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Summary

ABBREVIATIONS AND DEFINITIONS

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

Abbreviations

CFD – Computational Fluid Dynamics

DAL – Dimensioning Accidental Load

FPU – Floating Production Unit

HCRD – HSE Hydrocarbon Release Database

HP – High Pressure

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

LP – Low Pressure

MSF – Main Safety Function

PFD – Process Flow Diagram

P&ID – Piping and Instrumentation Diagram

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 can lead to a staggering or spread of fire, 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 particular direction. E.g.: floors and bulkheads in metal plate.

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 particular direction. E.g.: Pipes beam, groupings of small objects.

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 the conditions of operation and the accidental loads.

Escalation – Accidental scenarios of fire, explosion and release of toxic and/or flammable gases generated by another accidental scenario initiated and uncontrolled, resulting in an increase in the consequences in relation to the initial accidental event.

Exceedance Curve – a curve that represents the cumulative frequency at which an excess pressure value is matched or exceeded for a given monitoring point. The monitoring points shall be chosen according to the places of interest of the analysis, close to the MSF. The various explosion scenarios of a Unit are simulated with CFD and the effects recorded at the various monitoring points. The Exceedance Curve is obtained by attaching to each overpressure value the sum of all frequencies of all scenarios that equal or exceed such overpressure for each monitoring point.

Gas Cloud Explosion – Delayed ignition of a dispersed hydrocarbon volume with high combustion rate.

Involved Parties – Are the designer, the study executor and Petrobras involved in the preparation or follow-up of the explosion study.

Main Safety Function (MSF) – Function that a safety item shall fulfill to enable and/or guarantee the effectiveness of the emergency response, escape and abandonment strategy 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 the Safety Engineering Guidelines and shall remain available for the period of 1 (one) hour after the start of the incident.

Monitoring Panel – Monitoring plans created in the CFD software, where the total load is calculated.

Monitoring Point – Place of interest, where pressure variation is recorded over time.

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.

Scenario – It is an event considered at the point of interest having the combination of hazard, causes, effects and associated risk classification, considering Frequency and Severity.

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

Segment – Parts of a system that comprises piping and equipment between two SDVs or other blocks considered in the analysis.

Study Consulting – Is responsible for the execution of the explosion study, and may be a contracted company, either by the Designer or Petrobras, the Designer himself or an internal Petrobras workforce.

Triangular Impulse – typical representation of an explosion charge for design, where the overpressure variation over time is demonstrated by a triangular profile graph.

1. INTRODUCTION

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

From this study it is estimated the Dimensioning Accidental Load (DAL) in terms of overpressure and dynamic pressure loads to evaluate the designing and/or protection of the MSF, as well as to evaluate the annual frequency of impairment. In some cases, where existing structures in the project cannot be dimensioned to withstand estimated loads, other preventive or protective measures (barriers) shall be proposed and dimensioned to ensure structural integrity and to avoid impairment of MSF.

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

In the execution of the study, the requirements for analysis and management of operational risks of the National Agency of Petroleum, Natural Gas and Biofuels - ANP, Secretary of Labor of Ministry of Economy, Petrobras standard N-2782 - Applicable Techniques to Industrial Risk Analysis and Safety Engineering Guidelines.

This TS is intended to guide the execution of the explosion study and the elaboration of its respective report, complementing the requirements of the explosion study in the Petrobras' Safety Engineering Guidelines in force on the date of contract signature.

2. OBJECTIVES

This specification has the following objectives:

- Define the scope and criteria for carrying out the Explosion Study for the basic design phases, detailing project and assisted operation of the FPU or fixed units, hereinafter referred as to 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 monitoring 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 the explosion scenarios, their occurrence frequencies and the possible consequences for the Unit and using 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:

- Exceedance curves - calculate the exceedance curves (overpressure x cumulative occurrence frequency per year) for each module of the Unit with a focus on identifying the impacts on the existing MSF in each area (use of panels and monitoring points).

- Triangular pulse - calculate the duration of the triangular pulse associated with each accidental load for all MSF.

- Dimensional Accidental Loads (DAL) for the MSF, considering the overpressure value corresponding to the cumulative occurrence frequency of 2.50E-4 occ/year. Specify the accidental load factors (DAL) for the structural design of each of the MSF. Additional overpressures for topside main structure design corresponding to the occurrence frequencies of 1.00E-2 occ/year as well as 2.50E-3 occ/year shall also be presented.

- The impairment frequency of the MSFs.

- The study recommendations and the evidence of its implementation in the project. In the case of structural design, it is necessary to present the sizing criteria and the structural calculations that show the fulfillment of the performance standards contained in this technical specification.

4. REFERENCE DOCUMENTATION

As inputs for the 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 Risk Studies already performed for the Unit (mainly PHA).

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

- Indication of the type of floor that separates the decks (plate or grid floor);

- Memorandum describing the modes of operation of the Unit;

5. RELEVANT STUDY ASPECTS

The Explosion Study shall take into account at least the following aspects that influence the magnitude of the overpressure levels:

- Fluids composition, considering the presence and concentration of flammable or combustible components;

- Leak or discharge conditions into the environment;

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

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

- The quantity of equipment, components (E.g.: flanges, valves, instruments...) and other components and piping section that may leak;

- The environmental conditions to be used in the simulations;

- The size of flammable clouds resulting from hydrocarbons or other flammable fluids leaks into the environment;

- The ignition locations of the clouds, considering the type, quantity and distribution of possible sources of ignition.

6. SOFTWARE REQUIREMENTS

The explosion study shall be simulated with the use of CFD tools and shall comply with the requirements of Safety Engineering Guideline.

The analysis shall be developed using CFD software that automatically generates porous media from geometry files to represent congestion.

The approved software are: KFX (Kameleon) and FLACS. Other software shall be previously authorized by Petrobras before being used in the simulations.

7. WEATHER CONDITIONS

The meteorological conditions to be used in the study shall be those of the final location of the Unit. The use of the Meteoceanographic 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.

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

8. STUDY METHODOLOGY

The methodology to be adopted in the explosion study shall meet the requirements of the Safety Engineering Guidelines, complemented by the requirements contained in this TS.

In the study development methodology, the Response Curve modeling can be used to obtain algebraic models with parameters estimated from CFD results. These curves allow obtaining the results of explosion for thousands of cases, which would be impracticable with CFD, allowing an extensive statistical scan of scenarios. (E.g.: molecular modeling, Monte Carlo, etc.). If these models are adopted, they shall be described in detail and presented in the study report.

Any deviation from the methodology shall be presented for analysis and prior validation by Petrobras.

The following steps shall be taken in the development of the study:

8.1. Scenery Selection

The selection of the scenarios 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:

8.1.1. Originated from PHA

The explosion study shall simulate and evaluate at least all accidental scenarios identified in the Preliminary Hazard Analysis (PHA) that involved overpressure effects, whose initially risk categories for the "People" or "Asset" dimensions is classified as Moderate in severity categories IV or V, and Not Tolerable (all categories of severity and all dimensions), according to the Risk Tolerability Matrix presented in Safety Engineering Guidelines.

The study shall indicate all the simulated scenarios and corresponding PHA scenario. 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.

The Study Consulting shall include in the report a table with the correlations between the selected PHA scenarios and the various segments and sections of the analyzed systems.

8.1.2. Additional Scenarios

Accidental scenarios that have not previously been assessed in the PHA, or even if they have been and may have been classified as moderate with category lower than IV, but which are considered relevant by the parties involved during the study, shall also be considered in the explosion study. For example, in very confined or congested areas of the Unit where even small leaks can form significant explosive clouds, with serious effects to the Unit. These scenarios shall be clearly recorded and justified in the study report.

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

I. Volatile gas originated from non-stabilized oil pools on the main deck due to leaks on connections on the oil loading header;

II. Volatile gas originated from non-stabilized oil pools on the oil processing module(s) due to leaks on equipment and/or connections downstream of the last oil dehydrator;

III. Gas leaks on the tank’s ellipses associated to the HC Gas Blanketing System;

IV. Gas leaks on the connections of the closed venting header on the main deck;

V. Gas leaks on the connections of the inert gas purge header;

VI. Gas leaks on the connections of the hydrocarbon/inert gas distribution header.

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 HC Gas Blanketing System.

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 present on this report shall be performed by the study executioner and shall be approved by Petrobras prior to the start of the simulations.

8.2. Event Tree

The explosion 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.

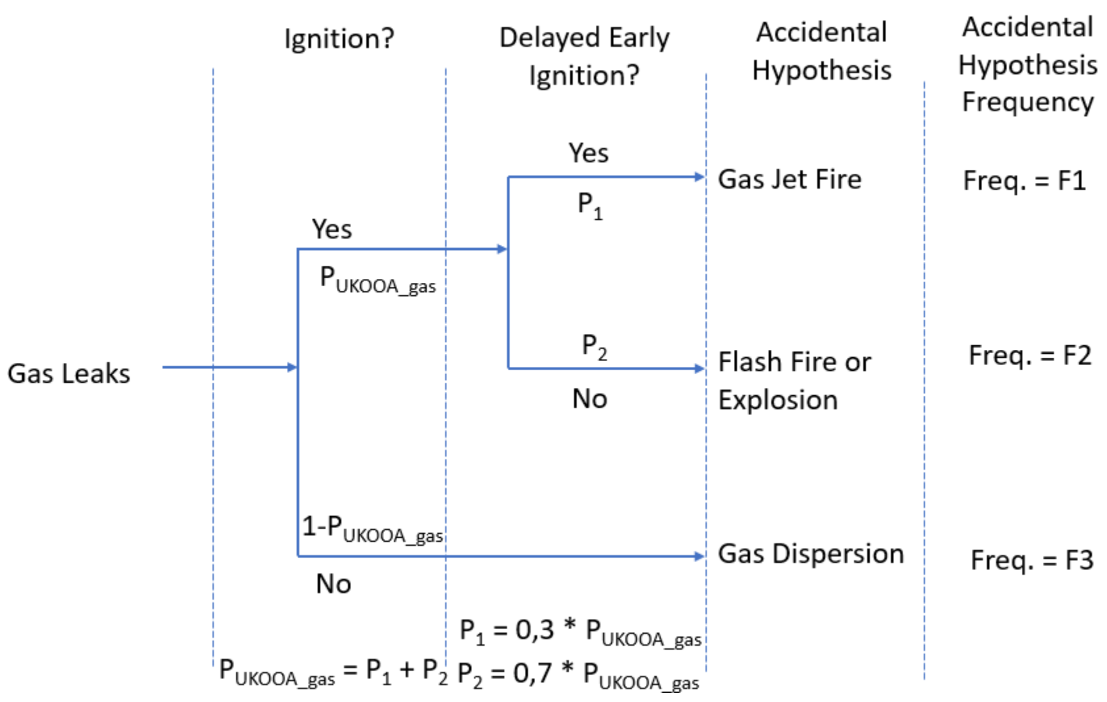


Figure 1: Event Tree for Flammable Gas Leaks

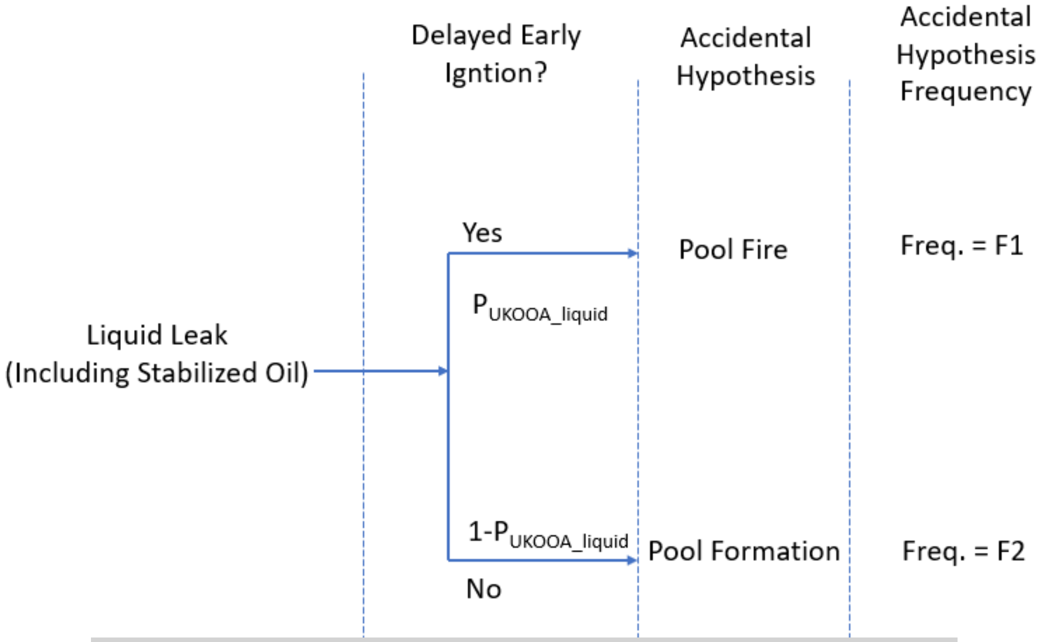
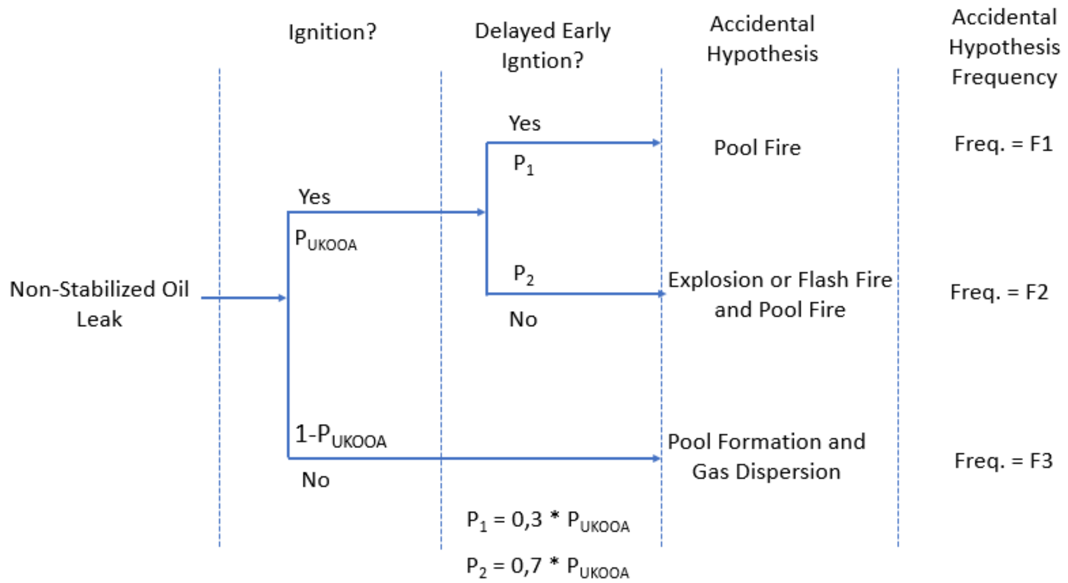


Figure 2: Event Tree for Liquid Leaks (including stabilized oil)



$P_{UKOOA} = 1 - (1-P_{UKOOA\_liquid})*(1-P_{UKOOA\_gas})$

Figure 3: Non-Stabilized Oil Leak

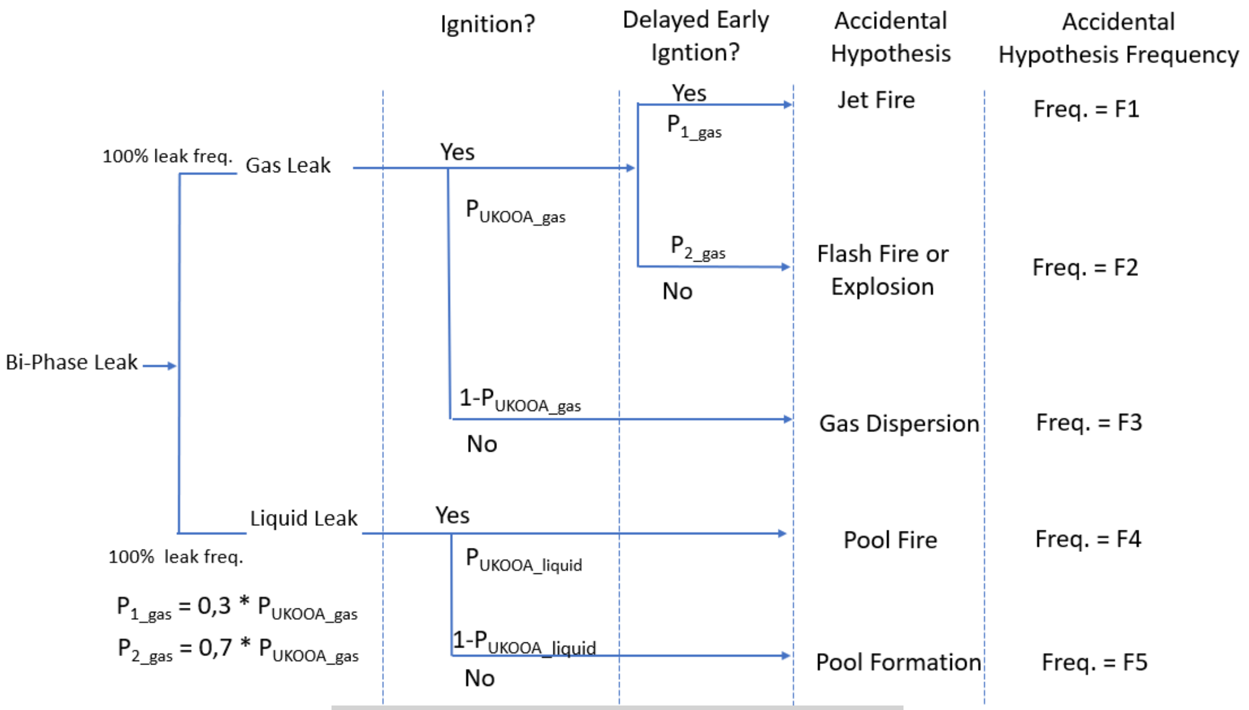


Figure 4: Event Tree for Bi-Phase Leaks

For the definitions of P_{UKOOA_gas} and P_{UKOOA_liquid} see item 8.7.

The Study Consult 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 explosion 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.

8.3. 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 their respective physicochemical properties of the fluids (flammable gases/vapors) presented in the report, and shall at least be indicated: stream composition, pressure, temperature, density, stream code, reference document (E.g.: PFDs, PI&Ds, data sheets, mass and energy balance, line isometric), mode of operation 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.

For this study the operational case to be used shall be 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 will be the responsibility thereof. In case of changes in the project formally requested by Petrobras, as change in the composition of fluids produced or increase / reduction of capacity of the plant that impact the study, will be the responsibility of Petrobras.

8.4. Segmentation

The representative segments of the PHA scenarios and the additional scenarios referred to in item 8.1.2 of this TS shall be simulated and evaluated 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 leak elements, the calculation of leak frequencies.

For the segmentation process, the following requirements shall be considered:

- PV, XV, TV, LV, manual block valves, shall not be considered as isolated parts. Exceptionally for segmentation 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.

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

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

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 leak by category (small, medium and large) for each component.
4. Associated SDVs tags of the segment.

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

8.5. Parts Count

It is mandatory that counting parts considered as leak sources (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 leak 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 Units 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 and new recommendations provided, if applicable.

8.6. Calculation of the Leak Frequency

The leak frequency for each component (E.g.: equipment, flange, piping, valve, instrument, etc.) 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 data banks used shall have information that allows to relate leak 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 leak 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 leak frequency is also added in straight sections of piping, according to the database, by the length of the respective sections.

It shall be noted that insulated 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.

8.7. 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 the reference 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 Safety Engineering Guideline, refers to the ignition probability defined in references above as “delayed”/ “late”.

For gas leak scenarios, the delayed ignition probability shall consider a split of 30% of UKOOA models values for immediate (“delayed”/ “early”) and 70% for delayed (“delayed”/ “late”).

For liquid leak scenarios, it shall be considered 100% of UKOOA liquid models values for delayed (“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 **Erro! Fonte de referência não encontrada.**.

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

8.8. Explosion Frequency Calculation

The explosion frequency calculation shall consider the product of the leak frequencies 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 leak ranges (small, medium and large).

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

The frequencies shall be module based the explosion frequencies shall be accumulated at each module considering only the leaks occurring at this module. However, these explosions produce overpressures at the module where the leak occurs as well as at neighbor's modules. Therefore, for each of those explosions, overpressures shall be monitored at the module and at the neighbors. These accumulated frequencies shall be associated to overpressures at the module its own and to different overpressures at the neighbor's modules (same leaks and frequencies producing overpressure at the others). Typical result is presented at Figure 2.

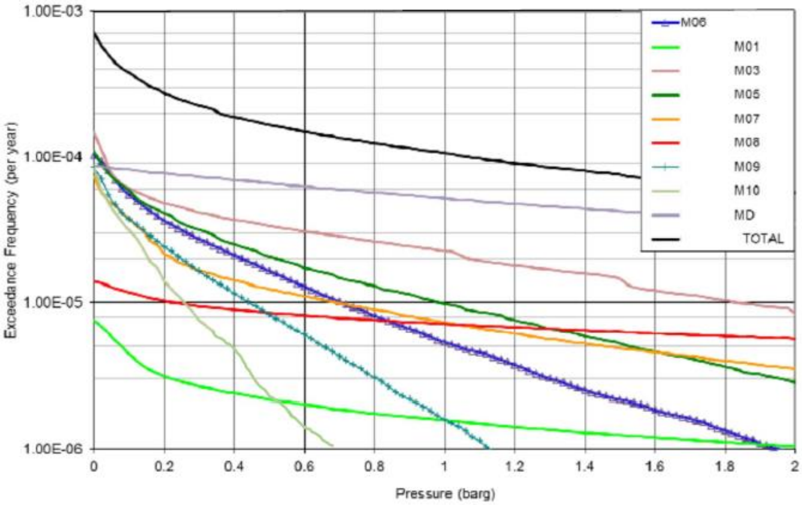


Figure 2: Example of exceedence curve of a module.

For the segments between emerged part of production risers and BSDVs and between production BSDVs and their choke valves, the explosions 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.

8.9. Leak Rates

The Study Consulting shall consider the three leak rate ranges (small, medium and large) set out in the Safety Engineering Guideline. In each of the bands different leak 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.

8.10. Leak Directions

The leak directions shall meet the constant in the Safety Engineering Guideline, 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.

The validation of the simplifications shall be based on a previous ventilation study, considering the use of the same geometric model to be used in the explosion analysis.

8.11. Requirements for Geometry and Level of Congestion

8.11.1. 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.

8.11.2. Level of Congestion

This item is applicable to Basic Design, FEED, and Detailing design.

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 II 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 with artificial 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. 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.

8.12. Selection of Leak Points to be Simulated

For the selection of the leak points, a meeting with the participation of the Design Engineer 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 leak points.

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

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

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

The simulations performed for a module / area cannot 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 adopted shall be discussed with the designer and validated with the participation of Petrobras. These shall be included in the report with their respective justifications.

8.13. Selection of Ignition points

Two (2) ignition points shall be considered on the gas clouds: one (1) in the middle and another at the cloud’s boundary.

8.14. Explosion Analysis

Explosion analysis shall consider the requirements of the Safety Engineering Guideline. From the results of the simulations a statistical and probabilistic treatment of the output data shall be performed for all simulated scenarios. The panels and monitoring points positioned in each MSF/primary structures shall accumulate the overpressure effects of the various simulated scenarios in the various areas of the Unit, which together shall compose the data for the construction of the exceedance curves of each MSF/module.

It is important to note that the explosion effects from the regions of riser balcony, riser pipe rack, and main deck shall also be considered in the composition of the exceedance curves.

In addition to the exceedance curves, figures with the overpressure levels shall be provided for scenarios that may prevent or impact the MSF. These figures shall allow the identification of the ignition site and the overpressure levels generated from it. Overpressure levels shall be indicated in a color scale.

8.15. Calculation of the Impairment Frequency / DAL

Unit MSF shall have their respective sizing loads (DALs) determined from the exceedance curves.

The exceedance curves shall be presented in a specific item of the report, identifying the Module / area and MSF to which they refer. For each MSF there shall only be one corresponding exceedance curve.

Each curve shall be presented with all the other contributory curves that make it up, as shown in Figure 2.

In a first step, for each MSF, a table shall be presented containing the DAL read in the Exceedance Curve corresponding to the tolerability criterion established in the Safety Engineering Guideline of 2.50E-4 occ/year and 1.00E-4 occ/year for the specific calculations of the primary structures of the MSF and the corresponding triangular impulse (duration of the impulse). The table shall indicate the levels of overpressure (overpressure loads) and drag forces (dynamic pressure loads). The results presented in this stage shall be validated by the Designer and by Petrobras.

In a second step, it is necessary to estimate what is the maximum overpressure that the MSF resists and the frequency of impairment associated with the exceedance curve, in addition to proving that the aforementioned impediment criteria are being met. These frequency values shall be inserted in addition to the table in the first stage, thus demonstrating the ALARP condition, that is, that the MSF are dimensioned for explosion loads with some clearance, considering the uncertainties existing in the calculations.

9. STRUCTURAL ANALYSIS

The structural analysis shall be performed by the designer considering the values of explosion loads (DAL) obtained in this study. The structural analysis shall demonstrate and show that, for each MSF, the loads normally considered in the design of the structures were considered accidental explosion loads (DALs).

- The standards to be considered in structural analysis as a result of explosion loads (DAL) shall be in accordance with ISO 13702 - Petroleum and natural gas industries - Control and mitigation of fires and explosions on offshore production installations - Requirements and guidelines.

- Structures of accommodation, modules, pipe racks and compartments / areas housing MSF shall comply with the structural criteria from I-ET-3010.00-1300-140-P4X-001 - Guidelines for Structural Design Against Blast Loads.

- Closing panels, floors, ceilings and decks of the environments / rooms that contain MSF may suffer permanent deformation, but they cannot fail / break or lose function.

- Supports of equipment and lines containing hydrocarbons shall not suffer permanent deformation or deformation under an elastic regime that may lead to the failure of such lines and equipment, in order to avoid staggering.

- Embarkation Stations, lifeboats and other lifeboats shall remain intact and functional after the effects of explosion. These areas shall be protected by bulkheads to prevent damage to vessels and people.

- The lines of the water and foam rings and the panels of the automatic deluge valves (ADVs) shall remain intact and functional.

- The escape function of all areas shall be guaranteed. In this way, the explosive dimension scenarios shall not cause simultaneous impairment of the existing routes.

- The deck over the cargo tanks on the main deck and risers shall remain intact.

- The unit's shutdown system (SDVs) and depressurizing system (HP+LP Headers and HP + LP Knock-out vessels + Flare Tower) shall remain intact (piping, brackets, valves, vessels supports and flare tower).

When blast walls are used in the design, they shall be properly calculated and certified for this purpose, so that they can be considered as protection barriers, having their characteristics duly described in the report, and locations indicated in the Unit Safety Plan.

The structural analysis shall consider the methodology and criteria according to I-ET-3010.00-1300-140-P4X-001 - Guidelines for Structural Design Against Blast Loads.

The structural analysis and implementation of other safeguards in the project shall be validated by Petrobras.

10. REQUIREMENTS FOR MONITORING MEETINGS

The study monitoring meetings shall follow the guidelines below:

10.1. General Considerations

The monitoring 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 monitoring meetings shall be held in the premises of the Study Consulting, except for the planning and analysis meeting of the project documentation, which shall be carried out at the Designer's premises. The meeting local may be changed by common agreement between the parties involved. Petrobras, at its discretion, may attend meetings by videoconference.

In the basic design phase, the necessary meetings are planning (10.2), documentation analysis (10.3), assumptions and methodology (10.4) and follow up and validation meetings (10.5).

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 shall be:

- Clarifications on objectives, scope of analysis and requirements of the study (Designer and Petrobras);

- Delivery of the project documentation as foreseen in item 4 of this TS (Designer), including the 3D model of the Unit;

- 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 focal points of the parties involved, the Study Executives involved, 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 as a result 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: Participant's study 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 Unit.

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 counter) 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 accompany the study by the Designer with the participation of Petrobras where the items provided for 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 contemplate the study steps foreseen in item 8 (Methodology) of this TS. Follow-up and validation meetings shall be provided in Table 1 below:

Table 1: Follow up and validation meetings.

Item	Meeting Agenda - Subjects	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 data:** Confirmation of process data, modes of operation.	9.3 9.4
R3	**Segment Validation and Inventory Calculation.**	9.5
R4	**Validation of count, leak frequency, ignition probability and explosion frequency:** Presentation of parts count, leak frequencies, ignition probabilities, explosion frequencies, validation of event tree calculations and exclusion of scenarios below the cutoff frequency.	9.6 9.7 9.8 9.9
R5	**Geometry Validation:** Presentation of the CFD model - evaluation of geometry, confinement, congestions before and after artificial congestion implementation and obstructions to be added in the model.	9.10
R6	**Validation of leak conditions and ignition points:** Definition of leak conditions, selection of leak points and ignition points to be simulated.	9.11 9.12 9.13 9.14

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: 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.

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 Item 8.6 of the Safety Engineering Guidelines and as specified in this document.

All assumptions of 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.

In the basic design phase, the report can be simplified by the designer based on the scope established for this phase of the project (item 4), and its content shall be defined and adjusted at the planning meeting together with Petrobras.

11.1. Partial Reports

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 late ignition probabilities considered and the calculation of the explosion 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 8.3 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 shall be defined by the Designer, in agreement with the Study Consulting, 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. QUALIFICATION TO CARRY OUT THE STUDY

Due to the complexity involved in the methodology and the use of the CFD software applicable to the explosion study, and also due to the importance of this study for the safety of the Unit, the elaboration was done by a qualified company.

14. APPLICATION OF CHECKLIST

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.

In the basic design phase there is no need to apply the complete checklist, considering only the items related to the scope of this design 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 ELEMENT COUNTING

<table>
<tr><th>TYPE OF ELEMENT</th><th>DIAMETER</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 engineering flowcharts (P&ID) - also considering FE, spectacle blind, FO and spool - and multiply the total of each system by the following factors :</td></tr>
<tr><td>D≤3"</td><td rowspan="3">Qtc GÁS</td><td rowspan="3">x 2,00</td><td>x 0,45</td><td rowspan="3">Qtc OIL</td><td rowspan="3">x 4,00</td><td>x 0,35</td><td rowspan="3">Qtc 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:
Qtc GAS = total quantity accounted for in system P&IDs GAS (for all diameter ranges)
Qtc OIL = total quantity accounted for in system P&IDs OIL (for all diameter ranges)
Qtc WELLS = total quantity accounted for in system P&IDs WELLS (for all diameter ranges)</td></tr>
<tr><td rowspan="4">BLOCKING VALVE</td><td colspan="10">Assign the locking valves to the engineering flow charts (P&ID) and multiply the quantitative by the adjustment 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 by the engineering flow charts (P&ID) and to directly use 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 by the engineering flow charts (P&ID) and to directly use 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">Calculate the check valves using engineering flow charts (P&ID) and use the quantitative data directly.</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 shutdown valves by the engineering flow charts (P & ID) and to directly use 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 using engineering flow charts (P & ID) and using the quantitative data directly.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
<tr><td rowspan="3">RELIEF VALVE (PSV)</td><td>D≤3"</td><td colspan="9" rowspan="3">Assign the relief valves to the engineering flow charts (P&ID) and use the quantitative data directly.</td></tr>
<tr><td>3"<D<12"</td></tr>
<tr><td>D≥12"</td></tr>
</table>

ANNEX II – 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
CO_2 Removal & HDCP		
1° Elevation	3,72	3,27
2° Elevation	2,68	2,06
3° Elevation	2,42	1,74
CO_2 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
CO_2 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
H_2S 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.