PETROBRAS	**TECHNICAL SPECIFICATION**	**No.:** **I-ET-3000.00-5400-98G-P4X-003**	
	CLIENT: -	**SHEET:** 1 of 44	
	JOB: -	-	
	AREA: -	-	
SRGE	**TITLE:** **FIRE PROPAGATION AND SMOKE DISPERSION STUDY**	**INTERNAL**	
		ESUP	

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INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL
A	EXCLUDE ANNEX II
B	EXCLUDE TEXT “LIST OF SUPPLIERS OF PETROBRAS (LCF)” IN SECTION 13
C	REVISED WHERE INDICATED
D	REVISED WHERE INDICATED
E	9.14 (EXCLUSION OF REQUIREMENTS ON COMPOSITE MATERIAL)
F	REVISED WHERE INDICATED
G	REVISED WHERE INDICATED

	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
DATE	MAR/11/20	JUL/23/20	SEP/23/20	JUN/22/22	JAN/24/23	MAR/23/23	MAY/11/23	APR/19/24	
DESIGN	ESUP	EPS	EPS	EPS	EPS	EPS	EPS	EPS	
EXECUTION	DANIELA	B79G	U4D4	U436	U436	U436	U436	U436	
CHECK	IGORG	EU4I	CWEQ	B79G	B79G	B79G	B79G	B79G	
APPROVAL	PAOLO	UP6E	UP6E	EK9U	EK9U	EK9U	EK9U	EK9U	

Summary

1. INTRODUCTION

The Fire Propagation and Smoke Dispersion Study is a consequence study used to evaluate the effects of fire scenarios identified in the Preliminary Hazard Analysis - PHA, initially classified as not tolerable in any of the dimensions (people, environment, asset, image of the Company) or moderates with severity category IV or V in the people and asset dimensions, on the Main Safety Functions (MSF) of a Floating Production Unit - FPU.

From this study are estimated the accidental loads due to fire to evaluate the need for protective measures for the MSF, as well as to evaluate the annual impairment frequency of MSF as a result of the thermal radiation, and smoke effects for the people.

The MSF are defined in the Petrobras Safety Engineering Guideline DR-ENGP-M-I-1.3.

Upon the execution of the study, the requirements for analysis and management of operational risks of the National Petroleum, Natural Gas and Biofuels Agency (ANP), Ministry of Labor and Social Security, Petrobras standard N-2782 - Applicable Techniques to Industrial Risk Analysis and Petrobras' Safety Engineering Guidelines shall be followed.

This Technical Specification (TS) is intended to supplement the requirements of the Study on Fire Propagation and Smoke Dispersion contained in the Safety Engineering Guideline, in force on the date of signature of the contract. It also aims at guiding the development of the study, and the preparation of its respective report.

2. OBJECTIVES

This specification has the following objectives:

- Define the scope, methodology and criteria for carrying out the Fire Propagation and Smoke Dispersion Study for the basic design, detailing project and assisted operation phases of the of the Floating Production Unit (FPU) or Fixed Unit, hereinafter referred to as the Unit. This TS may optionally be used as a guide in the operation phase of the Unit at the time of review of the study;

- Guide the dynamics for the planning, development and follow-up of the study by the parties involved and their final approval;

- Define the standardization, content and minimum requirements for presentation of the study report.

3. SCOPE OF THE STUDY

The study shall evaluate fire scenarios, their frequencies of occurrence and the possible consequences for the Unit and people, from the use of databases and Computational Fluid Dynamics (CFD) tools to simulate their effects in each region of the Unit. From the simulations and the technical analysis carried out, the following results shall be presented:

- The analysis of fire propagation, evaluating the possibility of escalation to other areas of the Unit;
- The evaluation of the structural integrity in the areas of interest of the Unit with the focus on identifying the impacts on the MSF in each area. The integrity of primary structures, secondary structures where their failure contribute to structural collapse, integrity of bearing structures of equipment containing significant hydrocarbon inventory shall be assessed;

  Note: Not applicable in Basic Design;
- The impairment frequency of escape and abandonment due to the toxic gases and low visibility, because of smoke dispersion;
- The impairment frequency of the MSFs;
- The assessment of the fire scenarios regarding to the necessary protections for critical system elements that need to operate in a fire condition and that may be exposed directly or indirectly to the fire's action, like the positioning of ADV's considering the need for manual actuation, among other items.

4. ABBREVIATIONS E DEFINITIONS

For the purpose of this specification the following abbreviations and definitions shall be considered:

Abbreviations

ADV – Automatic Deluge Valve

BSDV – Boarding Shutdown Valve

CCR – Central Control Room

CFD – Computational Fluid Dynamics

FPU – Floating Production Unit

HCRD – HSE Hydrocarbon Release Database

HSE – Health and Safety Executive - Great Britain's independent regulator for work-related health, safety and illness

MSF – Main Safety Function

P&ID - Piping and Instrumentation Diagram

PFD - Process Flow Diagram

PFP – Passive Fire Protection

PHA - Preliminary Hazards Analysis

SDV – Shutdown Valve

SIGEM -*Sistema Integrado de Gerenciamento de Empreendimentos* - Integrated System of Project Management

TS – Technical Specification

Definitions

Collapse - Any type of deformation or failure in structural elements that could lead to a fire spreading or propagation, contributing to the occurrence or aggravation of an accidental scenario.

Confinement - Condition of an environment or area where there is a solid barrier that prevents the acceleration of the flames in a direction. E.g.: plate floors and bulkheads.

Congestion - Condition of an environment or area where there is a porous barrier, or set of obstructions, that generate turbulence when passing a fluid, modifying the acceleration of the flames in a direction. E.g.: Piping, groups of small objects.

Depressurizing System - Valve, piping and vessel protection system, with manual or automatic actuation, to provide a rapid reduction of the pressure in the equipment, by releasing the inventory of the process plant to atmosphere in a safe place.

Designer - company responsible for the engineering design: basic design or detailing project, which may be Petrobras itself or contracted company to carry out the project.

Equipment Support Structure - Mechanical structure dimensioned to support the loads of the equipment in operation conditions, as well as the accidental loads.

Escalation - Spread of impact from fires, explosions, toxic gas releases to equipment or other areas thereby causing an increase in the consequences of a hazardous event.

Flash Fire - A fire in which the flame propagates in a flammable gas cloud without causing overpressures that cause severe damage to the Unit.

Jet Fire - Turbulent diffusion flame resulting from the combustion of a fuel continuously released with momentum in a particular direction.

Main Safety Function (MSF) - Function that a safety item shall fulfill to enable and/or guarantee the effectiveness of the emergency response strategy, escape and abandonment of the Unit during an accidental event. Included in this definition are other elements that shall be kept intact and functional in an accidental condition. These main functions are defined in item 8.4 of Safety Engineering Guidelines and shall remain available for one (1) hour after the beginning of the incident.

Overpressure - Pressure wave resulting from the energy released by the explosion phenomenon, significantly related to the fluid composition aspects, ignition condition, ignited fluid mass, confinement and congestion of impacted areas.

Parties involved - Are the Designer, Study Consulting and Petrobras involved in the preparation or monitoring of the study.

Pool Fire - turbulent diffusion fire burning above a horizontal pool of vaporizing hydrocarbon fuel under conditions where the fuel has zero or very low initial momentum.

Primary Structure - Structural part in which a failure will have significant consequences for the Unit, like the collapse of the structure of a module, loss of MSF, for example.

Scenario - Event considered at the point of interest having the combination of hazard, causes, effects and associated risk classification, considering Frequency and Severity.

Segment - Parts of a system comprising piping and equipment between safety block valves (SDV's) or other blocks considered in the analysis.

Secondary Structure - Structural part in which a failure will not have significant consequences for the Unit, without loss of MSF.

Section - Parts of the same segment that pass-through regions of interest of the analysis.

Study Consulting - Is responsible for the execution of the fire propagation and smoke dispersion study. Study Consulting may be an outsourced company hired by either the Designer or Petrobras, or it can be the Designer itself or an internal Petrobras workforce.

5. REFERENCE DOCUMENTATION

As inputs for the elaboration of Fire Propagation and Smoke Dispersion Study, the following documents shall be considered, at least at their revision “A” and with status of RELEASED WITH COMMENTS by Petrobras at SIGEM or another electronic document management system defined in a contract. The review of each document to be used shall be clearly indicated in the analysis report.

a) Process Flow Diagrams (PFDs);
b) Process and Instrumentation Diagrams (P&IDs)
c) 3D model of the updated Unit;
d) Meteoceanographic data;
e) Reports of the PHA already carried out for the Unit;
f) Calculation memory of the depressurizing system;
g) Material Safety Data Sheet (MSDS).

Additional documents shall be provided for the identification of other relevant aspects, such as:

– Indication of containment dikes at areas of equipment installation handling flammable and combustible fluids;

– Indication of the type of floor that separates the decks (plate or grade floor);

– Memorandum describing the modes of operation of the Unit;

Depending on the project phase, some of the documents mentioned above may not be available; in this case, Petrobras shall be consulted about its relevance to the preparation of the study.

6. RELEVANT STUDY ASPECTS

The Fire Propagation and Smoke Dispersion Study shall consider at least the following aspects that influence the magnitude and characterization of the fire scenarios:

– Fluids composition, considering the presence and concentration of flammable, combustible, toxic and/or asphyxiating components;

– Leak or discharge conditions to the environment (E.g.: leak rates, gas temperature, leakage direction, fluid phase, etc.);

– Confinement of areas by bulkheads, floors and large equipment;

– Congestion of areas by equipment, structures and piping among other items;

– The number of elements such as equipment, instruments, other components and piping section that may leak;

– The environmental conditions to be used in the simulations;

– The size of the jet fire and flammable pools resulting from the hydrocarbons or other flammable fluids leakage into the environment;

– Ignition probabilities.

7. SOFTWARE REQUIREMENTS

The Fire Propagation and Smoke Dispersion study shall be simulated with the use of CFD tools and shall comply with the requirements of the Safety Engineering Guideline.

The impairment evaluation of MSFs due to fire scenarios identified in the PHA, shall be performed using CFD software that uses finite volume or porosity meshes.

The approved software are: CFX, FLUENT, STAR-CCM+, KFX (Kameleon) and FLACS. Other software shall be previously authorized by Petrobras before being used in simulations.

8. WEATHER CONDITIONS

The meteorological and oceanographic parameters to be used in the study shall be those of the final location of the Unit. The use of the meteorological data in the study shall comply with the Safety Engineering Guidelines. In the study report, a table shall be presented with the directions of the wind, speeds of each wind direction, as well as the calm condition and all the considerations adopted in relation to the environmental data used in the study.

For jet fire scenarios, it shall be considered the wind that has the opposite direction of the leak direction.

For pool fires, it shall be considered at least 4 wind directions and the calm wind direction shall be one of them.

The wind speeds to be considered shall be the mean ones presented in the METOCEAN of the project as "*Mean Spd*".

The study report shall present a table with wind directions, wind speeds of each wind direction, as well as calm condition, and all the considerations and assumptions adopted for the simulations.

9. STUDY METHODOLOGY

The methodology to be adopted in the fire propagation and smoke dispersion study shall meet the requirements of the Safety Engineering Guidelines, complemented by the requirements contained in this TS.

The methodology for the shall follow the steps described in this technical specification. Any deviation from the methodology shall be presented to Petrobras for analysis and prior validation. The following steps shall be taken in the development of the study:

9.1. Scenarios selection

The scenarios selection to be evaluated in the study shall be carried out on risk-based; in this way, the scenarios shall originate from the following sources of information:

9.1.1. Originated from PHA

The fire propagation and smoke dispersion study shall, simulate and evaluate all the accidental scenarios identified in the PHA that involve thermal effects and smoke dispersion, whose initial categorization of risks for the dimensions "People" or "Asset" are classified such as Moderate in severity categories IV or V, and Non-Tolerable (all categories of severity and all dimensions), according to the Risk Tolerability Matrix presented in Petrobras standard N-2782.

The study shall indicate all the scenarios that shall be simulated, representative of the selected PHA scenarios. According to the experience and analysis of the Study Consulting, some scenarios may be grouped or even excluded from the analysis, however, these shall be technically justified and included in the report with the respective justifications. These cases shall be presented for analysis and prior validation by Petrobras.

9.1.2. Additional Scenarios

Accidental scenarios that have not been previously assessed in the PHA, identified during the study development, shall also be considered in the fire propagation and smoke dispersion study, such as scenarios resulting from design changes and operational changes.

Scenarios of leakage followed by ignition at the top riser in its emerge section shall be considered, and its frequencies analyzed according to criteria defined in this Technical Specification.

In addition to the above-mentioned scenarios, the following scenarios shall be simulated:

I. Pool fires (non-stabilized oil) on the main deck due to leaks on connections on the oil loading header;

II. Pool fires (non-stabilized oil) on the oil processing module(s) due to leaks on equipment and/or connections downstream of the last oil dehydrator.

The fire propagation study shall evaluate and demonstrate whether gas leaks on the locations presented below are credible or not.

The following scenarios shall be evaluated:

I. Jet Fire due to gas leaks from Tanks Ellipses associated to the "Structural Tanks Gas Recovery System";

II. Jet Fire due to gas leaks from Closed Venting Header connections on main deck;

III. Jet Fire due to gas leaks from Inert Gas Purge Header connections on the main deck;

IV. Jet Fire due to gas leaks from the Hydrocarbon Header/Inert Gas distribution header connections on the main deck.

For all above cases, it shall be considered the process simulation report for these specific scenarios issued by the process discipline during basic design phase which considers:

a) Gas carry under on the last stage of oil dehydration;

b) Volatiles gases released by oil in the oil cargo tanks;

c) Inertization of tanks associated with the Structural Tanks Gas Recovery System with fuel gas.

NOTE: Oil referenced in this process simulation report is called "non-stabilized oil" for the purposes of this study development/TS application.

The selection of the compositions presented on this report shall be performed by the study executioner and shall be approved by Petrobras prior to the start of the simulations.

9.2. Event Tree

The fire scenarios shall be represented in an event tree, where the values of each event shall be indicated in terms of frequency or probability of occurrence and final value of frequency of occurrence of each accidental hypothesis (E.g.: jet fire, pool fire, explosion, flash fire).

Figures below present the minimal event trees that shall be considered in the analysis which needs to be complemented by leak direction, wind direction/wind probabilities.

If there is any event that do not appears in figures below, Petrobras shall be consulted.

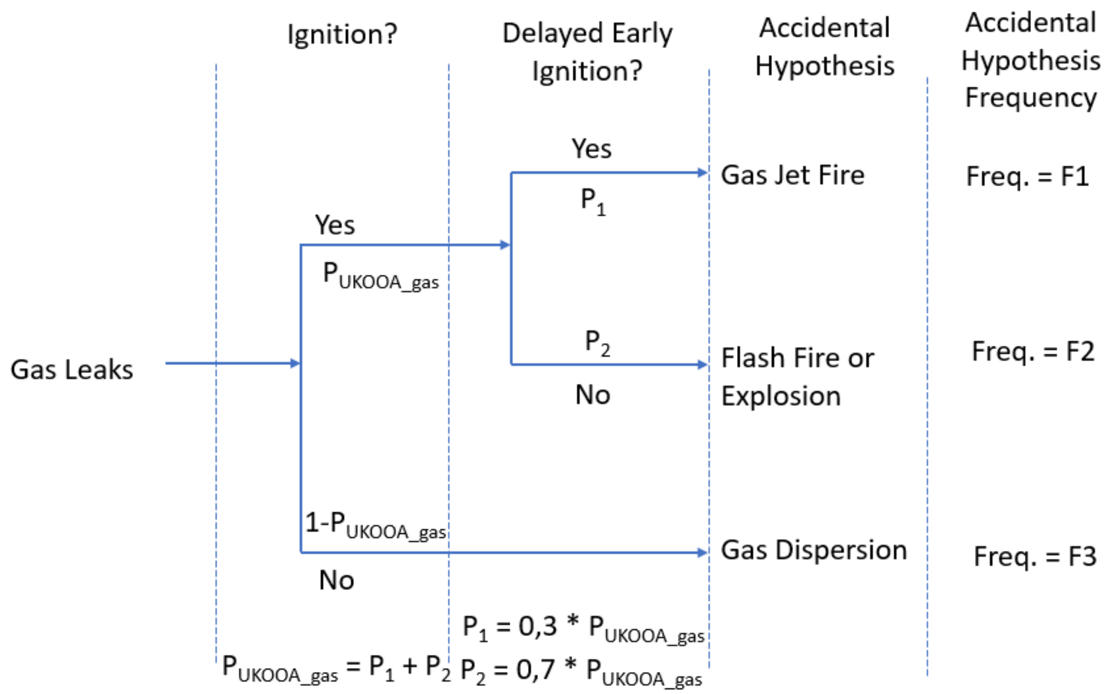

Figure 1: Event Tree for Flammable Gas Leaks

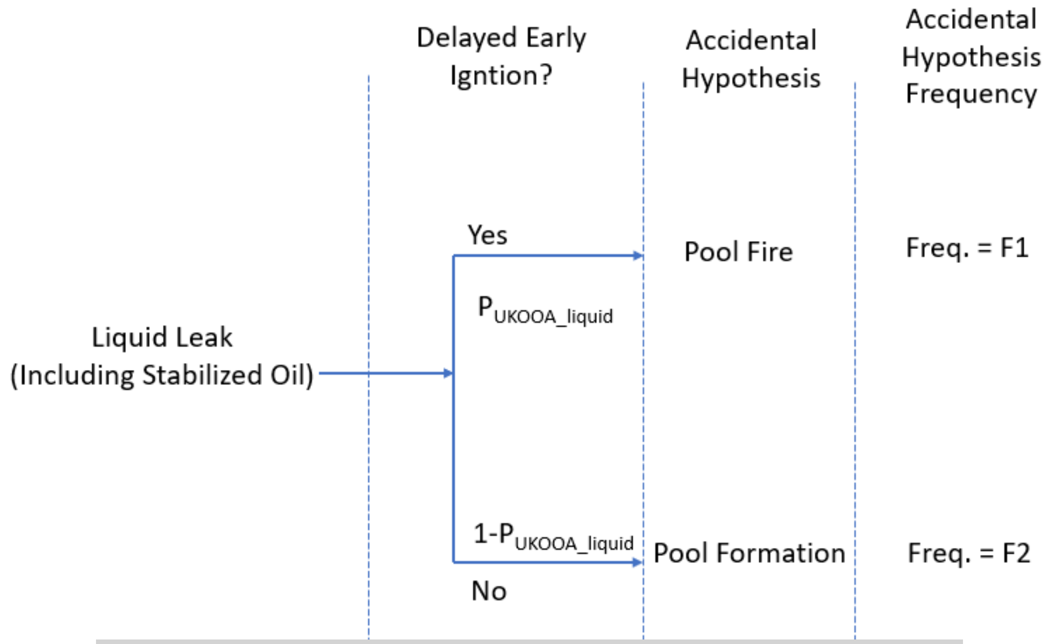

Figure 2: Event Tree for Liquid Leaks (including stabilized oil)

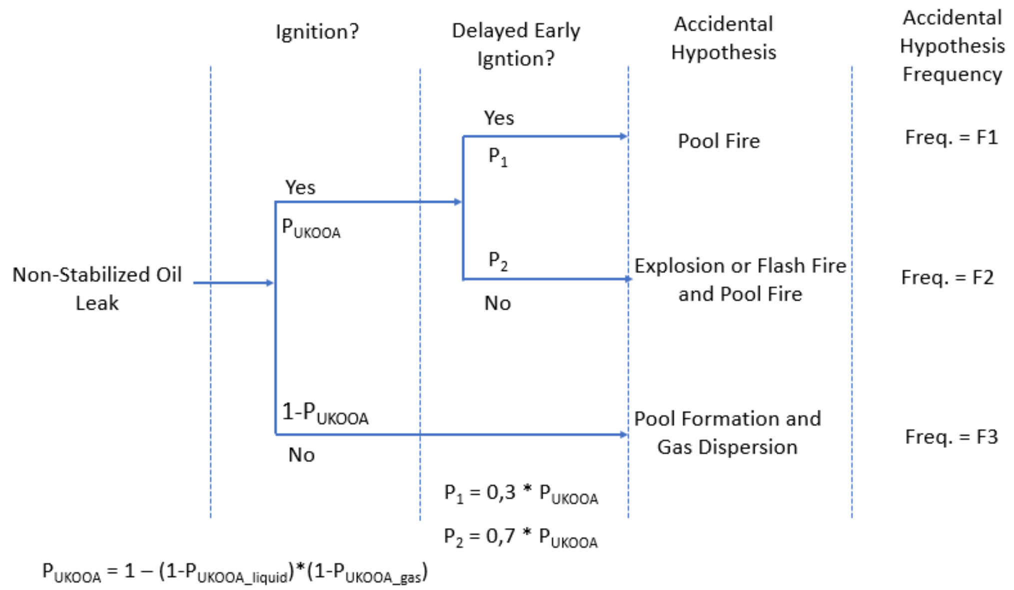

Figure 3: Non-Stabilized Oil Leak

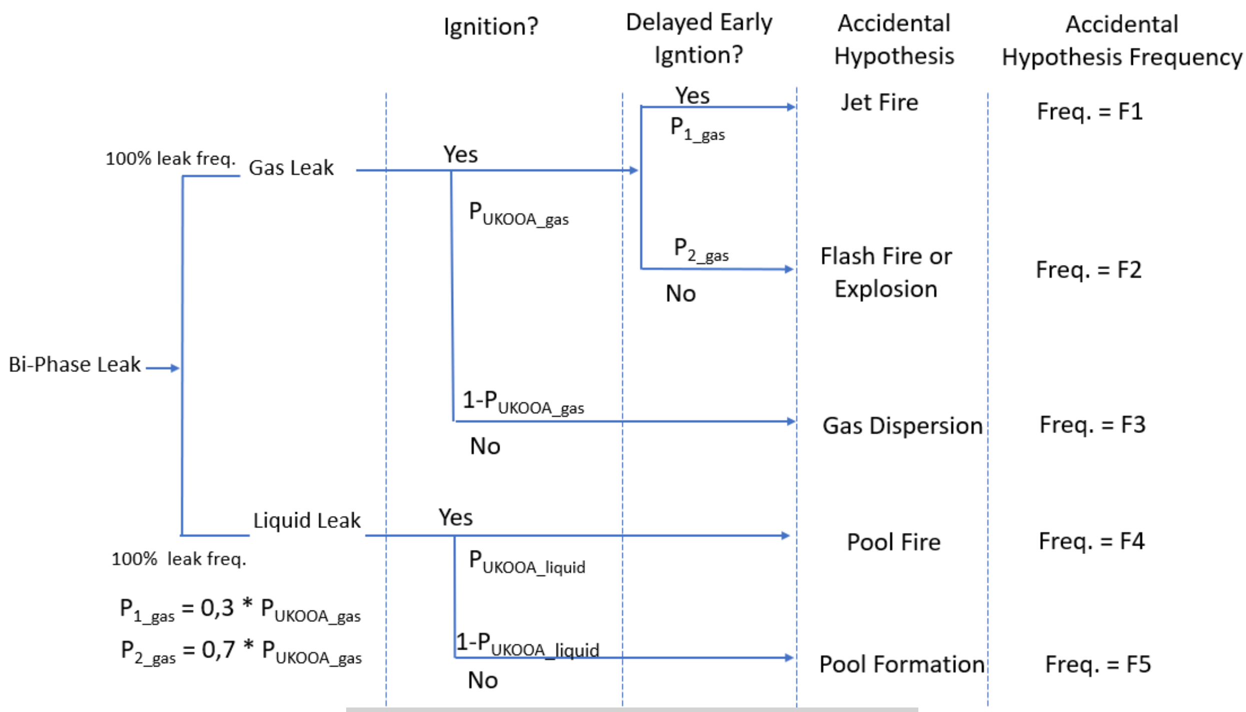

Figure 4: Event Tree for Bi-Phase Leaks

For the definitions of P_{UKOOA_gas} and P_{UKOOA_liquid} see item 9.8.

The Study Consulting shall prepare the event trees for all the scenarios defined in item 9.1 of this TS. The event trees shall be included in the study report with the frequency results of all accidental hypotheses, highlighting the values corresponding to the fire hypotheses, object of the study. The results shall be included in an annex to the report, preferably in a table format.

The event tree to be used in the frequency calculations of the accidental hypotheses shall be presented in a meeting for validation by the Designer and Petrobras before starting the calculations.

9.3. Process Data

For the determination of the flammable gases or vapors' properties and other data related to the process variables to be used in the study, only updated design data shall be used. All documents used as reference for obtaining the data shall be indicated in the item of reference documents of the report with the respective revisions.

All simulated cases shall have the respective physicochemical properties of the fluids (flammable gases/vapors) presented in the report, and shall at least be indicated: flow composition, pressure, temperature, density, flow code, reference document (E.g.: PFDs, PI&Ds, data sheets, mass and energy balance, line isometric), operation mode and other properties to track the origin and relevance of the information used. These data shall be provided by the Designer and presented for analysis and validation by Petrobras before being used in the simulations. Validation of process data shall be performed by experienced professionals involved in the project.

The operational case to be used for this study is Maximum Oil/Gas/Liquid.

It is the responsibility of the Designer to provide the reliable input data to be used in the simulations, so any detected errors that impact the results and that require new simulations is Designer's responsibility. In case of changes in the project formally requested by Petrobras, as change in the composition of produced fluids or increase/reduction of capacity of the plant that impact the study, will be the responsibility of Petrobras.

9.4. Depressurizing Assumptions

The study shall consider the depressurizing criterion adopted in the project. Depressurizing premises and calculation shall be provided by the Designer and presented in a specific item of the report. The Study Consulting shall use the depressurizing calculations to estimate leaks duration.

9.5. Segmentation and Inventory Calculation

The representative segments of the PHA scenarios and the additional scenarios referred to in item 9.1 of this TS shall be considered in the study, and the Study Consulting shall include as an annex to the report all those segments highlighted in the respective process documents (E.g.: PI&Ds, etc.), so that they can be clearly identified.

These segments shall be considered for the counting of leakage elements, the calculation of leakage frequencies and the calculation of hydrocarbon inventories, according to the criteria established in this TS.

For the calculation of the inventory of combustible and/or flammable fluids of a fire scenario, the one contained between SDV valves shall be considered and, in addition, meet the following requirements:

- PV, XV, TV, LV, manual block valves, shall not be considered as isolated parts. Exceptionally for **segmentation and segment inventory calculation these valves shall be considered segment limitation under the following conditions**:

  - PV, XV, TV, LV and/or manual block valves having located downstream of them pipes with service type of F (Flare), DA (Open Drain) and DF (Closed Drain);
  - PV, XV, TV, LV and/or manual block valves having located downstream of them blind flanges;
  - PV, XV, TV, LV and/or manual block valves having located downstream of them closed spectacle blind;
  - Manual block valves having located downstream of them instruments.

- Double check valves shall be considered as segment limitation and inventory calculation:

  - In these cases, for leak points selected upstream these valves (Segment 1A in Figure 5), leaked inventory shall consider BDV, if exists, plus inventory of the Segment 1A, plus a back inventory (Segment 1B in Figure 5) to be considered as an orifice that is sized with a diameter equal to 10% of the check valve´s nominal flow diameter.
  - For leak points selected downstream these valves (Segment 1B), it shall be considered associated inventory of this trapped segment (Segment 1B) for small releases, and for medium and large releases it shall be considered inventory of segment upstream double check valve (Segment 1A) plus the one downstream (Segment 1B).

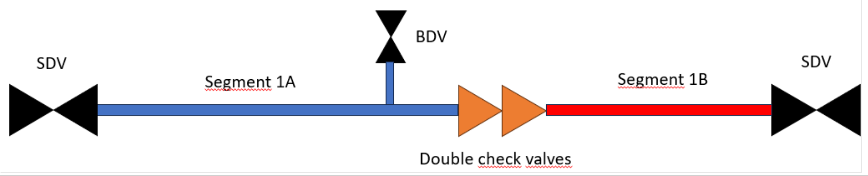

Figure 5:Illustration of upstream and downstream segmentation to double check valves.

NOTE: Exceptionally for piping collapse evaluation to be performed under the “Escalation Analysis Due to Collapse of Equipment and Piping Under Fire”, the segment between double check valves and SDV shall be considered as trapped if there is no BDV (Segment 1B).

Redundant equipment shall be considered in the segmentation/parts counts with a suggested utilization factor of at least 0,5.

Pig Lauchers/Receivers shall be considered in the segmentation/parts counts with suggested utilization factor of at least 0,5.

For the calculation of these inventories, it shall be considered the opening/closing times of SDVs, BDVs, BSDVs and SSDV on item 8.4.1 of DR-ENGP-M-I-1.3 considering "ON/OFF" closing/opening profile for consertive purposes.

For inventory calculation of Production Risers, Gas Injection Risers, Gas Lift Risers and Exportation Risers, there shall be considered the inventory of the longest existent riser of each type in the Project.

All P&Ids of all production risers, gas lift/gas injection lines, all production trains and compression trains shall be segmented and presented for Petrobras approval, not being accepted "typical" segmentation P&Id markups for these systems.

These segments shall appear in the report in the form of tables in a specific item that shall contain at least the following for each segment:

1. Description and identification of the segment;

2. Quantitative and description of the components (E.g.: equipment, flanges, instruments, accessories, etc.) associated to them by category of leak;

3. Frequency of leakage by category (small, medium and large) for each component;

4. Result of the segment inventory calculation in unit of mass (kg). The calculation shall consider the depressurizing system and the closing time of the respective SDVs. For calculation, the updated 3D model shall be used for lines with a diameter equal to or greater than 6". For lines less than 6" that have not been modeled, estimate routes shall be made with the assistance of the piping professionals of the Designer. This estimate shall be reported in the report as an annex;

5. Associated SDVs tags of the segment;

6. Associated BDVs tags of the segment and FOs sizes;

7. Graphs showing the frequencies versus leakage rates and net inventory by analyzed segment, for each category of leak, identifying the most critical segments according to their leak frequencies and leakage durations;

8. Graphs showing the frequency vs. leakage rate as a function of the gas mass in the segment, identifying the most critical segments according to their leakage frequencies and leakage durations.

These results shall be presented in a specific meeting for validation by the Designer and Petrobras before being used in the simulations.

9.6. Parts Count

It is fundamental that counting parts considered as sources of leakage (contributors) is the closest to the reality of the Unit in the operational condition (as built), in order to avoid imprecision in the calculation of leak frequency.

For the determination of the contributors in the calculation of the leakage frequency, the portion related to the straight sections of piping (holes in the pipeline) containing hydrocarbons, the updated 3D model shall be used for the measurement of the line lengths.

For the other contributing elements such as flanges, valves and other components, the counting shall be carried out in the following order of priority:

1. Unit data, if available (E.g.: 3D model or field count);

2. Data taken from updated project documentation (E.g.: P&IDs), with the participation of Process, Arrangement and Piping professionals of the Designer. In this case, the correction factors listed in the table in ANNEX I shall be applied;

3. Data from other existing installations of the same type (E.g.: FPSO / Semi-submersible, etc.) and production capacity, when available. In this case, the experience of professionals of process, arrangement and piping of the Designer and of Petrobras shall be used to validate the adequacy of the criterion of similarity and use of the data.

The definition of how elements shall be counted shall be carried out in a meeting with the participation of the parties involved. The accomplishment of the count is the responsibility of the Designer and shall occur with participation of the Study Consulting. The result of the count shall be presented in a table which shall be included in an annex of the report. The result of the count shall be sent for analysis and prior validation by Petrobras.

Risers identified as “Future” and/or “Reserved” and/or other similar nomenclature, they shall also be considered in the parts counts if they are identified as Production Risers, Gas Injection Risers, Exportation Risers and/or Gas Lift Risers.

The definition of how to count and how to use contributory elements that are not described in this item shall be discussed and agreed in a meeting with the parties involved.

At 90% of 3D model completeness, considering HULL and TOPSIDE, in the executive design, the study executioner shall perform a re-count considering 3D model database (E.g.: flanges, valves, straight sections of piping, equipment, instruments, etc.) when the difference between this new parts count and the previous one is equal or higher than 10%, the impairment frequencies shall be recalculated, new simulations performed and new recommendations provided, if applicable. In this case, other studies that depends on the results of this study, shall also be revised (E.g.: Escalation Analysis due to Collapse of Equipment and Piping under Fire).

9.7. Calculation of the Leak Frequencies

The leakage frequency for each component (E.g.: equipment, flange, piping, valve, instrument) shall be obtained by means of databases specified in the Safety Engineering Guideline. The use of any other database shall be previously agreed-upon with Petrobras.

The databases used shall have information that allows to relate leakage rates and the corresponding frequency of occurrence according to the element where the leak occurs (E.g.: flanges, valves, line segments, etc.) and their characteristics (E.g.: diameter, type, etc.), such as the HSE Hydrocarbon Release Database (HCRD) database.

The leakage frequency of the segment shall be obtained by the product between the number of elements counted in the counting step and the individual leak frequency of each type of component obtained in the database. The product of the linear leakage frequency is also added in straight sections of piping, according to the database, by the length of the respective sections.

It should be noted that piping sections may contain contributory elements in different physical areas and modules of the unit. The frequency portion of these elements shall be used where they are physically located (area where the leak occurs or near area).

For the segments between emerged part of production risers and BSDVs and between production BSDVs and their choke valves, the leak frequencies calculation shall also be performed at the shut-in pressures at the choke valves and for other pressures that is provided in the basic design phase. This evaluation shall be performed respecting the leak categories provided in the DR-ENGP-M-I-1.3 of small, medium, and large leaks.

The results of these calculations shall be presented in the report to be developed by the Study Consulting and shall be validated with the participation of the Design Engineer and Petrobras prior to the start of the simulations.

9.8. Ignition Probability Calculation

In the definition of the Ignition Probability, it shall be considered the correlations set out in one of the following references. The decision of the correlations to be used shall be approved by Petrobras.

- ENERGY INSTITUTE publication, Ignition Probability Review, Model Development and Look-Up Correlations - UK, Section 2 (Look-up Correlations) for Units Offshore. Each scenario shall be analyzed to determine the most appropriate correlation.
- IOGP Report 434-06 - Ignition Probabilities - Risk Assessment Data Directory. Each scenario shall be analyzed to determine the most appropriate correlation.

For the purposes of application of the concepts established in references in matter, the following terminology shall be used:

- Immediate ignition used in this TS and Safety Engineering Guideline, refers to the ignition probability defined in references above as “delayed”/ “early”;
- Delayed ignition used in this TS and Safety Engineering Guideline, refers to the ignition probability defined in references above as “delayed”/ “late”.

Based on these references, the following ignition probabilities models shall be considered:

- UKOOA_gas: LookUp Correlation Model 24 - Offshore FPSO Gas (Gas release from offshore FPSO process module);
- UKOOA_liquid: LookUp Correlation Model 26 - Offshore FPSO Liquid (Liquid release from typical offshore FPSO process module).

NOTE: Nomenclature used above is the same used in item 9.2.

The calculations shall be carried out by the Study Consulting, presented in the report, and shall be validated with the participation of the Designer and Petrobras before starting the simulations.

9.9. Fire Frequencies Calculation

The fire frequency calculation shall consider the product of leakage frequency by the likelihood of ignition. The calculated frequencies shall be presented in a specific item of the report and in the form of tables for the three leakage ranges (small, medium and large), allowing all leak frequencies and ignition probabilities considered in the calculations to be visualized.

If the sum of all fire scenarios in a fire frequency range (small, medium or large leak rates) is less than 1.00E-06 occurrences per year (E.g.: sum of frequency of all fire scenarios of medium leaks is lower than 1.00E-06 occurrences per year, etc.), fire scenarios in this frequency range do not need to have CFD fire simulations performed.

For the segments between emerged part of production risers and BSDVs and between production BSDVs and their choke valves, the fire frequencies calculation shall also be performed at the shut-in pressures at the choke valves and for other pressures that is provided in the basic design phase. This evaluation shall be performed respecting the leak categories provided in the DR-ENGP-M-I-1.3 of small, medium, and large leaks.

The results of the calculations of the fire frequencies shall be validated with the participation of the Designer and Petrobras before the simulations start.

9.10. Leak Rates

The Study Consulting shall consider the three leak rate ranges (small, medium and large) specified in the Safety Engineering Guideline. In each of the ranges different leakage rate values shall be adopted in order to represent the consequences spectrum of the scenarios and at least the following leak rates shall be used:

- Small: 0,5 kg/s and 2,0 kg/s;
- Medium: 4 kg/s, 12 kg/s and 24 kg/s;
- Large: 32 kg/s and full bore (note1).

Note 1: For the riser balcony area it shall be included the leak rate of 64 kg/s. The determined rates shall be validated with the participation of the Designer and Petrobras prior to the start of the simulations.

9.11. Leak Directions

The leakage directions shall be in accordance with Safety Engineering Guidelines, being possible to carry out simplifications since previously agreed with Petrobras. All the directions considered per scenario shall be presented in the report, as well as the justifications for possible simplifications.

9.12. Requirements for Geometry and Level of Congestion

9.12.1. Requirements for Geometry

The CFD geometric model used in the study shall meet the requirements set forth in the Safety Engineering Guideline.

The CFD geometric model shall be based on the most up-to-date 3D model available to the Unit or shall be constructed based on the actual geometry of the unit under consideration, when available.

For existing units, the as-built 3D model shall be used.

In the executive design, the minimum 3D model completeness that shall be used is at least 60% for topside and at least 60% for HULL.

9.12.2. Level of Congestion

The level of congestion of every elevation of used 3D model of all modules/areas shall be determined using approved software by PB (E.g.: FLACS) and presented for Petrobras validation.

For Basic and FEED Designs, the level of congestion of every elevation of module/area shall be artificially increased using established values of "*Maximum Density*" of table presented in Annex IV of this TS, and for the Detailing Design the "*Average Density*" ones. This analysis shall be presented in the report.

The level of congestion of every elevation of all modules/areas before artificial congestion and after artificial congestion implementation shall be presented for Petrobras validation prior the commence of the CFD simulations. This validation shall occur in a meeting with the parties involved. This analysis shall be presented in the report.

On Detailing Desing at 3D model completeness level of 90%, or superior, the level of congestion of every elevation of all modules/areas shall be determined without considering artificial congestion addition. If the difference between congestion levels considered is larger than 10%, CFD simulations shall be reperformed the elevation of the module/area that has this difference.

9.13. Selection of Leak Points to be Simulated

For the selection of the leakage points, a meeting with the participation of the Designer shall be held with Petrobras professionals of process and safety.

The objective of this meeting is to define the leakage points to be used in the CFD simulations for the representative segments of the scenarios selected for simulation. In order to do this, it is recommended the following characteristics to be considered: fluid composition, leakage rates, inventory, leakage frequencies, leakage directions, and area arrangement.

At that meeting, the Designer shall conduct a design review session using the Unit's updated 3D model to facilitate the selection and identification of leakage points.

The selection of leakage points shall occur to identify for each scenario / segment, in each module or area evaluated, the points that historically present a higher chance of leakage, not necessarily only the inlet and outlet of large inventory equipment, but also other susceptible points, such as connections on high vibration lines.

Other leakage points outside the module / area subject to the analysis, which due to their proximity, leakage direction and wind conditions may lead to fire impairment for this module / area, shall be identified and considered in the selection. The same consideration applies to modules / areas where there are no hydrocarbon leakage points, such as utility and service modules.

Leak points at riser balcony, riser pipe rack, offloading stations and main deck (if there are hydrocarbon equipment) shall also be considered.

The simulations performed for a module / area shall not be used in other modules regardless of the similarities of the process and arrangement conditions. This means that each module shall have its own simulations.

Any simplifications shall be discussed with the Designer and validated with the participation of Petrobras. These shall be included in the report with their respective justifications.

9.14. Analysis of Fire Propagation and Temperature Evaluation

For the execution of fire propagation analysis and temperature evaluation, the requirements defined in the Safety Engineering Guideline shall be met.

The integrity of the MSF with respect to the impact of the simulated fire scenarios shall be assessed. MSF shall remain available for one (1) hour after the start of the incident.

For the execution of the simulations, plated floors and bulkheads shall not be considered as tight to the passage of heat, except in cases where they have some certified protection, and in the latter case, the specific thermal insulation properties of the material shall be considered with the manufacturer's instructions. The Study Consulting shall describe these properties in a specific item of the report, as well as the influence of these barriers in the simulations.

Temperature and radiation results shall be presented to also evaluate the following items:

– Depressurization System: The Study Performer shall evaluate the fire scenarios that affect the Unit's depressurizing system (formed by: HP header supports, LP header supports, LP knockout vessel, HP knockout vessel and flare tower primary structure and piping support). The temperature limits established in item 9.19.1 of this TS shall be considered. If limits are exceeded, protective measures shall be recommended;

– BDVs with opening time delay (according to the requirements of item 7.3 of DR-ENGP-M-I-1.3) shall be protected by passive fire protection, for valve and actuator;

– Safety valves and valves that need to operate in an emergency: BDV protection shall be certified to ensure that the BDV surface temperature does not reach 200° C in 15 minutes (J15). The SDVs for the arrival of production wells, gas injection, gas lift and diesel injection and export risers, as well as their actuators, shall be protected with passive fire protection Class J60, regardless of the impairment frequency, that is, the application is deterministic and compulsory. The SDVs of the process plant do not require passive fire protection, considering that they will go to the safe position upon confirmation of fire detection;

– Deluge Valves: automatic deluge valves (ADV) shall be assessed for impact by fire scenarios from areas served by them. Local radiation shall be evaluated so that local manual actuation is not impeded, according to the criteria defined in item 9.19.1 of this TS. If the limit is exceeded, the change in the position of the affected ADV or other mitigating measures shall be considered.

As a result of the evaluations for each item above, the following information shall be provided on the report:

– Depressurization System: achieved temperature on all items that composes the depressurization MSF;

– Safety valves and valves that need to operate in an emergency: BDVs tags, location, considered impairment criteria, values found and Critical analysis (with indication and justification of the proposed measures) and type of PFP and its area extension, when applicable;

– Deluge Valves: ADVs tags, location, considered impairment criteria, values found and Critical analysis (with indication and justification of the proposed measures) and type of PFP and its area extension, when applicable.

9.15. Flame Characteristics Determination and Pool Fire Considerations

The Study Consulting shall determine and include in the report the flame characteristics of the simulated scenarios, as defined in the following items:

9.15.1. Jet Fire

At least the following characteristics shall be determined and presented:

– Length of the flames in meters (m) and the rate of mass leakage (kg/s) throughout the fire;

– Duration of the scenario in minutes, considering and indicating the actuation of the depressurizing system. It shall be presented the entire time duration of the scenario (E.g.: if duration is larger than 60 min, this time shall be presented);

– Inventory calculated for the scenario considering closing times of BSDVs or SDVs or submarine SDVs or Wet Christmas Trees, and BDVs closing time (if applicable), in m^3;

– Type of jet (gas or liquid);

– Pressure, in barg.

9.15.2. Pool Fire

At least the following characteristics shall be determined and presented:

- Flame height, in meters;
- Stationary pool fire diameter, in m^2;
- Duration of scenario in minutes. It shall be presented the entire time duration of the scenario (E.g.: if duration is larger than 60 min, this time shall be presented);
- Inventory calculated for the scenario considering closing times of BSDVs or SDVs or submarine SDVs or Wet Christmas Trees, and BDVs closing time (if applicable), in m^3;
- Heat combustion in kJ/kg;
- Calculated mass leak rate, in kg/s;
- Radiation generated by the scenario, in kW/m^2;
- Mass burning rate considered, in $kg.m^{-2}.s^{-1}$ or kg/s;
- Equilibrium leak rate (E.g.: mass burning rate x containment area of the module) (kg/s);
- Considered Containment area (m^2);
- Containment volume (m^3).

For conservatism reasons, the drainage system shall not be considered on the calculation of the pool fire diameters, and their determination shall be done considering presented rationale on Annex III.

Exceptionally for this item, semi-empirical software can be used.

9.15.3. Flash Fire

Flash fires are characterized by the flame front that moves through the cloud generating a potentially intense flame, which can have serious effects on people who may be located in the region where the flammable flash is found. However, due to their short duration and intensity, which shall not cause structural damage or damage to the equipment, flash fires will not be considered to impair the main safety functions or to analyze the consequences for equipment and structures.

Flash fire scenarios shall be treated in the report as information to warn Petrobras' operational areas about the need to adopt operational and administrative measures that minimize the exposure of people to these scenarios.

9.16. Smoke Dispersion Analysis

In the study of smoke dispersion, in addition to the provisions of the Safety Engineering Guideline, the smoke plumes, toxic/asphyxiating gases, temperature and simulated visibility for the various fire scenarios shall be evaluated in relation to risks to people.

In this evaluation, consideration shall be given to aspects that may result in the impairment of escape routes, abandonment stations, temporary refuges and other MSF due to the presence of smoke. The aspects that shall be evaluated in the study are:

- CO intoxication;

- CO_2 intoxication;

- Breathable air/O_2 depletion;

- Reduced visibility;

- Smoke temperature.

Figures shall be presented which clearly show the smoke dispersion of the scenarios considered in the platform, associated to concentrations by region. The contours of CO_2 concentration, CO concentration, O_2 depletion, smoke temperature and visibility shall be presented in the figures. The plots presented for each of the scenarios shall be those that demonstrate the conclusions/recommendations regarding the impairment of MSF.

The report shall present in a table the values found in the simulations, comparing them with maximum exposure limits of each of the aspects mentioned above, as provided in item 9.19.1 of this TS. Scenarios that impair escape routes and impact emergency evacuation shall be presented in figures, and the duration of such an impairment shall be indicated. In these cases, mitigating measures shall be evaluated and proposed.

9.17. Radiation Curves

In order to subsidize the preparation of the emergency plan of the Unit, the study consulting shall draw up graphs containing radiation curves (contours or isosurfaces) for 1,58 kW/m^2 and 4,73 kW/m^2, considering the times of 1 min., and in intervals of 15 minutes to the final duration of the scenario or 60 minutes, whichever is less.

The graphs containing the radiation curves shall be presented for all PHA scenarios of the large hydrocarbon releases that have a fire as consequence, whose initial risk categorizations for the "People" or "Asset" dimensions are classified as Moderate in severity categories IV or V, and Non-Tolerable (all categories of severity and all dimensions), according to the Risk Tolerability Matrix presented in Annex I of the Safety Engineering Guideline.

These graphs shall have a color subtitle with a scale that discriminates the curves, times and levels of the plans of interest, shall be elaborated considering the superior view of the modules and areas of the Unit and shall be presented as annexes to the study report.

9.18. Structural analysis

The structural analysis shall consider the provisions of item 8.4.8.2 of the Safety Engineering Guideline, supplemented by the requirements of I-ET-3010.00-1300-140-P4X-003 - FIRE-STRUCTURE ANALYSIS FOR PASSIVE FIRE PROTECTION DESIGN.

Note: Not applicable in Basic Design.

9.19. Impairment of the Critical Safety Items

9.19.1. Parameters Considered for Impairment

There are several parameters that can compete to impair MSF, such as temperature, radiation, toxic gases, among others. These parameters are presented in the table in ANNEX II. Each parameter has an associated tolerance limit value, as presented in the "impairment criteria" columns in the table of that annex.

A MSF shall be considered to be impaired when one or more of the criteria established for the set of associated parameters in the impairment analysis is exceeded.

9.19.2. Impairment Frequencies

The total impairment frequency of each MSF will be the sum of the frequencies of all scenarios that affect that MSF above the criterion established for each parameter defined in the table in ANNEX II. In the case of a scenario in which the MSF was impacted by more than one parameter, the frequency of this scenario was considered only once to compose the total impairment frequency.

9.19.3. Impairment Analysis

The total impairment frequencies of each MSF shall be compared according to the impairment frequency criterion established in the Safety Engineering Guideline, which corresponds to the value of 2.50E-04 occurrences/year.

NOTE: Exceptionally for structural impairment analysis to be performed in the Detailing Design, after performing the elastoplastic structural analysis, the scenarios that generate collapse for the same structure will be accumulated. When the accumulated value of 1.00E-04 occurrences/year is exceeded, the contributing scenarios shall be ordered by the severity of their impacts, prioritizing the PFP application recommendation for the scenarios that affect the most elements of that structure (greater m^2 applied) until the cumulative frequency falls below the criterion of 1.00E-04 occurrences/year.

These results shall be presented in the form of tables for each MSF, and recommendations shall be proposed in the specific item of the report for those cases where those frequencies exceed 2.50E-04 occurrences/year. The recommendations shall preferably act to reduce the frequency of MSF impairment. If this is not possible, they shall consider mitigating the consequences of the scenario.

10. REQUIREMENTS FOR FOLLOW UP MEETINGS

The study follow-up meetings shall follow the guidelines below.

10.1. General Considerations

The follow up of the development of the study shall be carried out by the team of the Designer with Petrobras participation in the cases mentioned in this specification.

The follow-up meetings shall be held in the office of the Study Consulting, with the exception of the planning and analysis of the project documentation meetings, which shall be carried out at the Designer's offices. The meeting local may be changed by common agreement between the parties involved. Petrobras, at its discretion, may attend meetings by videoconference.

The minutes of meetings shall be made available as a project document.

10.2. Planning Meeting

Meeting for the summary presentation of the project, clarification of aspects related to the objectives and scope of the study, delivery of project documentation, evaluation and necessary adjustments in the work schedule and resources required for the study, where the minimum agenda should be:

- Clarifications on objectives, scope of analysis and requirements of the study (Designer and Petrobras);
- Delivery of the project documentation as foreseen in item 5 of this TS (Designer), including the 3D model of the Facility;
- Presentation of the planned schedule for the execution of the study in accordance with the project schedule (Study Consulting and Designer).

Participants in the planning meeting: The single points of the parties involved, the professionals responsible for the study, and the Designers' disciplinary leaders responsible for the follow-up of the study shall be involved.

10.3. Documentation Review Meeting

Meeting for the analysis and validation of the project documentation required for the development of the study and preparation of the pending list, if any. The objective is to avoid errors and rework in studies due to possible failures or omissions of information in the documentation, which will serve as the input database for the study.

The meeting shall also cover the evaluation and validation of the Unit's 3D model as to its suitability for exporting or developing the CFD model.

From the analysis of the document list of project and documents provided, the Study Consulting may request clarification and clear questions about the information contained in the documents. In case of identification of pending documents or the need to provide other documents, the Designer shall inform the deadline necessary to solve the pending issues and/or to send the documents, in a way that does not affect the schedule for the study.

At the end of the meeting, the Study Consulting shall sign an accepted document containing the pending list, if any.

Note: The Designer, as responsible for project change management, shall inform the other parties involved of any change in the project that affects the study. Documents changed because of the project changes, affecting the study, shall be sent to the Study Consulting.

The Study Consulting shall evaluate the changes and report the impacts of the changes in the analysis and schedule. This information shall be sent formally to the designer and communicated to Petrobras.

Participants in the documentation analysis: professionals involved, and the discipline's design leaders shall be involved in the follow-up of the study. This meeting is optional for Petrobras.

10.4. Meeting of Premises and Methodology

Meeting for the presentation and definition of premises to be used in the study, clarification of the methodology and confirmation of basic data of the Installation.

The Study Consulting shall present the proposed premises for the development of the study and its doubts about the methodology proposed in this TS. The Designer with the participation of Petrobras shall clarify the doubts.

Assumptions shall be defined by mutual agreement between the parties involved and shall be included in the study report.

In addition to the premises and methodology, the Designer shall confirm the basic information for the start of the study, such as meteorological conditions, confirmation of the positioning coordinates of the Unit, the arrangement of risers (submarine and surface - arrangement at the risers balcony) and the MSF shall be evaluated in the study. The information shall be ratified or rectified by Petrobras.

Participants of the meeting of premises and methodology:

Participant professionals involved in the study and the discipline leaders of the Designer and Petrobras responsible for the follow-up of the study shall participate.

10.5. Follow up and Validation Meetings

Meetings to follow-up the study by the Designer with the participation of Petrobras where the items required in the methodology shall be addressed.

The Designer, in agreement with the Study Consulting, and considering the schedule for the study, shall present the agenda of meetings to follow up the development of the study. The meetings shall comprise the study steps foreseen in item 9 (Methodology) of this TS.

Follow-up and validation meetings shall be provided in Table 1 below:

Table 1: Follow up and validation meetings.

Item	Minimum Agenda	Ref.
R1	**Validation of accidental scenarios and the event tree:** Confirmation of the selected scenarios to be analyzed (PHA and Additional) and proposition of the configuration of the event tree.	9.1 9.2
R2	**Validation of process and depressurizing data:** Confirmation of process data, modes of operation and depressurizing conditions.	9.3 9.4
R3	**Segment Validation and Inventory Calculation.**	9.5
R4	**Validation of count, leak frequency, ignition probability and fire frequency:** Presentation of parts count, leak frequencies, ignition probabilities,	9.6 9.7 9.8

	fire frequencies, validation of event tree calculations and exclusion of scenarios below the cutoff frequency.	9.9
R5	**Geometry Validation:** Presentation of the CFD model - evaluation of geometry, confinement, congestion, and obstructions to be added in the model.	9.10
R6	**Validation of leak conditions:** Definition of the leakage conditions and selection of the leakage points to be simulated.	9.11 9.12 9.13

Table 1 is based on Petrobras' experience, and the number of meetings may be altered by mutual agreement between the parties involved, provided that all the items that compose the methodology and that require validation are addressed, as well as the analysis of results and recommendations are discussed and evaluated for their applicability to the project.

Participants in monitoring and validation meetings: Study Consulting, disciplines representants of Designer and Petrobras technicians involved in the study follow-up shall attend the meetings.

11. STUDY REPORTS

The final report, including its attachments, shall be issued in Portuguese and English. The report shall comply with the content required in the Safety Engineering Guideline and as specified in this document.

All simplification and premises adopted shall be presented and explained in the corresponding part of the report. The charts and figures of the reports shall be presented with the respective scales and captions. For the elaboration of the tables, graphs and figures, the units of the International System - SI shall be applied.

All charts and figures that support the conclusions and recommendations of the study shall be presented in the final report.

11.1. Partial Report

At least two partial reports shall be presented by the Study Consulting to Petrobras. The first, informative, shall contain at least: the premises, 3D model, geometry, mesh and simulation domain, ventilation study results, scenarios to be analyzed, scenarios discarded, segment definition and inventory calculation, frequency calculation the ignition probabilities considered and the calculation of the fire frequency.

The second, for comments, shall present the results of the computational simulations, all the analyzes foreseen in the scope of the study, conclusions, recommendations and actions to comply with the recommendations, in addition to the other items included in the first partial report.

11.2. Final report

The Final Report corresponds to the issue of the report under revision 0, original issue. For this issue, the comments made to the second partial report shall be met and implemented. Additional revisions shall be provided for any changes in the project that impact the study, as provided for in items 9.3 and 10.3 of this TS, or in the event that failures in the final emission are identified.

12. DEADLINES

According to the complexity of the project, the scope of the study and the deadlines established in the contract, it shall be defined by the designer, in agreement with the Study Consultant, the deadlines required for the study and the issuance of the partial and final reports. These deadlines shall be included in the schedule mentioned in item 10.2 of this TS.

13. TECHNICAL SKILLS TO CARRY OUT THE STUDY

Due to the complexity involved in the methodology and the use of the CFD software applicable to the study of gas dispersion, and due to the importance of this study for the safety of the Unit, it shall be carried out by a qualified company.

14. APPLICATION OF THE CHECKLIST (LV)

The Designer shall provide a checklist (LV), which shall be included as an annex to the report, as a follow-up to the activities of the Study Consulting. The LV shall contain the requirements of the Safety Engineering Guidelines and the requirements of this TS. The verification of each requirement shall have the identification and signature of the person in charge of the verification.

The verification of the part relating to the structural analysis shall be included in the project documentation. However, this documentation shall be referenced in the study report, with a clear indication of how and where the study recommendations were met.

Note: This is applicable on the detailing engineering phase.

15. INFORMATION SECURITY

In addition to the provisions of the Safety Engineering Guidelines, the Project Designer and the Study Consulting shall have a data security system that guarantees the integrity, reliability, traceability, confidentiality and inviolability of the data contained in the study and the data provided by Petrobras. All information shall be preserved against accidental or information security events for at least five years.

ANNEXES

ANNEX I - CORRECTION OF COUNTING PARTS

Table - CORRECTION FACTORS FOR COUNTING PARTS

<table>
<tr><th>ELEMENT TYPE</th><th>DIAMETERS</th><th colspan="3">GAS</th><th colspan="3">OIL</th><th colspan="3">WELLS</th></tr>
<tr><td rowspan="5">FLANGES</td><td colspan="10">Count flanges as per P & ID - also considering FE, figure 8, FO and spool - and multiply the total of each system by the following factors:</td></tr>
<tr><td>D≤3"</td><td rowspan="3">Qtt GAS</td><td rowspan="3">x 2,00</td><td>x 0,45</td><td rowspan="3">Qtt OIL</td><td rowspan="3">x 4,00</td><td>x 0,35</td><td rowspan="3">Qtt WELLS</td><td rowspan="3">x 3,00</td><td>x 0,45</td></tr>
<tr><td>3"<D<12"</td><td>x 0,35</td><td>x 0,45</td><td>x 0,50</td></tr>
<tr><td>D≥12"</td><td>x 0,20</td><td>x 0,20</td><td>x 0,05</td></tr>
<tr><td colspan="10">Subtitle:
Qtd GAS = total quantity accounted for GAS system in P&IDs (for all diameter ranges)
Qtd OIL = total quantity accounted for OIL system in P&IDs (for all diameter ranges)
Qtd WELLS = total quantity accounted for WELLS system in P&IDs (for all diameter ranges)</td></tr>
<tr><td rowspan="4">BLOCK VALVE</td><td colspan="10">Count the block valves in P&ID and multiply the quantitative by the corrections factors below:</td></tr>
<tr><td>D≤3"</td><td colspan="9">x 1,50</td></tr>
<tr><td>3"<D<12"</td><td colspan="9">x 1,20</td></tr>
<tr><td>D≥12"</td><td colspan="9">Use directly the quantitative found.</td></tr>
<tr><td rowspan="3">BLOWDOWN VALVE (BDV)</td><td>D≤3"</td><td colspan="9" rowspan="3">Count the blowdown valves in P&ID and use directly the quantitative found.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
<tr><td rowspan="3">CONTROL VALVE</td><td>D≤3"</td><td colspan="9" rowspan="3">Count control valves in P&ID and use directly the quantitative found.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
<tr><td rowspan="3">CHECK VALVE</td><td>D≤3"</td><td colspan="9" rowspan="3">Count check valves in P&ID and use directly the quantitative found.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
<tr><td rowspan="3">SHUTDOWN VALVE (SDV)</td><td>D≤3"</td><td colspan="9" rowspan="3">Count SDVs in P&ID and use directly the quantitative found.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
<tr><td rowspan="3">INSTRUMENTS</td><td>D≤3"</td><td colspan="9" rowspan="3">Count instruments in P&ID and use directly the quantitative found.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
<tr><td rowspan="3">PRESSURE SAFETY VALVE (PSV)</td><td>D≤3"</td><td colspan="9" rowspan="3">Count PSVs in P&ID and use directly the quantitative found.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
</table>

REFERENCE: TECHNICAL NOTE NT_ENG-E&P_PROJEN_010_201

ANNEX II – IMPAIRMENT CRITERIA

Main Safety Functions and Relevant Safety Items	Description	Impairment Criteria							
		Parameters to be checked	CO (ppm)	CO2 (ppm) (note 2)	Visibility (m) (note 5)	Smoke temperature (°C) to 30 min. (note 4)	Heat Flux (KW/m²) (note 1)	Temperature at structures (°C) (note 6)	O_2 Depletion (%) (note 9)
Accommodation Muster Station (primary and secondary refuge) CCR	Accommodation (including: Central Control Room (CCR) and Radio Room) Muster stations	- External bulkheads collapse; - Gas contamination (hydrocarbons, toxics and asphyxiates). (note 7)	100 (note 3)	30.000	3	90	NA	450	>19,5
Embarkation Stations	Embarkation Stations SB	- Primary structures temperatures; - Capacity of people stays waiting for evacuation.	100 (note 3)	30.000	3	90	1,58	450	>19,5
	Embarkation Stations PS		100 (note 3)	30.000	3	90	1,58	450	>19,5
Escape Routes	Escape Routes SB	Impossibility to escape due to the simultaneous impairment of primary escape routes, considering: - Floor collapse; - Asphyxia, toxicity, radiation, temperature or visibility. (note 8)	1.200	30.000	3	90	4,73	450	17
	Escape Routes PS		1.200	30.000	3	90	4,73	450	17
	Central Escape Routes		1.200	30.000	3	90	4,73	450	17
Modules Division	Division Modules Plates	Integrity of division modules plates.	NA	NA	NA	NA	NA	450	NA
Primary Structures	Primary Structures that Supports Process Modules (note 12)	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
Fireproof bulkheads	Open Areas (Process Areas) Fire Walls	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
Structures that supports equipment handling HC	Equipment containing significant HC inventory and its supporting structures.	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
	Risers (Production, Gas Lift, Gas Exportation and Gas Injection)	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
	Primary Structures that Supports Riser Balcony	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
Pipe-racks	Central Pipe-rack	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
	Riser Pipe-rack	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
	Naval Pipe-rack	Primary structures elements collapse.	NA	NA	NA	NA	NA	450	NA
Safety Equipment	FWP SB	External bulkhead collapse.	NA	NA	NA	NA	NA	450	NA
	FWP PS	External bulkhead collapse.	NA	NA	NA	NA	NA	450	NA

	Water Main Ring	Primary structures elements and piping supports collapse.	NA	NA	NA	NA	NA	450	NA
	Foam Main Ring	Primary structures elements and piping supports collapse.	NA	NA	NA	NA	NA	450	NA
	ADV (automatic deluge valves)	Impossibility to reach the valves due to high levels of radiation.	NA	NA	NA	NA	4,73	NA	NA
	Emergency Generator	External bulkhead collapse.	NA	NA	NA	NA	NA	450	NA
	Local Equipment Room (LER)	- External bulkhead collapse. - Gas contamination.	100 (note 3)	30.000	3	90	NA	450	>19,5
Depressuring System	HP+LP Headers and HP + LP Knock-out vessels + Flare Tower (Note 11) High Velocity Vent Structures	Primary structures elements and piping supports collapse.	NA	NA	NA	NA	NA	450 (Note 10)	NA
Main Deck	Main Deck over cargo tanks	Top tanks plates.	NA	NA	NA	NA	NA	450	NA
Hull	-	-	NA	NA	NA	NA	NA	450	NA
Mooring	Mooring lines	-	NA	NA	NA	NA	NA	450	NA
Rescue Boat	Embarkation area of the Rescue Boat	-Collapse of Davit; -Impossibility to reach the boat due to high levels of radiation.	NA	NA	NA	NA	4,73	450	NA

Legend:
NA – Not Applicable

Notes:

1 – Threshold allowed to personal exposure of 2 (two) to 3 (three) minutes, already considering solar radiation. Reference: API Std 521.

2 – Reference: NIOSH. The amount of 30.000 ppm is related to STEL (*Short Term Exposure Limit*) and the value of 40.000 ppm is related to IDLH (*Immediately Dangerous for Life and Healthy*).

3 - Considering 50% of the threshold presented at NIOSH (200 ppm).

4 - Threshold allowed to an exposure time up to 30 (thirty) minutes. Reference: "*Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment*" HSE Publication, at

http://www.hse.gov.uk/foi/internalops/hid_circs/technical_osd/spc_tech_osd_30/spctecosd30.pdf

5 – Reference: OGP *Risk Assessment Data Directory - Report No. 434 – 14, March 2010 – Vulnerability of Humans.*

6 – For probabilistic analysis of structure impairment, consult NOTE in item 9.19.3 and the Reference: I-ET-3010.00-1300-140-P4X-003 - FIRE-STRUCTURE ANALYSES FOR PASSIVE FIRE PROTECTION DESIGN.

7 – Air intakes gas monitoring.

8 – According to definition of IDLH presented at NIOSH: *"The purpose for establishing an IDLH value in the Standards Completion Program was to determine the airborne concentration from which a worker could escape without injury or irreversible health effects from an IDLH exposure in the event of the failure of respiratory protection equipment. The IDLH was considered a maximum concentration above which only a highly reliable breathing apparatus providing maximum worker protection should be permitted. In determining IDLH values, NIOSH considered the ability of a worker to escape without loss of life or irreversible health effects along with certain transient effects, such as severe eye or respiratory irritation, disorientation, and incoordination, which could prevent escape."*

9 – Reference: NR 33.

10 - Temperature to be considered also in piping and its supports.

11 –It shall be accounted on the impairment frequency of this MSF all scenarios that can lead to 450°C or more on the HP header or LP Header or HP knock-out vessel or LP Knock-out vessel or the Flare Tower.

12 – The primary structures of the Process Modules shall comprise the ones in the Topside Modules and the ones in the main deck area that support them (E.g.: Stools or other structural elements according to the project).

ANNEX III – Pool Fire Diameter Calculation Rationale

For conservatism reasons the drainage capacity shall not be taken into consideration when determining the pool fire diameters.

Based on this premise, the following cases can happen and shall be followed

Case 1 – Equipment´s Bund Designed to Drain Equipment´s Deluge

In this major case, it shall be calculated the maximum mass burning rate in the equipment´s bund (Q_max_burning_EqpBund):

Q_max_burning_EqpBund = Equipment´s Bund Area x Mass Burning Rate - Equation 1

Q_max_burning_EqpBund – kg/s;

Equipment´s Bund Area – m²;

Mass Burning Rate – kg/(m².s).

Based on this, the following three (3) situations can develop:

Case 1A – Leak Rate < maximum mass burning rate inside equipment´s bund (Q_max_burning_EqpBund)

In this situation, the pool fire area shall be calculated considering free spread inside equipment´s bund but limited to the area of the bund. See Figure 6 for illustration of described situation.

$$\text{Pool Fire Area} = \frac{\text{Q\_burn\_pool}}{\text{Mass Burning Rate}} \quad \text{- Equation 2}$$

Q_burn_pool – kg/s; Note 1

Pool Fire Area – m²;

Mass Burning Rate – kg/(m².s).

Note 1 – In this case, Q_burn_pool is the leak rate value.

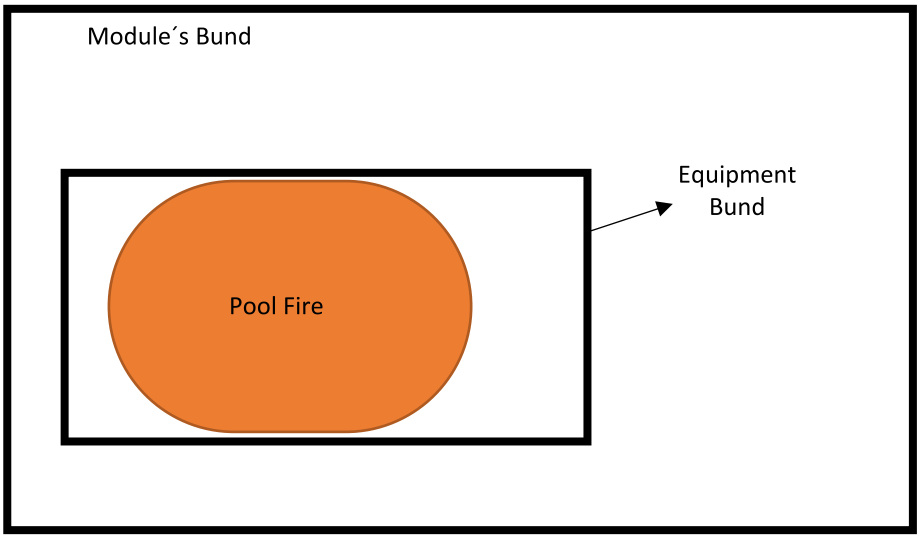

Figure 6 – Illustration of Case 1 A.

Case 1B - Leak Rate = maximum mass burning rate inside equipment´s bund (Q_max_burning_EqpBund)

In this situation, the pool fire area is equal to the equipment´s bund area. See Figure 7 for illustration of described situation.

Q_burn_pool = Q_max_burning_EqpBund - Equation 3

Q_burn_pool = kg/s;

Q_max_burning_EqpBund – kg/s.

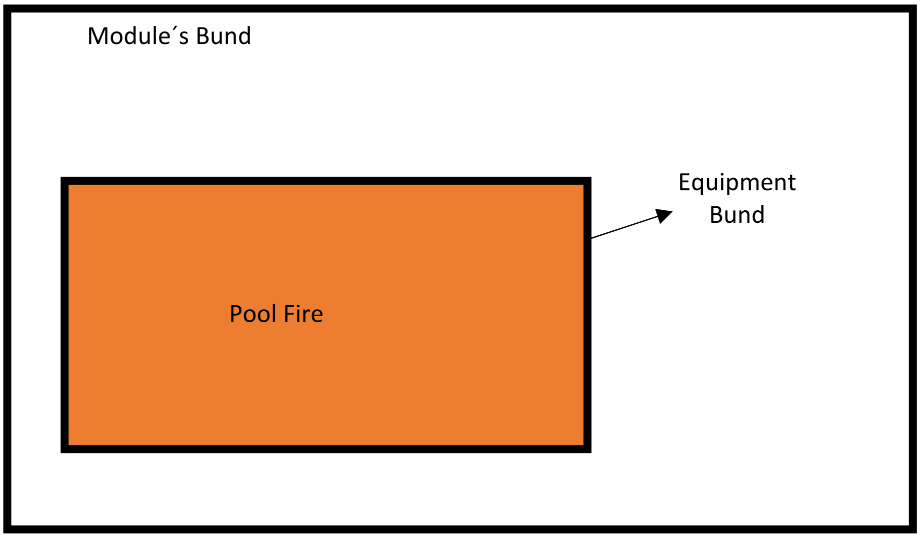

Figure 7 – Illustration of Case 1 B.

Case 1C - Leak Rate > maximum mass burning rate inside equipment´s bund (Q_max_burning_EqpBund)

In this situation, the pool fire area shall be calculated considering free spread inside deck´s floor bund but limited to it. See Figure 8 for illustration of described situation.

$$\text{Pool Fire Area} = \frac{\text{Q\_burn\_pool}}{\text{Mass Burning Rate}} \quad \text{- Equation 4}$$

Q_burn_pool – kg/s; Note 1

Pool Fire Area – m^2;

Mass Burning Rate – kg/(m^2.s).

Note 1 – In this case, Q_burn_pool is the leak rate value.

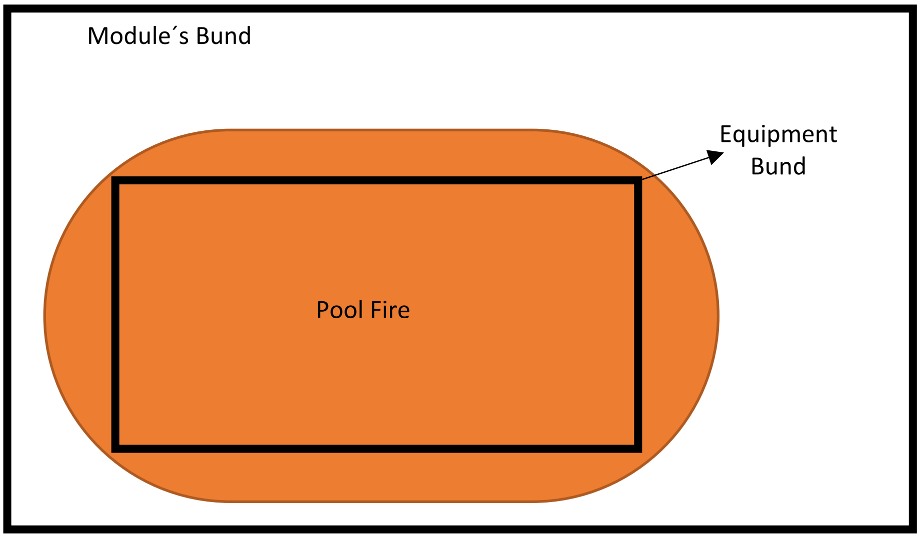

Figure 8 – Illustration of Case 1 C.

Case 1D - Leak Rate = > maximum mass burning rate inside deck´s floor bund

In this situation, the pool fire area shall be calculated considering the total area of deck's floor bund. See Figure 9 for illustration of described situation.

Note: In this case, if the leak rate is higher than others leak rates that are possible to happen based on the fire frequencies calculation, by conservative purposes it shall be considered that these higher leak rates produce the same consequences on the MSFs.

Q_burn_pool = Area Deck´s Floor x Mass Burning Rate - Equation 5

Q_burn_pool – kg/s;

Area Deck´s Floor – m²;

Mass Burning Rate – kg/(m².s).

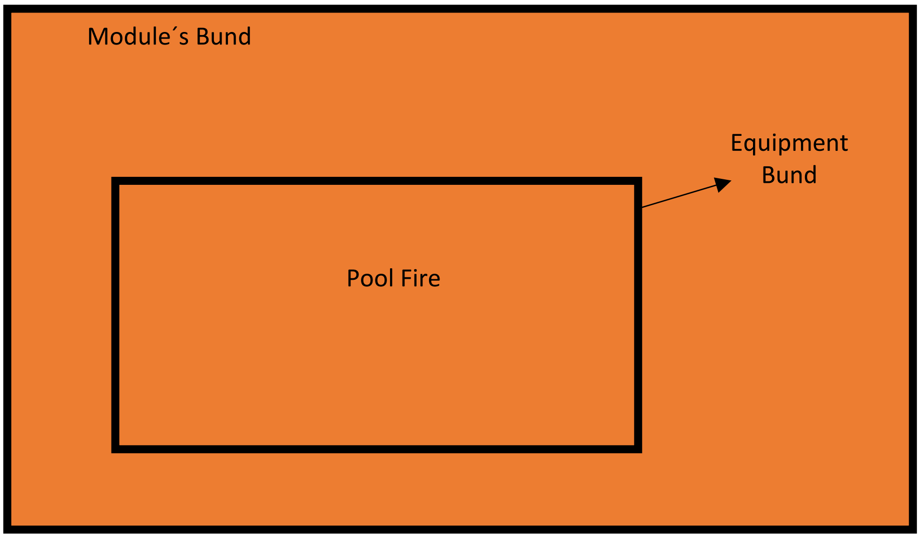

Figure 9 – Illustration of Case 1D.

Case 2 - Equipment´s Bund not Designed to Drain Equipment´s Deluge

In this situation, the deluge water of the equipment will overflow to deck´s floor of the module. The pool fire area shall be calculated using free spread of the pool <u>but limited to the area of deck´s floor bund</u>.

Initially, it shall be calculated the maximum mass burning rate in the Deck´s floor bund (Q_max_burning_DeckBund):

Q_max_burning_DeckBund = Area Deck´s Floor x Mass Burning Rate - Equation 6

Q_max_burning_ DeckBund – kg/s;

Area Deck´s Floor – m²;

Mass Burning Rate – kg/(m².s).

Based on this, the following two (2) situations can develop:

Case 2A - Leak Rate < maximum mass burning rate inside Deck's floor bund (Q_max_burning_DeckCont)

In this situation, the pool fire area shall be calculated considering free spread inside module´s bund but limited to it. See Figure 10 for illustration of described situation.

$$\text{Pool Fire Area} = \frac{\text{Q\_burn\_pool}}{\text{Mass Burning Rate}} \quad \text{- Equation 7}$$

Q_burn_pool – kg/s; Note 1

Pool Fire Area – m²;

Mass Burning Rate – kg/(m².s).

Note 1 – In this case, Q_burn_pool is the leak rate value.

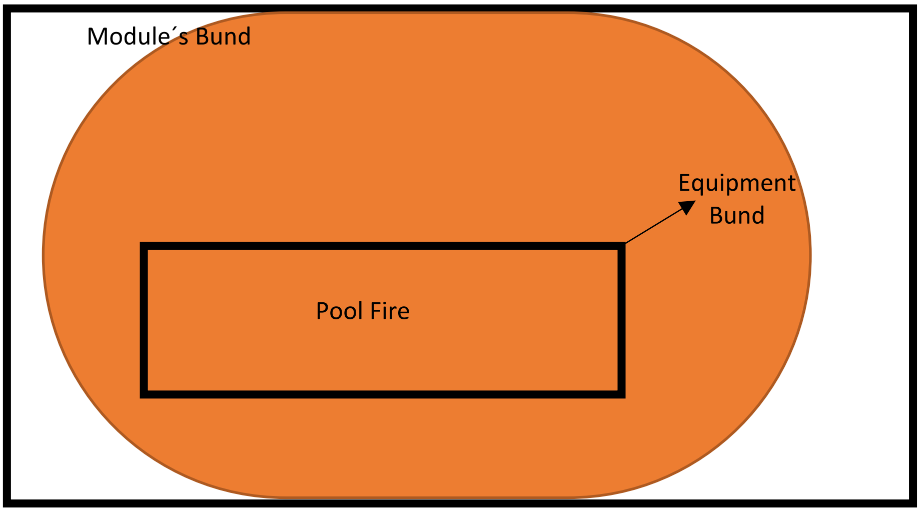

Figure 10 – Illustration of Case 2A.

Case 2B - Leak Rate >= maximum mass burning rate inside Deck's floor bund (Q_max_burning_DeckBund)

In this situation, the pool fire area is equal to total area of the deck's floor bund. See Figure 11 for illustration of described situation.

Note: In this case, if the leak rate is higher than others leak rates that are possible to happen based on the fire frequencies calculation, by conservative purposes it shall be considered that these higher leak rates produce the same consequences on the MSFs.

Q_burn_pool = Pool Fire Area Deck´s Floor x Mass Burning Rate - Equation 8

Q_burn_pool – kg/s;

Pool Fire Area Deck´s Floor – m²;

Mass Burning Rate – kg/(m².s).

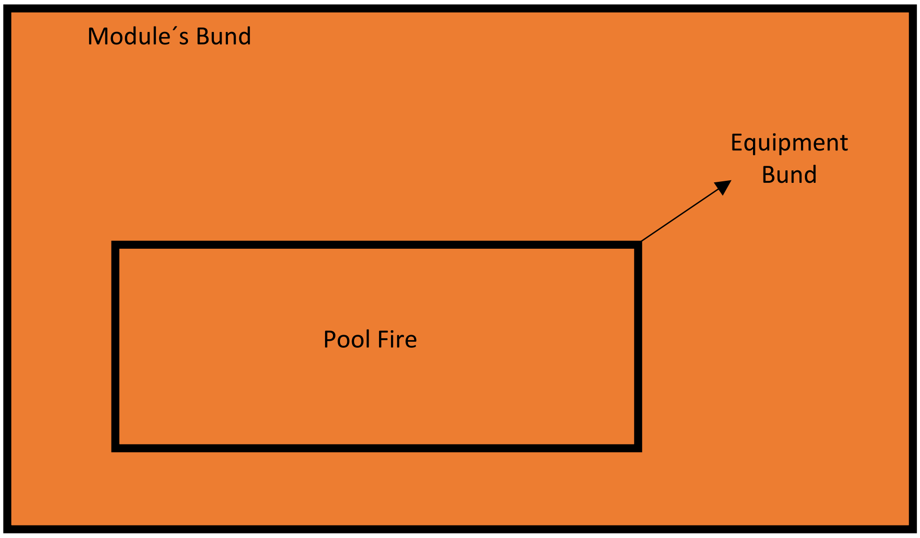

Figure 11 – Illustration of Case 2B.

ANNEX IV – Congestion Levels

System/Area	Maximum Density (m/m³) Note 1, Note 2, Note 3, Note 4, Note 5	Average Density (m/m³) Note 1, Note 2, Note 3, Note 4, Note 5
Central Pipe Rack	4,94	3,23
Chemical Unit		
1° Elevation	4,62	3,60
2° Elevation	6,08	5,20
Chemical Unit & Product Storage		
1° Elevation	4,98	2,49
2° Elevation	5,01	5,01
3° Elevation	2,43	2,43
CO2 Removal & HDCP		
1° Elevation	3,72	3,27
2° Elevation	2,68	2,06
3° Elevation	2,42	1,74
CO2 Compression		
1° Elevation	2,80	2,57
2° Elevation	3,72	2,72
3° Elevation	3,79	3,13
Compressor (Note 4)	6,28	3,03
CO2 Removal		
1° Elevation	4,02	3,01
2° Elevation	4,75	4,75
3° Elevation	4,97	4,97
4° Elevation	2,48	2,48
Exportation Gas Compression		
1° Elevation	3,85	3,29
2° Elevation	4,63	2,94
3° Elevation	3,90	3,27
Flare System		
1° Elevation	2,19	1,76
2° Elevation	3,39	2,47
Gas Dehydration (TEG)		
1° Elevation	2,49	2,49
2° Elevation	2,24	2,24
3° Elevation	2,13	2,13
Gas Dehydration (Zeolites)		
1° Elevation	3,19	2,92
2° Elevation	2,42	2,30
3° Elevation	2,26	2,19
4° Elevation	2,38	2,38
Gas Dehydration & Fuel Gas		
1° Elevation	2,77	2,73
2° Elevation	2,86	2,81
Gas Dehydration, Fuel Gas & HDCP		
1° Elevation	3,38	2,90

2° Elevation	3,14	2,84
Gas Injection		
1° Elevation	3,92	3,01
2° Elevation	2,47	1,80
H2S Removal System (Removal Fixed Bed)		
1° Elevation	2,32	1,72
2° Elevation	2,31	1,96
1° Elevation	3,41	2,39
2° Elevation	2,24	2,24
Hull Utilities & Hull Generation		
1° Elevation	2,84	1,42
2° Elevation	2,09	2,09
Laydown Area & Offloading Metering Skid	3,00	2,28
Main Deck		
STOOLS Designed	1,22	0,91
Steel Beams Designed	3,36	1,68
Main Gas Compression & VRU System		
1° Elevation	3,61	3,52
2° Elevation	4,36	4,28
Main Gas Compression		
1° Elevation	4,10	3,10
2° Elevation	3,11	2,28
3° Elevation	1,79	1,51
Oil Processing		
1° Elevation	2,15	2,04
2° Elevation	3,10	3,10
Oil Processing & Produced Water Treatment		
1° Elevation	3,83	2,08
2° Elevation	2,35	2,01
3° Elevation	1,46	1,15
Pig Launcher & Receiver (Modular Design)		
1° Elevation	3,11	2,76
2° Elevation	2,55	2,33
3° Elevation	3,47	2,71
4° Elevation	3,10	3,01
Pig Lauch & Receiver (Spaghettified Design)		
Main Deck Elevation	2,90	2,90
1° Elevation	1,21	1,16
2° Elevation	2,11	2,07
3° Elevation	1,80	1,75
4° Elevation	2,03	2,03
Power Generation		
1° Elevation	2,28	1,64
2° Elevation	4,24	3,00
3° Elevation	2,82	2,35

4° Elevation	1,52	1,52
Turbogenerator (Note 4)	1,60	1,59
Upper Riser Balcony	3,91	2,16
Utilities		
1° Elevation	3,01	2,20
2° Elevation	4,11	3,28
3° Elevation	1,93	1,59
4° Elevation	2,46	1,87
VRU System		
1° Elevation	2,25	2,14
2° Elevation	1,87	1,66
Water Injection & Sulphate Removal		
1° Elevation	2,65	1,94
2° Elevation	5,39	3,76
3° Elevation	6,07	5,07
4° Elevation	7,35	5,84
5° Elevation	5,48	5,07

Note 1: If an elevation is not found in table above, it shall be considered the congestion level of the most congested one if the elevation under analysis is not the last elevation of the module/area under analysis.
Note 2: If a system/area cannot be found in the table, congestions factors shall be applied based on system similarity. In case of coincidence in more than one system, the most congested elevations shall be considered.
Note 3: In case a system appears more than once in the table, it shall be considered the highest value. E.g.: CO_2 removal appears twice. If the design just have a module with this process, then 1° elevation shall consider the value of 4,09 m/m³.
Note 4: Values represent recommended congestion levels for one machine package.
Note 5: Modules last elevations do not need to be artificially congested.