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	CLIENT:		SHEET 1 de 24
	PROGRAM:		
	AREA:		
SRGE	TITLE: **ESCALATION ANALYSIS DUE TO COLLAPSE OF EQUIPMENT AND PIPING UNDER FIRE**		**INTERNAL**
			ESUP

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0	ORIGINAL
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SUMMARY

1. INTRODUCTION

The escalation analysis of Equipment and Piping under fire is a consequence analysis which aims to evaluate if piping and equipment exposed to fire scenarios analyzed in the Fire Propagation Study can lose their physical integrity and contribute to the frequency loss of installation Main Safety Functions -MSF, performing an escalation risk evaluation due to fire scenarios in the module itself and from neighbor modules. This physical integrity loss of Equipment and Piping will be hereafter called EPC (Equipment and Piping Collapse).

2. OBJECTIVES

The proposed evaluation on this technical specification has the following goals:

- Identify through the EPC analysis equipment and piping that can collapse due to fire scenarios originated in the modules where they are located and from fire scenarios originated from neighbor modules from them;

- Evaluate impairment on MSFs due to the physical loss integrity of equipment and piping;

- Determine impairment frequency on MSFs due to escalation;

- Recommend reduction measures to MSFs impairment frequency that had total impairment frequency impaired due to fire scalation and that overpass tolerability criteria stablished on Safety Engineering Guideline.

3. APPLICATION

This Technical Specification - TS is applicable to the detailing engineering design phase of the oil and gas Offshore Production Units and is not applicable to the conceptual and/or basic design phases. Any modification that occurs in the detailing phase and impacts the Fire Propagation Study, shall be considered in the EPC analysis.

4. SCOPE

The scope of the EPC analysis is according as follows:

1. It shall be analyzed all equipment's and piping that handle hydrocarbon (regardless of phase) and combustible liquids and/or inflammable. Not analyzed equipment/piping shall be pre-approved by Petrobras and justified in the report.

2. In the case of equipment handling hydrocarbon (regardless of phase) and combustible liquids and/or inflammable and considering that all of them shall be protected by water deluge system, according to the Safety Engineering Guidelines [4], and that deluge protection is not totally effective for jet fire scenarios, the equipment collapse analysis shall be performed to evaluate effects of impingement jet fire scenarios on equipment. It shall consider fire scenarios originated in modules where the equipment is located or in neighbor modules. It is not necessary to include in the evaluation pool fire scenarios, provided that, for these scenarios, the water deluge system is effective.

3. Isolated piping sub-segments between SDVs, check valves or control valves (therefore, non-depressurisable), that contain hydrocarbon (regardless of phase) and combustible liquids and/or inflammable, which inventory is above 100 kg, shall be properly identified and evaluated.

4. Evaluation of fittings, as valves, actuators and instruments are not scope of the analysis.

5. REFERENCES

[1] FIRE PROPAGATION AND SMOKE DISPERSION STUDY OF THE UNIT

[2] ISO 10.400, PETROLEUM AND NATURAL GAS INDUSTRIES - CASING, TUBING AND DRILL PIPE - EQUATIONS AND CALCULATIONS FOR PERFORMANCE PROPERTIES

[3] I-ET-3000.00-5400-947-P4X-001 – SAFETY STUDIES MANAGEMENT OF CHANGE

[4] DR-ENGP-M-I-1.3 – SAFETY ENGENEERING GUIDELINE

[5] NORSOK S-001/2018 – TECHNICAL SAFETY

[6] I-ET-3010.00-5400-433-P4X-001 – PASSIVE FIRE PROTECTION SYSTEM

6. ABBREVIATIONS AND DEFINITIONS

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

ABBREVIATIONS:

BDV – Blow Down Valves
CFD – Computational Fluid Dynamics
MSF – Critical Safety Function
DBP - Ductile Burst Pressure
EPC – Equipment and Piping Collapse
FEA– Finite Element Analysis
PFD – Process Flow Diagram
PFP – Passive Fire Protection
PHA – Preliminary Hazard Analysis
P&ID – Piping and Intrumentation Diagram
SDV – Shut Down Valve
TS – Technical Specification
UTS – Ultimate Tensile Strengh

DEFINITIONS:

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

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

Equipment and Piping Collapse – Loss of mechanical integrity of equipment or piping under fire.

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

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

Scenario - 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 comprising piping and equipment between shutdown valves (SDV's) or other blocks considered in the analysis.

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

7. METHODOLOGY AND REQUIREMENTS

The methodology to be used in the EPC analysis shall follow, at least, the presented on this TS and requirements described on this item. General diagram of the analysis can be seen on ANNEX I – EPC ANALYSIS GENERAL DIAGRAM of this TS.

7.1. General Requirements

The EPC analysis shall consider at least:

1. One (1) escalation level, that is, after evaluating and determining equipment and piping that collapse, it shall be performed evaluation of fire scalation effects on MSFs.

2. The EPC analysis shall be made using temperature distribution over time and space, simulated with CFD, of the fire scenarios analyzed in the Fire Propagation Study [1] of the installation.

3. Temperature to be used in the analysis shall be the one incident on equipment and piping surfaces. Approaches that only consider air temperature to evaluate these elements shall not be used.

4. For piping and equipment which have liquid inside, the heat transfer to the liquid under operation condition shall be considered in the analysis.

5. It shall be used data from Installation Fire Propagation Study [1] such as: segments, parts counts, leak frequencies, ignition probabilities, fire frequencies, evaluated fire scenarios, leak rates, leak directions, geometry (if possible), selected leak points to perform simulations, MSFs impairment frequencies, analyzed MSFs, stablished premises (if applicable), etc.

6. All fire scenarios in the Installation Fire Propagation Study shall be analyzed. Those that do not impair MSFs shall be clearly justified on the analysis report. See item 8 of this TS.

7. Provided that this analysis is fully dependent on Installation Fire Propagation Study [1], face any change on this study, as described on Management of Change TS [3], the EPC analysis shall also be revised aiming to reevaluate possible impacts.

8. On EPC evaluation due to fire, it shall not be used CFD simulated thermal flows performed on other modules or other elevations by analogy. EPC evaluation shall be based only on incident thermal flows from CFD simulations that reach the equipment/piping under analysis.

9. The EPC analysis shall be performed using real thermal flows simulated on CFD that reach external surface of these elements and considering equipment´s geometry effects and shadow effects that can affect incident flows.

10. Methodologies that only uses average or peak thermal flows to evaluate EPC shall not be used.

11. The peak radiation over time to be used shall be the max heat flux density obtained from the CFD simulations;

12. The average thermal flow over time to be used shall be 37,5% of peak thermal flow over time obtained from CFD simulations (based on the ratio between Surface Average Heat Flux and Local Peak Heat Flux for leak rates > 2 kg/s, of table A.4 of API 521);

13. For piping collapse evaluation, the peak radiation shall be applied in an area equivalent of 1% of the pipping total area.

14. For equipment collapse evaluation, the peak radiation shall be applied in an area equivalent of 1% of the equipment total area.

15. In case of piping segments are located in one or more elevations with plated floor, they shall be evaluated considering the segments parts and their thermal flows that reach these parts, according to their physical location using Installation 3D model (E.g.: piping that is located on modules M-09 and M-10: The piping segment part located on M-09 shall be analyzed considering thermal flows from M-09 fires and the part located on M-10, shall be analyzed using fire thermal flows reaching the segment part at M-10). In these cases, each piping segment shall be analyzed receiving thermal flow from the region (also considering their elevation) where they are located. A unique thermal flow for all the segments shall not be used.

16. Two cases shall be considered on the EPC analysis, as following:

    CASE 1: Considering fire scenarios originated in one module or region, evaluate EPC in the module where the elements are located, where this analysis shall be performed for all modules/areas considered in the Fire Propagation Study.

CASE 2: Considering fire scenarios originated in one module or region, evaluate EPC on neighbor modules where this analysis shall be performed for all modules/areas considered in the Fire Propagation Study.

17. It is not necessary to evaluate piping which are direct connected to atmospheric systems, except specified MSFs as defined on Installation Fire Propagation Study, as well as drainage pipes.

18. It is not necessary to evaluate EPC of piping containing liquid fluid and/or flammable, which nominal diameter is less than 2 in (2”) and it´s inventory is less than 100 kg.

19. Isolated piping segments between SDVs, check valves or control valves (therefore, non-depressurisable), containing liquid and/or flammable gas, which inventory is higher than 100 kg, shall be properly identified and evaluated, for CASE 1 and CASE 2 above mentioned, in topic 16.

20. The existence of isolation/personal protections on equipment and piping (ex: personal protection (PP), thermal isolations, etc.) shall be considered on the analysis, which information regarding these isolations/protections shall be provided by the Designer to the Study Consulting. However, it is highlighted that they shall not be considered as PFP, unless they have been certified under fire tests accordingly to Passive Fire Protection TS [6] and according to the protection rating at which equipment and/or piping required to be protected, in case recommended by the study. In these cases, designer shall provide all necessary information regarding installed protections to the Study Consulting.

21. Process Requirements:

For EPC analysis, the following shall be considered:

- It shall be used the depressurizing curve of each BDV that composes the systems to be analyzed.
- It shall be used the depressurizing curves obtained from process dynamics simulations during detailing design which shall be provided by the Designer.
- The design case to be used of the depressurizing curves is the “Hot Blowdown”.
- It shall be considered the release rates through PSVs, PRVs, and others relieve systems, where they exist.
- The depressurizing effect on actuating stress and, also, on thermal profile applied on equipment/piping, shall be considered;
- The physical-chemical operational streams properties variation due to temperature variation at each evaluated item is part of the analysis (E.g.: operational temperature, density, viscosity, operational pressure, stream composition, etc.). If Study Consulting demonstrates that this variation does not significantly impacts on

the analysis, it shall be approved by Petrobras and registered in the report. See item 8 of the TS.

- The temperature variation on internal walls as function of external wall temperature of the analyzed item, provided that it will lead to the fluid's internal pressure increase, which can lead to the collapse of the item.

22. Materials properties using up-to-date design documents by the time of the analysis development, which shall be provided by the Designer.

23. It shall not be considered simultaneous occurrence of fire events leading to loss of the physical integrity of piping or equipment.

24. Additionally, for equipment it shall be considered the following aspects:

    - Equipment volumes;
    - Equipment materials, size and geometry;
    - Equipment design codes.

25. The softwares to be used in the analysis shall be pre-approved by Petrobras and a description of them shall be presented in the report, item 8 of the TS.

26. Pre-approved software is VessFire.

27. The analysis can preferably be performed using FEA. In case another analysis methodology is used, Study Consulting shall demonstrate methodology effectiveness to liquid and gaseous fluids, which shall be pre-approved by Petrobras and be presented on report, item 8 of the TS.

28. All equipment and/or piping associated to the oil/gas process trains and their stand-by shall also be evaluated.

29. All existent system's by-passes shall be evaluated.

30. All sub-segments and derivations from system main piping shall also be evaluated.

31. Applied methodology shall be risk-based approach. It shall evaluate frequency and consequences associated to the escalation scenarios. Methodologies that consider only consequence or only frequency shall not be used.

32. The EPC which have occurrence frequency smaller than 1,00E-06 occurrences/year, do not need to have protections recommendations. On equipment and piping analysis it shall only be counted leak direction frequencies that can lead to the collapse of analyzed equipment and piping.

33. PFP characteristics to be applied on equipment and piping originated from this analysis shall comply with disposed on TS on reference [6].

34. The PFP project shall comply with disposed on TS on reference [6].

7.2. Piping Loss of Physical Integrity Analysis Requirements

The piping collapse analysis shall consider movement restrictions imposed by supports and equipment inlets.

For pipes with External Diameter and Thickness ratio between 15 and 20, both criterion provide approximate results. However, when External Diameter and Thickness ratio is out of this range, it is recommended the following:

- Usage of "Ductile Burst Criteria" for pipes which External Diameter and Thickness ratio is smaller than 15.
- Usage of "Rupture Stress Criterion" for pipes which External Diameter and Thickness ratio is greater than 20.

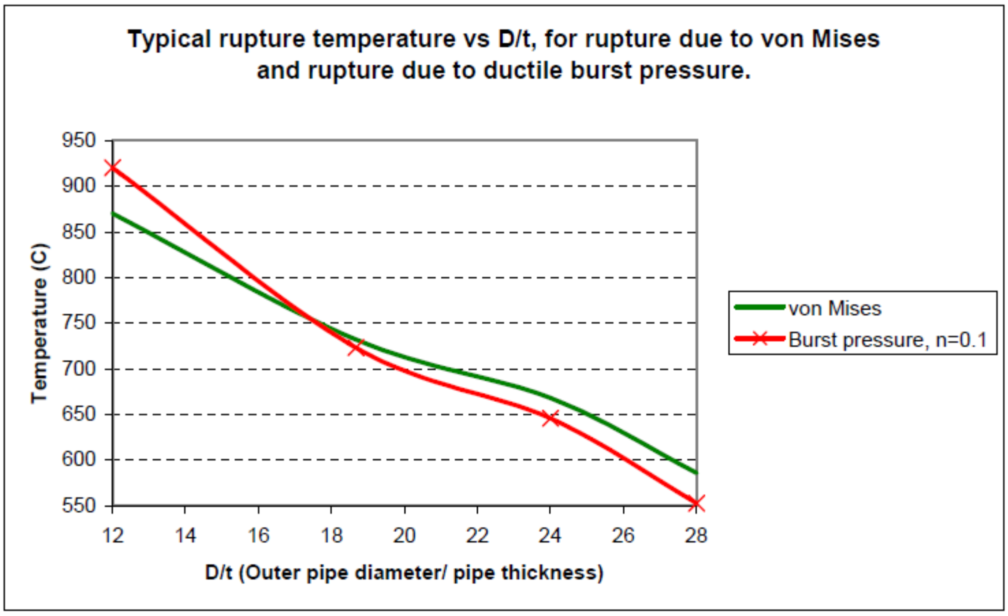

Figure 1: Difference between rupture temperature based on "Ductile Burst Criteria" and "Rupture Stress Criterion".

For piping exposed to internal pressure, radial stress, circumferential and longitudinal shall be calculated by Lamé equations as below:

$$\sigma_r = \frac{\left(pd^2 - \frac{pd^2D^2}{4r^2}\right)}{D^2 - d^2} \qquad (1)$$

$$\sigma_h = \frac{\left(pd^2 + \frac{pd^2D^2}{4r^2}\right)}{D^2 - d^2} \qquad (2)$$

$$\sigma_l = \frac{pd^2}{D^2 - d^2} \quad (3)$$

Where:

D → Pipe external diameter
d → Pipe internal diameter, d = D - 2t
p → Internal pressure
r → Radial coordinate
t → Pipe thickness

σ_l → Longitudinal stress

σ_h → Circumferential stress

σ_r → Radial stress

$$\sigma_a = \frac{F_a}{A_p} + \frac{M}{W} \quad (4)$$

Where:

σ_a → Longitudinal stress due to external forces
AP → Pipe section area
W → Pipe section resistance module
F_a → Axial force
M→ Maximum bending moment through the pipe

The resultant maximum axial stress, $\boldsymbol{\sigma}_{ax}$, on section is given by equation:

$$\sigma_{ax} = \sigma_l + \sigma_a \quad (5)$$

7.2.1. Rupture Stress Criterion

To determine pipe failure exposed to pressure and axial stress, the von Misses stress shall be calculated as follows:

$$\sigma_e = \left(\sigma_r^2 + \sigma_h^2 + \sigma_{ax}^2 - \sigma_r\sigma_h - \sigma_r\sigma_{ax} - \sigma_h\sigma_{ax}\right)^{\frac{1}{2}} \quad (6)$$

Where:

σ_{ax} → Axial stress

σ_e → Equivalent stress

σ_h → Circumferential stress

σ_r → Radial stress

The onset of yield is defined as

$$\sigma_e = f_y \qquad (7)$$

$\sigma_e \le f_y$, Corresponds to the elastic behavior

f_y → Yield strength of a representative tensile specimen

Substituting equations (1), (2) and (5) in equation (6), and applying yield criterion (7):

$$f_y^2 = \left(\frac{pd^2}{D^2 - d^2}\right)^2 + 3\left(\frac{p\,D^2}{D^2 - d^2}\right)^2 + \sigma_{ax}^2 - 2\frac{pd^2}{D^2 - d^2}\sigma_{ax} \qquad (8)$$

Substituting equations (3), (5) in equation (8):

$$f_y^2 = 3\left(\frac{p\,D^2}{D^2 - d^2}\right)^2 + \sigma_a^2 \qquad (9)$$

Although the von Misses criterion is based on elastic behavour, in a way that yielding occurs when, $\sigma_e = f_y$, it is assumed here that von Misses equivalent stress formulation is valid for stress above the yield stress, and, therefore, pipe rupture is defined when:

$$\sigma_e = UTS \qquad (10)$$

Where,

UTS → Ultimate Tensile Stress.

The final equation to compare the resistance limit is given by equation (11).

$$\sigma_e^2 = 3\left(\frac{p\,D^2}{D^2 - d^2}\right)^2 + \sigma_a^2 \le UTS \qquad (11)$$

The use of more accurate methods, alternatively to the proposed one, can be evaluated along with Petrobras. The aditional longitudinal stress, σ_a, shall be calculated, considering additional weight loads from pipe / valves / accessories / derivations etc. The longitudinal stress σ_{displ}, which represents support restrictions and pipe thermal alongation, shall be considered as part of stress σ_a. However, when material starts to yield this stress component usually desappears, and σ_{displ} can be neglected.

Considering this, the following simplifications can be made:

- $\boldsymbol{\sigma}_a$ = 30 MPa in many cases will represent a conservative approach. This value is from loads due to pipe weight itself, segments located between supports without the presence of concentrated weights;
- If pipe space has the presence of the weight of valves / connections / subsegments, etc, $\boldsymbol{\sigma}_a$ shall be calculated instead of using the proposed 30 MPa. This calculation shall include all external loads, and the calculated longitudinal stress component shall be used as value for $\boldsymbol{\sigma}_a$, even if it is smaller than 30 MPa.

When a pipe stress model is available, it is recommended to set pipe stress model´s pressure term to zero to get an idea of the longitudinal stress component (this resource can be useful in one or other pipe where stress of 30 MPa can be in a big degree of conservativeness).

7.2.2. Ductile Burst Criteria

The Burst criteria for pressurized pipe is based on equations from reference [2].

For an exposed pipe exposed only to the internal pressure, the Burst pressure is:

$$p_{iR} = 2k \frac{t}{D - t} f_{u,T} \qquad (12)$$

Where the correction factor, k, based on piping deformation and material strain hardening is:

$$k = \left[\left(\frac{1}{\sqrt{3}} \right)^{1+n} + \left(\frac{1}{2} \right)^{1+n} \right] \qquad (13)$$

t→ Pipe thickness
D→ Pipe external diameter
$f_{u,T}$ → Ultimate strength at elevated temperatures
n → Hardening index

The value of correction factor, k, for different hardening index, n, is given on

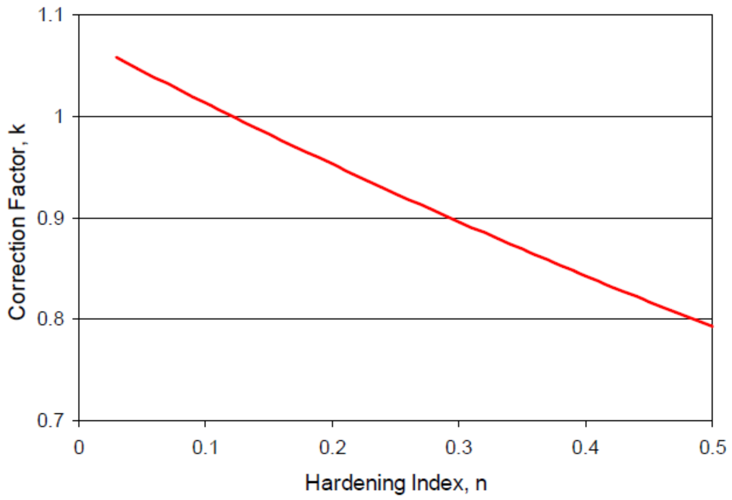

Figure 2: Values of correction factor, k, as function of hardening index n

In the presence of an axial stress or compression stress different from cap-end conditions, the general equation for ductile rupture is:

$$p_{iRa} = \min\left[\frac{1}{2}(p_{iM} + p_{iT}), p_{iM}\right] \tag{14}$$

With:

$$p_{iT} = p_{ref} \tag{15}$$

$$p_{iM} = \frac{\left(k_L + k_M^{0.5}\right)}{k_N} p_{UTS} \tag{16}$$

Where:

$$p_{UTS} = 2\frac{t}{D-t} f_{u,T} \tag{17}$$

$$p_{ref} = \frac{1}{2}\left(p_{ref\,M} + p_{ref\,T}\right) \tag{18}$$

$$p_{refM} = \left(\frac{2}{\sqrt{3}}\right)^{1+n}\left(\frac{1}{2}\right)^{n} p_{UTS} \tag{19}$$

$$p_{refT} = \left(\frac{1}{2}\right)^{n} p_{UTS} \tag{20}$$

$$k_M = k_L^2 - k_N k_O \tag{21}$$

$$k_L = \left(\frac{2}{3}\right)\left[1 - 2t\frac{e^{-n}}{D-t}\right] e^{-n}\left\{\frac{\sigma_a}{f_{u,T}}\right\} \tag{22}$$

$$k_N = 1 + \left(\frac{1}{3}\right)\left[1 - 2t\frac{e^{-n}}{D-t}\right]^2 \tag{23}$$

$$k_O = \left(\frac{4}{3}\right)\left\{\frac{\sigma_a}{f_{u,T}}\right\}^2 e^{-2n} - \left(\frac{p_{ref\,M}}{p_{UTS}}\right)^2 \tag{24}$$

And,

p_{iR} → Internal pressure at ductile rupture

p_{iRa} → The p_{iR} adjusted for axial load

$f_{u,T}$ → The ultimate strength at elevated temperature

σ_a → The longitudinal stress due to the external force.

For carbon steel, the hardening index n is normally between 0,06 and 0,14.

For stainless steel, the hardening index n can be as big as 0,30. For Burst pressure calculations, n shall be obtained by a direct adjust on relation true stress-yield using the following equation:

$$\sigma_c = C\varepsilon^n$$

Where:

$$C = \left(\frac{1}{n}\right)^n f_u$$

f_u → Tensile strength, UTS, of a representative tensile specimen
n → Hardening index used to obtain a curve fit of the true stress-strain curve derived from the uniaxial tensile text
ε → True strain

σ_c → True stress

If sufficient information regarding the stress strain relation is not available, the following values for n can be used:

Carbon Steel: n = 0,10
Stainless Steel: n = 0,15

7.2.3. Piping Physical Integrity Loss Criteria

To determine whether pipe will collapse or not, it is necessary to calculate rupture pressure or rupture stress of elements that composes it. Actuating stress as well as internal pressure for every event instant of time shall be compared with element UTS stress or DBP.

The piping loss of physical integrity is defined when von Misses stress versus UTS curves, or von Misses stress versus DBP curves as a function of time, crosses each other.

The stress comparison curves as a function of time shall be presented on report of item 8 for all evaluated piping.

7.3. Equipment Physical Integrity Loss Criteria

Equipment physical integrity loss characterizes when von Misses stress versus UTS curves as a function of time crosses each other.

The stress comparison curves as a function of time shall be presented on report of item 8 for all evaluated equipment.

7.4. Escalation Evaluation Criterion and MSF Impairment Frequency Calculation

7.4.1. Equipment Escalation Evaluation Criterion

For equipment escalation evaluation, it is not necessary to evaluate MSFs impairment, provided that it is not acceptable equipment rupture which collapse occurs before 10 minutes from fire start or internal pressure at collapse moment exceeds 4,5 barg according to industry practice [5].

For equipment that are in this condition, the following steps shall be followed:

1. Applicable to CASE 1 and CASE 2:

   Reevaluate all equipment that collapsed using FEA, if they have not been assessed using this methodology;

2. Applicable to CASE 1 and CASE 2:

   If equipment collapse is confirmed on step 1, depressurizing system associated to the equipment shall be reassessed (E.g.: BDV FO diameter, PSV, PRV, etc.) in order to check whether it is possible to re-adjust this system to avoid equipment collapse. This evaluation shall be made by the Designer and the Study Consulting and shall comply with maximum depressurizing system release rate due to processing or equipment limitations;

3. Applicable to CASE 1 and CASE 2:

   If it is not possible to perform step 2, equipment wall thickness shall be increased, if possible.

   In this case, it shall be demonstrated by the Study Consulting repeating step 1 that with the new wall thickness does not lead to equipment collapse, and this shall be demonstrated alongside with the new values on report of item 8;

4. Applicable only on CASE 2:

If it is not possible to perform steps 2 to 3, it shall be calculated the required time to open BDVs in a way that do not lead to equipment physical loss of integrity.

For this kind of analysis, it is also responsibility of Study Consulting and Designer to determine the BDVs opening sequence that indicates the smallest PFP area to be applied on equipment, which used softwares and premises of this analysis shall be pre-approved by Petrobras and also be described and detailed on report of item 8;

5. Applicable to CASE 1 and CASE 2:

If it is not possible to perform steps from 2 to 4, it shall be applied PFP on the equipment. In this case, Study Consulting shall inform temperature and time at moment of collapse for the protection design. Study Consulting and Designer shall inform the PFP rating (E.g.: J-15, J-60, etc.), material specification and it´s certificate, which shall comply with disposed on Passive Fire Protection TS [6].

7.4.2. Piping Escalation and MSF Impairment Frequency Calculation Criterion

After pipe collapse analysis is performed for each fire scenario identified on Installation Fire Propagation Study, it shall be verified if physical integrity loss of these elements is capable to impair some Installation MSFs. The impairment criterion disposed on Annex III of the Fire Propagation Study TS [1] shall be used for this evaluation.

For piping collapse effects analysis, it shall be considered piping full-bore rupture. To represent thermal effects of this rupture, it shall be chosen representative segment of the module that has better similarity in terms of frequency, inventory (E.g.: physical-chemical properties, volume, etc.) and leak rate. In case of Installation Fire Propagation Study did not make CFD simulations on any similar segment that might be used, it is Study Consulting's responsibility to perform additional CFD simulations to perform this evaluation.

For piping collapse effects analysis on MSFs, it shall be considered the thermal records as function of time of the initial fire scenario that leads to piping collapse, and, additionally, thermal records as a function of time of the representative segment referred on above paragraph. For this analysis, it shall be considered MSFs protections recommended on the Installation Fire Propagation Study, aiming to identify additional protection, or relocation of the existent ones.

In case of some of the MSFs is impaired due to piping collapse, the scenario fire frequency that led to the collapse shall accumulated for the MSF that are affected by the initiator scenario. This process shall be repeated for all others fire scenarios that can affect the analyzed piping.

Once this process is finished, the total impairment generated by the escalation scenarios for every MSFs shall be summed to the impairment frequencies for fire load for every MSFs that were calculated on Installation Fire Propagation Study.

The MSFs impairment calculation frequencies shall be made separately for CASE 1 and CASE 2.

If this new impairment frequencies are higher than the tolerability criterion stablished on Safety Engineering Guidelines [4], it shall be followed the following process aiming to guarantee that the MSFs total impairment frequency are below of the tolerability criteria:

1. Applicable to CASE 1 and CASE 2:

   Reevaluate all equipment that collapsed using FEA, if they have not been assessed using this methodology.

2. Applicable to CASE 1 and CASE 2:

   If piping collapse is confirmed on step 1, depressurizing system associated to the piping shall be reassessed (E.g.: BDV FO diameter, PSV, PRV, etc.) in order to check whether it is possible to re-adjust this system to avoid piping collapse.

   This evaluation shall be made by the Designer and the Study Consulting and shall comply with maximum depressurizing system release rate due to process or equipment limitations.

3. Applicable to CASE 1 and CASE 2:

   If it is not possible to perform step 2, change spec for a superior one, if possible.

   In this case, it shall be demonstrated by the Study Consulting, repeating step 1, that with the new spec piping collapse is not possible. This evaluation shall be demonstrated alongside with the new values on report of item 8.

4. Applicable only on CASE 2:

   If it is not possible to perform steps 2 to 3, it shall be calculated the required time to open BDVs in a way that do not lead to piping physical loss of integrity.

   For this kind of analysis, it is also responsibility of Study Consulting and Designer to determine the BDVs opening sequence that indicates the smallest PFP area to be applied on piping. The software used and premises of this analysis shall be pre-approved by Petrobras and described and detailed on report of item 8.

5. Applicable to CASE 1 and CASE 2:

   If it is not possible to perform steps from 2 to 4, it shall be applied PFP on piping. In this case, Study Consulting shall inform temperature and time at the moment of collapse for the protection design. Study Consulting and Designer shall inform the PFP rating (E.g.: J-15, J-60, etc.), material specification and it´s certificate, which shall comply with disposed on Passive Fire Protection TS [6].

8. ANALYSIS REPORT

By the end of the analysis, Study Consulting shall issue reports that contain, at least, the following requisites described in this item. The final report shall be issued in Portuguese and in English. The partial report can be issued in one of these idioms, preferably in Portuguese.

8.1. Partial Report

At least one partial report shall be issued by the Study Consulting to Petrobras.

The first one informative, shall contain, at least:

1. Installation description;
2. Reference documents;
3. Methodology;
4. Softwares descriptions used in the analysis;
5. Methodology description used to perform PFP optimization to be applied on piping;
6. Premises;
7. Analyzed fire scenarios;
8. Meteorological conditions;
9. Depressurizing criteria;
10. Considered SDVs closing time;
11. List of analyzed piping and equipment, informing:
    a. Tag;
    b. Equipment/pipe material;
    c. Associated BDV and/or PSV. If the segment cannot be depressurizing, this shall be indicated;
    d. External diameter (mm);
    e. Equipment/Piping thickness (mm);
    f. Operational pressure (bar);
    g. Thermal isolation thickness, if existent (mm);
    h. Type of thermal isolation, if existent;
    i. Equipment or piping associated P&ID;

j. Equipment or piping physical location;

k. Equipment or piping associated PFD;

l. Equipment or piping associated stream of the PFD;

12. Tables containing equipment and piping analysis results with, at least, the following:

    a. Piping/equipment tag;

    b. Equipment or piping physical location;

    c. Internal pressure at the instant of collapse (bar);

    d. Elapsed time from fire start until physical integrity loss (s);

    e. Released inventory at the moment of collapse (kg);

    f. Equipment/piping surface temperature at the moment of collapse (°C);

    g. Piping/equipment that had physical integrity loss.

    h. For equipment that occur physical integrity loss, indicate which recommendation was chosen from steps presented on item 7.4.1.

    i. For piping that occur physical integrity loss, indicate which recommendation was chosen from steps presented on item 7.4.2.

13. Fire scenario that generates the physical integrity loss of equipment/piping, informing module and segment at which the fire is originated.

14. Table with optimized BDV’s opening times in seconds, applicable only to CASE 2, illustrating fire origin module, BDV’s tags and BDV’s module physical location.

15. Summarized table containing all total frequencies of MSFs, detailing impairment frequencies from Fire Propagation Study and those from piping collapse analysis under fire.

16. Table listing P&IDs associated with equipment/piping that had protection recommendations;

17. Conclusions;

18. Recommendations also having:

    a. If PFP is recommended on piping or equipment, a table shall be presented having, at least:

        i. Recommendation number;

ii. Equipment/piping tag;

iii. Physical location of equipment/piping;

iv. Type of PFP information (eg: intumescent coating or blanked) with protection rating (E.g.: J-15, J-30, J-60, etc.) indication and equipment and/or piping collapse temperature to be protected;

v. All equipment and/or piping associated to their trains their back-up shall also be informed;

vi. In piping case, there shall be informed of all pipes that need to be protected, including by-passes, segments and sub-segments;

vii. PFP area and weight associated to the protected equipment and/or piping segments;

19. Annexes containing:

a. Meetings records shall be presented in annex, especially those that validates methodology stages;

b. Editable electronic spreadsheet having all evaluated fire scenarios and all MSFs, with the correlation between scenarios and MSF impairment. This table shall also have impairment frequencies from Installation Fire Propagation Study, the impairment from piping collapse analysis and the total (sum of the previous two frequencies). This table shall also allow to modify BDV's opening times according to the fire scenarios and recalculate MSFs impairment frequencies due to piping collapse by this modification, according to example presented on ANNEX II – EDITABLE ELECTRONIC TABLE EXAMPLE;

c. Comparison curves of stress versus resistance (UTS) as a function of time of all equipment and piping evaluated on items 7.2 and 7.3;

d. Indication of piping segments to be protected on isometrics, with protection rating to be applied. Study Consulting and Designer are responsible to present this information.

e. Indication of piping segments to be protected in P&IDs. Study Consulting and Designer are responsible to present this information.

8.2. Final Report

The Final Report corresponds to the issuance of the report under revision 0, original issuance. For this issuance, 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 Management of Changes TS [3], or if it is identified any necessity to correct items in the report.

Final report issuing is Designer's responsibility. Final report shall complement Study Consulting's report and, additionally, study recommendations treatments to be implemented by the designer. Report codification and its stamp shall identify the designer as document issuer. Codification shall be accordingly to Petrobras standard N-1710 and its format accordingly to N-381.

9. MEETINGS

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

9.1. General Considerations

The follow up of the development of the study shall be carried out by the team of the Designer with Petrobras participation, where 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 revision.

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.

9.2. Planning Meeting

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

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

- Delivery of the project documentation necessary for the analysis, including the 3D model of the Facility.

- 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:

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 10 working days for comments of partial report and 10 working days for comments of final report by Petrobras.

9.3. 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 shall sign an accepted document containing the pending list, if any.

Note: The Designer, as responsible for project’s changes management, must inform the other parties involved of any change in the project that affects the study and update the documentation 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.

The participants in the documentation analysis shall comprise professionals involved in the design and the discipline's leaders. This meeting is optional for Petrobras.

9.4. Meeting of Premises and Methodology

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

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

Assumptions shall be defined by mutual agreement between the parties involved and shall be included in the study report, item 8.

Participants of the meeting of premises and methodology shall comprise professionals involved in the study, the discipline leaders of the Designer and Petrobras responsible for the follow-up of the study.

9.5. Meeting of Follow Up and Presentation of Preliminary Version of the Study Report

Meeting dedicated to present analysis results, proposed recommendations and partial report.

This meeting shall happen before partial and final reports issuing.

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

10. 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 9 of this TS.

11. TECHICAL 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).

12. 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.

13. 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.

14. ANNEX I – EPC ANALYSIS GENERAL DIAGRAM

Annex%20I.PPTX

15. ANNEX II – EDITABLE ELECTRONIC TABLE EXAMPLE

Annex II.xlsx