

ZENER Lomé, Togo

Propane Storage Tank Farm

Quantitative risk assessment

Doc. No. P0030364-1-H2 Rev. 1 – April 2022

Rev.	Description	Prepared by	Controlled by	Approved by	Date
1	Issue for Construction	M. Galmozzi	M. Pontiggia	G. Uguccioni	29/04/2022
0	First Issue	M. Galmozzi	M. Pontiggia	G. Uguccioni	13/04/2022

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ABBREVIATIONS AND ACRONYMS

BDV	Blow Down Valve
ESDV	Emergency Shut Down Valve
ET	Event Tree
FERA	Fire and Explosion Risk Assessment
H&MB	Heat & Material Balance
IDLH	Immediately Dangerous to Life and Health
LC	Lethal Concentration
MOV	Motor Operated Valve
PES	Potential Explosion Source
PFD	Process Flow Diagram
P&ID	Piping & Instrument Diagram
PSV	Pressure Safety Valve
RP	Release Point
SDV	Shut Down Valve
VCE	Vapour Cloud Explosion

1 INTRODUCTION

1.1 GENERAL

Scope of the work is the development of the Quantitative Risk Assessment (QRA) for the Zener LPG Terminal and Storage Facilities. This study will cover the existing terminal facilities and proposed Propane storage terminal of Zener (with a capacity of 3000 tonnes) to be developed alongside its Butane filling station, namely, import and export pipelines, storage, compressor station and loading station.

ZENER's LPG storage site is made up of two parts: one part for bulk storage and the other part for loading gas cylinders. The bulk storage area is composed of tanks for the storage of butane (2500 tons) which is the existing one and the other part consists of propane storage tanks (3000 tons) under construction. A water tank for firefighting with a capacity of 1500 m³ is present. The plant is equipped with four firefighting pumps: a diesel pump with a flow rate of 780 m³/h, two electric pumps of 280 m³/h each and a jockey pump for maintaining pressure in the pipeline for firefighting. The firefighting system is managed automatically by a deluge system. Three pump houses are present, one for the butane storage area and the other two for the propane storage site. There are in addition two tank truck loading station and a control room. For the gas bottle unloading area, there are a 12-bottle filling carousel, a fixed bottle loading station and three storage tanks (260 m³).

Compared to the neighborhood, Zener plant is located in the industrial zone. It should be noted that in the east side of the plant there is a bare land serving as a security corridor between Zener plant and the global contour power station, to the west there are SORETRAP company stores, to the north the SOTOTOLE store and to the south the Lomé-Aného road.

1.2 SCOPE OF THE DOCUMENT

A Quantitative Risk Assessment (QRA) is a systematic process, which assesses the overall risks of the complete facilities due to hazards from Fire, Explosions, Toxic Gas events etc. This study will cover the existing terminal facilities and proposed Propane storage terminal of Zener (with a capacity of 3000 Tonnes) to be developed alongside its Butane filling station, namely, import and export pipelines, storage, compressor station, loading station and ship unloading operation.

The QRA will estimate the risks to individuals, group of individuals, population and internal building from all major risk contributors during normal operations of the plant.

1.3 COMPANY REFERENCE DOCUMENTS

The following company documents have been considered:

BNH-2001-HSE-PID-001_Rev.000B	PID for Fire Water Network - Propane Facilities
BNH-1018-PR-002	PID for Fire Water Network - Butane Facilities
BNH-2001-HSE-LYT-001_Rev.000B	Fire Fighting Pipeline & Equipment Layout Plan – Propane Facilities
BNH-2001-HSE-LYT-002_Rev.000B	F&G Detection Layout – Propane Facilities
BNH-2001-HSE-LYT-003_Rev.000B	Escape Route Layout
BNH-2001-HSE-PHL-001_Rev.000B	HSE Philosophy
BNH-2001-HSE-PHL-002_Rev.000B	F&G Detection Philosophy
BNH-2001-HSE-RPT-001_Rev.000B	Fire Water Demand Report – Propane Facilities
BNH-2001-HSE-DS-001_Rev.000B	Data Sheet for Fire Fighting Equipment

BNH-2001-HSE-LYT-004_Rev.000B Fire Piping Support Layout – Propane Facilities

2 QRA METHODOLOGY

The QRA will be carried out according to the following steps:

- ✓ Hazard Identification;
- ✓ Frequency assessment;
- ✓ Consequences assessment;
- ✓ Risk assessment.

2.1 IDENTIFICATION OF CREDIBLE HAZARDS

The scope of this step of the assessment is to identify potential sources of loss of containment from process equipment included in the Scope of Work.

Loss of containment from process equipment such as pipework, valves and flanges is possible due to different causes, such as corrosion or mechanical defects or failure due to incorrect operations.

In order to identify credible hazardous events that can lead to Fire, Explosion and Flammable Gas Dispersion scenarios, loss of containment events will be independently taken into account within the plant areas with isolated flammable inventory. This is due to the fact that on detection of a condensate or gas flammable release, the process is automatically shut down and isolated by means of emergency shutdown valves (ESDVs) according to Zener Cause & Effect Chart [17].

More details about identification of credible hazards and its relevant assumptions are given in Paragraph 3.1.

According to assumptions given in Paragraph 3.1, as a result the plant area will be firstly subdivided into Isolatable Sections and then, basing on streams specifics, Release Points will be defined within each Isolatable Section in order to better account for operative conditions and location of the potential releases.

Details on how Isolatable Sections and Release Points are identified are provided in Paragraph 3.2 and 3.3.

Accidental releases due to random rupture events from equipment and piping will be evaluated considering a range of possible rupture sizes, from small to major and assuming that a loss of containment event may occur within all the process items of the installation containing flammable substances.

More details about release cases and their relevant assumptions are given in Paragraph 3.4.

2.2 FREQUENCY ASSESSMENT

For each identified scenario (i.e. identified Release Point in relevant Isolatable Section), the relevant release frequency will be assessed based on the expected rate of failure associated to selected release section dimensions (defined in Paragraph 3.4).

2.2.1 Random Rupture – Parts Count

The frequency with which hydrocarbon releases may potentially occur for each Release Point will be calculated through the "parts count" exercise.

The foresaid method involves counting items (valves, flanges, instrument connections, vessels and other equipment) and estimating piping length from the available documentation (P&IDs, PFDs and Plant Layout) for each representative Isolatable section and multiplying the number of equipment parts with generic release frequency for each component, provided by the IOGP Data Directory [1], [15], to obtain the total release frequency. With regard of the length of the piping, it shall be determined based on the isometric drawings (when available) or estimated from layout information.

Finally, it is worth remarking that spare units will not be considered for the calculation of the release case frequency (i.e. frequency of release will be calculated accounting for the working unit(s) only whereas for spare unit(s) no frequency of release will be assigned since they are normally without flow).

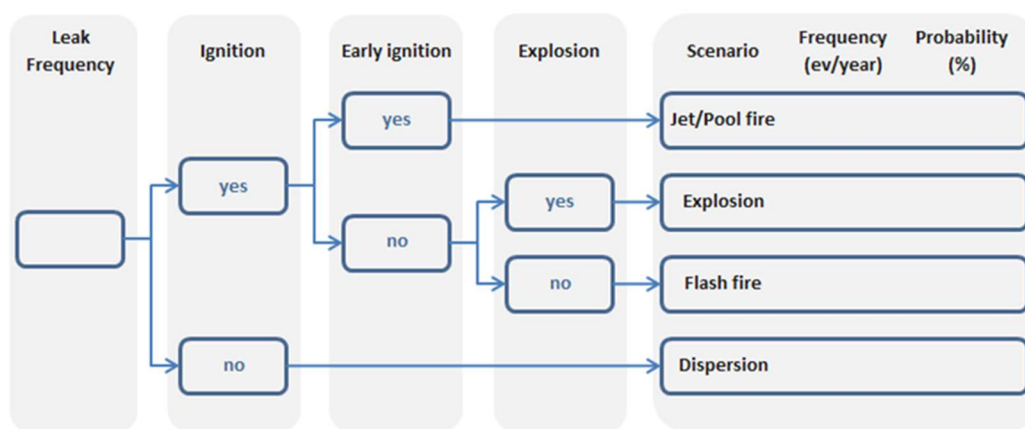
More details about parts count exercise, its relevant assumptions and outcomes are given in Paragraph 3.5.

2.2.2 Event Tree Analysis

Starting from the release frequency of occurrence calculated as described in the previous paragraph, the frequency of each specific scenario (Jet / Pool fire, Flash Fire, Explosion and Dispersion) will be calculated for each Release Point identified by Event Tree Analysis, adopting ignition probability values from international literature (IP-UKOOA report [2] and OGP report [10]).

An Event Tree (ET) is a visual representation of all the events which can occur in a system during an escalating incident sequence. The starting point ("initiating event") is the undesired accidental event (in this case, the loss of containment of hazardous material). The "trees" display the sequences of events: each possible scenario is quantified on probabilistic basis. Each branch of the event tree represents a separate accident sequence (that is a defined set of functional relationships between the initiating event and the subsequent events), as shown in figure below (Figure 2-1):

Figure 2-1: Typical Event Tree



More details about event tree analysis and its relevant assumptions are given in Paragraph 3.6.

A credibility threshold in terms of number of individual scenarios per year is set in order to avoid overestimation of effects. The assumed threshold values are reported in Paragraph 3.7.

2.2.3 Frequency assessment for BLEVE

The frequency of BLEVE will be calculated for each tank as the sum of the frequency of Jet fire events impairing the considered tank for more than 5 minutes with a thermal radiation higher than 37.5 kW/m².

2.2.4 Results

The computed results of the Event Tree Analysis will be presented in the form of tabulated values. The frequencies of occurrence of final hazardous scenarios (Jet / Pool Fire, Flash Fire, Explosion and Dispersion) starting from leakage frequencies will be calculated for each Release Point identified. BLEVE frequency will be calculated and presented for each tank.

2.3 CONSEQUENCE ASSESSMENT

Consequence assessment has the purpose to establish the potential outcomes of an accidental release of a toxic or flammable material, to:

- ✓ Flash Fire: establish the distance reached by flammable concentrations in case of flammable clouds (release of gas or evaporation of flammable liquid pools);
- ✓ Jet/Pool fire: establish the distance to hazardous levels of heat radiation;
- ✓ Explosion: establish the distance to hazardous levels of overpressure;

The DNV PHAST software version 8.22 [3] is used to analyze the credible incidental scenarios which can occur in consequence of a loss of containment event; simulations will be based on the process data provided (operating conditions, composition, etc.) [16].

The following incidental scenarios are taken into account:

- ✓ Jet Fire;
- ✓ Pool Fire;
- ✓ Flash Fire;
- ✓ Explosion;
- ✓ BLEVE

The Explosion analysis requires additional elaboration of the gas dispersion data, to ensure that explosion is simulated only if the gas cloud reaches areas where the congestion is such to cause explosion. Also, only the amount of gas that is contained within a congested area is considered. This allows a more realistic assessment of the explosion overpressures.

The credible explosion scenarios assessment will therefore be performed in the following steps:

- ✓ Identification of congested areas in each facility;
- ✓ Flammable gas dispersion analysis to assess the probability of involvement of each flammable release on the identified congested areas;
- ✓ Explosion frequency assessment for each of the identified congested areas;
- ✓ Explosion consequences modeling.

More details about consequence assessment and its relevant assumptions are given in Paragraph 3.8; fluid composition and its relevant assumptions are given in Paragraph 3.9 and definition of congested areas and its relevant assumptions are given in Paragraph 3.10.

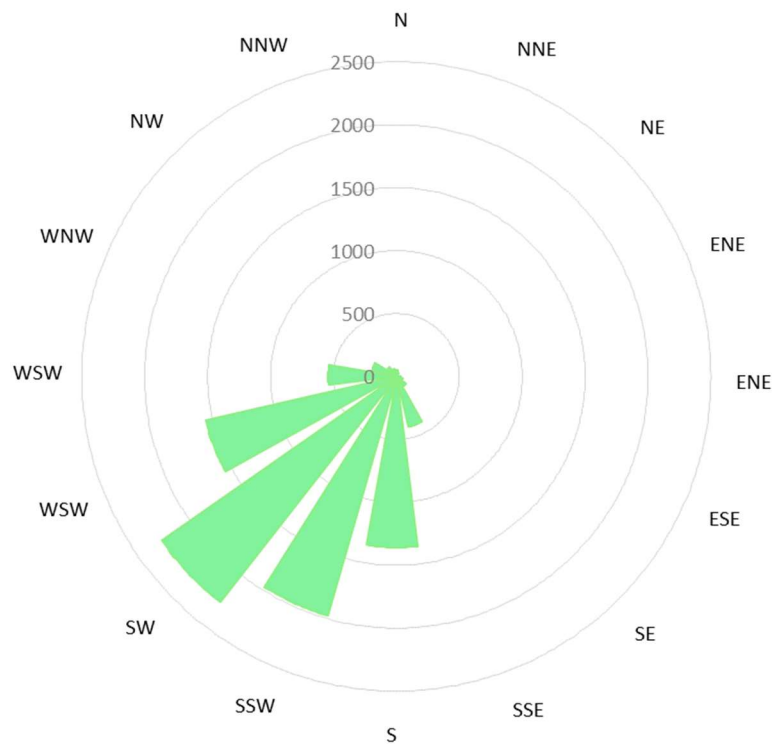
2.3.1 Meteorological conditions

Basing on information provided by Client, weather conditions (historical meteorological data of air temperature, relative humidity, wind direction and intensity) will be considered to perform the consequence analysis.

In particular, meteorological data that will be used to conduct the consequence assessment will be those found in meteoblue web site [12], where information relative to Lomé, Togo will be considered to be applicable to the area of interest.

Regarding wind direction, the following wind rose data for year 2019 (Figure 2-2) are available.

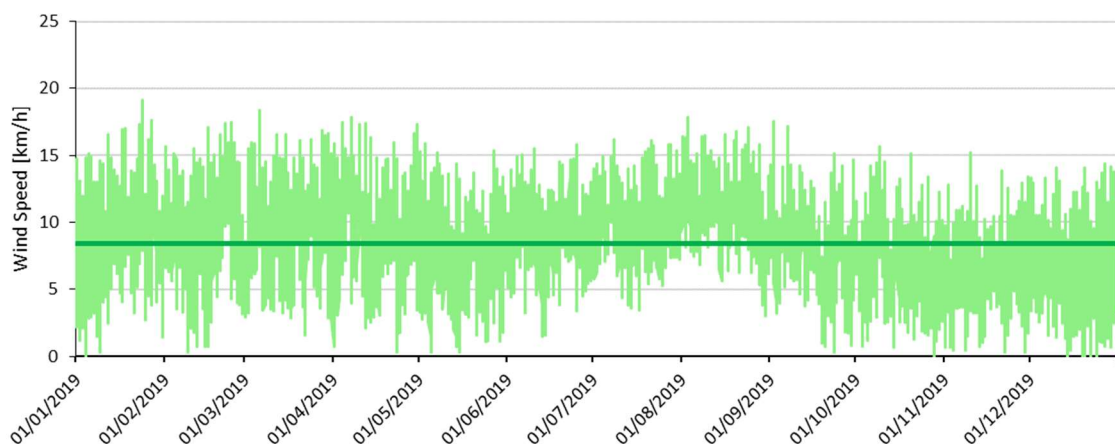
Figure 2-2: Wind rose data



The wind rose shows how many hours per year the wind blows from the indicated direction, From the Figure, we can identify that the wind blows mainly from SW.

Regarding wind speed, observed data at 10 m of altitude are available for the year 2019. These are shown in the following Figure 2-3.

Figure 2-3: Wind speed in 2019



As shown in the figure above, the minimum recorded wind speed is lower than 1 km/h, the maximum is around 20 km/h (5 m/s). The yearly mean wind speed is around 8 km/h (2 m/s).

For consequences and risk calculations, the literature suggests the use of two atmospheric stability classes [4]: stable atmosphere (Pasquill Class F) and neutral atmosphere (Pasquill Class D). Moreover, it is suggested to use two specific wind intensities: for the Pasquill Class F, a wind velocity of 2 m/s is to be used (hence, class 2F) and for the Pasquill Class D, 5 m/s (hence, class 5D). Stable conditions are associated to lower dilution and higher concentration at ground level, due to a more difficult mixing of the pollutant within the vertical layers of the atmosphere. Low velocities are considered to reduce dilution effect due to wind turbulence effects while medium-high velocities are used to maximize the reachable distance of the cloud dispersion. Higher wind speeds are not considered because the correspondent high degree of turbulence would considerably increase dilution effects and thus leading to less severe consequences.

Considering available wheatear data, it is possible to observe that common literature approach previously introduced will be substantially representative of the meteorological conditions for the area of interest.

Therefore, the consequence analysis will be carried out considering the following atmospheric conditions:

- ✓ Class 2F (i.e. Pasquill stability class F and 2 m/s wind speed);
- ✓ Class 5D (i.e. Pasquill stability class D and 5 m/s wind speed);

2.3.2 Results

Results for the consequence assessment are the distances to the reference values of heat radiation (considering decrease of release flow rate with time following plant shutdown), distance to the reference values of peak overpressure, distance to flammability limits, explosive mass, jet flames length and pool diameter as applicable.

The computed results of the consequence assessment will be presented in the form of

- ✓ Identification of Potential Explosion Source (PES)
- ✓ tabulated distances for each identified risk sources, for each rupture diameter and for each weather condition

The following threshold will be considered:

- ✓ for fire scenarios these will be in terms of heat radiation at 4.8, 6.3, 9, 12.5 and 37.5 kW/m² at 0 min for risk to people and 12.5 kW/m² and 37.5 kW/m² at 10 min for risk to assets
- ✓ for explosion scenarios these will be in terms of overpressure at 0.07, 0.14, 0.28, 0.3, 0.35, 0.5 barg
- ✓ for flammable dispersion scenarios these will be in terms of flammable concentration distances at LFL and LFL/2 calculated at peak flow rate
- ✓ for BLEVE:
 - overpressure will be at 0.07, 0.14, 0.28, 0.3, 0.35, 0.5 barg;
 - heat radiation will change with regard to BLEVE duration.

2.4 QRA RISK ASSESSMENT

A Quantitative Risk Assessment (QRA) is a systematic process, which assesses the overall risks of the complete facilities due to hazards from Fire, Explosions, Toxic Gas events etc. This study will cover the existing terminal facilities and proposed Propane storage terminal of Zener (with a capacity of 3000 Tonnes) to be developed alongside its Butane filling station, namely, import and export pipelines, storage, compressor station, loading station and ship unloading operation.

The QRA will estimate the risks to individuals, group of individuals, population and internal building from all major risk contributors during normal operations of the plant.

2.4.1 Targets to be considered

Within QRA analysis, effects on workers safety and population will be considered. The following group of people will be considered:

- ✓ External population
- ✓ Operators working in office
- ✓ Operators working in Control Room
- ✓ Operators working in Filling center
- ✓ Operators working in Existent Gantrys
- ✓ Operators working in New Gantrys
- ✓ Operators working in Security Post

2.4.2 Risk ranking

Individual risk is the frequency at which an individual may be expected to sustain a pre-fixed level of harm from the deployment of specified hazards.

The level of harm for people is conventionally assumed the risk of death, and usually expressed as the frequency associated to fatality events per year.

The frequencies and the impacts of all the accidental scenarios will be taken into account in the calculation of the overall, aggregated, risk.

Location-specific individual risk (LSIR) identifies the risk calculated in a particular location, assuming permanent presence (24 hours per day, 365 days per year) of a hypothetical individual.

LSIR takes into account:

- ✓ Frequency of the release events;
- ✓ Likelihood of specific conditions determining the outcomes (including e.g. ignition probability, weather conditions, wind direction probabilities, etc.);
- ✓ Vulnerability (i.e. the fatality probability related to physical effects such as heat radiation, overpressure);
- ✓ Location of release sources according to project documentation;

The LSIR at a given location X is then calculated as follows:

$$LSIR(X) = \sum_l \lambda_l * \sum_s P_{scen_{s,l}} * \sum_w (P_{wind} * V(X))_{l,s,w}$$

where:

λ_l	Release Frequency (sum over release events, index l)
$P_{scen_{s,l}}$	Scenario Probability, given the release (sum over outcome scenarios, index s)
P_{wind}	Meteorological condition (including direction) Probability (sum over wind directions, index w)
V	Vulnerability

Individual Risk Per Annum (IRPA) is defined as the risk of fatality to a named individual, belonging to a working category present in the installation. Practically, IRPA values will be calculated from the corresponding LSIR values (outdoor or indoor) by including the 'presence probability' factor. Considering a realistic probability of presence, exposure risk level will decrease (because it would correspond a probability value lower than 1). However, to do so, it should be known the probability of presence of the personnel. Basing on information provided by Client relating to personnel presence (time duration, location, number of individuals), presence probability will be defined accordingly.

2.4.3 Risk Ranking for Fire Scenarios

For the assessment of fire heat radiation within the QRA the probit method will be used.

The Probit is a statistic method (namely the inverse cumulative distribution function associated with the standard normal distribution) widely used for regression modelling of binary response variables. In risk assessment, it is applied to calculate a “probability unit” linearly dependent upon the logarithm of the absorbed dose from which the percentage of people affected by a selected binary outcome (in this analysis fatality/no fatality) can be obtained.

Below is reported the Probit equation:

$$Pr = a + b \ln(I^n \cdot t)$$

Where:

- ✓ I: heat radiation
- ✓ t: time
- ✓ a: -36.38
- ✓ b: 2.56
- ✓ n: 1.333

In the following Table (Table 2-1), the vulnerability associated to the threshold values for heat radiation and an exposure time of 20 s, calculated with the above Probit equation, are given.

Table 2-1: Heat radiation thresholds and the correspondent people vulnerability

Radiation Flux (kW/m ²)	Fatality probability (%)	Exposure time (s)
4	1	20
12.5	10	20
37.5	99	20

People inside fireproofed shelters, buildings or enclosures shall be assumed to be safe. People inside not fireproofed buildings or enclosures shall be supposed to be exposed to a vulnerability rates equal to 10% of the probability of fatality for outdoor people.

2.4.4 Risk Ranking for Flammable gas dispersion scenarios

For Flash Fires it will be assumed that personnel located inside the footprint of the LFL have a 100% probability of fatality if they are outdoor and 50% of fatality if they are indoor, while the probability outside the footprint shall be assumed as zero as per Guidelines for Quantitative Risk Assessment (TNO Purple Book [4]).

People inside pressurized gastight shelters, buildings or enclosures shall be assumed to be safe.

2.4.5 Risk Ranking for Explosion Scenarios

The probability of fatality for workers in outdoor is 100% at 0.5 barg overpressure as per OGP Risk Assessment Data Directory, Report No. 434-14, “Vulnerability of Humans” [14]. This means that a 100% probability will be assumed for personnel exposed to overpressures equal or greater than 0.5 barg. In addition, in order to take into account of the effects arising from asset vulnerability, a 50% fatality probability will be assumed for personnel (within plant areas) exposed to overpressures equal or greater than 0.3 barg.

Table 2-2: Peak overpressure reference values for outdoor

Overpressure (barg)	Fatality probability (%)
0.07	1
0.3	50
0.5	100

People inside blast-proofed shelters, buildings or enclosures will be assumed to be safe if the incident overpressure on the building does not exceed the design value for blast resistance, otherwise for people indoor the probability of fatality depends on the strength of the building as defined in OGP Report No.434-15 [11] and API RP 752 [8]. In the Table below are reported the vulnerability values for indoor people that are applicable to all building designed without any blast resistance.

Table 2-3: Peak overpressure reference values for indoor

Overpressure (barg)	Fatality probability (%)
0.07	10
0.3	100

2.4.6 Risk Ranking BLEVE

For the assessment of BLEVE events, the thermal dose will be used to establish the probability of fatality. As reported in HSE UK [13], the following fatality will be considered basing on Thermal Dose Units (tdu):

Table 2-4: Thermal dose unit reference values

Thermal Dose Units (tdu) [(kW/m ²) ^{4/3} s]	Fatality probability (%)
1000	1
2000	50
3200	100

In order to associate to each thermal dose the relative thermal radiation threshold, the following correlation will be used:

$$I \left[\frac{kW}{m^2} \right] = \left(\frac{Thermal\ dose\ [tdu]}{t\ [sec]} \right)^{\frac{3}{4}}$$

Where:

- ✓ "I" is the thermal radiation
- ✓ "t" is the BLEVE duration in seconds (calculated by means of PHAST)

Therefore, for each BLEVE events, the duration will be calculated and then the thermal radiation values corresponding to 1000, 2000, 3000 tdu (respectively 1%, 50% 100% of fatality probability).

2.4.7 Risk Tolerability

To assess the tolerability of Risk to people, internationally accepted practices and literature will be used. Table 2-5 provide the risk levels used by HSE UK [18] for personnel.

Table 2-5: IR Acceptability Criteria (workers and industrial areas)

Level of IR	Risk Criteria
Broadly acceptable region	Risk < 1.00E-06 ev/y
ALARP Region	1.00E-06 ≤ Risk < 1.00E-03 ev/y
Unacceptable region	Risk ≥ 1.00E-03 ev/y

For residential areas, is considered acceptable a value of LSIR minor than 1E-06.

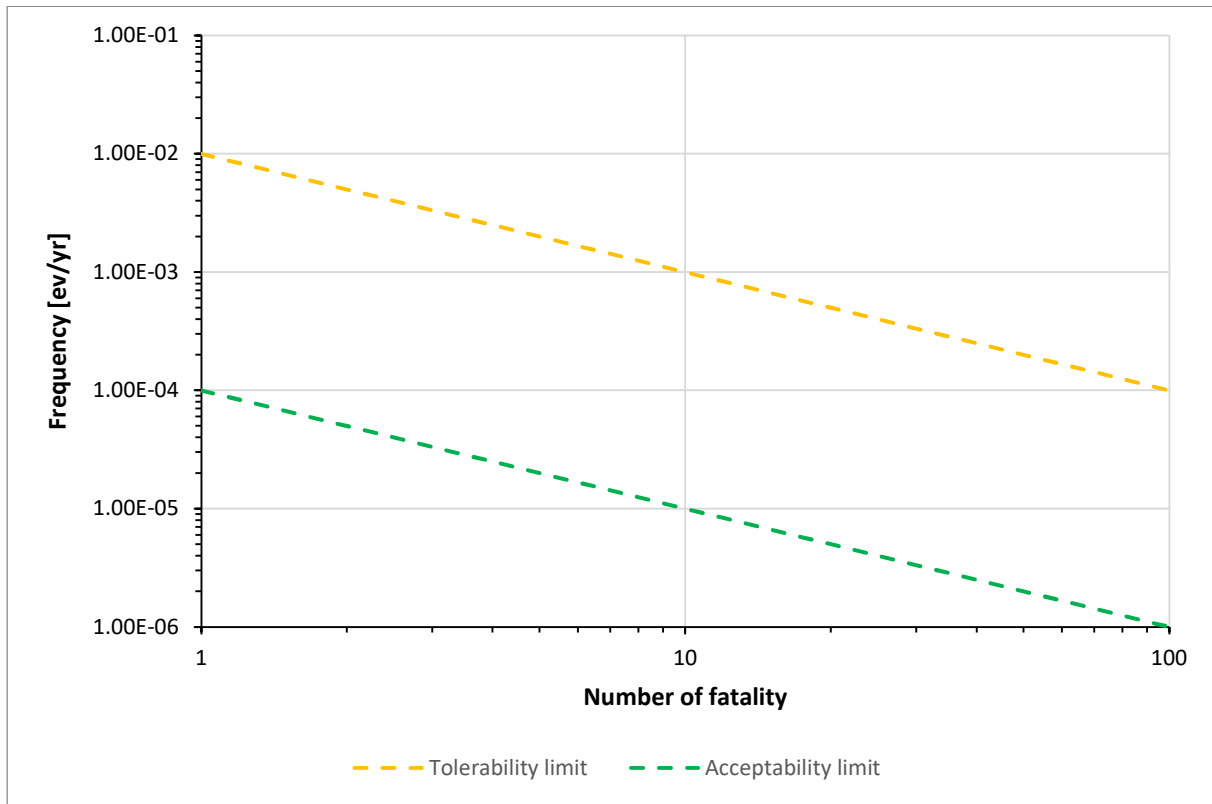
All Hazards assessed in the ALARP will be subject to ALARP demonstration to confirm the present preventive or mitigation measures or to identify additional measures to ensure that the risk is ALARP.

For hazards assessed in the High-Risk (Unacceptable) Region, additional preventive or mitigation measures shall be implemented to reduce the risk to at least ALARP.

Social risk will be also evaluated through F-N curve where will be shown the number of fatalities vs the sum of frequencies of the related events.

In the following graphs are shown the tolerability and the acceptability limit as suggested in HSE UK.

Figure 2-4: Tolerability and Acceptability limits of F-N curve



2.4.8 Results

The computed results of the QRA study will be presented in the form of risk maps for considering all the possible scenarios (LSIR iso-risk curves). Individual Risk Per Annum (IRPA) will be also calculated for personnel inside the plant

Societal risk will be presented in terms of F-N curves.

3 ASSUMPTION REGISTER

The purpose of this section is to present all the assumptions for the QRA analysis.

3.1 LOSS OF CONTAINMENT SCENARIOS

Loss of containment from process equipment such as pipework, valves and flanges is possible due to different causes, such as corrosion or mechanical defects or failure due to incorrect operations. Events related to process deviations will not be considered.

The loss of containment events that will be analyzed are those referred to as "random ruptures", i.e. those caused by unexpected failures due to material defects, fabrication errors, excessive wearing or corrosion, maintenance errors, etc.

In order to identify credible hazardous events that can lead to Fire, Explosion and Flammable Gas Dispersion scenarios, loss of containment events will be independently taken into account within the plant areas with isolated flammable inventory. This is due to the fact that on detection of a condensate or gas flammable release, the process is automatically shut down and isolated by means of emergency shutdown valves (ESDVs) and depressurized via blowdown valves whenever applicable.

As reported in paragraph 3.8, according to [4] two (2) minutes will be considered necessary for the complete isolation of the sections.

The result of the isolation process will be the division of the plant in section separated each other and isolated by isolation elements. Section isolation boundaries shall be defined by:

- ✓ Shut down valves (SDVs & ESDVs);
- ✓ Blow down valves (BDVs) and relief valves (PSVs).

It is important to clarify that although check valves, generic control valves and rotating equipment can limit the inventory within an Isolatable Section, they will be conservatively not used to define the Isolatable Sections.

The identification of Isolatable Section will be performed considering project PFD and P&IDs.

In addition, since Isolatable Sections may be characterized by different operative streams (changes in composition, phase, pressure and temperature) and they may extend throughout large areas of the installation, Release Points will be identified within each Isolatable Section in order to better account for operative conditions and location of the potential releases. Different Release Points are normally considered in an Isolatable Section taking into account the following conditions:

- ✓ Isolatable Section with different process assets: in order to better quantify the risk, different Release Points are created in case of Isolatable Section including equipment located in different area of the plant; the risk contribution of piping connecting two different equipment is included in the Release Point of the equipment itself if its length is not significant. However, if piping distance between two equipment is large, it is advisable to create a dedicated Release Point;
- ✓ Isolatable Section with pressure drop: in case of Isolatable Section in which a pressure drop is realized (e.g., due to pressure control valve), two (or more) Release Points are considered in order to better characterize the consequences following the releases at different pressures.

Plant sections treating non-flammable components or flammable components with not significant amounts of flammable components will be not included in the hazardous scenarios identified for QRA analysis.

3.2 ISOLATABLE SECTIONS

The identified Isolatable Sections are detailed in paragraph 4.1.

It should be noted that:

- ✓ From available P&IDs, actuated valves (ROV) are provided in inlet and outlet liquid line of each tank, while on gas pipe no actuated valve are present

-
- ✓ From available P&IDs, actuated valves (ROV) are provided in the liquid inlet header from Jetty, while on vapour balance header no actuated valve are present

3.3 RELEASE POINTS

A Release Point is defined as a portion of the plant characterized by homogeneous operative and boundary conditions; Release Point identification will account,:

- ✓ Operative parameters (pressure, temperature, composition, phase, etc.);
- ✓ Equipment location in the plot plan;
- ✓ Isolatable inventory.

3.4 HOLE LEAK SIZES

Referring to [1], for process equipment inside battery limit, the following release cases, defined in terms of equivalent hole size diameter, will be analyzed:

- ✓ Small: 7 mm;
- ✓ Medium: 36 mm;
- ✓ Large: 112 mm;
- ✓ Very large: 150 mm.

Referring to [15], for pipeline outside battery limit (from/to Jetty and Kekeli plant), the following release cases, defined in terms of equivalent hole size diameter, will be analyzed:

- ✓ Small: 15 mm;
- ✓ Medium: 60 mm;
- ✓ Large: 80 mm;
- ✓ Very large: 150 mm.

Hole size diameters, for both process equipment and for pipeline, are chosen as the diameter of the average hole area on the ranges reported in OGP [1] [15].

3.5 PARTS COUNT

The following general rules have been taken into account to perform parts count:

- ✓ Valves are considered welded to piping;
- ✓ Each spectacle blind will be counted as two flanges;
- ✓ A spectacle blind connected to a valve is associated to 1 flange joint;
- ✓ Expanders and reducers are assumed to be welded;
- ✓ Valves separating a hazardous plant section and a non-hazardous plant section (e.g. PSVs, normally closed valves, etc.) are counted as a whole valve and two flange faces. However, the presence of any spectacle blind downstream the valve is not accounted for;
- ✓ Unless indicated, all instruments and associated fittings (valves and flanges) are taken as having diameters less than or equal to 2";
- ✓ Temperature sensors are not counted as instruments due to their design (they are not in contact with the hazardous inventory). They are only counted as one flange joint where it fits the piping;
- ✓ As per the IOGP database [1], an instrument consists of the instrument itself and up to 2 valves and 4 flanges. Whenever the design shows more than 2 valves, the additional valves and associated flanges are accounted for;
- ✓ ROVs are taken as actuated valves while hand valves are considered as manual valves;
- ✓ A pipe length multiplier of 1.1 will be used to account for uncertainties in the length calculation, for example due to changes in elevation that cannot be accounted for from the plan drawing; the leak frequency of a pipe is based on per meter length [1]. For this reason, the length of the pipes will affect the leak frequency calculation. In addition, the piping length estimation will affect the assessment of the Isolatable Section inventories used to determine the duration of an incidental scenario;
- ✓ Spare units will not be considered for the calculation of the release case frequency (i.e. frequency of release will be calculated accounting for the working unit(s) only whereas for spare unit(s) no frequency will be assigned since they are normally sections without flow).
- ✓ With regard to pipelines from/to Jetty and Kekeli plant, the Gas pipeline frequency has been considered because liquid propane or butane are clean fluid and therefore comparable to gas.

Basing on these assumptions, the total frequency of a scenario will be the sum of failure frequencies of each equipment item.

Outcome of the parts count exercise is given in appendix A.

3.6 EVENT TREE ANALYSIS

Ignition probability will be calculated accordingly to the IP-UKOOA report [2] based on the following equation:

$$P_{\text{ignition}} = 10^{a \cdot \dot{M} + b}$$

where:

- ✓ P_{ignition} is the total ignition probability;
- ✓ \dot{M} is the mass release rate (kg/s);
- ✓ a and b are fitting coefficient of the experimental correlation.

Fitting coefficients are assessed based on Small Plant Gas (LPG) correlation data, as provided in the IP-UKOOA. This model is embedded in SAFETI.

3.7 CREDIBILITY THRESHOLD

In order to avoid overestimation of effects, scenarios with a very low probability of occurrence, so to be considered in practice not credible to occur, will be discarded from the analysis.

Threshold value for credibility of individual scenarios will be set to 10^{-6} events/year.

3.8 CONSEQUENCE ASSESSMENT

Releases will be simulated considering the height of discharge at 2 m unless there is evidence of different height to be considered.

The release direction and distribution depending on the geometry of the system and the phase of the release. In particular, the direction of the gas releases is assumed horizontal in order to maximize the effect of related scenarios; the direction of liquid releases is assumed downward impinging on the ground to maximize the pool formation effects.

In order to perform time-dependent calculations, the Time Varying modelling embedded in Phast is used. This model takes into account of the change in the storage conditions and calculates release-rate as the release continues; this model required the material inventory of the section, which will be estimated considering available project documentation, as P&IDs, Equipment List and Layouts.

It may be observed that, when assessing the risk to people exposed to fire scenarios, the damage is usually determined by what happens in the first 10-20 seconds of the event, therefore in this case the initial (peak) flow-rate is a reasonable assumption; only in case of process stream downstream a pump the flow rate will be limited to the 100% of the operating flowrate of pump itself.

It is worth underlining that two (2) minutes [4] are considered necessary for the complete isolation of the section. This duration takes into account the time for leakage detection by Fire & Gas detection system, and time for complete closure of the section ESD Valves.

The intervention time has an effect on the maximum amount of material that can be released from an Isolatable Section, and on the depressurization to be used for the assessment of the Jet / Pool Fires or toxic Dispersion. Therefore, the maximum amount of material released is the sum of the mass discharged before the isolation, plus the inventory of the isolated section.

No mitigation effects deriving from spontaneous or induced depressurization is conservatively considered.

Regarding Explosions simulation:

- ✓ Explosion can occur if the flammable mass is equal to or higher than 100 kg,
- ✓ Explosion can occur if the cloud is within a congested area,
- ✓ TNO multi-energy model will be used to assess Explosion scenarios,
- ✓ consequence assessment will be carried out conservatively considering peak flow rate for physical effect calculation.

3.9 FLUID COMPOSITION

Two different hazardous fluids are present in the plant:

- Pure butane for existing facilities
- Pure propane for new facilities

In the following tables are reported the physical properties butane and propane:

Table 3-1: Butane properties

TEST / PARAMETER	UNITS	TEST METHOD	TANK QUALITY
Relative Density at 60°F/60°F		ASTM D2598	0,574
Vapour Pressure at 37,8°C	kPa	ASTM D2598	329
Sulphur, Total	ppm	ASTM D6667	42
Copper corrosion	Class	ASTM D1838	1A
Hydrocarbon Composition	% vol	ASTM D2163	
Ethane			0,003
Propane			0,435
Iso-Butane			46,562
n-Butane			52,881
Iso-Pentane			0,072
n-Pentane			0,015
Pentane & Heavier			0,094
Butane content			99,443
Free Water		Visual	Nil
MON	Rating	ASTM D2598	93,30

Table 3-2: Propane properties

TEST / PARAMETER	UNITS	TEST METHOD	QUALITY
Heating Value	kJ/kg	ASTM D3588	> 46360
Wobbes Index %PCI	MJ/m ³	ASTM D3588	22 - 75
Relative Density at 60°F/60°F	Kg.m ⁻³	ASTM D3588	~ 505
Molecular Weight	g.mol ⁻¹	ASTM D2598	~ 44,1
Vapour Pressure at 50°C	Bar	ASTM D2598	15,1
Copper corrosion	Class	ASTM D1838	1A
Hydrocarbon Composition			
Ethane, C ₂ H ₆	%mol	ASTM D1945	0 - 0,5
Propane, C ₃ H ₈	%mol	ASTM D1945	85 - 100
Butanes & heaviers	%mol	ASTM D1945	0 - 15
Contaminants			
Particulates <5µm	ppmw	ASTM D2709	<5
Particulates >5µm	ppbw	ASTM D2709	<5
Na ; K	ppmw	ASTM D3605	<0.1
H ₂ S	ppmv	ASTM D5504	Report
Sulphur, Total	ppmwt	ASTM D3246	Report
Other metals	ppmwt	ASTM D3605	Report
Lube oil	ppmw		<0.5
Other impurities			Report

3.10 CONGESTED AREAS

RINA Consulting will adopt the methodology described in TNO Yellow Book [5] to identify all the congested areas in the plant.

4 QRA RESULTS

4.1 ISOLATABLE SECTIONS AND RELEASE POINTS

According to the available PFD and P&ID, with the methodology described in the previous paragraphs, the following isolatable section and release points have been identified:

Table 4-1: Isolatable Sections and Release point

Isolatable section	Release point	Description	Phase	Material	T [°C]	P [bar]
IS1	RP1	Tank T-101	Liquid	Propane	32	12
IS2	RP2	Tank T-102	Liquid	Propane	32	12
IS3	RP3	Tank T-103	Liquid	Propane	32	12
IS4	RP4	Tank T-104	Liquid	Propane	32	12
IS5	RP5	Tank T-105	Liquid	Propane	32	12
IS6	RP6	Tank T-106	Liquid	Propane	32	12
IS7	RP7	Tank T-107	Liquid	Propane	32	12
IS8	RP8	Tank T-108	Liquid	Propane	32	12
IS9	RP9	Tank T-109	Liquid	Propane	32	12
IS10	RP10	Tank T-110	Liquid	Propane	32	12
IS11	RP11	Tank n° 01	Liquid	Butane	32	3.5
IS12	RP12	Tank n° 02	Liquid	Butane	32	3.5
IS13	RP13	Tank n° 03	Liquid	Butane	32	3.5
IS14	RP14	Tank n° 04	Liquid	Butane	32	3.5
IS15	RP15	Tank n° 05	Liquid	Butane	32	3.5
IS16	RP16	Tank n° 06	Liquid	Butane	32	3.5
IS17	RP17	Tank n° 07	Liquid	Butane	32	3.5
IS18	RP18	Tank n° 08	Liquid	Butane	32	3.5
IS19	RP19	Tank n° 09	Liquid	Butane	32	3.5
IS20	RP20	Pump P-001	Liquid	Propane	32	23
	RP21	Pump P-002	Liquid	Propane	32	23
	RP22	Pump P-003	Liquid	Propane	32	23
	RP23	Pump P-004	Liquid	Propane	32	23
	RP24	Kekeli Pump 01	Liquid	Propane	32	12
	RP25	Kekeli Pump 02	Liquid	Propane	32	12
IS21	RP26	Pump-1	Liquid	Butane	32	12
	RP27	Pump-2	Liquid	Butane	32	12
	RP28	Pump-3	Liquid	Butane	32	12
	RP29	Pump-4	Liquid	Butane	32	12
IS22	RP30	Compressor C-001	Gas	Propane	32	10.3
IS23	RP31	Compressor LC-001	Gas	Butane	32	1.9
IS24	RP32	New Gantry I	Liquid	Propane	32	15

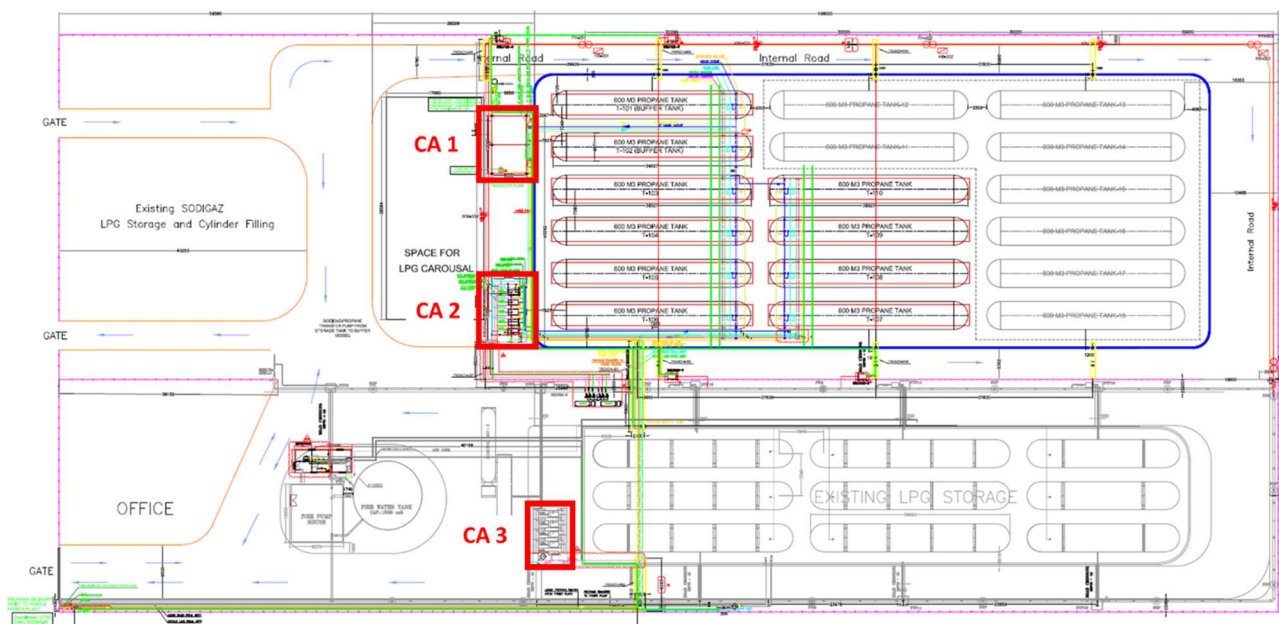
Isolatable section	Release point	Description	Phase	Material	T [°C]	P [bar]
	RP33	New Gantry II	Liquid	Propane	32	15
IS25	RP34	Existing Gantry I	Liquid	Butane	32	4.5
	RP35	Existing Gantry II	Liquid	Butane	32	4.5
IS26	RP36	New Gantry I	Gas	Propane	32	10
	RP37	New Gantry II	Gas	Propane	32	10
IS27	RP38	Existing Gantry I	Gas	Butane	32	1.5
	RP39	Existing Gantry II	Gas	Butane	32	1.5
IS28	RP40	Existing tank Cylinders (3 tanks)	Liquid	Propane	32	10.4
IS29	RP41	Pipeline from Jetty to B.L.	Liquid	Propane	32	12
IS30	RP42	Pipeline from Jetty to B.L.	Gas	Propane	32	10
IS31	RP43	Pipeline from B.L. to Kekeli plant	Liquid	Propane	32	12

4.2 CONGESTED AREAS

In total, 3 Congested Areas (CA) have been identified (Figure 4-1):

- ✓ Kekeli pumps shed (CA 1)
- ✓ New pumps shed (CA 2)
- ✓ Existing pumps shed (CA 3)

Figure 4-1: Identified Congested Areas



4.3 EVENTS FREQUENCY ASSESSMENT

4.3.1 Fire events frequency

Adopting the Event Tree Analysis methodology detailed in paragraph 2.2.2, the frequencies of occurrence of final hazardous scenarios starting from leakage frequencies have been calculated. In order to avoid overestimation of effects, scenarios with a very low probability of occurrence, so to be considered in practice not credible to occur, will be discarded from the analysis.

Threshold value for credibility of individual scenarios is set to 10^{-6} events/year.

4.3.2 Explosion events frequency

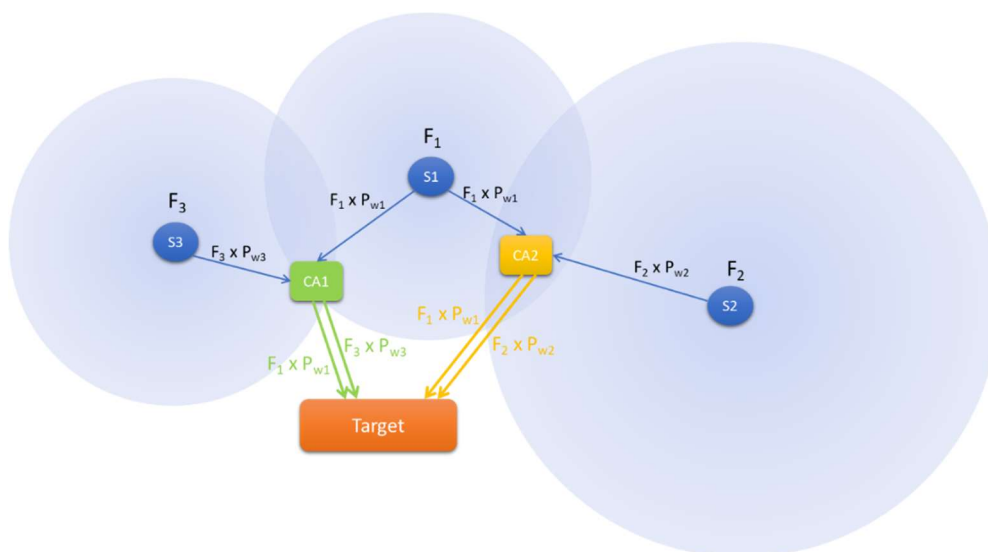
The Explosion analysis requires additional elaboration of the gas dispersion data, to ensure that explosion is simulated only for the areas where the congestion is such to cause explosion and that can be reached by the gas cloud. Also, only the amount of gas that is contained within a congested area shall be considered. This allows a more realistic assessment of the explosion overpressures.

For this study, all the identified congested areas (shown in Figure 4-1) have been considered as Potential Explosion Sources (PES).

The frequency of explosion has been calculated according to the following steps (see Figure 4-2):

1. Identify for each release point (and relative leak size and weather condition) the congested areas that are reached by a concentration of flammable greater than or equal to LFL and associate to each congested area the frequency (F_n) related to the event (flammable dispersion with late ignition);
2. Assuming that the wind blows with equal probability from every direction, calculate the probability that from each possible release point the flammable dispersion may involve each congested area (P_{wn}). This probability is calculated as the ratio between the opening angle of the dispersion with concentration greater than LFL and the full turn angle (360°);
3. For each congested area, by multiplying the frequency calculated in the step 1 and the probability calculated in the step 2, we obtain the frequency to have a flammable mass that is given by each release point;
4. For each congested area, it is possible to obtain the explosion frequency by summing up all the frequencies computed in step 3 (considering that an ignition occurs)

Figure 4-2: Geometrical scheme representing the methodology to compute the explosion frequency in correspondence of the congested areas



4.3.3 BLEVE events frequency

The frequency of BLEVE has been calculated for each tank, for the cylinders and for trucks during loading operation in existing and new gantries as the sum of the frequency of Jet fire events impairing the considered Item for more than 5 minutes with a thermal radiation higher than 37.5 kW/m².

In the following Table 4-2 are reported the BLEVE frequencies for each tank:

Table 4-2: BLEVE frequency

Item	BLEVE Frequency [ev/yr]
T-101	1.5E-05
T-102	2.5E-05
T-103	4.0E-05
T-104	4.1E-05
T-105	4.1E-05
T-106	5.2E-05
T-107	4.9E-05
T-108	6.7E-05
T-109	7.1E-05
T-110	7.3E-05
T-1	4.5E-05
T-2	1.1E-05
T-3	1.3E-05
T-4	2.2E-06
T-5	7.1E-06
T-6	7.6E-05
T-7	4.4E-05
T-8	3.1E-05
T-9	4.4E-05
Cylinders	8.8E-05
Trucks in new Gantry	4.0E-05
Trucks in existing Gantry	4.5E-05

On the base of company reference documents, in this study BLEVE have been neglected from all facilities because, as reported in company reference documents:

- ✓ Existing butane storage tanks, existing gantries and existing pumps house are provided of spray nozzles and sprinklers distributed around the perimeter of each equipment;
- ✓ New propane storage tanks, new propane pump house and new Kekeli pump house will be provided of spray nozzles and sprinklers distributed around the perimeter of each equipment.

It has also been confirmed that new cylinders filling area and new gantries will be provided of the same kind of BLEVE prevention measures.

Considering all these prevention measures, BLEVE scenarios is not credible.

4.4 QRA RISK ASSESSMENT RESULTS

Simulation in PHAST has been performed without using the time varying model because release flow rate in the first 5 minutes is almost constant and therefore the peak flow rate was assumed to last for the entire release duration.

4.4.1 Buildings sheltering effect

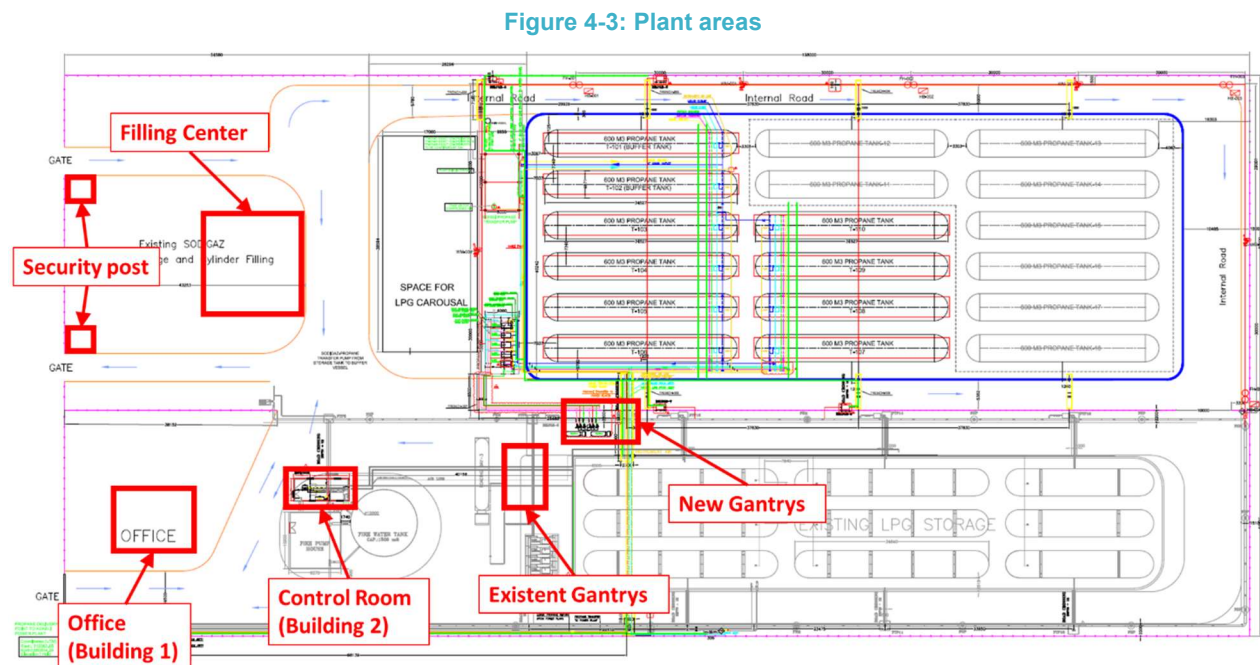
QRA results shown in the following paragraph 4.4.3 have been worked out considering the following assumption:

- ✓ For explosion events, as reported in paragraph 2.4.5, two different vulnerability functions have been used, one for outdoor and one for indoor. It has been considered that probability of fatality inside the building is higher than outdoor because of projectiles due to possible failure and breakage of the structures such as shards of glass, bricks fall etc. The multienergy model embedded in Phast consider both confined VCE and unconfined explosion;
- ✓ For flammable dispersions, it has been conservatively assumed that buildings are not gas tight and therefore the probability of fatality indoor and outdoor is the same. The same vulnerability function has been used for indoor and outdoor.

4.4.2 Manning Level

There is only 1 team working 10 h/day (from 8:00 a.m. to 6:00 p.m.) Therefore, for each operator, the probability of being in the plant (individual presence probability) is equal to 41.7%.

It has been considered that operators will stay in the areas of the plants identified in the following Figure 4-3:



It has been considered that there are in total 158 people inside the plant. People are distributed in the areas of the plant as reported in Table 4-3.

Table 4-3: Number of persons in each work group

Plant Area	N. of Persons
Office (Building 1)	30
Control Room (Building 2)	8
Filling Center	104
Existent Gantrys	5
New Gantrys	5
Security Post	6
TOTAL	158

4.4.3 LSIR and IRPA results

LSIR map has been worked out and provided in Figure 4-4. The map has been worked out by means of SAFETI, considering the following colours:

- ✓ Red line represents a fatality equal to $1E-06$ ev/yr
- ✓ Purple line represents a fatality equal to $1E-05$ ev/yr
- ✓ Light blue line represents a fatality equal to $1E-04$ ev/yr
- ✓ Orange line represents a fatality equal to $1E-03$ ev/yr

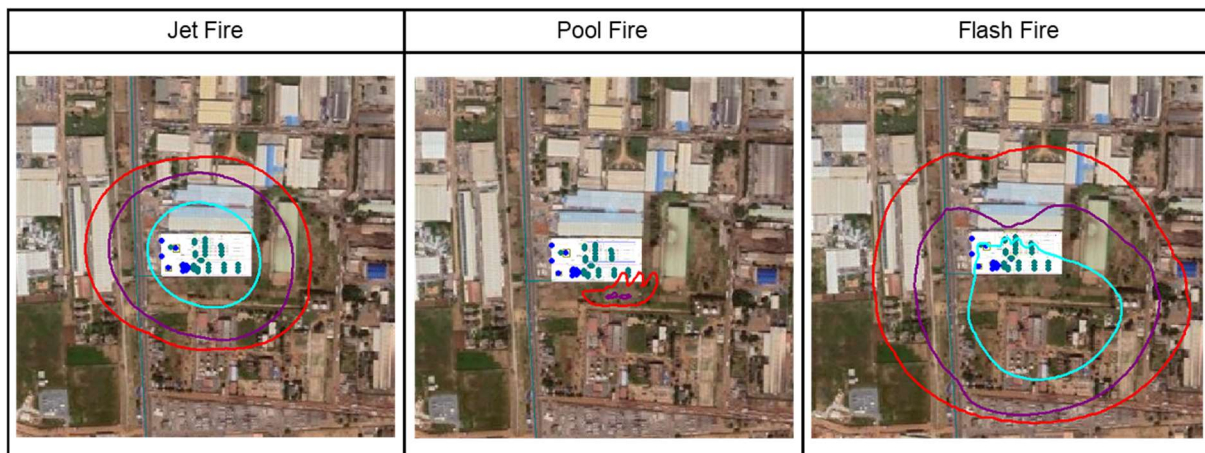
Green and blue point in Figure 4-4 are respectively the release point and the target considered.

Figure 4-4: LSIR map



In order to understand the dominant scenario that generates $1E-04$ outside the plant, a comparison between the exceedance maps computed for jet fire, pool fire and flash fire at the same level of vulnerability (threshold with 100% of fatality) is reported in the following figure:

Figure 4-5: Comparison between Jet Fire, Pool fire and Flash fire



Observing the geometry of LSIR contour and how it is affected by the wind, the dominant scenario that generates $1E-04$ outside the plants is the flash fire. In addition to Flash fire there is a little contribute of Jet fire in the north part of the plant.

In the following Table 4-4 are reported, for each area of the plant, all the LSIR values.

Table 4-4: LSIR table

Area	LSIR Total
Office (Building 1)	4E-04
Control Room (Building 2)	7E-04
Filling Center	1E-03
Existent Gantrys	9E-04
New Gantrys	8E-04
Security Post	3E-04

In order to calculate the Individual Risk Per Annum (IRPA), as reported in paragraph 4.4.3, for each operator, the probability of being in the plant is equal to 41.7% (10 hours of working per day).

In Table 4-5 are reported the IRPA values for each group working in the different areas of the plant and the relative risk level (as per criteria given in Section 2.4.7).

Table 4-5: IRPA table considering the design buildings criteria

Area	IRPA	Risk
------	------	------

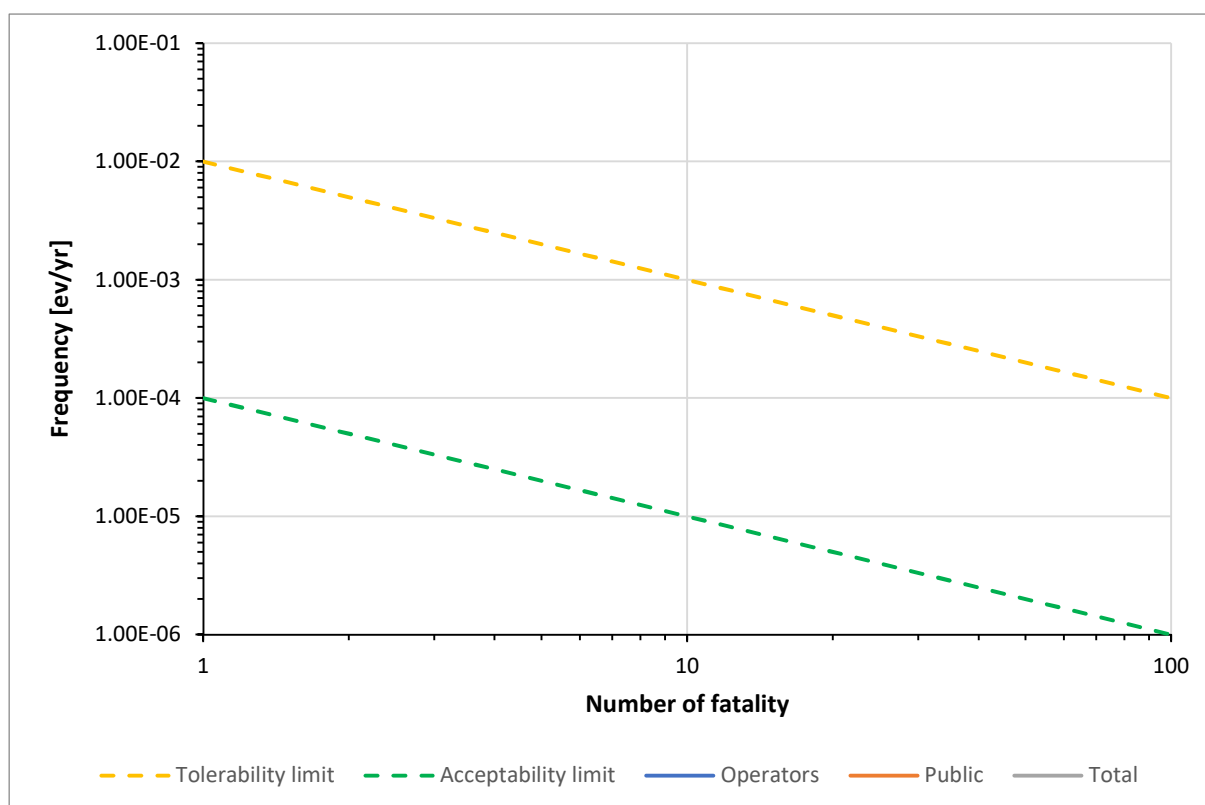
Office (Building 1)	1.67E-04	ALARP
Control Room (Building 2)	2.92E-04	ALARP
Filling Center	4.17E-04	ALARP
Existent Gantrys	3.75E-04	ALARP
New Gantrys	3.33E-04	ALARP
Security Post	1.25E-04	ALARP

4.4.4 F-N curve

Societal risk has been calculated considering that external population has a density of 1000 people/km² according to the representative population density of industrial areas.

In the following figure are reported F-N curves for operators, public and the sum to obtain the total F-N curve.

Figure 4-6: F-N curves



4.5 EXCEEDANCE CURVE ON BUILDINGS

For each building, the following exceedance curves have been calculated:

- ✓ Heat radiation from fire event
- ✓ Overpressure

In order to obtain exceedance curves for a specific building, all the effects of each scenario impacting on a building have been identified and sorted in descending order (from the higher to the lower effect); then the cumulative frequency is calculated.

It is also possible to identify the event impacting on a building with a cumulative frequency of $1E-04$. This is considered the dimensioning event for design criteria of the building as suggested by [8]

In this way, buildings can be designed to withstand all events with consequences up to the dimensioning event, while events with higher consequences of the dimensioning event are neglected because the cumulative frequency is lower than $1E-04$ events/year.

4.5.1 Thermal radiation

Exceedance frequency of 37.5 kW/m^2 on each building is higher than $10E-04 \text{ ev/year}$ therefore all the buildings have to be fireproofed in accordance to API Recommended Practice 752 [8].

Below are reported exceedance frequency maps for jet fire and pool fire events at 37.5 kW/m^2 considering the following colours:

- ✓ Red line represents a frequency equal to $1E-06 \text{ ev/yr}$
- ✓ Purple line represents a frequency equal to $1E-05 \text{ ev/yr}$
- ✓ Light blue line represents a frequency equal to $1E-04 \text{ ev/yr}$

Figure 4-7: Exceedance frequency maps for Jet fire at 37.5 kW/m^2



Figure 4-8: Exceedance frequency maps for Pool fire at 37.5 kW/m²



As it is possible to observe from figures above, pool fire events are not a problem because 1E-04 is never reached. Instead, Jet fire events generate an exceedance frequency of 1E-04 that extends beyond the limits of the plant.

There isn't any area inside the plant with an exceedance frequency lower than 1E-04 and therefore, even a relocation of buildings will not be sufficient to avoid the fireproofing design of all buildings inside the plant.

4.5.2 Overpressure

In the figure below the overpressure exceedance curves from explosion for each building are reported:

Figure 4-9: Overpressure exceedance curve impacting on office (building 1)

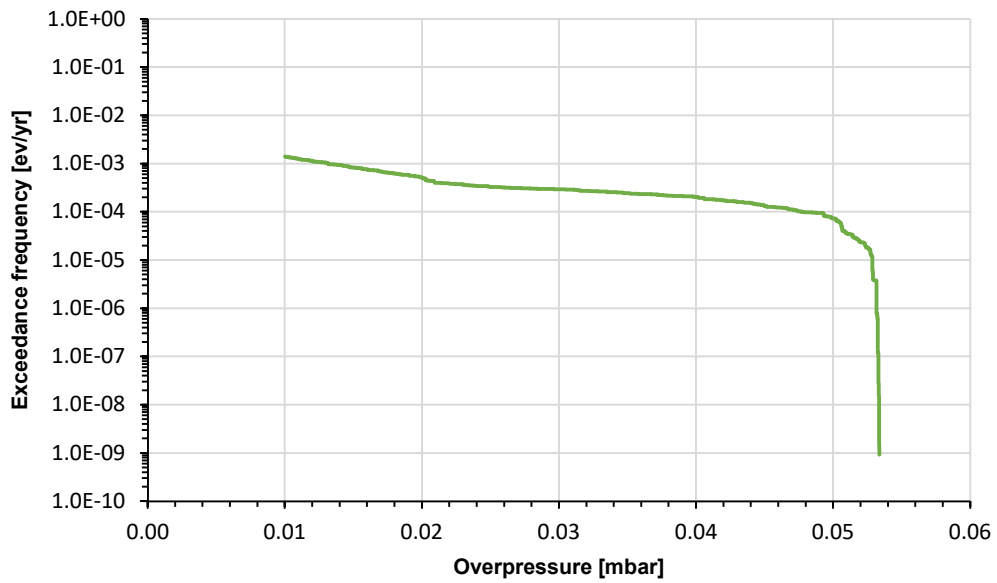


Figure 4-10: Overpressure exceedance curve impacting on control room (building 2)

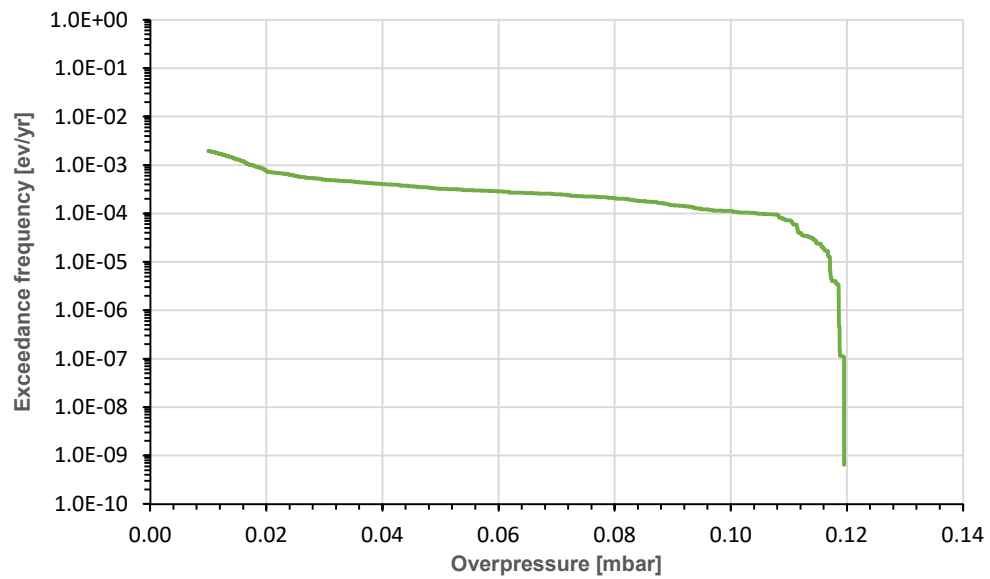


Figure 4-11: Overpressure exceedance curve impacting on Filling Center

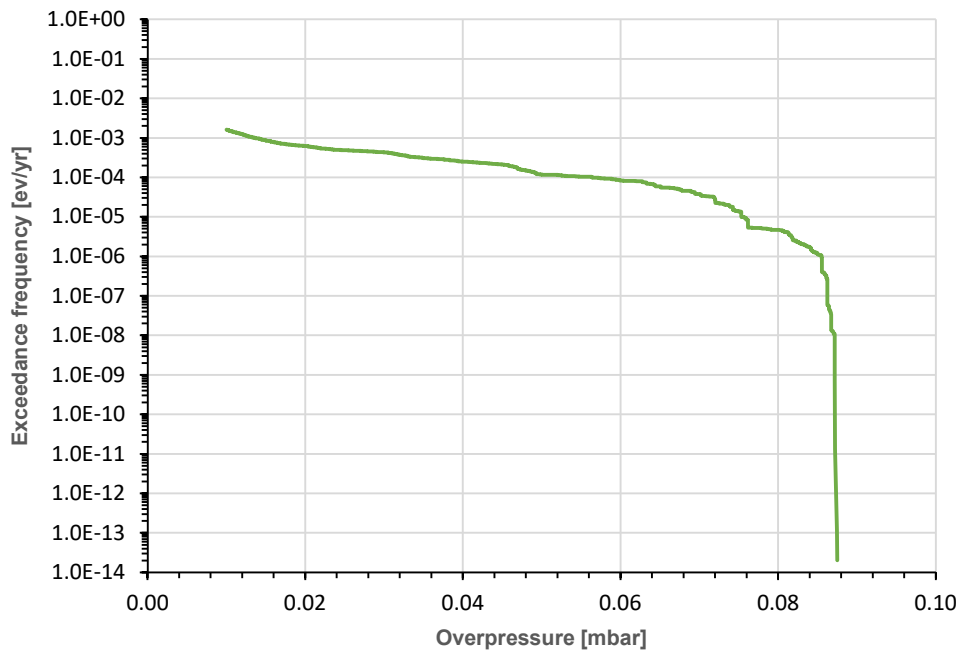
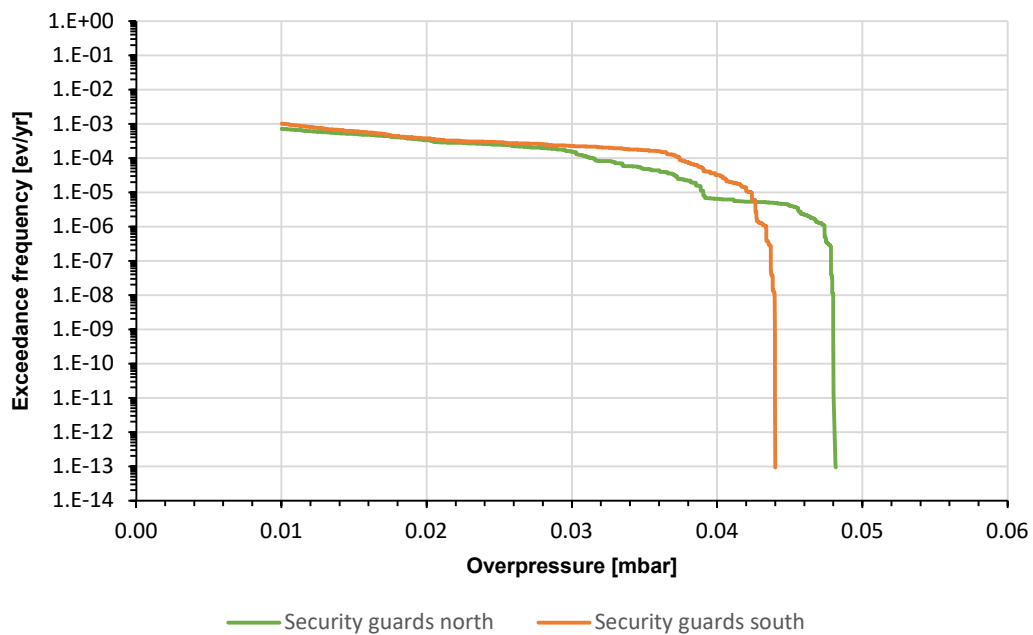


Figure 4-12: Overpressure exceedance curve impacting on security posts



In the table below are reported the overpressure impacting on each building with a frequency of 1E-04:

Table 4-6: Overpressure impacting each building with a frequency of 1E-04/year

Building	Overpressure [mbar]
Office (Building 1)	0.048
Control Room (Building 2)	0.104
Filling Center	0.056
Security guard north	0.031
Security guard south	0.037

5 CONCLUSIONS AND RECOMMENDATIONS

The analysis has allowed to calculate the values of Individual and Societal risk associated to the operation of the plant and the heat radiation and overpressure values impacting on plant buildings with the assumptions and criteria described in Sections 2. and 3.

BLEVE consequences has been neglected from this study because it has been considered that there will be appropriate firefighting protection on each tank able to avoid BLEVE scenario.

The results of the risk assessment are as follows:

- ✓ LSIR values for workers and for population are acceptable because:
 - Fatality frequency of 1E-03 is confined in small area located inside plant area;
 - Fatality frequency of 1E-04 is confined inside industrial area;
 - Fatality frequency in residential areas is always minor than 1E-06.
- ✓ Individual Risk Per Annum (IRPA) for operators in all the considered areas inside the plant is in the ALARP region according to HSE UK thresholds.
- ✓ F-N curves both for operators and public are within the tolerability limit (ALARP region).

Given the exceedance curves of the heat radiation and overpressure on buildings it will be necessary to protect buildings from fire and explosion events as recommended in Sections 4.5.1 and 4.5.2

The following specific recommendations should be implemented:

- ✓ Provide training for operators on prevention and response to major fire and explosion events;
- ✓ Ensure that emergency plans and company standards consider actions to deal with major fire and explosion events;
- ✓ Fatality frequency of 1E-04 and 1E-05 and exceedance frequency for heat radiation at 37.5 kW/m² of 1E-04 and 1E-05 are extended beyond the limits of the plant and therefore it is recommended a coordination with local authorities and other industrial activities around ZENER plant in order to update off-site emergency planning

6 REFERENCES

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- [3] DNV, "PHAST", Version 8.22 (Theory Manual and Validation report);
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- [5] TNO "Yellow Book" - Method for calculation of physical effects
- [6] TNO "Green Book" – Methods for the determination of possible damage to people and objects resulting from releases of hazardous materials
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- [8] API Recommended Practice 752, "Management of Hazards Associated with Location of Process Plant Buildings", 2nd Edition (November 2003)
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- [17] BNH-2001-CHT-002 rev.000B Cause & Effect Chart
- [18] HSE UK, 28/06/2012, "Failure Rate And Event Data For Use Within Risk Assessment";

MGA10/MAP/GMU:mga10

Appendix A

Parts count

Doc. No. P0030364-1-H2 Rev. 1 – April 2022





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