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| PETROBRAS | **TECHNICAL SPECIFICATION** | No.: I-ET-3000.00-5400-98G-P4X-002 | |
| | CLIENT: | | SHEET: 1 of 33 |
| | JOB: - | | - |
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| SRGE | TITLE: **GAS DISPERSION STUDY** | | INTERNAL |
| | | | ESUP |

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# Summary

## 1. ABBREVIATIONS AND DEFINITIONS

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

### Abbreviations

CFD – Computational Fluid Dynamics

FPU – Floating Production Unit

HAZOP – Hazard and Operability Study

HCRD – HSE Hydrocarbon Release Database

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

P&ID - Piping and Instrumentation Diagram

PFD - Process Flow Diagram

PHA - Preliminary Hazards Analysis

SDV – Shutdown Valve

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

TS – Technical Specification

### Definitions

Cloud - Three-dimensional representation, in views or cuts, of gas leaks or discharges simulation with color scale indication of the gas dilution profile in the atmosphere in a given gas concentration interest contour;

Contour of interest – Cloud physical limits at a given concentration value for the gas dispersed;

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;

Detection Coverage - Percentage of clouds detected in relation to the universe of simulated clouds.

Discharge - Expected release of gas from a closed system, directly into the atmosphere.

Gas Detection System - Fixed system for the detection and monitoring of toxic, asphyxiating and/or flammable gases of the Unit, consisting of gas detectors, control

systems, alarms and actuators that initiate or carry out safety actions in cases of leaks;

Leakage - Unplanned release of gas from a closed system into the atmosphere;

Leakage Scenario - Result of a leak, considering leak direction and rate, wind direction and speed, the cloud size and considering the gas Lower Flammable Limit (LFL) value, or gas concentration.

Involved Parties - Are the Designer, the Study Consulting and Petrobras involved in the preparation or follow-up of gas dispersion study.

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

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

Stationary cloud - Cloud that in a certain time after the beginning of the leak / discharge presents stabilization of its composition / concentration, maintaining a constant spatial profile.

Stagnation region – Region in which the ventilation analysis in open areas of the Unit presents recirculation regions or low airflow velocity (<0.5m/s), limiting air renewal and allowing the accumulation of gas;

Study Consulting - Is responsible for the execution of the gas 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.

Voting - Logical design configuration of the gas detection system. Voting of gas detectors in a fire zone / monitored area resulting from gas detection at a predefined concentration level shall initiate safety actions such as alarm activation, dampers closure, emergency shutdown, etc.

## 2. INTRODUCTION

The Gas Dispersion Study is a study used to evaluate the dispersion of flammable, toxic and asphyxiating gases arising from gas leakage scenarios and operational gas discharges in order to define the location and quantification of gas detectors installed in open areas.

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), Secretary of Labor of Ministry of Economy, Petrobras standard N-2782 - Applicable Techniques to Industrial Risk Analysis and Petrobras' Safety Engineering Guidelines shall be followed.

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

## 3. OBJECTIVES

This specification has the following objectives:

- Define the scope, methodology and criteria for carrying out the Gas 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.

## 4. SCOPE OF THE STUDY

The study should evaluate the gas dispersion from the gas leak scenarios and operational gas discharges (Vents, Vent Post and exhaust discharges from machines) to provide consistent information for:

- The design of the gas detection systems, including the selection, positioning and quantification of detectors in order to enable alarms and safety actions of the Unit, in case of leaks;

- The project for adequate positioning (coordinates - x, y, z) of equipment vents (vessels, tanks, etc.), Vent Post and machine exhaust discharge (internal combustion engines and turbines) in order to avoid compartments contamination (air intakes), operational areas and other places of passage or permanence of people on the Unit, as well as, avoid undesired interferences in the gas detection system, in case of operational gas discharges;

- Evaluate the impairment frequency of escape routes, because of the gas leakage scenarios.

These evaluations shall be carried out with Computational Fluid Dynamics (CFD) tools for simulations.

From the simulations analysis, the following results shall be presented:

### A. Selection and positioning of detectors in open areas

Selection, positioning and quantification of detectors in order to optimize the gas detection system and guarantee the detection coverage specified in this TS.

### B. Positioning of Cargo Tank Vent Post and Process Vents

Indicate the proper positioning of the Vents - exhaust gases dispersion analysis from process vents and vent posts, in order to verify possible interferences on the detection

system and verify their influence in the air intakes to avoid contamination of closed spaces and other places where there are risks to people (work and passage areas / transit of people in the Unit). The study shall provide alternatives for proper positioning of the vents, whenever any of the risk situations mentioned above are identified.

**C. Positioning of exhaust discharges of equipment (engines and turbines)**

Indicate the proper positioning of exhaust discharges. Analysis of gas dispersion of exhaust discharges from machinery such as: internal combustion engines and turbines for driving generators and compressors. The study shall check their influence on the air intakes, in order to avoid contamination of indoor environments and other spaces of the Unit where there is a risk to people, such as intoxication, suffocation or burns. The study shall provide alternatives for proper positioning of the chimneys, whenever identified risk situations as mentioned above.

**D. Positioning of detectors in air intakes**

Indicate the need to install toxic and / or asphyxiating gas detectors ($H_2S$ and $CO_2$) in air intakes - Analysis of toxic and asphyxiating gases dispersion ($H_2S$ and $CO_2$) in order to evaluate the need to monitor these gases in air intakes of manned compartments.

Note: There is no need to evaluate flammable gas contamination, since all air intakes in manned compartments shall be monitored by hydrocarbon detectors, regardless of the study.

**E. Impairment frequency for escape routes**

Calculate the impairment frequency of escape routes by toxic and/or asphyxiating gases - Gas dispersion analysis in order to assess the impairment frequency of escape route by toxic and asphyxiating gases arising from leak scenarios.

In addition to meeting the requirements of the Safety Engineering Guidelines, the study shall include aspects related to the detection system regarding the installation, inspection, maintenance and interference with structures and equipment. The analysis of the above aspects shall be presented or referenced in the study report, in order to show that these aspects were duly considered and treated.

## 5. REFERENCE DOCUMENTATION

As inputs for the elaboration of Gas Dispersion Study, the following documents shall be considered, in its most up-to-date version and with status of RELEASED 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) Equipment data sheets containing hydrocarbons or other flammable products (FDs);

e) Safety Data Sheet;
f) Meteoceanographic data;
g) Reports of the PHA already carried out for the Unit;
h) Plan of hazardous area classification;
i) Equipment list;
j) Material Safety Data Sheet (MSDS)

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

- Location of close compartments air intakes, process equipment vents, flammable product storage vents, fuels and chemicals, as well as discharges of internal combustion equipment (turbomachinery);

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

## 6. RELEVANT STUDY ASPECTS

The gas dispersion study shall consider at least the following aspects that influence the dispersion analysis of the gas leakage scenarios:

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

- Leak or discharge conditions into the environment (leakage 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 geometry and arrangement of the evaluated region;

- 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.

## 7. SOFTWARE REQUIREMENTS

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

In open areas where vents are being evaluated or in completely confined areas, general purpose CFD software may be adopted (Ex. Fluent, CFX, STAR-CCM+, etc.). This

software cannot be applied in process areas and utilities for design of the detection system, where only FLACS and KFX (Kameleon) software can be adopted.

Other software must be previously authorized by Petrobras before being used in the 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 must 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 most frequent wind speed must be obtained from the weighted average of the most frequent speed values in each of the eight directions. The weighting is performed by the number of occurrences of each most frequent velocity considered in the calculation. When frequency values or number of occurrences are provided by speed ranges, use the average value of the speed range.

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 gas 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 study shall evaluate the dispersion of flammable, toxic and asphyxiating gases resulting from the gas leakage scenarios identified in the Preliminary Hazards Analysis (PHA).

Due to the preventive character of the detection system, where the detection of leaks is sought in its initial stage, the scenarios mentioned above, for designing the

detection system, shall be simulated with small leak rates as defined in the Safety Engineering Guideline.

The evaluation shall indicate the scenarios that shall be simulated and those that can be grouped or even eliminated since previously agreed and validated with Petrobras. All scenarios that are not simulated shall be justified and listed in the final report.

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

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 gas dispersion study, such as scenarios resulting from design changes and operational changes.

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

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

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

III. Gas leaks on the tanks ellipses associated to the Structural Tanks Gas Recovery 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 the oil in the oil cargo tanks;

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

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.

## 9.2 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 (for example: 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 must 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.

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.

## 9.3 Lea / Discharge Rates

For the simulations of the scenarios related to each one of the topics presented in item 4, regarding the scope of the study, consider the process data according to item 9.2 and the leakage / discharge rates according to the following assumptions:

A. **Positioning of gas detectors in open areas** - leak rate calculated according to item 9.10 of this TS;

B. **Analysis of vents discharges** - discharge rate for the most critical flammability and toxicity conditions;

C. **Analysis of internal combustion equipment discharges** - discharge rate for the various operating conditions of the equipment;

D. **Positioning of gas detectors in air intakes by leaks** - leakage rate considering line rupture in scenarios that may lead to toxic and/or asphyxiating gas to the air intakes of the Unit's various compartments (note 1);

E. **Impairment of escape routes by gas leaks** - leakage rates of scenarios that may impact escape routes (note 1).

**Note 1:** The concentration values for impairment of escape routes are defined in the table in ANNEX D.

The Study Consulting shall conduct the analysis based on the clouds in steady state. Evidence shall be provided to prove that the gas cloud used has reached the stationary cloud condition.

### 9.4 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.

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 analysis of gas dispersion.

### 9.5 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 the Basic Design phase, the 3D model shall be complemented with design information, consulting the Process, Arrangement and Piping professionals of the Designer.

For existing units, it is fundamental that the confinement and congestion degree of the CFD model represents the reality of the Unit in the operational condition (as built). In this case, data from the Unit itself shall be used.

CFD geometric models from different points of view shall be observed by evaluating the degree of congestion to be used in the simulations and comparing it with those observed in Unit photos (when available) or 3D model photos, adjusting the CFD model when necessary.

The simplifications and use of congestion factors shall be validated with the participation of the Designer and Petrobras.

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.

### 9.6 CFD Modeling

The Study Consulting shall present the detailing of the modeling options adopted in the CFD software. Definitions of the mesh, domain, turbulence models, boundary conditions and convergence shall be presented and justified.

### 9.7 Ventilation Analysis

A ventilation analysis shall be performed considering the Unit geometry, weather conditions and the domain defined to support the decisions regarding the simplifications for the directions and wind speeds, as well as to identify the possible regions of stagnation where there may be gas accumulation.

## 9.8 Selection of Leak Points

For the selection of the leakage points, a meeting with the participation of the Design Engineer including the disciplines of Process, Safety, Structure and Piping and professionals of Petrobras shall be held, and the participation of an experienced Petrobras operator is recommended.

The purpose of this meeting is to define the leakage points to ensure that all locations in the assessed areas with the possibility of gas presence are monitored. To do this, it shall be taken into consideration at least characteristics such as: fluid composition, leakage rates, leakage directions, directions and wind speed, the process data of the released gas, the arrangement of the area (considering confinement and congestion by equipment/piping and other obstacles).

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 the leakage points shall be done in order to identify for each scenario / segment, in each module or area evaluated, the points that present a chance of leakage, not necessarily only the inputs and outputs of large inventory equipment, but also other susceptible points, such as connections on high vibration lines.

For this selection, P&IDs, 3D model, arrangement and isometric drawings shall be used. All points shall be indicated in the report with their respective coordinates, segment indication, location description and TAG of the equipment / line.

It should be noted that the segments might contain elements in different physical areas and modules of the Unit, which shall be taken into account in the analysis. In addition, in the same section, it is recommended to choose points that, regardless of the frequency, present themselves in distinct locations of the area / module, in order to characterize the different clouds formed in the module.

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.

## 9.9 Assessment of the Impairment of Escape Routes

Leakage frequencies shall be calculated in gas dispersion analyzes for the purpose of assessing escape routes impairment. For the other items of the scope of this technical specification, the use of leak frequencies is not applicable.

To assess escape routes impairment, items 9.9.1, 9.9.2 and 9.11.4 of this ET shall be used, as well as the tolerability criteria set out in the Safety Engineering Guideline.

### 9.9.1 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 (field count);

2. Data taken from updated project documentation (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 A shall be applied.

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

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

### 9.9.2 Calculation of leak frequency

The leak frequency is used only to assess escape routes impairment.

The leakage frequency for each component (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 must be previously agreed with Petrobras.

The databases used shall have information that allows relating leakage rates and the corresponding frequency of occurrence according to the element where the leak occurs (flanges, valves, line segments etc.) and their characteristics (diameter, type etc.). such as the HSE Hydrocarbon Release Data Base (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 in straight sections of pipe by the length of the respective sections, according to the database, is also added.

It should 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).

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 Designer and Petrobras prior to the start of the simulations.

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.

## 9.10 Methodology For Determining Leak Rate for Gas Detectors Positioning in Open Areas

The evaluation presented on this topic is deterministic and, therefore, there shall not be used leak and/or explosion frequencies on it.

For the determination of the leak rate to be used for flammable gas detectors positioning in open areas, it shall be performed a parametric analysis on every module and/or area that gas detectors shall be located, in order to determine which leak rate generates a maximum overpressure of 0,1 barg. To perform this evaluation, the requirements below shall be followed:

I. For each module and/or area of the Unit, there shall be performed a parametric gas dispersion analysis variating the leak rate and determining their stoichiometric volumes. The items below shall be implemented on this evaluation:

   a. Leak points shall pre-approved by Petrobras;

   b. Four (4) leak directions for each leak point;

   c. For each leak point, eight (8) wind directions shall be considered. For each of them at least three (3) wind speeds shall be analyzed, which are:

      i. The most frequent wind speed;

      ii. The wind speed corresponding to calm weather;

      iii. Another speed between the calm weather speed and the most frequent speed shall be simulated in order to characterize the consequences as a function of the cloud sizes.

   d. It shall be used at least five (5) different leak rates in the small leak range which are: 0,3 kg/s, 0,5 kg/s, 1 kg/s, 1,5 kg/s and 2 kg/s. These leak rates can be changed and/or additional ones can be included in common agreement with Petrobras. In case of the value of 0,1 barg is achieved in any these leak rates, it is not necessary to run another leak rate;

II. For all cases simulated on item “I” above, there shall be run explosions simulations in order to determine the maximum overpressures generated on the monitor points on the module and/or area under analysis. These explosions

simulations shall comply with the Explosion Study TS (I-ET-3000.00-5400-98G-P4X-001), where applicable;

III. The following tables and graphics shall be presented for every module and/or area under analysis:

a. A table presenting for all the cases: leak point, leak direction, wind direction, wind speed, leak rates, stoichiometric volume, maximum overpressure and indication of the leak rate that generates maximum overpressure of 0,1 barg;

b. A graphic presenting the stoichiometric volume ($m^3$) x leak rates (kg/s);

c. A graphic presenting the stoichiometric volume ($m^3$) x maximum overpressures (barg).

Gas clouds that have stoichiometric volumes capable of generating overpressures smaller or equal to 0,01 barg do not need to have placed flammable gas detectors. However, they need to be checked for asphyxiating or toxic gas detectors. These cases shall be identified on the gas mapping worksheet as “Out of Monitoring Interest Field”.

Before the evaluation requested on this topic to be performed, the items requested shall be approved by Petrobras prior to its beginning, and the simulations to be run for gas detector locations shall only be started after the leak rates established on item “III” of this topic are approved by Petrobras.

On modules and/or areas where there can be concentrations of $CO_2$ higher than flammable gas, the requested analysis on this item shall be performed for the case which has higher concentration of flammable gas and another for the higher concentration of $CO_2$. For the case where there is $CO_2$ concentrations higher than flammable gas, this analysis shall determine whether the contour of 30.000 ppm of $CO_2$ is bigger than the 60% LII of flammable gas one. In affirmative case, this leak rate shall be used to allocate dedicated $CO_2$ gas detector on this contour. For the other case, there shall be installed dedicated flammable gas detectors.

On modules and/or areas where there can be streams with concentrations of $H_2S$ higher than 50 ppm, the requested analysis on this item shall be performed. This analysis shall determine whether the contour of 20 ppm of $H_2S$ is bigger than the 60% LII of flammable gas one. In affirmative case, this leak rate shall be used to allocate dedicated $H_2S$ gas detector on this contour.

### 9.11 Requirements for Evaluation of Vents and Internal Combustion Equipment Discharges

Before the beginning of the evaluation of gas dispersion from vents and internal combustion equipment discharges, the designer shall develop a list containing all vents and exhausts of internal combustion equipment’s from HULL and TOPSIDE, which shall be approved by Petrobras.

All vents and exhausts of all systems from HULL and TOPSIDE shall be presented on the list and it shall be presented on the report.

For the evaluation of streams that may be discharged on vents, all possible scenarios shall be considered, there is, operational cases and process accidental cases as well. Some accidental examples, but not limited to them, are shell/tube rupture of heat exchangers and contamination of the heating/cooling system side of it by combustible, flammable, asphyxiating or toxic compounds; gas blow-by scenarios; contamination of one system by compounds that are not expected to have combustible, flammable, asphyxiating or toxic compounds, etc.

The following vents shall also be presented on the list and be justified but do not need to have gas dispersions performed:

a) Vents isolated by blind flanges, single or double blocks, locked closed valves or normal closed valves;

b) Vents that in any circumstance only releases noncombustible, nonflammable, nontoxic or non-asphyxiating fluids at temperatures equal or lower than 60°C;

c) Vents that for all compounds on the stream have concentrations values equal or lower than the concentration limits presented on DR-ENGP-M-I-1.3-R5 and Annex D of this TS. This is applicable for all operational modes equipment or system;

d) Vents of piping-in-piping systems designed according to class regulations (i.e.: the ones presented on master gas valves of IGGs);

e) Vents in open areas which maximum release rate is lower than 0,1 kg/s considering all operational modes of the system or equipment.

The list shall contain, at least, the following items and shall be issued respecting model given in Annex E: (note 3)

I. Vent or exhaust line tag;

II. Vent or exhaust location;

III. Vent or exhaust elevation;

IV. Associated system description;

V. Associated equipment description;

VI. Composition of the released gas; (note 2)

VII. Density of the composition, in kg/m³;

VIII. Molecular weight of the composition;

IX. Temperature, in °C;

X. Discharge rate, in kg/s;

XI. Discharge rate, in m³/h;

XII. P&ID where the vent or exhaust is referenced;

XIII. Document where the composition is referenced;

XIV. Document where the discharge rate is referenced.

Note 2: For compounds which their concentration is lower than 1% vol/vol, shall also have their concentration shown in ppm.

Note 3: Designer shall insert new compounds, if required, if they are not listed on Annex E.

In cases where there are asphyxiating, toxic and/or flammable/combustible gas on the stream of the vent and/or exhaust, at least three cases shall be simulated: one with the highest concentration of flammable/combustible compounds, one with the highest concentration of asphyxiating compounds and another with the highest concentration with toxic compounds.

In all cases, the streams with lower temperatures shall be used.

Specifically for the vent post analysis, 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 the oil in the oil cargo tanks;

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

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.

## 9.12 Simulation of Dispersions

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 must have its own simulations.

The dispersion simulations shall take into account each of the following aspects according to each study objective:

### 9.12.1 Considerations for topic A of item 4

<u>Positioning of detectors in open areas</u>

For the leakage points selected according to item 9.8, the gas cloud simulations shall be performed considering the objectives and premises defined in the Safety Engineering Guidelines and in this TS.

Fire zones of the same module separated by grade floors may be evaluated as a single region of interest for dispersion simulations. Therefore, for these cases, gas clouds originating in a fire zone can also be detected by detectors from other adjacent zones. This solution, if adopted, shall be clearly stated in the report so that the necessary actions can be implemented in the project.

The simulations shall consider the variation of the volumetric concentration of the gases, and the contours of the clouds shall be presented in the limits of interest according to the type of gas, according to the provisions of the Safety Engineering Guideline.

9.12.2 Considerations for topics B and C of item 4

Analysis of the discharge of vents and analysis of the discharge of internal combustion equipment

In addition to the provisions of the Safety Engineering Guideline, in order to evaluate the simulation of vent gases and the exhaust gases from internal combustion equipment dispersion, gas clouds shall be simulated in the directions of air intakes and places with person's presence. In addition, the existence of clouds that may interfere with the Unit's gas detection system shall be evaluated and corrective actions for vent repositioning and equipment discharges shall be recommended.

9.12.3 Considerations for topic D of item 4

Positioning of detectors in air intakes, caused by leaks

In addition to the provisions of the Safety Engineering Guidelines, to assess the need to install toxic and asphyxiating gas detectors ($H_2S$ and $CO_2$) in the air intakes, scenarios of gas leaks shall be simulated whose clouds are oriented towards air intakes. For the decision of the need to positioning detectors for these regions of interest, it is necessary to consider the concentration of the simulated clouds and the defined impairment criteria for each type of gas, according to the table in ANNEX D.

9.12.4 Considerations for topic E of item 4

Impairment of escape route, caused by leakage

In addition to the provisions of the Safety Engineering Guideline, in order to assess the impairment of escape routes by toxic and/or asphyxiating gas clouds, shall be considered clouds that may cause simultaneous impairment of the existing main escape routes.

In order to evaluate the impairment of escape routes, the concentration of the simulated clouds and the defined impairment criteria for each type of gas shall be considered, according to the table in ANNEX D, and the impairment frequencies defined in the Safety Engineering Guideline.

### 9.13 Positioning and Optimization of the Detection System in Open Areas

Depending on the simulations performed according to item 9.10, the positioning of detectors shall be determined. The detection of gas when mixing hydrocarbons and $CO_2$ shall comply with the provisions of the Safety Engineering Guidelines.

Note: For normally well-ventilated areas of the Unit, such as the above-floor area of the process modules, where the gas clouds in the contour of interest are generally very small, the need for detection shall be evaluated together with Petrobras, considering possible consequences for people and Unit.

A minimum of 3 detectors shall be allocated for each gas cloud within the 60% interest boundary of LII for $CH_4$, 30,000 ppm for $CO_2$ and 20 ppm for $H_2S$.

The detectors shall be positioned prioritizing the sites that concentrate the largest number of gas clouds, for each type of gas to be detected. The process of allocating the detectors shall use an optimization algorithm in order to meet the detection criteria according to and must be previously agreed with Petrobras.

From the results of the simulations and the initial arrangement of the detectors, the total number of detectors can still be optimized, with the participation of Petrobras.

## 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 or included as an annex to the report in its final review.

All validation decisions (of premises, of data, of geometry among others) shall be included in the final study report as an annex. Those responsible for each party involved shall sign the validations.

### 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:

- Presentation of the Project for the Study Consulting - (Designer);
- 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;
- Sizing the teams of the designer and executor of the study that will participate in the preparation and follow-up of the study, with the definition of the matrix of responsibilities;
- Presentation of the focal points of each involved party and identification of the responsible of each discipline of each involved party that will participate in the follow-up meetings and the validations required in this TS;
- Presentation of the planned schedule for the execution of the study in accordance with the project schedule (Study Consulting and Designer);
- Definition of locations, resources needed and duration of follow-up meetings (Designer and Consulting Performer).

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.

Note: The schedule shall include a deadline of twenty working days for comments on reports (partial and final) by Petrobras.

### 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 must 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 must sign an accepted document containing the pending list, if any.

Note: The Designer, as responsible for project change management, must 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 must 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 must clarify the doubts.

This meeting aims to validate the scenarios of gas leakage to be simulated, to consolidate the premises defined in this TS and other additional ones not covered by this TS and the Safety Engineering Guidelines, and shall contemplate at least the following:

- Validation of leakage points: it shall be noted that piping sections may contain elements in different physical areas and modules of the Unit. In addition, in the same section, it is preferable, if necessary, to choose points that, regardless of the frequency, appear in different locations of the area/module;

- Types of detectors to be allocated: depending on the presence of toxic, flammable and asphyxiating gases, it shall be verified that suitable detectors are being provided in the areas according to the currents, contents and prescriptions of the Safety Engineering Guideline and this TS;

- Voting logic: how many detectors and in which zones/areas will be voted with each other;

- Detection logic: how many detectors must be included for detection of each scenario (cloud);

- Wind and jet directions: it shall be evaluated the variability and applicability of the dispersions to be simulated. Some very similar cases can be extrapolated, while others may simply disperse out of the unit and be not considered;

- Deleted scenarios: justifying, agreeing and documenting deleted scenarios;

- Check and report the composition and conditions of the streams to be used in the leaks. In case of existence of toxic/asphyxiating gases include in the analysis of impairment of escape routes, as listed in the table in ANNEX D.

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, risers' arrangement (subsea and surface - arrangement at the riser balcony) and escape routes which shall be evaluated in the study. The information shall be ratified or rectified by Petrobras.

Participants of the meeting of premises and methodology: 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. Monitoring 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 | **Planning Meeting**:<br>Presentation of study schedule. | 10.2 |
| R2 | **Documentation Review Meeting:**<br>Review of documentation. | 10.3 |
| R3 | **Geometry validation**:<br>Presentation of the CFD model - evaluation of geometry, confinement, congestion and obstructions to be added in the model. | 9.5 |
| R4 | **Validation of parts count:**<br>Presentation and validation of parts count to be used in the analysis of impairment of escape routes. | 9.8 |
| R5 | **Premises and Methodology:**<br>Validation of leakage points, types of detectors to be used, voting logic, wind and leak directions to be used, justified scenarios for not being simulated, | 8<br>9.1<br>9.3<br>9.4<br>9.2 |
| R6 | **Leak Rate for Gas Detectors Positioning in Open Areas:**<br>Presentation of the analysis´s results of leak rates to be used for open area gas detector's location. | 9.10 |
| R6 | **Validation of results and compliance with recommendations**:<br>Presentation, discussion and validation of the results of dispersion simulations and impairment frequencies. | 9.9 |
| R7 | **Validation of optimization results**:<br>Presentation of the results of detectors optimization, dispersions of equipment vent, vent posts and exhausted gases of equipment. | 9.10 |

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.

### 10.6. Presentation of Preliminary Version of the Study Report Meeting

Meeting to present the final report before its issue to Petrobras. The final report is the responsibility of the Designer. The final report shall include the report of the Study Consultant plus the treatment of the study recommendations to be implemented in the project by the Designer. The codification of the report and its stamp must identify the designer as originating from the document. The coding shall be in accordance with Petrobras N-1710 and the format in accordance with N-381.

The presentation shall focus on the main accidental events, the main results, conclusions and recommendations of the study. The treatment given to each of the study recommendations shall be addressed.

Participants in the study report presentation meeting:

The single points of the parties involved, professionals from Study Consultant responsible for the study and the discipline leaders of the Designer and Petrobras responsible for the follow-up of the study shall be involved. At this meeting, it is recommended the participation of professionals from operation and maintenance of the Unit.

## 11. STUDY REPORTS

The final report 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. In addition, the minutes of the meetings shall be presented in annex, especially those that have validation of stages of the methodology. The charts and figures of the reports shall be presented with the respective scales, captions, the rose of the winds, and predominant direction of the wind. For the elaboration of the tables, graphs and figures, the units of the International System - SI must 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 one partial report shall be submitted by the Study Consulting to Petrobras for acceptance prior to the issuance of the final report.

The Partial Report shall contain at least the requirements:

- Premises (item 9.3);
- 3D model and geometry (item 9.5);
- Mesh and simulation domain (item 9.6);
- Results of ventilation analysis (item 9.7);
- Process data (item 9.2);
- Scenarios to be analyzed (item 9.1);
- Leakage points (item 9.8);

- Not simulated scenarios (item 9.1);
- Definition of segments (items 9.1 and 9.8);
- Calculation of leak rate (item 9.3 and 9.10);
- Results of the simulations (item 9.11);
- P&ID and PFD attached (item 9.2);
- Table of ANNEX C - Process data;
- List of vents and exhausts evaluated on study (item 9.11).

### 11.2. Final report

The Final Report corresponds to the issuance of the report under review 0. It shall contain all the requirements of item 11.1, take into account the comments made to the Partial Report, and additionally contain:

- Attached meeting minutes (item 10.1);
- LV attached (item 14);
- Table of ANNEX B.

Additional revisions shall be provided for cases where there are project changes that impact the study or if failures in the final emission are identified.

The report containing the optimization of the detection system shall be carried out together with the evaluation of the detection system coverage and the possible impacts on safety, recording the following information in the report:

- Total number of simulated clouds;
- Total number of clouds detected;
- Total number of undetected clouds;
- Total number of clouds detected by at least three (3) detectors;
- Total number of clouds detected by each detector (by detector tag in the project documentation);
- Identification of the clouds detected by each detector (by detector tag in the project documentation);
- Identification of the detectors that monitor each cloud;
- Detection coverage curve;

- Volume of gas cloud in the contour of interest, in m³;
- Stoichiometric volume of flammable gas cloud in the contour of interest, m³;
- Volume of the gas cloud between the upper and lower limits of flammability (see ANNEX B).

## 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 also due to the importance of this study for the safety of the Unit, it shall be carried out by a qualified company, belonging to the contractual list of suppliers of Petrobras (LCF).

## 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.

Verification of the part relating to the adequacy of the detector installation as to feasibility aspects for inspection, testing, maintenance and analysis of interference with structures and equipment shall be included in the project documentation or as an annex to the report. In case it does not count as an annex, this documentation shall be referenced in the study report in a specific item, with a clear indication of how and where the study recommendations were met.

## 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.

# 16. ANNEXES

## ANNEX A - CORRECTION OF COUNTING PARTS

Table - CORRECTION FACTORS FOR COUNTING PARTS

| ELEMENT TYPE | DIAMETERS | GAS | | | OIL | | | WELLS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| FLANGES | 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: | | | | | | | | | |
| | D≤3" | Qtd GAS | x 2,00 | x 0,45 | Qtd OIL | x 4,00 | x 0,35 | Qtd WELLS | x 3,00 | x 0,45 |
| | 3"<D<12" | | | x 0,35 | | | x 0,45 | | | x 0,50 |
| | D≥12" | | | x 0,20 | | | x 0,20 | | | x 0,05 |
| | **Subtitle:**<br>Qtd GAS = total quantity accounted for GAS system in P&IDs (for all diameter ranges)<br>Qtd OIL = total quantity accounted for OIL system in P&IDs (for all diameter ranges)<br>Qtd WELLS = total quantity accounted for WELLS system in P&IDs (for all diameter ranges) | | | | | | | | | |
| BLOCK VALVE | Count the block valves in P&ID and multiply the quantitative by the corrections factors below: | | | | | | | | | |
| | D≤3" | x 1,50 | | | | | | | | |
| | 3"<D<12" | x 1,20 | | | | | | | | |
| | D≥12" | Use directly the quantitative found. | | | | | | | | |
| BLOWDOWN VALVE (BDV) | D≤3" | Count the blowdown valves in P&ID and use directly the quantitative found. | | | | | | | | |
| | 3"<D<12" | | | | | | | | | |
| | D≥12" | | | | | | | | | |
| CONTROL VALVE | D≤3" | Count control valves in P&ID and use directly the quantitative found. | | | | | | | | |
| | 3"<D<12" | | | | | | | | | |
| | D≥12" | | | | | | | | | |
| CHECK VALVE | D≤3" | Count check valves in P&ID and use directly the quantitative found. | | | | | | | | |
| | 3"<D<12" | | | | | | | | | |
| | D≥12" | | | | | | | | | |
| SHUTDOWN VALVE (SDV) | D≤3" | Count SDVs in P&ID and use directly the quantitative found. | | | | | | | | |
| | 3"<D<12" | | | | | | | | | |
| | D≥12" | | | | | | | | | |
| INSTRUMENTS | D≤3" | Count instruments in P&ID and use directly the quantitative found. | | | | | | | | |
| | 3"<D<12" | | | | | | | | | |
| | D≥12" | | | | | | | | | |
| PRESSURE SAFETY VALVE (PSV) | D≤3" | Count PSVs in P&ID and use directly the quantitative found. | | | | | | | | |
| | 3"<D<12" | | | | | | | | | |
| | D≥12" | | | | | | | | | |

*REFERENCE: TECHNICAL NOTE NT_ENG-E&P_PROJEN_010_2016

## ANNEX B: DETECTORS LOCATION X SCENARIOS (example)

Table - DETECTORS LOCATION X IDENTIFIED SCENARIOS

| Scenario number | Module | Leak Rate | Leak Direction | Coordinates | | | Wind Direction | Wind Speed | Detectable cloud volume (m³) | Detectors by cloud (1) | Open path detectors | | Point detectors | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | X | Y | Z | | | | | | | | |
| 001 | M01 | | | | | | | | | | | | | |
| 002 | M01 | | | | | | | | | | | | | |
| 003 | M02 | | | | | | | | | | | | | |
| 004 | M02 | | | | | | | | | | | | | |
| 005 | M03 | | | | | | | | | | | | | |
| 006 | M03 | | | | | | | | | | | | | |
| 007 | M03 | | | | | | | | | | | | | |

Note (1) - The open path detectors are counting in pairs.

# ANNEX C – PROCESS DATA SHEET

| | Nº | REV. |
|---|---|---|
| FOLHA DE DADOS | SDV- - INVENTÁRIO 5 | 00 |
| UNIDADE: PLATAFORMA | FOLHA: 1 DE 1 | |

**DOCUMENTOS DE REFERÊNCIA:**

| | | |
|---|---|---|
| 1 | - | I-DE- - Maximum Flowrate |
| 2 | - | LevantamentoComprimentoLinhasGás.xls |
| 3 | - | Comprimento linhas de gás- |
| 4 | - | |
| 5 | - | |

**DESCRIÇÃO**

Das SDVs 1210716/718/21/22 passando pelos permutadores P-1210701A/B/C/D, pelo lançador LP-1231701 até as SDVs SDV-1231731/13 de exportação.

| DADOS GERAIS | | | OBSERVAÇÕES |
|---|---|---|---|
| Tipo de material: | gás | | |
| Pressão : | kPa | 7251 | [1] |
| Temperatura: | ºC | 9.0 | [1] |
| Peso molecular: | kg/kmol | 23.4 | [1] |
| Densidade (gás) | kg/m$^3$ | 111.1 | |
| Densidade (óleo) | kg/m$^3$ | 508.8 | [1] |
| k (Cp/Cv) | [ - ] | 1.24 | |
| Poder calorífico (PCI) | kcal/kg | 10860 | |
| Fator de compressibilidade (Z) | [ - ] | 0.65 | |
| Fração de Líquido | [-] | 0.044 | [1] |
| Tempo de detecção ($T_D$) | s | 60 | |
| Tempo de bloqueio do inventário ($T_F$) | s | 34 | |
| Diâmetro da maior válvula de bloqueio | in | 34.0 | |
| Tempo de fechamento da válvula | in/s | 1.0 | |
| Tempo total de bloqueio do inventário ($T_T$) | s | 94 | |

**CÁLCULO DO INVENTÁRIO ESTÁTICO**

| | | |
|---|---|---|
| **Volume estático gás** | m$^3$ | 62.8 |
| **Volume estático óleo** | m$^3$ | 2.9 |

| N. | DESCRIÇÃO | TAG | Diâmetro (in) | Comprimento (m) | Volume Gás (m3) | Volume Óleo (m3) | |
|---|---|---|---|---|---|---|---|
| 1 | Das SDVs 1210717/718/21/22 até a entrada dos permutadores P-1210701A/D | 18"-PC-F16-7005-PP | 18.00 | 8.942 | 1.18 | 0.05 | [2] |
| | | 18"-PC-F16-7009-PP | 18.00 | 1.919 | 0.25 | 0.01 | [2] |
| | | 20"-PC-F16-7009-PP | 20.00 | 34.323 | 5.54 | 0.25 | [2] |
| 2 | Das SDVs 1210717/718/21/22 até a entrada dos permutadores P-1210701A/D | 16"-PC-F16-7037-PP | 16.00 | 7.198 | 0.73 | 0.03 | [2] |
| | | 16"-PC-F16-7073-PP | 16.00 | 7.314 | 0.74 | 0.03 | [2] |
| | | 10"-PC-F16-7058-PP | 10.00 | 6.033 | 0.24 | 0.01 | [2] |
| | | 10"-PC-F16-7057-PP | 10.00 | 6.251 | 0.25 | 0.01 | [2] |
| | | 10"-PC-F16-7022-PP | 10.00 | 6.263 | 0.25 | 0.01 | [2] |
| | | 10"-PC-F16-7010-PP | 10.00 | 6.25 | 0.25 | 0.01 | [2] |
| 3 | Da saída dos trocadores P-1210701A/D até a exportação | 16"-PC-F16-7065 | 16.00 | 0.586 | 0.06 | 0.00 | [2] |
| | | 10"-PC-F16-7065 | 10.00 | 2.527 | 0.10 | 0.00 | [2] |
| | | 10"-P-F10-7059 | 10.00 | 5.399 | 0.20 | 0.01 | [2] |
| | | 16"-P-F10-7059 | 16.00 | 1.389 | 0.14 | 0.01 | [2] |
| | | 16"-PC-F16-7061 | 16.00 | 0.586 | 0.06 | 0.00 | [2] |
| | | 10"-PC-F16-7061 | 10.00 | 2.241 | 0.09 | 0.00 | [2] |
| | | 16"-P-F10-7060 | 16.00 | 2.263 | 0.22 | 0.01 | [2] |
| | | 10"-P-F10-7060 | 10.00 | 5.691 | 0.21 | 0.01 | [2] |
| | | 16"-PC-F16-7039 | 16.00 | 0.229 | 0.02 | 0.00 | [2] |
| | | 10"-PC-F16-7039 | 10.00 | 5.819 | 0.23 | 0.01 | [2] |
| | | 10"-P-F10-7040 | 10.00 | 2.471 | 0.09 | 0.00 | [2] |
| | | 16"-P-F10-7041 | 16.00 | 5.282 | 0.52 | 0.02 | [2] |
| | | 20"-P-F10-7041 | 20.00 | 1.165 | 0.18 | 0.01 | [2] |
| | | 16"-PC-F16-7012 | 16.00 | 0.586 | 0.06 | 0.00 | [2] |
| | | 10"-PC-F16-7012 | 10.00 | 2.454 | 0.10 | 0.00 | [2] |

## ANNEX D - RELEVANT CONCENTRATIONS OF TOXIC GASES

| Criteria to be assessed | Description | Criteria | | | |
|---|---|---|---|---|---|
| | | Parameters to be checked | CO (ppm) | $CO_2$ (ppm) (note 1) | $H_2S$ (ppm) |
| Allocation of sensors at air intakes | Air intakes (i.e., Accommodations, Temporary Refugee, etc.) | Contamination by gas (hydrocarbons, toxic and asphyxiating) (note 3) | 100 (note 2) | 30.000<br>1000 (Note 7) | 8 (Note 5) |
| Embarkation Stations | Capacity of people to stay waiting for evacuation. | Contamination by gas (toxic and asphyxiating) | 100 | 30.000 | 8 (Note 5) |
| Escape Routes Impairment (Note 4) | Escape Route SB | Impossibility to escape due to the impairment of the main escape routes at the same time, considering:<br>Asphyxiation and toxicity. | 1.200 | 30.000 | 50 (Note 6) |
| | Escape Route PS | | 1.200 | 30.000 | 50 (Note 6) |
| | Central Escape Route | | 1.200 | 30.000 | 50 (Note 6) |

Notes:

1. Reference: NIOSH. The value of 30.000 ppm corresponds to STEL (*Short Term Exposure Limit*);
2. Considering 50% of NIOSH thresholder (200 ppm);
3. Air intakes gas monitoring;
4. According to definition of IDLH in 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*."
5. Reference: Safety Engineering Guideline;
6. Reference: Limit for $H_2S$ based on N-2282 and limit for $CO_2$ based on Annex IV of Safety Engineering Guideline*;*
7. Air intakes shall not be impacted by gases exhausted from discharges of machines with a concentration greater than 1000 ppm of $CO_2$, according to ABNT/NBR 16401-3:2008.

# ANNEX E – VENTS AND EXHAUSTS LIST