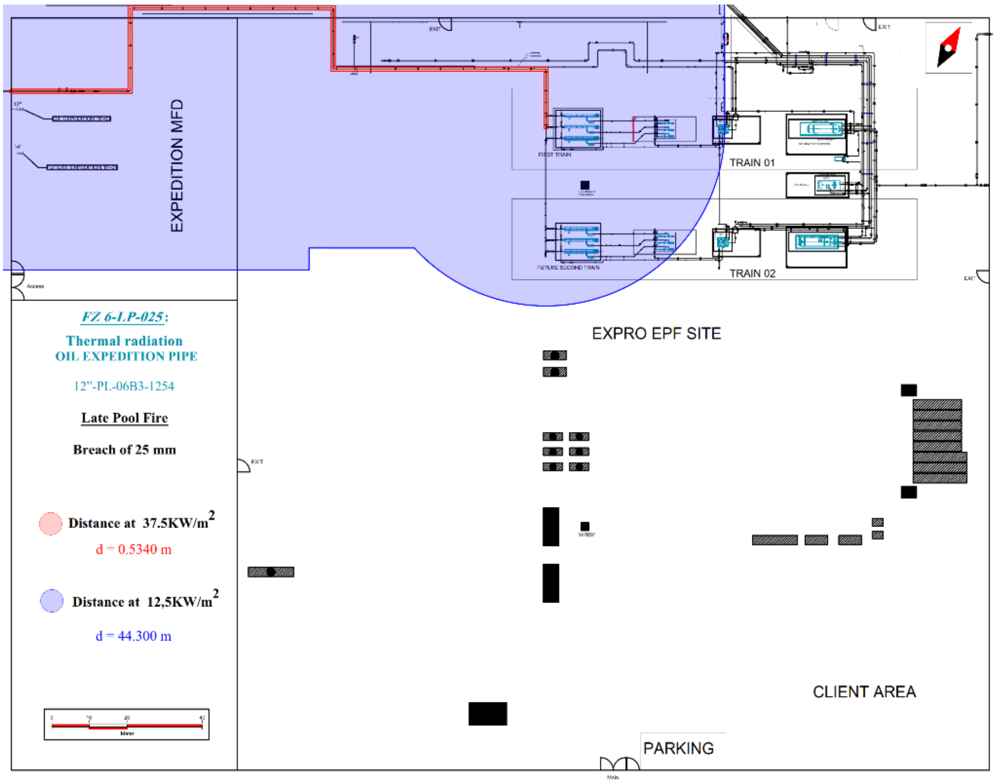


Figure D-123 Scenario FZ-6-LP-025 contours

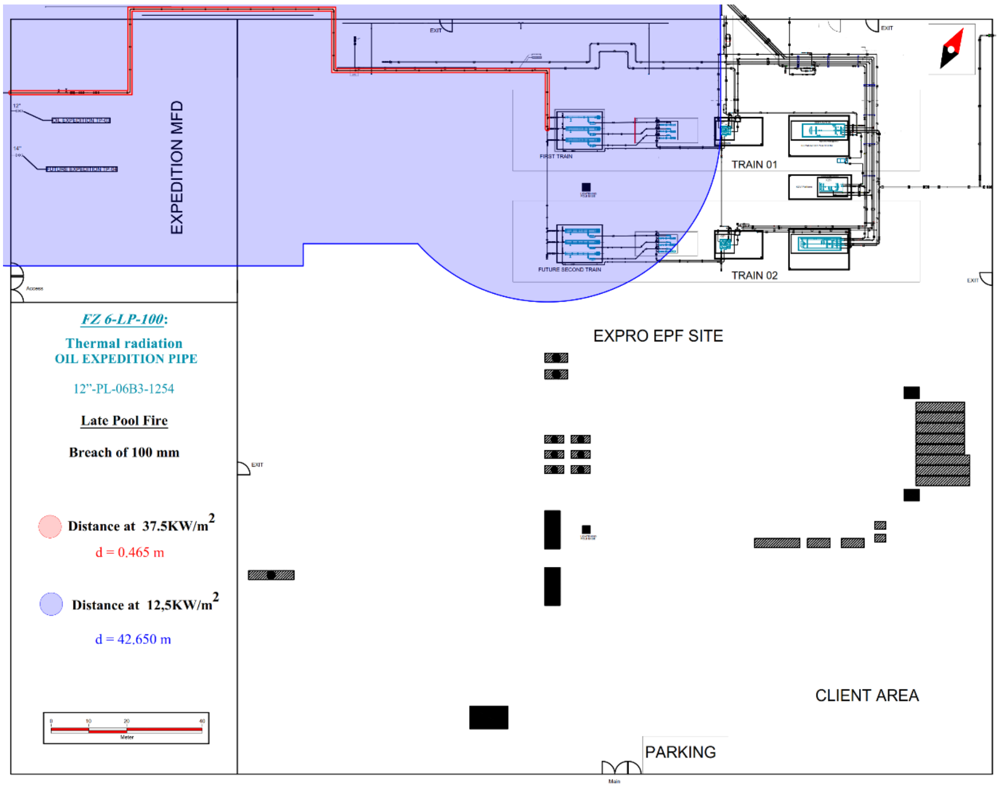


Figure D-124 Scenario FZ-6-LP-100 contours

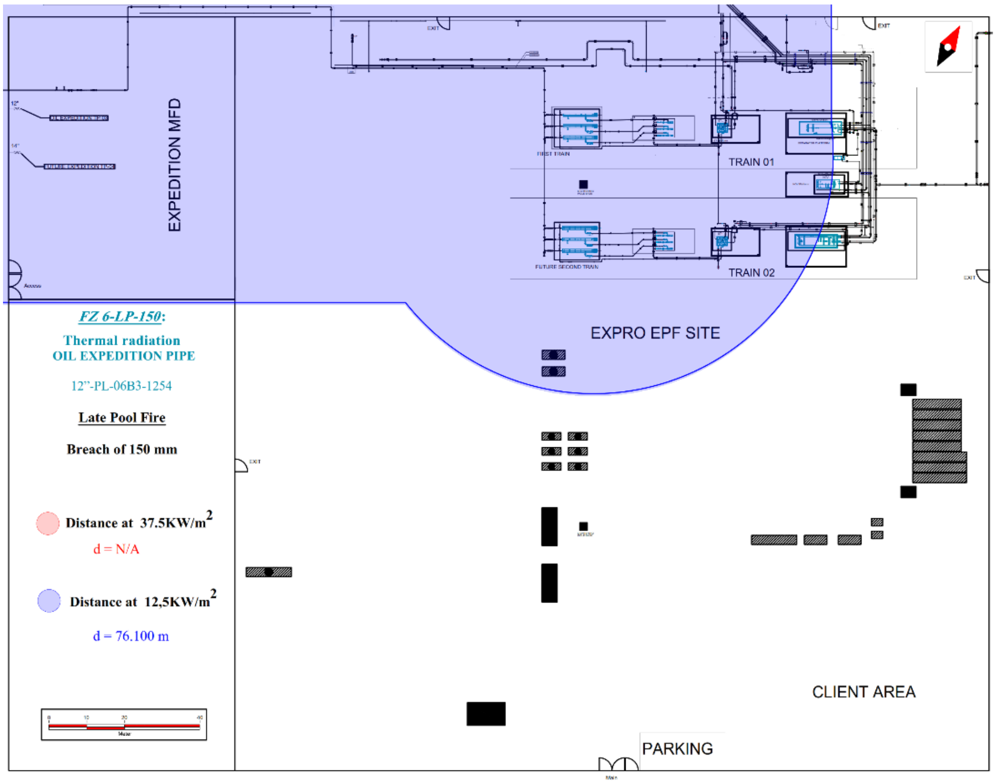


Figure D-125 Scenario FZ-6-LP-150 contours

D.13 Scenario N°7: Loss of Containment in the Gas Expedition Pipe 10”-Pv-06b3-1039:

Table D-40 Scenario FZ-7-005 modeling results

SMALL BREACH			
Description: The initiating event is the loss of containment of **gaseous hydrocarbon** due to a small breach (5 mm) in the **gas expedition pipe** 10”-PV-06B3-1039			
Leak flow (Kg/s)	0.017		
Jet fire with a velocity of 679.99 m/s in summer and 638.76 m/s in winter			
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m)
Summer	1.621	1.710	0.758
Winter	1.678	1.670	0.727
Vapor Cloud Explosion			
Amount of gas released (Kg)	20.4		
	Summer	337.19	

Total volume of the cloud (m^3)	Winter	300.44	
Cloud radius (m)	Summer	5.4401	
	Winter	5.234	
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m
Summer	N/A	N/A	N/A
Winter	N/A	N/A	N/A

Table D-41 Scenario FZ-7-025 modeling results

MEDIUM BREACH			
Description: The initiating event is the loss of containment of gaseous hydrocarbon due to a medium breach (25 mm) in the gas expedition pipe 10”-PV-06B3-1039			
Leak flow (Kg/s)	0.429		
Jet fire with a velocity of 679.99 m/s in summer and 638.76 m/s in winter			
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m)
Summer	7.104	7.000	3.144
Winter	7.341	7.210	3.219
Vapor Cloud Explosion			
Amount of gas released (Kg)	257.4		
Total volume of the cloud (m^3)	Summer	4254.5	
	Winter	3790.9	
Cloud radius (m)	Summer	12.665	
	Winter	12.187	
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar In m	Distance at 700 mbar In m
Summer	N/A	N/A	N/A
Winter	N/A	N/A	N/A

Table D-42 Scenario FZ-7-100 modeling results

LARGE BREACH	
Description: The initiating event is the loss of containment of gaseous hydrocarbon due to a large breach (100 mm) in the gas expedition pipe 10”-PV-06B3-1039	
Leak flow (Kg/s)	6.861

Jet fire with a velocity of 679.99 m/s in summer and 638.76 m/s in winter			
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m)
Summer	24.649	24.750	11.467
Winter	25.434	26.190	12.405
Vapor Cloud Explosion			
Amount of gas released (Kg)	2058.1		
Total volume of the cloud (m^3)	Summer	34021	
	Winter	30314	
Cloud radius (m)	Summer	25.326	
	Winter	24.370	
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m
Summer	N/A	N/A	N/A
Winter	N/A	N/A	N/A

Table D-43 Scenario FZ-7-150 modeling results

CATASTROPHIC BREACH			
Description: The initiating event is the loss of containment of gaseous hydrocarbon due to a catastrophic breach (>150 mm) in the gas expedition pipe 10”-PV-06B3-1039			
Leak flow (Kg/s)	15.445		
Jet fire with a velocity of 679.99 m/s in summer and 638.76 m/s in winter			
Atmospheric condition	Flame length (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m)
Summer	35.330	35.960	16.902
Winter	36.443	38.250	18.362
Vapor Cloud Explosion			
Amount of gas released (Kg)	926.7		
Total volume of the cloud (m^3)	Summer	15317	
	Winter	13648	
Cloud radius (m)	Summer	19.411	
	Winter	18.678	
Atmospheric condition	Distance at 200 mbar in m	Distance at 350 mbar in m	Distance at 700 mbar in m

Summer	N/A	N/A	N/A
Winter	N/A	N/A	N/A

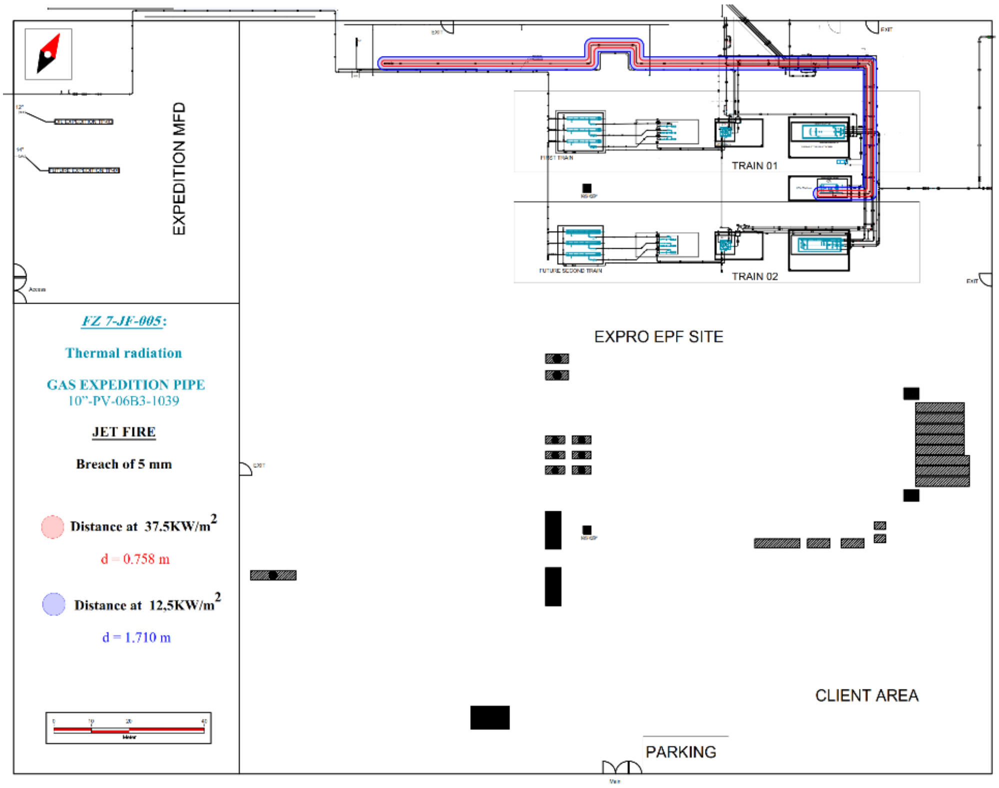


Figure D-126 Scenario FZ-7-JF-005 contours

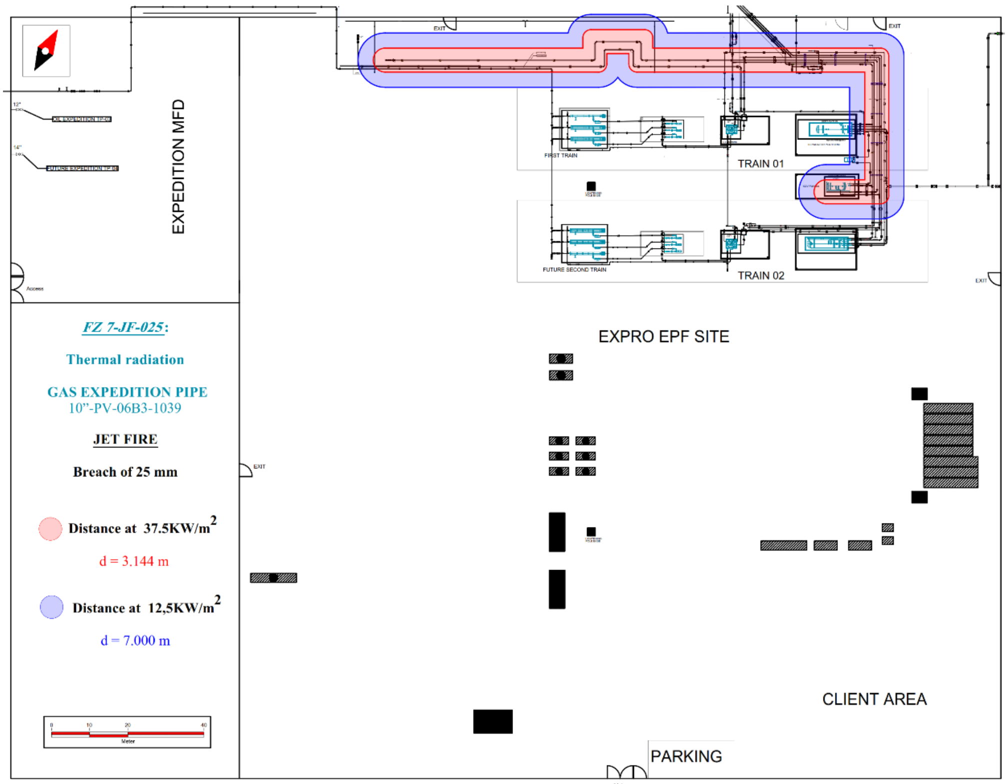


Figure D-127 Scenario FZ-7-JF-025contours

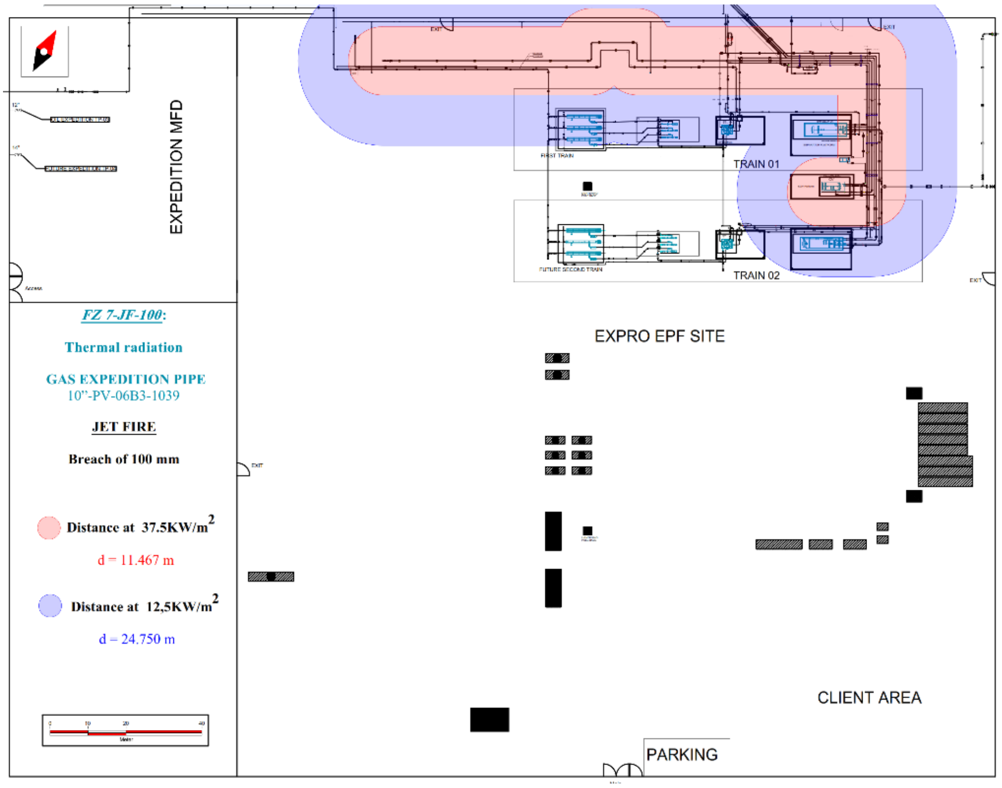


Figure D-128 Scenario FZ-7-100 contours

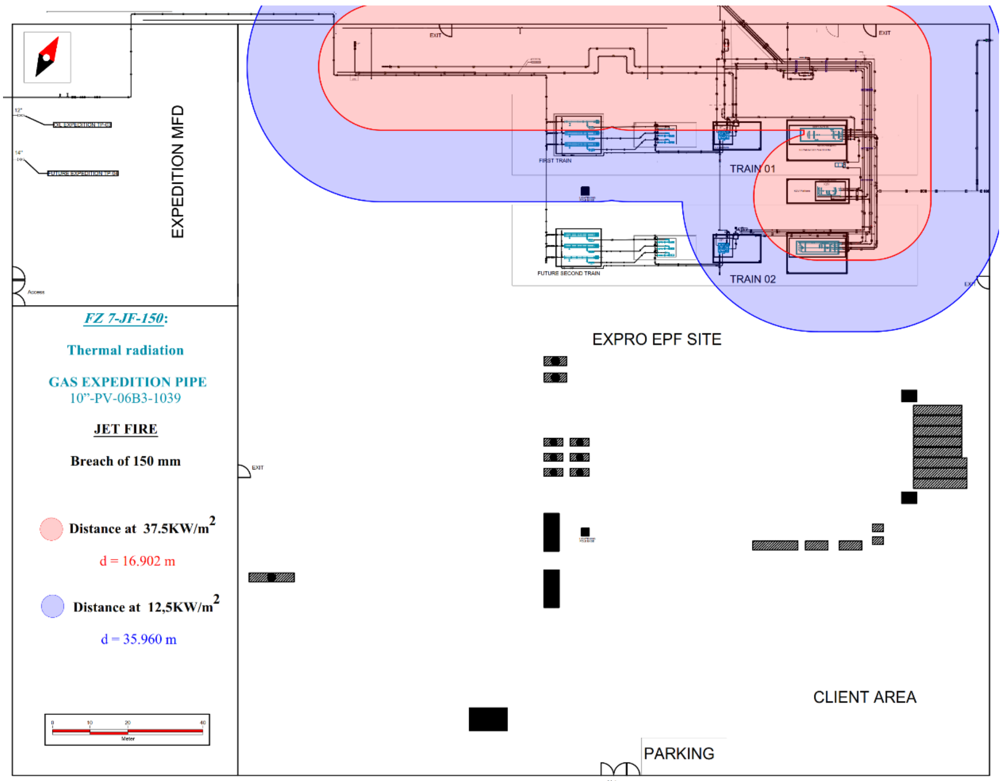


Figure D-129 Scenario FZ-7-150 contours

D.14 Scenario N°8: Loss of Containment in the Diesel Tank:

Equipment : DIESEL TANK		
Description	DIESEL TANK	
Design parameter	Capacity	
Operating parameter	Pressure	1 atm
	Temperature	40 °C
Substance	Diesel	

Table D-44 Scenario FZ-8 modeling results

SCENARIO N°8				
Description: The initiating event is the loss of containment of **liquid hydrocarbon** due to a s breach in the Diesel tank which leads to the formation of an inflammable pool with a surface of 24m^2.				
Pool fire with a diameter of 5.527m				
Atmospheric condition	Retention dike width (m)	Flame height (m)	Distance at 12.5 KW/m^2 in (m)	Distance at 37.5 KW/m^2 in (m
Summer	8	5.251	5.800	N/A
	3		3.760	N/A
Winter	8	5.082	6.200	N/A
	3		4.000	N/A

Vapor Cloud Explosion				
Vaporization rate (Kg/s)	Summer	0.135	Evaporated amount (Kg)	40.701
	Winter	0.070		21.175
Total volume of the cloud (m^3)	Summer	552.37		
	Winter	287.37		
Cloud radius (m)	Summer	6.412		
	Winter	5.157		

Atmospheric condition	Distance at 200 mbar	Distance at 300 mbar
Summer	N/A	N/A
Winter	N/A	N/A