QUANTITATIVE RISK ASSESSMENT (QRA) GUIDELINE

EGPC-PSM-GL-008

PSM GUIDELINES

The Egyptian Process Safety Management Steering Committee (PSMSC Egypt)
PSM TECHNICAL SUBCOMMITTEE (PSMTC)

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1. Introduction

The Oil and Gas industry has hazards and Risks that are inherent to its assets, activities, operational locations, and products. The Companies belong to The EGPC and the Holding Companies, (including the Egyptian Natural Gas Holding Company (EGAS), the Egyptian Petrochemical Holding Company (ECHEM) and the South Valley Petroleum Holding Company (GANOPE)), are committed to pursuing no harm to people and the community and managing Risks through effective controls. Companies shall manage all Risks to As Low as Reasonably Practicable (ALARP).

The Oil and Gas industry' Risks accompanied with process failures and chemical releases contain severe consequences which should be managed quantitatively. The Quantitative Risk Assessment (QRA) is a component of an organization's total Risk management: it is a part of the Companies' Risk Management Program. QRA is used to help evaluate potential Risks when qualitative methods cannot provide adequate understanding of the Risks and more information is needed for Risk management.

The QRA is a formal and structured quantitative analysis methodology used to help Companies manage Risk and improve safety through identifying the Major Hazards (i.e. identify incident scenarios), evaluating the associated likelihood and consequences to people, and calculating Risk levels in a numerical way for comparison with Risk Tolerability Criteria, and defining recommendations for guaranteeing proper Risk management is in place. QRA helps to make facilities handling hazardous chemicals safer by supporting Risk Based Decision Making.

2. Purpose

This Guideline describes the main components of the QRA studies and its main outputs, as well as establishes consistent requirements for planning, conducting, documenting, reviewing and approving the QRA studies for the Companies belong to The EGPC and the Holding Companies.

All QRA studies carried out for the Companies belong to The EGPC and the Holding Companies shall be in accordance with the requirements of this Guideline.

This QRA guideline focuses on protecting people inside and around the Major Hazard facilities, while protection of Assets will be covered in the Fire and Explosion Risk Assessment (FERA) Guideline, (EGPC-PSM-GL-009). *(Note: The FERA scope and deliverables could be covered as a part of the QRA-especially if the study scope is not big or complicated).*

This Guideline aims to provide a framework for:

- When and How to use the QRA,
- What is expected from the QRA,
- The QRA Methodology,
- The Scope of the QRA study,
- The minimum contents of the assumption register,
- Understanding the QRA results, beyond the obvious statistical meanings,
- The consequences modelling and the complete QRA results,
- How to compare the QRA Risk results to the EGPC & Holding Companies' Quantitative Tolerable Risk Criteria,
- Supporting the demonstration that Risk levels are reduced As Low As Reasonably Practicable (ALARP Demonstration),
- The QRA report main components.

3. Scope

This document stipulates the mandatory requirements applicable to the Egyptian General Petroleum Corporation (EGPC) and Oil and Gas Holding Companies, including the Egyptian Natural Gas Holding Company (EGAS), the Egyptian Petrochemical Holding Company (ECHEM) and the South Valley Petroleum Holding Company (GANOPE) covering all of their operational subsidiaries, state-owned companies, affiliates and joint ventures.

ENTITIES and their COMPANIES and contractors shall ensure that all requirements listed herein are fully understood, implemented, complied with and monitored at all times including current operations, existing and future projects during the whole projects' lifecycle from feasibility till decommissioning.

4. Definitions & Abbreviations

ENTITIES: hereinafter are used to indicate EGPC and Holding Companies i.e., EGAS, ECHEM and GANOPE that are required to enforce implementation of this standard across their COMPANIES.

COMPANIES: hereinafter are used to indicate operating company, subsidiary, affiliated, Joint Venture companies that are required to comply with ENTITIES' standards.

For Definitions and Abbreviations refer to PSM Glossary document EGPC-PSM-GL-011.

5. Linked Internal Standards and Guidelines

- Risk Management Standard EGPC-PSM-ST-001,
- Process Safety Studies in Major Projects Guideline EGPC-PSM-GL-002,
- Major Accident Hazard Management Guideline EGPC-PSM-GL-006,
- Fire and Explosion Risk Assessment (FERA) Guideline EGPC-PSM-GL-009,
- Process Safety Key Performance Indicators (KPIs) Guideline EGPC-PSM-GL-025,
- ALARP Demonstration Guideline EGPC-PSM-GL-010,
- PSM Glossary of Definition and Abbreviation Guideline EGPC-PSM-GL-011,

6. General Requirements

- The QRA study shall be executed for the Major Hazard site(s)/ facility(ies) (handle, process, store, transport, distribute, hazardous material) exposed to total/partial /permanent/temporary occupancy of workers, as well as, for the presence of people (public) nearby the site(s)/facility(ies),
- The QRA shall be conducted by competent personnel,
- The QRA shall not be conducted in isolation,
- The QRA shall use appropriate data,
- The QRA shall use the correct level of details,
- The QRA shall use appropriate software / models,
- The QRA objectives shall be to reduce Risk rather than prove acceptability,
- The QRA shall reduce Risk to ALARP rather than a fixed level,
- The QRA shall represent the reality.

7. QRA Lifecycle through Project Different Phases

The QRA can be applied in the initial siting and design of the facility (Greenfield) and during its entire life (brownfield), while the maximum benefits result when QRA is applied at the beginning (conceptual and design stages) of a project and maintained throughout its life. The QRA helps in comparing options during the design phase or for modifications during operations.

7.1. Greenfield

When a new facility starts from scratch, and where the QRA is mandatory, the QRA shall be executed through the following different project phases, (the objective of the study may be also varied for each project phase):

7.1.1. Evaluation / Concept Selection Phase

QRA process starts at concept stage. In some cases, Preliminary QRA may be carried out during concept stage especially where several options have been identified. This allows a comparison of the relative Risk levels from the different options to support the decision making process.

(Note: Refer to Process Safety Studies in Major Projects Guideline EGPC-PSM-GL-002; The Preliminary *Risk Studies are a simplified form of the QRA, based upon a combination of generic technology/process data and site-specific data. Due to the basic nature of the available information on the technologies and processes at this stage of the project, the analysis uses industry data, such as the likelihood of fires/explosions for similar facilities. The consequence part of the analysis may use either estimate for inventories and process conditions or generic industry data from similar facilities. Available site-specific data includes meteorological data, and locations of hazardous inventories, local communities, workforce, and other areas of interest. These* Preliminary *Risk Studies are unlikely to be as accurate in absolute terms as the QRA studies conducted at later stages of the project when the detailed design has evolved. However, the application of* Preliminary *Risk Studies to multiple options in a comparison approach largely overcomes the problem of inaccuracies in the assumptions used in the absence of definitive data. The difference in Risk between options is the important factor, not the absolute level of Risk. This allows the Project Management Team to compare the safety Risks between options and rank them accordingly. It can also provide insights into potential business interruption and property damage related Risks between options)*

7.1.2. Basic Engineering / Front End Engineering Design (FEED)

A Comprehensive QRA shall be performed during the FEED Stage of the project in order to provide a numerical estimate of onsite and/or offsite Risk exposures to people or other areas of interest. This allows Risk levels to be compared with corporate Risk Tolerance Criteria and provides input where

Risk reduction measures are required to demonstrate ALARP on decisions regarding strategies to mitigate Risk, which need to be resolved prior to the detailed design stage of the project.

7.1.3. Detailed Engineering

The QRA study conducted during the FEED shall be updated, as required, during the Detailed Engineering Phase based on newly established information/data especially vendor-designed equipment data. QRA also forms the basis for the Operation Phase.

7.2. Brownfield

(Existing facilities/ under development/ new expansion projects/ revamp projects) the following should be considered:

7.2.1. For existing facilities, where QRA is not available,

- The QRA shall be carried out at the first available opportunity (earliest).

7.2.2. For existing facilities, and new expansion to be established

- An integrated QRA for the existing and the planned facilities shall be carried out. (Ref. 7.1.).

7.2.3. For existing facilities, where QRA is available,

The QRA shall be reviewed, and revalidated or updated, if required, based on:

- If significant changes to facilities (e.g., modification in process, feed changes, new technology), barriers, manning level, building functionality or building occupancy, etc. are observed or carried out.
- During developing and updating the Company Safety Case study,
- Every 5 years the QRA to ensure integrated Risk from all existing facilities including modification and brownfield projects is considered.

(Note: Where there are no significant changes identified over five years and the outcomes of previous QRA report are still applicable and technically robust, and there is no required update for the QRA. In such case, Companies shall develop technical justifying note for revalidation of the study with relevant supporting documents (such as QRA Consultant revalidation report, and if any HAZID, Risk Register review, MOC, etc. are executed for the existing facility), and submit to the EGPC and the Holding companies for approval).

8. QRA Methodology

The basis of QRA methodology is to identify incident scenarios and evaluate the Risk by defining the frequency of failure, the probability of various consequences and the potential impact of those consequences. The Risk is defined in QRA as a function of probability or frequency and consequence of a particular accident scenario [1]:

$$\text{Risk} = F(s, c, f)$$

S= Hypothetical Scenario   ***C***= Estimated Consequence(S)   ***f***= Estimated Frequency

This "function" can be extremely complex and there can be many numerically different Risk measures (using different Risk functions) calculated from a given set of s, *c, f*.

The objective of QRA Methodology is to cover the following activities:

- Set the QRA scope and define the assumption register contents.
- Define the potential event sequences and potential incidents. This may be based on qualitative hazard analysis for screening level analysis. Complete or complex analysis is normally based on a full range of possible incidents for all sources.
- Evaluate the incident outcomes (consequences). Some typical tools include vapor cloud dispersion modelling and fire and explosion effect modelling.
- Estimate the incident impacts on people.

- Estimate the potential incident frequencies. Fault Trees or generic databases may be used for the initial event sequences. Event Trees may be used to account for mitigation and post release events.
- Estimate the Risk. This is done by combining the potential consequence for each event with the event frequency, and summing over all events.
- Evaluate the Risk. Identify the major sources of Risk and determine if there are cost-effective process or plant modifications which can be implemented to reduce Risk. Often this can be done without extensive analysis. Small and inexpensive system changes sometimes have a major impact on Risk.
- Do the Risk Evaluation against legally required Risk Tolerability Criteria if available, or internal corporate guidelines (as applied in our case), or comparison with other processes or more subjective Criteria.
- Identify and prioritize potential Risk Reduction Measures if the Risk is considered to be excessive.

(The QRA methodology flowchart illustrated in Figure 1)

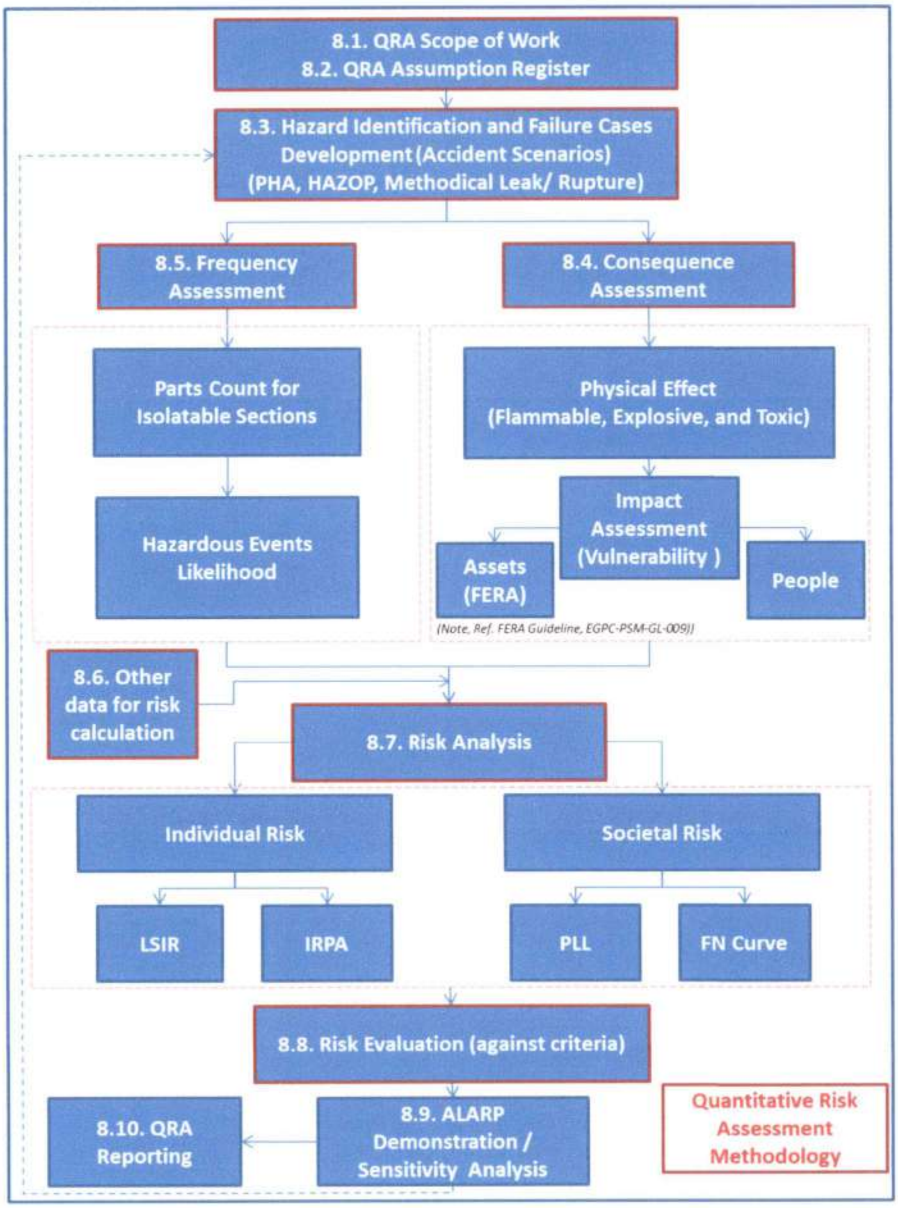

Figure 1: The QRA Methodology Flowchart

8.1. QRA Scope of Work

The Company is responsible for identifying the scope of work of the QRA study, and submitting it to the QRA Consultant to prepare the assumption register in order to start the execution of the study, or In case of the Company has the capabilities to execute the QRA study internally (by its competent staff and using accredited software), the scope of the study shall be submitted to or prepared in co-operation with the QRA internal concerned department (the loss prevention/ process safety/ QRA team). *(Note: The scope of work could be identified through a meeting with the QRA Consultant(s)).*

The scope of a QRA includes necessary details to define the QRA as a single document and includes:

8.1.1. The Objective of The QRA Study,

The QRA may have one or more objectives depending on the driving factor(s) to execute the study; these **driving factors (triggers)** may be one or more of the followings:

- A legal requirement,
- An engineering requirement (loss prevention point of view),
- Support the Safety Case development,
- Support a decision-making process,
- Demonstrate that the Risk to workers and public is acceptable and controlled.
- Required by shareholders,
- Part of a bidding process for new project.

Examples for **specific objectives** for the QRA are:

- Identify hazards in a certain process,
- Assess the significance of each incident in terms of on-site & off-site impact,
- Predict the frequency of occurrence,
- Determine the extent of harmful consequences,
- Identify and provide Risk Reduction Measures to ensure the Risk is "As Low As Reasonably Practicable" (ALARP),
- Demonstrate that the preferred Risk Reduction Measure reduces Risk to ALARP.

8.1.2. The Facility Description,

The scope of the work shall contain a brief description for the facility to elaborate the main processes, main equipment, handled materials types and inventories, operating and design parameters, and the facility location.

8.1.3. Types of Risks to be Evaluated,

The choice of the types of Risk to be addressed by the QRA will depend on the objectives identified, the QRA evaluated Risk mainly focus on the loss of life for workers and public in terms of individual and Societal Risk. (*Note: The QRA focuses mainly on the loss of life, and for assets loss / vulnerability refer to (FERA) Guideline, EGPC-PSM-GL-009).*

8.1.4. QRA Deliverables,

The scope of work must define the deliverables of the study and shall include the followings:

- Hazard identification (potential hazardous events),
- The incident scenarios, include the causes, and the consequences/impact analysis,
- Estimate the likelihood of events,
- Risk estimation and evaluation, for both indoor and outdoor populations / vulnerabilities, in terms of:
    - Societal Risk (PLL and FN curve),
    - Individual Risk (LSIR and IRPA),

  - The cumulative Risk at different Risk ranking points,
- Proposal for Risk-reduction measures,
- The sensitivity study, (if it is required to be performed), should be considered in the study deliverables.
- Re-evaluation the Risk considering the study recommended Risk reduction measures (i.e. to rerun the results and re-evaluation the Risk after agreeing the suggested reduction measures with the Company, to assure the effectiveness of these measures to reduce the Risk to ALARP).
- *(Note: Annex D – Tables D1 & D2 give a full list of the QRA study deliverables)*

8.1.5. Boundaries of the QRA,

The boundaries of the QRA should clearly define which facilities' hazards and personnel *(including neighboring facilities)* are to be included, or excluded, from the study, *(Note: With consideration to 7.2.2.).*

8.1.6. Requirements,

The following requirements shall be considered for the study:

- Must be based on a realistic analysis of the potential hazards,
- Must include an accurate estimate of the potential level of harm and likelihood,
- Must be followed by comparison results to the EGPC & Holding Companies' Quantitative Risk Tolerability Criteria,
- Conclusions have to be drawn on the level of Risk and the need or not for change/improvement,
- Written down so that the enforcing authority can audit it,
- The software to be used for the QRA should be valid, internationally recognized, and licensed. The software name, version, license number, and the software validation certificate should be provided by the Consultant.
- The Company, according to its system, has the choice to require a number of the study copies in hard and/or soft form.
- The Company shall require and archive the study native file, to make it easier and faster to run any required integration or any future changes in the revalidation process.
- The quality of the assessment and the acceptability of the conclusions will reflect the Company's commitment to Risk management and regulation(s).

8.1.7. Identification of Resources,

- The QRA Consultant to develop a schedule to breakdown the QRA activities , responsibilities and the deadline for each activity (end point),
- The QRA Consultant to submit the details of all personnel who will work and assist with the QRA activities, the Company has the full right to check the CV's of these personnel to check their knowledge and capabilities to execute the QRA.

8.1.8. Kick-Off Meeting,

A kick off meeting shall be held between the Company and the QRA Consultant, or internally among the concerned department if the study will be executed internally in order to:

- Discuss the study scope of work in details,
- Check the study required data which should be availed by the Company (e.g. PFD, P&ID'S, process data, design data, ...) , and to discuss alternatives for missing data (if applicable),
- Submit the EGPC & Holding Companies' Quantitative Risk Tolerability Criteria to the Consultant, and any other required, Entities or Company standard , and guidelines,
- Determine the site visit date, if required,
- Any other requirements.

8.1.9. Finalize the Scope,

It is essential to finalize the scope of work following the kick-off meeting considering the followings:

- The final scope may be modified to add any additional or missing requirements agreed through the meeting,
- State for the Company available data and the alternative for the missing (if applicable),
- The site visit final date (optional),
- The assumed and agreed final Risk ranking points,
- The study endpoint date.

8.2. Assumption Register

After the kick-off meeting and finalize the scope of work between the Company and the Consultant, the Consultant shall establish the study' Assumption Register to show:

- The study different assumptions,
- The available data to be used,
- The missing data (if any) alternatives and assumptions,
- The references to be used,

The QRA will contain several assumptions: these assumptions shall be listed in the QRA report so that results are fully traceable and repeatable and so that it can be verified that the assumptions reflect site reality.

All assumptions used in QRA should be developed on a "conservative best estimate" basis. All assumptions made during the QRA shall be documented, reviewed and approved by the Company prior to use. The Company approval on the Assumption Register is permission for the Consultant to start the study activities.

The register shall contain the assumptions for at least the following sections *(Note: Some sections could be merged if applicable):*

- ***Failure Case Definition (Identification of potential Loss Of Containments- LOCs)***
- ***Parts Count / Isolatable Sections***
- ***Release Location and Orientation (Direction)***
- ***Consequence Assessment – Discharge***
- ***Physical Effect Potential Outcomes***
- ***Impact Assessment Criteria***
- ***Consequence Results Height of Interest***
- ***Indoor / Outdoor Vulnerability***
- ***Process/Model Assumptions***
- ***Leak Frequencies and Hole Sizes***
- ***Event Trees***
- ***Ignition Probability***
- ***Explosion Modelling***
- ***Manning Distribution***
- ***Meteorological Data***
- ***Modification Factor(s)/ and other Judgemental Assumption(s) (if used)***
- ***Risk Calculation***
- ***Risk Acceptance Criteria***
- ***Sensitivity Analysis (if required)***
- ***The Study Deliverables.***
- ***Software to be used name, version and license number***
- ***References.***

8.3. Hazard Identification

All potential Major Accident Hazards associated with the facility or operation shall be taken forward for QRA assessment. The potential hazardous event is usually called the 'top event' (e.g. hydrocarbons leaks from process equipment, storage facilities, risers or pipelines).

Generally, there are two types of considered hazards, process and non-process:

- Process hazards generally consist of onshore/offshore process facilities, storage facilities, piping/pipelines, etc.
- Non-process hazards consist of occupational hazards, transportation Risk, escape and evacuation Risk, ship collision, dropped object, etc.

Hazard Identification and failure case development techniques such as HAZID, HAZOP, & Methodical Leak/Rupture, along with the Company Major Accident Hazard (MAH) list are used to identify the Major Accidental Hazards associated with project facilities.

(Note1: Choice of suitable technique is driven by the objective of the QRA, e.g. Preliminary Hazard Analysis can be used for a simple QRA but would not be suitable for a comprehensive QRA, and likewise, a methodical leak/rupture is suitable for the comprehensive and would be overkill for a simple QRA)

(Note2: Reference should also be made to accidents and incidents that have occurred in the oil and gas industry and that are relevant to the Company operations.)

Hazard Identification contains the main following steps:

- Review site all materials and identify those that are hazardous,
- Review process, utilities, and storage PFD's to identify areas of concern,
- Identify the Isolatable Sections: Hazardous Events shall be defined in terms of the Isolatable Sections and their operating conditions. Isolatable sections are defined and bounded by the location of, Emergency Shut-Down Valves (ESDVs), Locked close manual valves, check valves rated for the maximum Pressure, and pumps / compressor that will tripped upon fire /leak scenario, *(Note: Special consideration shall take place to the effect of presence of: Emergency Depressurization Valves (EDPVs), Control Valves, different materials compositions and phases, and different operating parameters).* The isolatable sections shall be clearly marked on the P&ID,
- Identify the Hazardous Inventories (Inventory Analysis) for each Isolatable Section,
- Determine the Source Terms for all accidental events, the Source Term means the rate at which hazardous material reaches the environment and the conditions of the material (e.g. temperature, composition).

8.3.1. Developing the Failure Case (Accident Scenarios)

Once the hazards are identified, the Accident Scenarios for the QRA can be generated;

Figure 2: Failure Case Development inputs

Failure cases are identified for the following categories:

- Pipework, risers, valves, flanges, fittings and associated equipment
- Pressure vessels / tanks
- Atmospheric storage tanks
- Intermediate bulk containers
- Pipelines
- Flexible hoses

Failure cases are distinguished from each other by the following conditions:

- Release location: it is necessary to account for release location when defining failure cases, as the Risks to personnel depend on where they are located with respect to failure case locations.
- Process parameters: temperature and pressure can have a significant impact on initial leak rate and subsequent consequences.
- Isolatable section: the action of isolation valves and size of isolatable inventory affects the release rate profile and duration of release.
- Material / phase released: the behavior of leaks, and therefore the subsequent consequences, can vary significantly according to the fluid phase.

(Note: The Failure Cases shall be developed for each Isolatable Section based on the different previous conditions to capture appropriate Risk profile and release events.)

8.3.2. Developing the Failure Cases using the Methodical Leak/Rupture

When using the Methodical Leak/Rupture approach for Failure cases development, it is common to use **the hole size categories**, (within each range, a representative size will be assigned for the Consequence Modelling failure Case):

- Small: 1mm to 10mm size hole,
- Medium: 10mm to 50mm size hole,
- Large: 50mm to 150mm size hole,
- Rupture: > 150 mm,

8.4. Consequence Assessment

8.4.1. Failure Cases (Accident Scenarios) Possible Outcomes

The development of the top event into a serious incident gives estimation for the expected failure cases (accident scenarios), the outcomes depend on: the effect of the process parameters, the release hole size, the phases of the hazardous material, the elevation and direction of the release point, the safety systems, the weather conditions, the confinement and congested areas, and presence of ignition sources. QRA studies use Event Trees to model the chronological series of events. **Event Tree provides a systematic method to ensure all potential outcomes as a result of a specified top event are identified.** Development of credible accident scenarios using Event Trees provides a structure to the conceptual and physical escalation scenario analysis.

The possible outcomes from different hydrocarbons releases are:

- **Flash Fire**

A flash or cloud fire occurs when a cloud of gas burns without generating any significant overpressure. The cloud is typically ignited on its edge, remote from the leak source. The combustion zone moves through the cloud away from the ignition point. The duration of the flash fire is relatively short, but it may stabilize as a continuing jet fire from the leak source. The major hazard to people for those within the burning envelope (including those who might be above on elevated structures). Flame duration and intensity for most flammable clouds are insufficient to cause a significant thermal radiation hazard outside the flame envelope. Where congestion or confinement exists, flame speeds can accelerate to hundreds of m/s and overpressure effects will result in an **Explosion**.

- **Jet Fire**

A jet fire is a turbulent diffusion flame, resulting from the combustion of a fuel continuously released with significant momentum in a particular direction (i.e. a jet). The flame can emit fatal levels of radiant heat to the surrounding area. Jet fire events are considered to occur following the immediate ignition of a continuous release involving flammable gases.

- **Pool Fire**

A pool fire is a turbulent diffusion flame burning above a horizontal pool of vaporizing flammable liquid, with little or no momentum. The flame can emit fatal levels of radiant heat to the surrounding area. Pool fire events are considered to occur following the ignition of a release (continuous or instantaneous) of hydrocarbon liquids, where a substantial liquid fraction remains following the release. When first ignited, the fire spreads rapidly across the full extent of the hydrocarbon pool and proceeds to consume the liquid at a characteristic burning rate. For a continuous release ignited early, the pool fire grows until equilibrium is reached where burning at the surface just balances the release rate.

- **Explosion (VCE - Vapor Cloud Explosion)**

A Vapor Cloud Explosion (VCE) occurs following the ignition of a flammable vapor cloud mixed with air in a congested area. Within the congested area, the flame accelerates to velocities high enough to produce significant levels of overpressure, which could then cause fatalities. VCE events may occur following the delayed ignition of a release (continuous or instantaneous) of flammable vapor or following vaporization of a liquid release. Several features need to be present for a vapor cloud explosion with damaging overpressure to occur: First, the released material must be flammable and at suitable conditions of pressure or temperature. (Such materials include liquefied gases under pressure: ordinary flammable liquids particularly at high temperatures and/or pressures: and non-liquefied flammable gases). Second, a cloud of sufficient size must form prior to ignition (dispersion phase). *(Note: If ignition occurs instantly, a large fire, jet flame, or fireball may occur, but significant blast-pressure damage is unlikely. While if the cloud be allowed to form over a period of time (1-5 minutes) within a process area, then subsequently ignite, blast pressures that develop can result in extensive, widespread damage, ignition).* Third, a sufficient amount of the cloud must be within the flammable range of the material to cause extensive overpressure. *(Note: The portion of the vapor cloud in each region depends on many factors, including type and amount of the material released: pressure at time of release: size of release opening: degree of confinement and congestion: and wind, humidity, and other environmental effects. In these appropriate conditions, a vapor cloud will generally have three regions: A rich region near the point of release: A lean region at the edge of the cloud: and A region in between that is within the flammable range).* Fourth, the blast effects produced by vapor cloud explosions can vary greatly and are determined by the speed of flame propagation. In most cases, the mode of flame propagation is deflagration. Under extraordinary conditions, a detonation might occur.

- **Fireball / BLEVE (Boiling Liquid Expanding Vapor Explosion)**

A fireball is a burning fuel-air cloud, whose energy is emitted primarily in the form of radiant heat. Fireballs were considered to occur following the immediate ignition of large vapor releases. They were also considered possible following the immediate ignition of a large release of liquefied gas. *(Note: Radiation effects due to the fireball depend on: The diameter of the fireball as a function of time and the maximum diameter of the fireball: the height of the center of the fireball above its ignition position as a function of time (after liftoff): the surface-emissive power of the fireball: the duration of combustion).* As combustion must progress inwards, and this takes from 15 – 45 seconds depending on size, these fire events tend to rise during the event due to buoyancy effects. **Normally, a fireball refers to combustion of a gaseous undiluted flammable cloud (i.e. pure hydrocarbon) and a BLEVE (Boiling Liquid Expanding Vapor Explosion) to the same event for liquids (also undiluted hydrocarbon).**

These both result in rapid combustion from the edge inwards as air progresses into the hydrocarbon. A BLEVE has an associated overpressure due to the rapid expansion of the flashing liquid, whereas a fireball may have no associated overpressure. In general terms, transient thermal radiation from a BLEVE is more significant to people than the overpressure, but a small number of large fragments can be thrown large distances, beyond the thermal and overpressure hazard zones, and are also a small Risk. Fireball or BLEVE's effects will be determined by the condition of the line or vessel's contents and of its walls at the moment of failure. These conditions also relate to the cause of container failure, which may be: external fire, mechanical impact, corrosion, overpressure, metallurgical failure.

- **Flammable Gas Dispersion**

Releases of gas (or gas flashed from liquid releases) form clouds that are dispersed by the initial momentum of the release, turbulence around the obstructions, natural ventilation, and the wind. The sizes of these gas clouds above their lower flammable limit (LFL) are important in determining whether the release will ignite. For toxic gas releases, the sizes of the clouds determine the zones within which fatalities may occur. Dispersion describes the process by which hazardous material released into the atmosphere is diluted by the air and transported away from the source. The degree of dilution is dependent upon the amount of turbulence present, either in the atmosphere or generated by the released material itself. The process of dispersion may be understood as changes in a number of key properties of the cloud: movement of the cloud downwind from the release point, spreading of the cloud, dilution of the cloud by entraining air, change of height of the cloud above the ground. A cloud released instantaneously is carried by the wind bodily away from the release point and spreads out in all directions. A continuous release forms a plume which spreads sideways as its front edge travels away from the release point with the wind and initial release velocity. If the release stops within the timescale of interest, the plume will detach from the release point and continue to spread and move downwind. The dispersion of a cloud of released material is controlled, fundamentally, by two properties of the cloud and two of the atmosphere:

Cloud Properties: (a) Density, (b) Velocity relative to the surrounding air,

Atmosphere Properties: (a) Wind speed, (b) Stability).

- **Toxic Gas Dispersion,** (see Flammable Gas Dispersion)

  Figure 3 shows examples for possible outcomes from gas and liquid release events. *(Note: The only case not included in Figure 3 is that of BLEVE (Boiling Liquid Expanding Vapor Explosion), which refers to the failure of a pressure vessel as a result of its external heating from a fire.)*

- Accordingly, for each identified Isolatable Section and Failure Case, the physical effects (consequence) shall be identified (Section 8.4.2.).
- *(Annex A – Table A1 gives an example and sample for the Process Hazards, Events, Sequences, Incident Outcomes, and consequences [1]).*

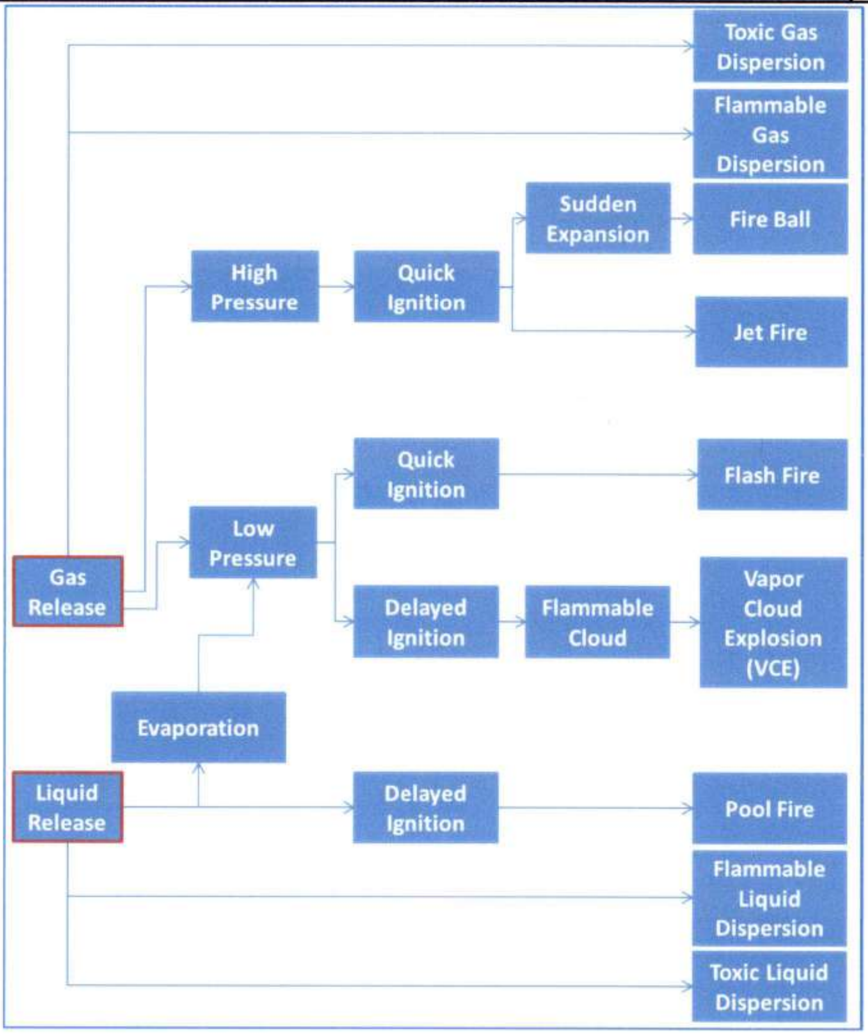

Figure 3: Example for possible outcomes from gas and liquid release events (Ref. [7] - with adaptation)

8.4.2. Physical Effect Modelling

The Physical Effect refers to the possible consequences from releases of hydrocarbons and toxic gases. (For example, this may be the extent of a gas cloud's flammability or toxicity or it may be a measure of thermal radiation or explosion overpressure). Figure 4 shows the stages of developing the Hydrocarbons (HC) release into the main physical effects (Toxic, Flammable, and Explosion).

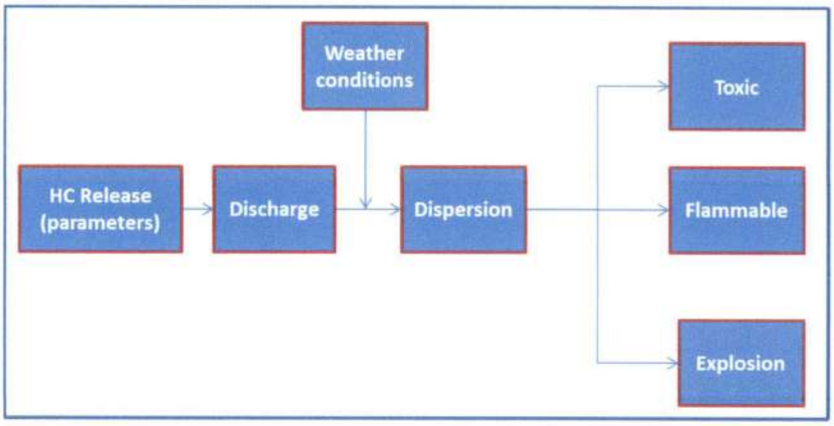

Figure 4: The stages of developing the HC releases into the main physical effects

Physical effects shall be calculated to identify which parts of the facility, community, Company personnel and the public may be exposed for each potential event and the extent of that exposure. This exposure used to estimate the potential for further failure, escalation, impairment, injury, etc. and contribute to decisions on the need to reduce such Risks.

Once the release rate has been estimated the calculation of physical effects will depend on many other factors (such as: wind profile, obstruction, congestions, ignition sources, exposure duration,).

The physical effect modelling determines the dispersion profile and extend of various physical effect such as toxic/ flammable dispersion, flash fire envelope, jet fire, pool fire, explosion effect, smoke dispersion, etc.

The potential outcomes of various 'physical effects' for a given release profile for each scenario under consideration shall be reported in the QRA Report.

Table1 gives list of the possible physical effects (consequences) apply for each failure case category.

Failure case category	possible physical effects					
	Jet fires	Pool fires	Fireballs	BLEVEs	Flash fires	Explosions
1. Pipework, risers, valves, flanges, fittings and associated equipment	Y	Y	N	N	Y	Y
2. Pressure vessels / tanks	Y	Y	Y	Y	Y	Y
3. Atmospheric storage tanks	N	Y	N	N	Y	Y
4. Intermediate bulk containers	N	Y	N	N	N	N
5. Pipelines	Y	Y	N	N	Y	Y
6. Flexible hoses	Y	Y	N	N	Y	Y

Table 1: the probable physical effects which apply for each failure case category (Ref. Typical Industry Practice).

The following list gives indicative values/scales at which the physical effects could be measured (these measures, as well as the vulnerability given values (Annex B), to be used for estimating the probable physical effect and its impact on human for emergency cases):

8.4.2.1. Jet Fire:

Release rate, jet flame length, Surface Emissive Power (SEP), downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2.

In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.

8.4.2.2. Pool Fire/Sea Pool Fire:

Release rate, pool diameter, SEP, downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2.

In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.

8.4.2.3. Fireball/BLEVE:

Fireball radius, BLEVE radius, downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2.

In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.

8.4.2.4. Flammable Gas Dispersion Results

Distance 0.5 LFL (Lower Flammable Limit), LFL and UFL (Upper Flammable Limit), (At all points and heights of interest (e.g. HVAC inlet, sources of ignition, EER measures (Evacuation, Escape and Rescue activities), etc.)).

8.4.2.5. Toxic Gas Dispersion Results

Distance downwind represents specific adverse health effect, on various considered populations onsite and offsite, from specific concentration of toxic material for various exposure times, (more details are given in 8.4.4.3, and *Annex B (B) & Annex B (B-3)*).

8.4.2.6. Smoke (mostly for offshore facilities):

CO, CO2 concentrations at, downwind distance to various effective concentrations (more details are given in IOGP Report no. 434-14).

8.4.2.7. Explosion Overpressure Results

Downwind distance to 30mbar, 70mbar, 100mbar, 200mbar, 300mbar and 500mbar.

In addition, explosion overpressure and impulse duration at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.

8.4.2.8. Bund Fire/Rim Seal Fire/Full Surface Fire

Diameter, SEP, downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2.

In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.

Physical Effect Notes:
(1) Justification for the selected SEP shall be furnished/ provided for the pool fire (land/sea) scenarios.
(2) For the pool fire: the drainage system limits the pool size and reduces the impacts of its consequences (e.g. from evaporation from pools, or overly-large pool fires). The QRA software models typically do not have capability to model a drainage system. The Consultant must use his judgement and to agree with the Company to determine the pool credible size to avoid the exaggerated conservatism in results.
(3) Bund fire and full surface fire scenarios considering credit for the smoke.
(4) Radiation levels, flammable concentration and toxic concentration (H2S and SO2) shall be reported at various populations identified for the new facilities and existing facilities (if any).
(5) Explosion overpressure results along with associated impulse duration shall be reported for the critical buildings, non-critical buildings, and manned/unmanned buildings.

8.4.3. Height of Interest for Consequence Results

The consequence results should be extracted at certain height, called height of interest, the results may be quite different at each height due to the behaviour and properties of different consequences. The following is the recommended guide for the consequence results different height of interest, otherwise should be justified by the Consultant and agreed by the Company:

- All consequences effects on people shall be calculated at 1 meter above ground level,
- For ingress into buildings, the concentration shall be monitored at the building openings heights (e.g. air intake, windows, unsealed and non-closed doors), where such information is not available, 2m & 3m heights to be considered,
- For multi-story units, heights shall be based on where major equipment are located,
- All other equipment can be considered at ground level.

8.4.4. *Impact Assessment & Vulnerability of Human*

As part of impact assessment, vulnerability of humans to the consequences of major hazard events at onshore and offshore installations, primarily those producing and/or processing hazardous fluids are established. The focus is on Fatality Criteria as QRAs generally address fatality Risks: however injury thresholds can also identified where appropriate.

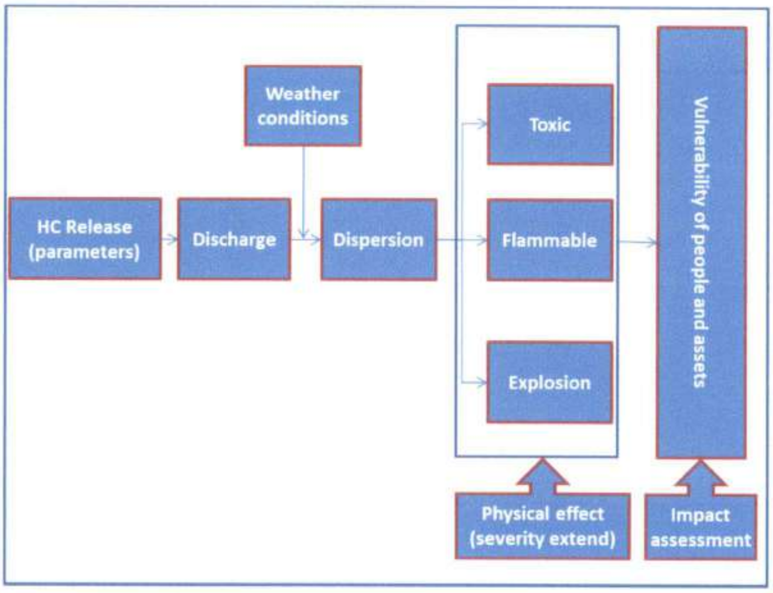

Figure 5: The stages of developing the HC releases into the Impact assessment

The impact assessment is generally expressed in terms of:

a) Lethality, which is fraction/percentage of the exposed population who would suffer fatality on exposure to a given consequence level.
b) Probit, which is a function that relates lethality to the intensity or concentration of hazardous effect and the duration of exposure.

Generally, the following consequences are considered as part of impact assessment:

- Fire Scenarios (radiation levels)
- Explosions (blast overpressure)
- Toxic Gases (toxic gas exposure)
- Smoke (toxic fumes exposure)

8.4.4.1. *Fire Scenarios:*

Humans are vulnerable to fire in the following ways:

- Engulfment by the fire
- Thermal radiation from the fire (outside the fire)
- Inside a building that is exposed to fire/radiation

The relation between fire type and potential vulnerability illustrated in Table 2

Fire Type	Potential Vulnerability		
	Engulfment	Radiation	Inside Building
Flash Fire	Yes	No	Possible
Jet Fire	Yes	Yes	Yes
Pool Fire	Yes	Yes	Yes
Fireball/BLEVE	Yes	Yes	Possible

Table 2: Impact Assessment of Fire type (Ref. [2])

8.4.4.2. Explosion:

Explosions generate overpressures and drag forces that in turn result in damage to buildings and structures, and generate missiles (fragments of damaged structures, window glass shards, or loose objects). The effects of overpressure on humans are normally categorised as follows:

- Direct or Primary: injury to the body as a result of the pressure change
- Secondary: injury as a result of fragments or debris produced by the overpressure impacting on the body
- Tertiary: injury as a result of the body (especially the head) being thrown by the explosion drag and impacting on stationary objects or structures.

For QRA, lethality is not typically estimated independently for these effects: instead, an overall lethality is estimated based on the combination of these effects. Casualties requiring medical treatment from direct blast effects are typically produced by overpressures between 1.0 and 3.4 bar. However, other effects (such as secondary effects and thermal injuries) are so predominant that casualties with only direct blast injuries make up a small part of an exposed group.

8.4.4.3. Toxic:

Various approaches are used to determine the consequences of toxic gases and have various purposes:

- IDLH (Immediately Dangerous to Life or Health),
- ERPG/AEGL (Emergency Response Planning Guideline / Acute Exposure Guideline Level),
- Probit, (recommended to be used for Risk Calculations, as it takes into account both concentration and duration of exposure).
- SLOT (Specific Level Of Toxicity), DTL (Dangerous Toxic Load) & SLOD (Significant Likelihood Of Death).

Toxicity Notes:

(1) IDLH ("Immediate Danger to Life or Health") is the maximum concentration from which escape is possible within 30 minutes without any escape-impairing symptoms or irreversible health effects. It used as the limiting value for the onset fatalities.

(2) ERPGs – Emergency Response Planning Guidelines – they are used (in the USA) to plan emergency response to an incident, knowing the likely ranges of health effects resulting from the incident and consequent numbers of casualties.

(3) The probit approach has been used with probit functions being developed for a wide range of toxic materials. They enable the lethality to be estimated for any combination of concentration and duration of exposure, including time dependent concentrations (resulting from time varying release rates). They are recommended to be used to provide fine resolution in fatality estimates, especially for third party (offsite) Risks onshore.

(4) The SLOT (Specified Level Of Toxicity) DTL (Dangerous Toxic Load) is usually defined as the dose that results in highly susceptible people being killed and a substantial portion of the exposed population requiring medical attention and severe distress to the remainder exposed. As such it represents the dose that will result in the onset of fatality for an exposed population (commonly referred to as LD1 or LD1-5).

(5) The SLOD (Significant Likelihood of Death) DTL is defined as the dose to typically result in 50% lethality (LD50) within an exposed population and is the value typically used for group Risk of death calculation onshore.

(6) The SLOT and SLOD DTLs technique has been proposed and developed by the UK HSE as an alternative to the probit approach.

(7) The use of probits approach is recommended.

(Annex B – Gives details to determine and understand the different values of Vulnerability of Human for different Consequences/Impacts of Major Hazard Events).

8.5. Frequency Assessment

8.5.1. Parts Count (Equipment Count) for Isolatable Sections:

For each failure case, in each isolatable section, equipment is counted to provide input to estimating leak frequencies. This is known as a 'parts count'.

The frequency of each leak scenario and size identified is estimated by combining parts counts for each equipment item with Leak frequencies.

A 'parts count' involves counting each and every equipment item in each section identified as set out in but not limited to:

- PFDs
- P&IDs
- Equipment list
- Layouts and plot plans

For equipment (pipework, risers, flanges, valves etc.) where the release frequency is line/connection diameter dependent, a separate count is made for each such diameter. The P&IDs are marked-up as equipment is counted to ensure that every item has been included.

8.5.2. Hazardous Events Likelihood

There are two basic forms that the likelihood of an event may be expressed:

- Frequency: number of events or outcomes per defined unit of time e.g. a 6inch ESD valve has a failure frequency of 10-4 times per year
- Probability: measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty.

The Quantitative estimates of hazardous events likelihood are usually derived using a combination of the following approaches:

8.5.2.1. Plant/Facility Specific Data

Failure rate data generated from collecting information on equipment failure experience at a plant are referred to as plant-specific data. A characteristic of plant-specific data is that they reflect the plant's process, environment, maintenance practices, and choice and operation of equipment.

One advantage of using plant data is that it already encompasses all common relevant contributory aspects including the reliability of equipment, human factors, maintenance, operation, operational methods, quality of construction and inspection, for the facility itself, the plant/facility Data are:

- based on previous experiences
- database with regular updates

8.5.2.2. Generic Failure Frequencies

Data accumulated and aggregated from a variety of plants and industries are called Generic Data, (sometimes are called Historical Data). With inputs from many sources, generic failure rate data can provide a much larger pool of data. However, generic data are derived from equipment of many manufacturers, a number of processes, and many plants with various operating strategies. Generic failure rates/ frequencies for various components are available in various historical accidental databases such as IOGP, OREDA, UK HSE HCR, Purple Book, etc. These frequencies in conjunction with parts count, hole size, and distribution are used to determine the failure frequencies.

Notes:

(1) When using the Generic Failure Frequencies data, it usually gives conservative results, and to avoid obtaining exaggerated failure data due to the differences between the conditions of the QRA study facilities (e.g. design and operating conditions), especially for the new facilities (which usually come with new design and technology), and the multisource of the generic data, the QRA Consultant, after making an engineering judgment, can use modification factor(s) to make the failure data more suited to the facilities under the study.

(2) Decreasing the time of getting the facilities in service (usage time), using the safety system(s) to decrease the inventories and the time of the facility' blowdown, shall also be reflected on the failure frequencies.

8.5.2.3. Using Modelling Techniques

Modelling techniques to estimate incident frequencies from more basic data are used when suitable historical data are not available or are inadequate. Various techniques are available, but the most common and widely used techniques are Fault Tree Analysis (FTA) and Event Tree Analysis (ETA).

8.5.2.3.1. Fault Tree Analysis (For Top Event Frequency Estimation)

Fault Tree analysis is a common probabilistic technique widely used in system reliability and safety studies. It allows the user to concentrate on a particular system failure, which usually gives rise to the 'top event'. Fault Tree analyses are performed using a top-down approach. Starting with a top-level event, Fault Tree analysis is performed by working down to evaluate all the contributing events that may ultimately lead to the occurrence of the top-level event. The resulting Fault Tree diagram is a graphical representation of the chain of events in the analysed system or process, built using events and logical gate configurations. The probability of the top-level event can then be determined by using mathematical techniques. By ascribing frequencies to each basic cause**, the frequency of the Top Event can be calculated**. This requires knowledge of basic cause failure rates. The best practice in selecting basic cause failure rates should be the use of supplier data for new installations and of historical data of the plant for existing installations. There are also a number of generic databases available which assign basic cause failure rates. Throughout the construction and analysis of Fault Tree, assumptions will also have to be made regarding the ways in which the facility is operated and maintained. These assumptions (repair rates, inspection time, etc.) should be set out together with the project Maintenance group.

- Top event is the accident and broken into its component causes
- Frequencies come from historical data and informed judgement

8.5.2.3.2. Event Tree Analysis (For Failure Cases Probability Estimation)

Event tree analysis (ETA) is an analysis technique for identifying and evaluating the sequence of events in a potential accident scenario following the occurrence of an initiating event.

ETA utilizes a visual logic tree structure known as an Event Tree (ET). The objective of ETA is to determine if the initiating event will develop into a serious mishap. An ETA can result in many different possible outcomes from a single initiating event, and it provides the capability to obtain **a probability for each outcome (failure case)**. *(Note: For the most of modern complete QRA software the Event Tree is built-in the software),* ETA Diagram structure illustration is shown in figure 6,

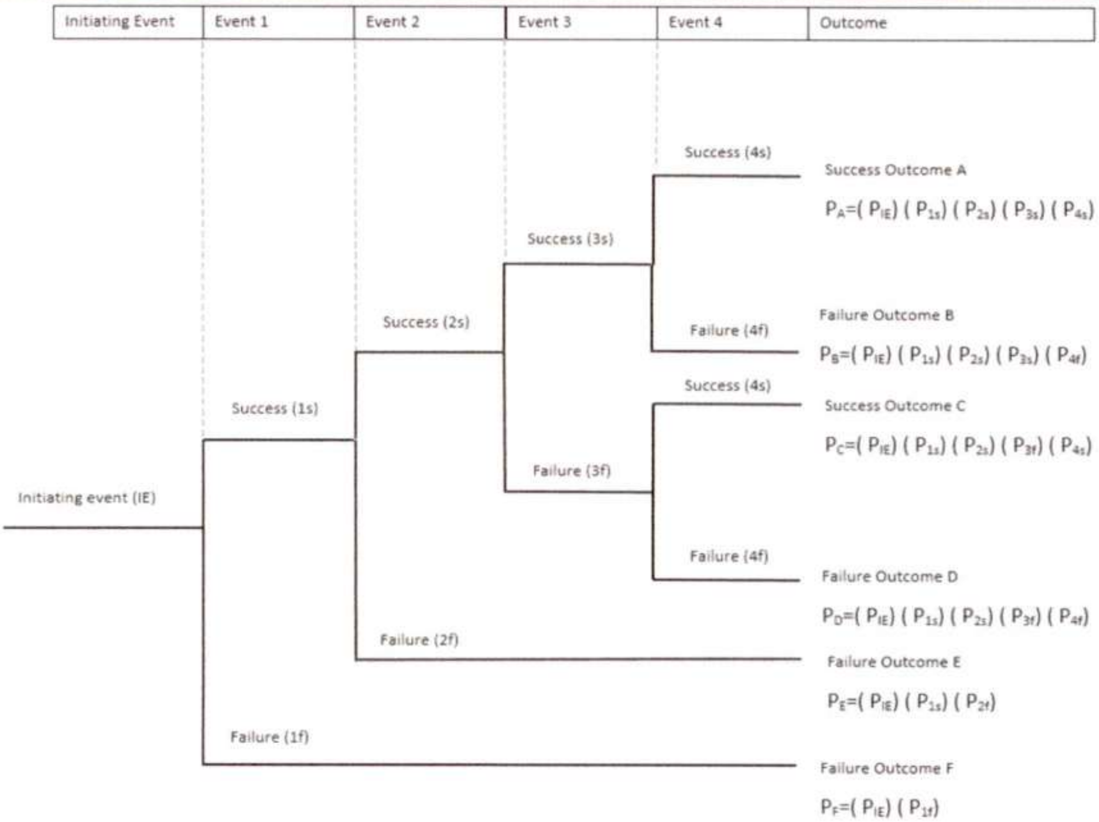

Figure 6: ETA Diagram structure

The main nodes of the Event Tree are mainly relevant to the probability of ignition (immediate/delayed) and probability of explosion, the event frequency of each incident scenario (consequence) is derived by multiplying the failure frequency by the probabilities along the Event Tree branches that lead to that scenario. *(Note: The failure frequencies are expressed as a frequency (e.g. number of occurrences per year). The event probabilities are real probabilities (i.e. a dimensionless number between 0 and 1)).*

(Annex C - Figures C1-C5 provide examples for Event Tree for a range of different release types)

8.5.2.4. Judgemental Evaluation

When historical data is not available, or only available for facilities operating in different circumstances, it is necessary to use engineering judgement or rely on the opinion of experts to interpret data for comparable equipment in order to make a best estimate. Such judgements should not be too optimistic and should be clearly recorded and formalized as part of assumption register.

- Occurrences are rare and/or data is not available
- May be suitable for basic Risk assessments

8.5.2.5. Software

A numbers of software are also available for the frequencies estimation, these software programs use a combination of the previous failure frequency approaches.

8.5.3. Frequency Estimation

The failure frequency for each failure case for each isolatable section needs to be represented by one frequency value (e.g. it would consider all large leaks from all the base elements in each isolatable section as they are all part of the single failure case for this isolatable section). Failure frequencies are applied to all items of equipment (e.g. pipes, flanges, valves), within the failure cases (as they are all part of the single failure case).

The failure frequency for the failure case is the sum of the failure frequencies of the base elements multiplied by the number of base elements.

In general the failure case frequency is given by this simple equation: $$F = \sum_{i=i}^{n} n_i f_i$$

Where:

F is the frequency of incident.

n_i is the number of base elements i.

f_i is the frequency of failure for base elements i

8.6. Other Data for Risk Calculation

In order to complete the Risk Calculation some other data should be collected, calculated, and considered (e.g. Process and Plant Data, Chemical Data, Environmental Data, [1]), hereafter some of the most important required data:

8.6.1. Ignition Sources and Ignition Probability

Personnel are normally more likely to be fatally injured if the release of flammable material is **ignited**. In order to account for the difference in Risk associated with ignited releases and **unignited** releases, it is necessary to determine the ignition sources and estimate the probability of ignition. As well as, the time at which a release is ignited has a significant influence on the corresponding consequences. The flammable gas leaks which are **ignited immediately** are likely to result in jet fires. *(For clarification: UKOOA model is used to estimate the Immediate Ignition probabilities based on leak rates of flammable material. (e.g. assuming ignitions that occur within 30 seconds of a leak are classified as immediate, the probability of immediate ignition is taken to be 36% of the overall ignition probability)).*

While, if flammable gas leaks are **delayed** in their ignition, there is likely to be a higher degree of gas build-up on the facility, resulting in a higher explosion Risk than leaks which are ignited immediately. The probability of delayed ignition occurring is dependent on a dispersing release encountering an ignition source, and is calculated according to the dispersion characteristics of each event (including the duration), the characteristics of the defined ignition sources.

Ignition sources types differ from on site to out sites (e.g. ground flares, overhead electrical cable, on site human activities (hot work), out site human activities (cooking), vehicles, trains, etc.). *(As an example for the ignition source defined on site, it is assumed to ignition probability, given that a flammable cloud overlaps the ignition source, is equal to 1).*

(Note: Guideline available from IOGP Report 434-06 shall be used for the Ignition Probabilities).

(Note: For the most of complete QRA software, the ignition probabilities are built in the software and it is a matter of choosing the ignition sources location and types).

8.6.2. Explosion Data

The Explosion involves the release of flammable gas or vapor within a confined or highly congested area followed by a **delayed ignition**. A confined explosion can result in multiple fatalities as well as resulting in damaging overpressures on equipment and buildings (will be covered in the Fire and Explosion Risk Assessment (FERA) Guideline, (EGPC-PSM-GL-009)). The over pressure generated will depend on the degree of congestion and confinement of the area and the gas cloud size (mass).

Explosion probabilities are determined based on the overlap between LFL clouds and congested areas.

It is necessary to define congested or confinement areas of the site which have the appropriate attributes for pressure generation. Congested areas can give flame acceleration and subsequently overpressure in the event of a flammable cloud within the congestion being ignited. Typical congested areas are process plant, vessels, tanks, and pipework. *(Note: Areas in the open air e.g. over open ground or between large structures such as the storage tanks, are not regarded as congested or confined).*

8.6.3. Meteorological Data (Weather Conditions and Probabilities)

Weather conditions at the time of the release have a major influence on the extent of dispersion. The primary factors are the wind speed and the atmospheric stability. Atmospheric stability is an estimate of the turbulent mixing: stable atmospheric conditions lead to the least amount of mixing and unstable conditions to the most.

The atmospheric conditions are normally classified according to six Pasquill stability classes (denoted by the letters A through F). The stability classes are correlated to wind speed and the quantity of sunlight.

During the day, increased wind speed results in greater atmospheric stability, while at night the reverse is true. This is due to a change in vertical temperature profiles from day to night.

Within the stability classes, A represents the least stable conditions while F represents the most stable. (i.e. more stable weather conditions cause dispersing clouds to sustain for longer distances at higher concentrations. That can lead to greater flammable mass and higher toxic dose compared to less stable weather conditions).

Pasquill Stability classes are:

- A very unstable – sunny, light winds
- A/B unstable – as with A only less sunny or more windy
- B unstable – as with A/B only less sunny or more windy
- B/C moderately unstable – moderate sun and moderate winds
- C moderately unstable – very windy/sunny or overcast/light wind
- C/D moderately unstable – moderate sun and high wind
- D neutral – little sun and high wind or overcast/windy night
- E moderately stable – less overcast and less windy night than D
- F stable – night with moderate clouds and light/moderate winds

During the day, increased wind speed results in greater atmospheric stability, while at night the reverse is true. This is due to a change in vertical temperature profiles from day to night.

Within the stability classes, A represents the least stable conditions while F represents the most stable. (i.e. more stable weather conditions cause dispersing clouds to sustain for longer distances at higher concentrations).

Table 3 - Meteorological Conditions Defining the Pasquil-Gifford Stability Classes (Gifford, 1976).

	Daytime insolation			Nighttime conditions		Anytime
Surface wind speed, m/s	Strong	Moderate	Slight	Thin overcast or >4/8 low cloud	≥3/8 cloudiness	Heavy overcast
<2	A	A–B	B	F	F	D
2–3	A–B	B	C	E	F	D
3–4	B	B–C	C	D	E	D
4–6	C	C–D	D	D	D	D
>6	C	D	D	D	D	D

Table 3: Meteorological Conditions Defining the Pasquil-Gifford Stability Classes (Gifford, 1976). (Ref. [1])

8.6.3.1. For the purpose of QRA study the following requirements for the weather conditions should be applied

- Two weather conditions are selected to represent the average wind conditions during the year considering the day and night conditions.
- The average weather conditions shall be calculated depends on at least the last five years weather conditions.
- Weather data should be based on data from Egyptian meteorological authority.
- In the absence of detailed meteorological data for a particular site, two common weather combinations (stability and wind speed) should be used, The UK-HSE recommends using two representative weather conditions to model the dispersion of each release scenario. Wind stability class 5D and class 2F:
  - 5D - neutral stability and 5 m/s wind speed. This is typical of daytime conditions with relatively high wind and cloud cover, leading to moderately turbulent conditions.
  - 2F - stable conditions and 2 m/s wind speed. This is typical of night-time conditions with moderate cloud cover, where there is limited turbulence and hence limited dilution of dispersing clouds.

8.6.4. Population and Manning Level Distribution

It is necessary to know the population distribution on and around the site to estimate the Societal Risk. However, it is still necessary to determine the location of the people whose Individual Risk is being estimated.

a) Offsite Population:

The population distribution is often defined as population density. Sources of population data for an area are census reports, detailed maps, aerial photographs, and site inspections by the analyst. Special attention must be made to the various types of population (i.e., residential or industrial), the indoor and outdoor percentage, and the day/night variations and concentrations of people such as hospitals, mosques/churches, or schools.

(Note: Appropriate provision for future development is also important).

In absence of enough data, typical population density estimates for different categories of occupancy are [1]:

- Urban: 19,000-40,000 people/square mile
- Suburban 5000-19,000 people/square mile
- Scattered housing: 250-5000 people/square mile

b) Onsite Population/Manning Level:

The manning level shall be identified for each worker group: it should be assigned a rotation/shift pattern, and the time spent at each area of the facility/plant versus time spent in the control room/offices/accommodation shall also be estimated. These estimates shall be used to calculate the Individual Risk in form of IRPA to each person within each worker group.

8.7. Risk Analysis

The consequences and frequencies are combined in an integrated QRA model to give numerical Risk values. (*Note: Other non-process hazards also need to be analysed, such as personnel transport, occupational hazards, ship collision, aircraft impact and natural hazards. Each has its own specialist method for Risk Analysis*).

Risks to people may be expressed in two main forms:

a) Individual Risk:

The Risk experienced by a person and it shows the frequency at which an individual (worker or public) may be expected to sustain a given level of harm from the realization of specified hazards. It is usually taken to be the Risk of death and usually expressed as a Risk per year. It is divided into:

- IRPA, Individual Risk Per Annum: Individual Risk mostly expressed in the form of Individual Risk Per Annum (IRPA). The IRPA is a representative worker of a given workers group considering expected occupancy at all the locations he is expected to be present within the hazardous location throughout the year. This includes plants, accommodations, recreational activities, etc. The calculation excludes the duration for which personnel is not present at the site due to reasons such as annual leave, personnel is considered not exposed to facility operations or occupational Risk during this duration.
- LSIR, Location Specific Individual Risk / Risk contours: Risk contours are iso-Risk contours plot represent the geographical variation of the Risk for a hypothetical individual who is positioned at a particular location for 24 hours per day, 365 days per year.

b) Societal (or Group) Risk:

The Risk experienced by the whole group of people exposed to the hazard. Where the people exposed are members of the public, the term Societal Risk is often used. Where workers are isolated and members of the public are unlikely to be affected, the term group Risk is often used. In this document, the term Societal Risk is used to encompass both public and worker Risk. There are two forms of Societal Risk:

- FN Curve / Diagram: The FN curve is the curve of cumulative frequency versus numbers of fatalities on a logarithmic scale. FN curves are frequency-fatality plots, showing the cumulative frequencies (F) of events involving N or more fatalities.
- PLL, Potential Loss of Life: The other main measure for Societal Risk is the annual fatality rate, where the frequency and number of fatalities are combined into a Potential Loss of Life (PLL), which is a convenient one-dimensional measure of the total number of expected fatalities.

8.7.1. Process Risk Presentation:

Calculated process Risk shall be presented based on Risk various indicators as outlined in table 4 below.

	LSIR	Process IRPA	PLL	F-N Curve (Workers)	F-N Curve (Public)
Onshore	- LSIR Contour for each unit / segment / isolatable section - Cumulative LSIR contour	For each worker group	For each worker group	Gathering places (accommodations / administrative buildings / mess / canteen /rest places / entertainment places...etc.)	For nearby public population
Offshore	LSIR value for each deck	For each worker group	For each worker group	Gathering places (accommodations / mess / canteen /rest places / entertainment places...etc.)	—
Note	*Results illustrated in form of:* *- Contours on geographical maps or plot plan, graphs, curves, and* *- Tables shall be provided to show the Risk values for both indoor and outdoor vulnerabilities (for both onsite and offsite populations).*				

Table 4: Process Risk Presentation- Risk various indicators

(Annex D – Tables D1 & D2 give a full list of the QRA study deliverables)

8.7.2. Other Risks Analysis

8.7.2.1. Non-Process Risk

As part of non-process Risk assessment, following Risks are studied for various process facilities/installations, where applicable.

- Ship Collision Risk Assessment
- Transport Risk Assessment
- Dropped Object Risk Assessment
- Occupational Risk Assessment

8.7.2.2. Ship Collision Risk Assessment

As part of the ship collision Risk assessment, it is important to determine the Risk of platform-ship collision under mainly 2 categories i.e. passing ship collisions and infield ship collisions. It is recommended to use guidelines available from IOGP Report 434–16 for the ship collision Risk assessment. *(Note: If any specific information is to be considered, it shall be documented as part of the assumption register).*

8.7.2.3. Transportation Risk Assessment

8.7.2.3.1. Marine Transport Risk Assessment

Marine transport Risk is determined using the FAR rates. The FAR (fatalities per 1E8 exposed Hours) where crew boats are used to transport other personnel to and from offshore facilities is expressed as below:

- *FAR = 30 + (26/Transit Time Per Journey in Hours)*

(Note: This method is very high-level assessment but adopted for typical QRA report based on the guidelines given in IOGP Report 434 – 10).

8.7.2.3.2. Aviation Risk Assessment

Aviation Risk assessment includes determination of Risk for helicopter and fixed wing transport Risk associated with facilities under consideration.

The following methods are recommended.

- *Individual Risk (IR) per journey = In-flight IR + Take-off & landing (TO/L) IR*
- *In-flight IR = Accident frequency in-flight (per hour) × Flight time (hours) × Probability of fatal accident × Probability of death in fatal accident*
- *TO/L IR = Accident frequency in TO/L (per flight stage) × No of flight stages per journey × Probability of fatal accident × Probability of death in fatal accident*

8.7.2.3.3. Road Transport Risk Assessment

Road transport Risk assessment shall be included to determine the Risk to people. Risk assessment to include Risk due to transportation and also due to transportation of hazardous material.

8.7.2.4. Dropped Object Risk Assessment

Where separate Dropped Object Study is carried out, any Risk to the people shall be considered in the QRA based on the calculated dropped object frequency and impact energy.

8.7.2.5. Occupational Risk Assessment

Occupational Risk is associated with day to day activities (operation) of the facilities and is generally presented as FAR (Fatal Accident Rates). If It is required that as part of the QRA study, occupational Risk is calculated for the various workers group based on the time spend in the facilities (field) over the year.

(Note: Guidelines available from IOGP Report 434-12 shall be used to determine FAR rates).

8.7.2.6. Escape and Evacuation Risk Assessment

Generally, escape and evacuation Risk are determined for the offshore facilities.

The following shall be considered as minimum following escalation cases to be studied as part of the QRA Report if identified as Risk contributors to personnel.

- Potential fatalities due to escalated scenario such as BLEVE, Fireball, Boil over, Catastrophic Vessel Failure, secondary explosion or toxic releases, etc.
- Potential fatalities during evacuation such as use of lifeboat/ life raft/ rescue boat, impairment of muster location, impairment of TR, impairment of both the escape route etc.

(Note: Guidelines are available in IOGP 434-19 for determination of evacuation Risk for various evacuation modes, evacuation scenario probabilities and evacuation frequency. Evacuation frequency shall be obtained by considering all the scenarios requiring evacuation).

8.7.2.7. H2S Zoning

Locations where a H2S hazard exists must be classified according to the potential threat from H2S based on the precautions needed to allow people a good chance to escape in the event of an accidental release of H2S. As part of the QRA Report, it is required that H2S zoning is carried out for facilities containing H2S or existing H2S zoning is updated to reflect the new facilities being added.

8.7.2.8. Occupied Building Risk Assessment

It measures the Risk to people in occupied buildings in a process plant against the MAH impacts (fire, explosion, toxic, smoke impairment, etc.). The OBRA can help determining if the occupants of a building are being subjected to unnecessary Risk and identifying where additional protection would be advised to eliminate, control, and mitigate the consequence(s) of any potential Major Accidents and to demonstrate that the Risk(s) is as low as reasonably practicable (ALARP).

The MAH impacts shall be studied as part of the OBRA. Both the location and the design of occupied buildings can significantly affect the survivability of people inside buildings in the event of a Major Accident. The MAH impacts shall be studied for the residential buildings, accommodation buildings and industrial buildings which are either occupied or are used post emergency for EER measures. The overall summary of Risk assessment shall be made available in QRA Report.

The Occupied Building calculated Risk represents an annual frequency that individual might be killed from a MAH while occupying a specific building. And it is calculated by multiplying the Building Risk with the fraction of individual occupancy in a specific building (e.g. 40 hrs. /week).

The calculated Occupied Building Risk contribution to the Individual Risk is compared with the following Risk Tolerability Acceptance Criteria;

- *10-5/yr. for new buildings,*
- *10-4/yr. for existing buildings*

And the MAH impacts in the OBRA shall include the following:

- *Flash fire,*
- *0.5 LFL,*
- *Heat radiation that leads to damage to the building based on building construction material,*
- *Overpressure due to explosion that leads to damage to the building based on building construction material,*
- *Toxic gas AEGL 2 value at building.*

OBRA Notes: (Otherwise shall be justified by the Consultant and agreed by the Company):

(1) Occupied Building is a Building that personnel occupy while doing a major part of their work, such as control rooms, laboratories, office buildings, maintenance work areas, outside operator buildings, or a building with a primary purpose that necessitates people to occupy it, such as field labs, lunch-rooms, locker facilities used to change clothes, showers, restrooms or toilets (lightweight plastic porta-toilets are excluded from this definition).

(2) Other Portable Building that has a primary purpose to house or store equipment or materials are considered an "occupied building" if any of the following conditions apply:

- *An individual spends on average 10 hours or more a week inside the building.*
- *10 or more people are in the building at any given time.*
- *A group spends an average of 200 exposure hours or more a week inside the building.*
- *The building is used for accommodation or sleeping.*

(3) Observation shelters provided for weather protection for the marine, road, or rail loading operator may, in consultation with the Company, be excluded from the definition of an occupied building. By nature, such buildings are small and require a large amount of window area to satisfy operational safety requirements with the loading operations.

(4) If a building is required to be occupied in the event of emergency, in such cases, buildings shall be designed as TR (Temporary Refuge: is an enclosed place where people can muster whilst investigations, emergency response and evacuation preparations are undertaken).

(5) The fire and Explosion Assessment for the building itself is carried out as part of the FERA study.

8.7.2.9. Simultaneous Operations (SIMOPS) QRA

Oil and Gas operations involve many simultaneous activities / operations where people can get exposed to significant Risk. Therefore, it is important that these activities and potential SIMOPS are looked at during the development of QRA study where information is available or a separate SIMOPS QRA can be conducted.

The two main examples for the SIMOPS are:

- Two different operation activities conducted adjacent to each other (e.g. drilling activities conducted adjacent to live production or processing facilities).
  (For this case the Risk from both operation activities shall be combined).
- Construction activities conducted adjacent to live production or processing facilities.
  (For this case Risk from existing production activity on construction personnel shall be studied and the QRA can be reviewed where available to determine the Risk to construction personnel).

The SIMOPS assessment shall also consider additional precautions put in place for the duration of the SIMOPS and additional increases in Risk due to activities or presence of additional manpower.

8.7.2.10. Integrated Risk Assessment

Once various Risks such as process Risk, non-process Risk, escape & evacuation Risk, etc. are determined the overall Risk shall be determined by combining Individual Risk from all these factors. For brownfield or modifications projects/QRA, existing facilities Risk shall also be considered.

8.8. Risk Evaluation

Once Risks are identified and analysed, Risks should be evaluated against set Criteria. It must be ensured that all Risks are evaluated to meet and comply with EGPC and Holding Companies' Quantitative Risk Tolerance Criteria.

(Annex E – Shows the QRA Tolerance Criteria- as per mentioned in the Risk Management Standard EGPC-PSM-ST-001).

8.9. ALARP Demonstration

The QRA shall provide a clear demonstration that the Risk is (or will) be reduced to ALARP. ALARP process starts by identification of the Major Risk Contributors. These Major Risk Contributors are further broken down to determine the top contributors to Risk.

Risk reduction measures are identified against these contributors to reduce the Risk, as well as identifying hierarchy of controls for these Risk reduction measures.

The QRA Consultant shall:

- Identify and provide Risk reduction measures to ensure the Risk is "As Low As Reasonably Practicable" (ALARP),
- Demonstrate that the preferred Risk reduction measure reduces Risk to ALARP by rerun the results after agreeing the suggested reduction measures with the Company, (this will help to assure the effectiveness of these measures to reduce Risk to the ALARP).

ALARP demonstration (including the Cost Benefit Analysis, if required), should be in accordance with the ALARP Demonstration Guideline EGPC-PSM-GL-010 & the Risk control measures option should be in accordance with the Risk Management Standard EGPC-PSM-ST-001 (7.7.Risk Treatment & Annex E- Risk Control Measures).

8.9.1. Some options for Risk prevention and mitigation

Risk is a combination of likelihood and consequence so Risk prevention and mitigation will influence one or both of these to reduce the overall level of Risk, the following practices gives some options for developing that:

8.9.1.1. Option for mitigation and reducing of consequences

- Plant siting and layout
- Substitution of material
  - Using less flammable / less volatile / less toxic materials

- Reducing inventory (during design) / Active systems for inventory reduction (divert the inventory from process in case of accident).
- Reducing severity of process conditions
  - Reduction of temperature/pressure may result in lower discharge rates in case of accidents
- Limiting ignition sources
- Emergency preparedness and response
  - Emergency plans and procedures
  - Emergency protection systems (Using Passive and Active fire protection and fire fighting instruments).

8.9.1.2. Option for prevention and reducing of likelihood

- Substitution of material
  - avoid use of hazardous materials and substitute with less hazardous ones (e.g. avoid use of corrosive material)
- Reducing severity of process conditions
  - Use of lower process condition (temperature/pressure/..etc.) would reduce mechanical failure of the equipment
- Use of high safety factors
  - Increasing margin between design and operating conditions would reduce the likelihood of mechanical failure
- Asset Integrity Management Systems such as Risk Based Inspection (RBI) programmes
- Process interlocks and shutdown systems
- Improve the reliability of safety systems
- Effective safety management systems
  - Safe systems of work practice are in place
  - Hazards are identified and controlled

8.9.2. Sensitivity Analysis

The Sensitivity Analysis generally takes place to fulfil ALARP Criteria. It is the act of analyzing the effect of output by changing one or more of the inputs to the system. It is often used when there is uncertainty in a particular input. (For example, a Sensitivity Analysis may be performed when trying to decide whether to store LPG using pressurized technology or refrigerated technology). The different obtained Risks provide the basis for the Risk management decisions making process. Some typical examples for the elements which can subject to Sensitivity Analysis are:

- Leak frequencies
- Leak locations
- Ignition probabilities
- Wind data
- Operating conditions
- Release durations
- Vulnerability Criteria
- Population data

(Note: The Sensitivity Analysis should be a part of the assumption register and the QRA report).

8.10. QRA Reporting

QRA report shall document all the key assumptions, facility description, assessment details and all relevant calculations and information used in the assessment. The report shall be submitted in Hard and soft copy as per needed by the Company, and should be subjected to the document control procedure of the Company. The QRA report shall contain at least the following sections:

- *Executive Summary & conclusion*
- *Section 1– Introduction/ Objective/Scope*
- *Section 2 – Facility Overview*
- *Section 3 – QRA Methodology*
- *Section 4 – Site Description*
- *Section 5 – Hazard Identification*
- *Section 6 – Failure Cases*
- *Section 7 – Consequence Assessment*
- *Section 8 – Frequency Assessment*
- *Section 9 – Ignition Probabilities*
- *Section 10– Explosion Probabilities*
- *Section 11 – Weather Conditions*
- *Section 12– Manning Levels*
- *Section 13– Process Risk Assessment*
- *Section 14 – Non-Process Risk Assessment (if required)*
- *Section 15 – Integrated Risk Assessment*
- *Section 16 – Risk Results and Assessment (indoor and outdoor Risk results)*
- *Section 17 – Sensitivity Analysis (if required)*
- *Section 18 – Major Risk Contributor Analysis & Risk Reduction Measures*
- *Section 19 – ALARP Demonstration*
- *Section 20 – Conclusion & Recommendations*
- *Section 21 – References*
    - *Appendix 1 – Assumption Register*
    - *Appendix 2 – Plot Plans, Layouts, etc.*
    - *Appendix 3 – Isolatable Section & Failure Case Marking*
    - *Appendix 4 – Part Count and Failure Frequencies*
    - *Appendix 5 – Meteorological Data*
    - *Appendix 6– Populations densities*
    - *Appendix 7 – Inventory Calculations*
    - *Appendix 8 – Consequence Results (Flammable gas, fire and explosions) & Contours*
    - *Appendix 9 – LSIR - FN Curves*
    - *Appendix 10 – Risk Ranking Reports*

(Note: It is up to the Company to require any of the appendixes to be part of the study body.)

9. Action Plan

Inconsistence with the Risk Management standard EGPC-PSM-ST-001, the following should be recorded and respond as action plan in the corresponding form:

- All the identified Risk reduction measures/recommendation shall be documented and clearly highlighted as part of action plan, and in the corresponding safety case.
- All QRA recommendations related to the engineering shall be closed prior to design is finalized.
- All QRA recommendations related to construction, fabrications, installations, commissioning etc. shall be closed out prior to carry out the operation.

- For existing operations, where QRA is carried out, facilities being in operations, certain recommendations may require much longer time to implement due to reason such as time when next major maintenance window is available, or recommendation itself requires modification which is governed by project requirements, or it is associated with long lead items, etc. In such cases, short-term and long-term recommendations shall be clearly highlighted.
- All long-term recommendations shall be tracked clearly with definite timeline and taken forward to Risk register for follow-up.

10. Compliance Assurance

Holding Companies will conduct a compliance audit of this Guideline at approximately three-year intervals: these audits will be in addition to HSE internal audits.

The main audit deliverable is a formal and structured report for the attention of the HSE Risk Management Steering Committee.

11. Performance KPIs

Generally, Key Performance Indicators (KPIs) for this Guideline will be considered in the Process Safety Key Performance Indicators (KPIs) Guideline EGPC-PSM-GL-025.

Specifically, any QRA shall be conducted 100 % compliance as per requirements of this Guideline.

12. Deviation

No deviation is allowed from the requirements of this guideline.

13. References

[1] Centre for Chemical Process Safety (CCPS) & American Institute for Chemical Engineers (AICHE) (2000), Guidelines for – Chemical Process Quantitative Risk Analysis- 2nd edition.

[2] The International Oil and Gas Producers association (IOGP) March 2010, report no. 434-14 vulnerability of Humans.

[3] Health & Safety Executive (UK-HSE). (2008), Hazardous installations director's (HID'S), Approach to (As Low As Reasonably Practicable) ALARP Decision.

[4] UK Offshore Operators Association (UKOOA). (1999), industry guidelines on – A Framework Risk Related Decision Support.

[5] Health & Safety Executive (UK-HSE). (2009), research report 703, Societal Risk: Initial briefing to Societal Risk Technical Advisory Group.

[6] Evaluating Process Safety in The Chemical Industry (2000) – A User's Guide to Quantitative Risk Analysis.

[7] Marc J Assael & Konstantions E. Kakosimos (2010) – Fires, Explosions, and Toxics Gas Dispersions – Effects Calculation and Risk Analysis.

[8] Centre for Chemical Process Safety (CCPS) (2009), Guidelines for - Developing Quantitative Safety Risk Criteria.

[9] Canadian Society for Chemical Engineering (CSChE). (2004), Risk Assessment – Recommended Practices for Municipalities and Industry.

[10] DNV Risk Acceptance 2015, Criteria and Risk Based Damage Stability. Final Report -0165, Rev. 1, part 1: Risk Acceptance Criteria.

[11] Risktec Essentials (2018), Risk-Based Decision Making and ALARP (An Introduction to Making Risk-Based Decisions and Reducing Risks As Low As Reasonably Practicable (ALARP)).

[12] Risktec Essentials (2018), Quantitative Risk Assessment (QRA) (An Introduction to the Quantitative Assessment of Risks Associated with High Hazard Facilities).

[13] Centre for Chemical Process Safety (CCPS) (1989), Guidelines for Process Equipment Reliability Data with Data Table.

[14] The International Oil and Gas Producers association (IOGP) Sept. 2019, report no. 434-06 Ignition Probabilities.

[15] The International Oil and Gas Producers association (IOGP) March 2010, report no. 434-16 Ship/Installation Collisions.

[16] The International Oil and Gas Producers association (IOGP) March 2010, report no. 434-10 Water Transport Accident Statistics.

[17] The International Oil and Gas Producers association (IOGP) March 2010, report no. 434-12 Occupational Risk.

[18] The International Oil and Gas Producers association (IOGP) March 2010, report no. 434-19 Evacuation and Scape Rescue.

14. List of Annexes

- Annex A – Table A1 gives an example and a sample for the Process Hazards, Events, Sequences, Incident Outcomes, and consequences.
- Annex B – Gives details to determine and understand the different values of Vulnerability of Human for different Consequences/Impacts of Major Hazard Events.
- Annex C – Figures C1-C5 provide examples for Event Tree for a range of different releases.
- Annex D – Tables D1 & D2 give a full list of the QRA study deliverables.
- Annex E – The QRA Tolerance Criteria- as per mentioned in the Risk Management Standard EGPC-PSM-ST-001.

Annex A – Table A1 gives an example and a sample for the Process Hazards, Event Sequences, Incident Outcomes, and Consequences. [1], which could be used as a checklist for hazard identification, development of event sequence, with some possible outcomes, and consequences determination

Process Hazard	Event Sequence			Incident outcomes
	Initiating events	Intermediate events		
Significant inventories of: • Flammable materials • Combustible materials • Unstable materials • Corrosive materials • Asphyxiants • Shock sensitive materials • Highly reactive materials • Toxic materials • Inerting gases • Combustible dusts • Pyrophoric materials **Extreme physical conditions:** • High temperatures • Cryogenic temperatures • High pressures • Vacuum • Pressure cycling • Temperature cycling • Vibration/liquid hammering	**Process upsets:** • Pressure • Temperature • Flow rate • Concentration • Phase/state change • Impurities • Reaction rate/heat of reaction • Spontaneous reaction • Polymerization • Runaway reaction • Internal explosion • Decomposition • Container failures • Pipes, tanks, vessels, • Process deviations • gaskets/seals • Equipment malfunctions • Pumps, valves, instruments, • sensors, interlock failures • Electrical, nitrogen, water, • Loss of utilities • refrigeration, air , heat • transfer fluids, steam, • ventilation **Management systems failure Human error** • Design • Construction • Operations • Maintenance • Testing and inspection **External events** • Extreme weather conations • Earthquakes • Nearby accidents' impacts • Vandalism/sabotage	**Propagating factors** • Equipment failure • safety system failure **Ignition sources** • Furnaces, flares, incinerators • Vehicles • Electrical switches • Static electricity • Hot surfaces /cigarettes **Management systems failure** **Human errors** • Omission • Commission • Fault diagnosis • Decision-making **Domino effects** • Other containment failures • Other material release **External conditions** • Meteorology • Visibility	**Risk reduction factors** • Control /operator responses • Alarms • Control system response • Manual and automatic emergency shutdown • Fire/gas detection **safety system responses** • Relief valves • Depressurization systems • Isolation systems • High reliability trips • Back-up systems **Mitigation system responses** • Dikes and drainage • Flares • Fire protection systems • (active and passive) • Explosion vents • Toxic gas absorption **Emergency plan responses** • Sirens/warnings • Emergency procedures • Personnel safety equipment • Sheltering • Escape and evacuation **External events** • Early detection • Early warning • Specially designed structures **Training** **Other management systems**	**Analysis** • Discharge • Flash and evaporation • Dispersion • Neutral or positively buoyant gas • Dense gas **fire** • Pool fires • Jet fires • BLEVES • Flash fires **Explosions** • Confined explosions • Vapor cloud explosions (VCE). • Physical explosions • dust explosions • Detonations • Condensed phase detonations • Missiles **Consequences Effect analysis** • Toxic effects • Thermal effects • Overpressure effects **Damage assessments** • Community • Workforce • Environment • Company assets

Table A1: A sample for the process Hazards, Event Sequences, Incident Outcomes, and Consequences. (Ref. [1]), *Annex B – Gives details to determine and understand the different values of Vulnerability of Human for different Consequences/Impacts of Major Hazard Events*

B- The Vulnerability of Human

In order to understand the vulnerability different values, the following terminologies shall be identified:

The Vulnerability is the probability that an individual is fatally injured from being exposed to a given consequence effect or threshold." And sometimes referred to as: lethality /fatality rate /fatality probability.

Fatality is used to refer to qualitative effect

Lethality refers to the quantitative effect, namely the fraction/percentage of the exposed population who would suffer fatality on exposure to a given consequence level.

Radiation is here always used to refer to thermal radiation.

Probit: a function that relates lethality to the intensity or concentration of a hazardous effect and the duration of exposure. It typically takes the form:

$Pr = a + b \ \ell n V$

Where Pr = probit   a, b are constants   V = "dose", typically:

For toxic materials:

$V = (c^n t)$

Where c = concentration   n = constant   t = exposure duration

For thermal radiation:

$V = (I^{4/3} t)$

Where I = thermal radiation   t = exposure duration

The Vulnerability data and Criteria are driven from the international data directory and the reliable relevant references, e.g. the International Oil and Gas Producers association (IOGP) report no. 434 (14) – March 2010 (vulnerability of humans), report no. 434 (15) – 4 March 2010– (vulnerability of plant/structure), Guidelines for Quantitative Risk Assessment, 'Purple Book', Publication Series on Dangerous Substances, CPR 18E, Human Vulnerability to Thermal Radiation Offshore, Health and Safety Laboratory, HSL/2004/04, Chemical Industries Association (CIA) Guidance for the Location and Design of Occupied Buildings on Chemical Manufacturing Sites (3rd Edition), American Petroleum Institute API 521, API RP 752 & API RP 753

From the previous references the following information concerning the vulnerability of humans to the consequences of major hazard events producing and/or processing hydrocarbon fluids, has been driven *(Not, for further and more deep information the previous references, as well as other related references, could be visited).*

B-1 Fire (Thermal Radiation)

B-1-1- Engulfment by fire:

A person momentarily and only partially exposed directly to fire is most likely to suffer pain and non-fatal burns.

A person fully or substantially engulfed by fire can be considered to suffer fatality.

For the purposes of QRA, the following lethality levels are recommended:

- 100% lethality for people outdoors engulfed by a jet fire, pool fire or fireball
- 100% lethality for members of the public outdoors engulfed by a flash fire

• 50% to 100% lethality, depending on ease of escape, for workers wearing fire resistant clothing made from fabrics *(meeting the requirements of NFPA 2112 [11] or equivalent .. reference IOGP- Report no. 434-14.).*

B-1-2- Thermal Radiation

The effects of thermal radiation depend strongly on the thermal radiation flux, the duration of exposure, the type of clothing worn, the ease of sheltering, and the individual exposed. Hence, the information provided below provides guidance on the range of effects rather than exact relationships between thermal radiation and effects valid in all circumstances.

Table (B1) summarizes thermal radiation exposure effects over a range of radiation fluxes.

Table (B2) sets out Thermal Radiation Criteria applicable to longer fire durations, i.e. to jet fires and pool fires, for which the exposure duration is more dependent on the ability to escape than on the fire duration.

(Note: ANSI/API Standard 521 sets out permissible design levels for thermal radiation exposure to flares. for which the exposure duration is more dependent on the ability to escape than on the fire duration).

Thermal Radiation (kw/m^2)	**Effect**
1.2	Received from the sun at noon in summer
2	Minimum to cause pain after 1 minute
less than 5	Will cause pain in 15 to 20 seconds and injury after 30 seconds' exposure
Greater than 6	Pain within approximately 10 seconds: rapid escape only is possible
12.5	Significant chance of fatality for medium duration exposure.
25	Likely fatality for extended exposure.
35	Significant chance of fatality for people exposed instantaneously.

Table B1: Thermal Radiation Exposure Effects (Ref. [2])

Thermal radiation (kW /m2)	**Effect**
35	Immediate fatality (100% lethality)
20	leading to fatality unless rescue is effected quickly
12.5	Extreme pain within 20 s: movement to shelter is instinctive: fatality if escape is not possible. Outdoors/offshore: 70% lethality Indoors onshore: 30% lethality*
6	Impairment of escape routes
4	Impairment of embarkation areas
Note: People indoors are only vulnerable if they have line-of-sight exposure to thermal radiation, hence a lower lethality than for people outdoors.	

Table B2: Thermal Radiation Criteria (use for jet and pool fire) (Ref. [2])

For short exposures (up to a few tens of seconds, **typical of fireballs**), thermal radiation dose units (tdu) should be used:

Dose (tdu) = $(I^{4/3})t$

Where I = incident thermal flux (kW/m2) t = duration of exposure (s)

Thermal dose units thus have the units $(kW/m2)^{4/3}s$.

Table B3 sets out Thermal Dose Criteria, which should be used for fireballs.

Thermal Dose Units ((kW/m2)4/3s)	Effect
1000	1% lethality
1800	50% lethality, members of the public
2000	50% lethality, offshore workers
3200	100% lethality

Table B3: Thermal Dose Fatality Criteria (use for fireballs) (Ref. [2])

B-1-3- Thermal Radiation for People Inside Buildings

People inside buildings may be vulnerable to the building catching fire if combustible building material is exposed to the fire (either to a directly impinging fire or to radiation).

Two types of ignition are recognized:

- Piloted ignition, resulting from the flame impinging directly on a surface
- Spontaneous ignition, resulting from exposure to thermal radiation from a fire.

Personnel inside a building are vulnerable to the building catching fire if they cannot escape in sufficient time. This will depend on the time to ignition as compared to the time to alert the people inside to the source fire to evacuate.

People inside a building are also vulnerable if escape routes are exposed to thermal radiation in this case the Criterion of 6 kW/m2 can be applied.

B-2 Explosion (Blast Overpressure)

B-2-1- For people Onshore, Outdoors and in the Open

The following lethality levels are recommended:

- 0.35 bar overpressure: 15% lethality for people outdoors, in the open,
- 0.5 bar overpressure: 50% lethality for people outdoors, in the open,

B-2-2- For people onshore, outdoors but adjacent to buildings or in unprotected structures (e.g. process units),

The following lethality levels are recommended:

- 0.35 bar overpressure: 30% lethality for people outdoors,
- 0.5 bar overpressure: 100% lethality for people outdoors,

B-2-3- For People Indoors

The lethality level depends on the building type as well as the overpressure. Two frequently used sets of relationships between lethality level and overpressure are presented in API RP 752, and CIA Guidance.

B-2-4- For Personnel Offshore in Modules Affected by an Explosion,

The following approach is suggested:

- 100% lethality for personnel in the module where the explosion occurs, if the explosion overpressure exceeds 0.2 to 0.3 barg
- 100% lethality in adjacent modules if the intervening partition (wall or deck) is destroyed by the explosion.

  (Note: A more sophisticated approach could involve more detailed study of other explosion characteristics: overpressure phase duration and impulse. A probabilistic approach is recommended to estimate the likelihood of exceeding overpressures that could result in immediate fatality, escalation within the module, and escalation to adjacent areas).

B-3- Toxic Gases (Toxic Gas Exposure)

The most likely toxic gas present in oil and gas production hydrocarbon fluids is Hydrogen Sulphide (H2S). The effects likely to be experienced by humans exposed to various concentrations of H2S are described in table B4

H2S Concentration	Effect
20 – 30 ppm	Conjunctivitis
50 ppm	Objection to light after 4 hours exposure. Lacrimation
150 - 200 ppm	Objection to light, irritation of mucous membranes, headache
200 - 400 ppm	Slight symptoms of poisoning after several hours
250 - 600 ppm	Pulmonary edema and bronchial pneumonia after prolonged exposure
500 - 1000 ppm	Painful eye irritation, vomiting.
1000 ppm	Immediate acute poisoning
1000 - 2000 ppm	Lethal after 30 to 60 minutes
> 2000 ppm	Rapidly lethal

Table B4: Effects of Exposure to Hydrogen Sulphide (Ref. [2])

Table B5 gives the SLOT & SLOD DTL Values and Probit Constants (concentration in ppm, duration in minutes) for deferent toxic gases,

Table B6 gives example concentrations (ppm) to give 1% and 50% Lethality for 10 minute and 30 minute Exposures for deferent toxic gases.

Material	HSE SLOT & SLOD			HSE Probit			TNO Probit		
	SLOT	SLOD	"n"	a	b	n	a	b	n
Ammonia	3.78×10^8	1.09×10^9	2	-43.24	2.32	2	-16.33	1	2
Carbon Monoxide	40125	57000	1	-67.68	6.64	1	-7.26	1	1
Chlorine	1.08×10^5	4.84×10^5	2	-15.33	1.55	2	-4.89	0.5	2.75
Hydrogen Sulphide	2×10^{12}	1.5×10^{13}	4	-30.08	1.16	4	-10.87	1	1.9
Sulphur Dioxide	4.66×10^6	7.45×10^7	2	-10.23	0.84	2	-16.89	1	2.4
Hydrogen Fluoride	12000	41000	1	-36.44	4.16	1	-8.70	1	1.5
Nitrogen Dioxide	96000	6.24×10^5	2	-11.61	1.24	2	-16.26	1	3.7

Table B5: The SLOT & SLOD DTL Values and Probit Constants (concentration in ppm, duration in minutes) for deferent toxic gases (Ref. [2])

Material	10 minutes, 1% lethality		30 minutes, 1% lethality		10 minutes, 50% lethality		30 minutes, 50% lethality	
	HSE SLOT	TNO Probit	HSE SLOT	TNO Probit	HSE SLOD	TNO Probit	HSE SLOD	TNO Probit
Ammonia	6148	4218	3550	2435	10149	13523	5859	7808
Carbon Monoxide	4013	2063	1338	688	5700	21203	1900	7068
Chlorine	104	105	60	71	220	573	127	384
Hydrogen Sulphide	669	371	508	208	1107	1265	841	709
Sulphur Dioxide	683	1327	394	840	2729	3504	1576	2217
Hydrogen Fluoride	1200	422	400	203	4100	1996	1367	960
Nitrogen Dioxide	9600	90	3200	67	62400	168	20800	125

Table B6: Examples for the concentrations (ppm) to give 1% and 50% Lethality for 10 minute and 30 minute Exposures for deferent toxic gases (Ref. [2])

Annex C – Figures C1-C5 are examples for Event Tree for a range of different releases

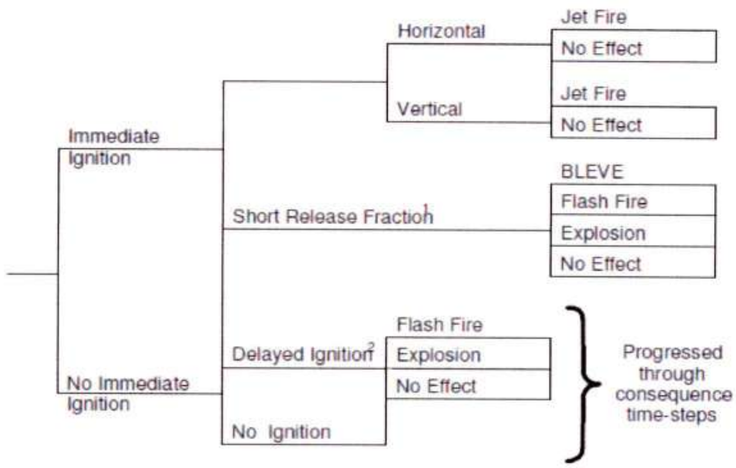

Figure C1: Continuous release without rainout

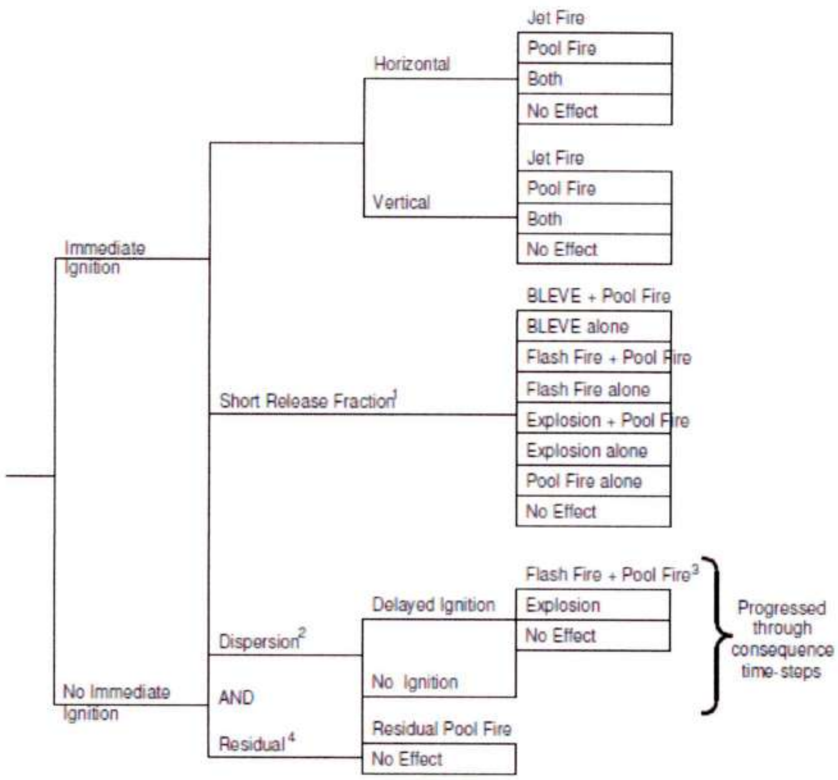

Figure C2: Continuous release with rainout

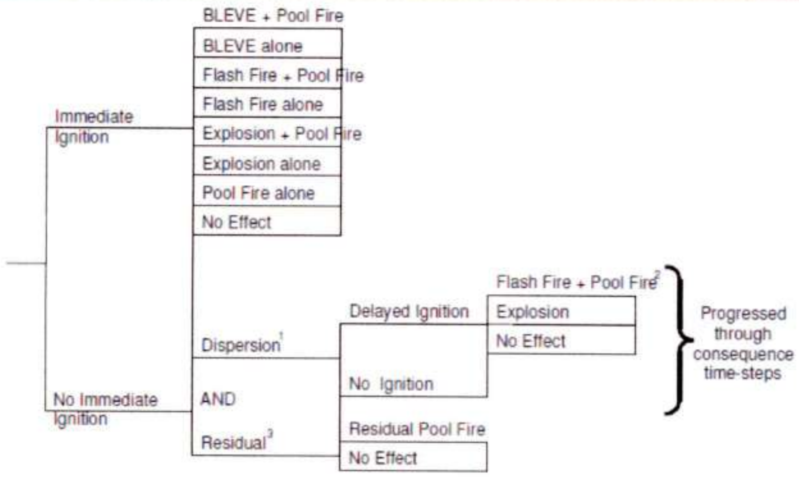

Figure C3: Instantaneous release with rainout, no vaporising pool left behind

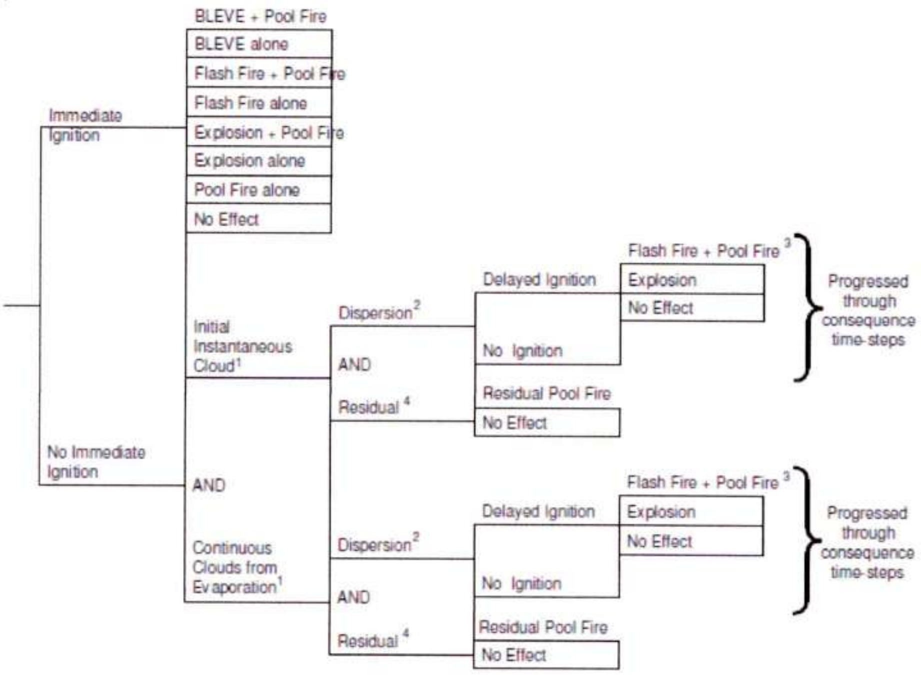

Figure C4: Instantaneous release with rainout, vaporising pool left behind

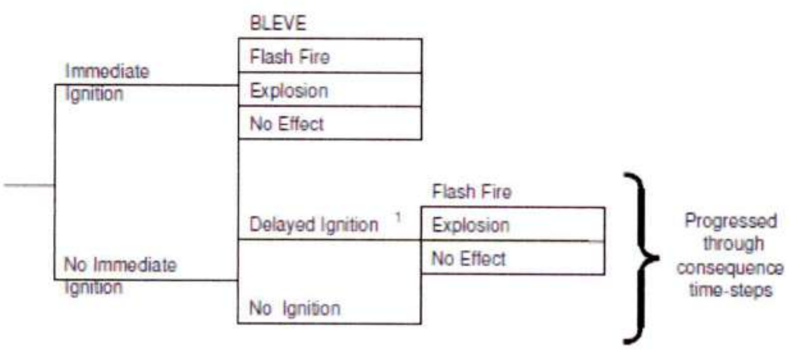

Figure C5: Instantaneous release without rainout

Annex D – Tables D1 & D2 give a full list of the QRA study deliverables

Table D1 gives the Consequence deliverables

Consequence Forms	Consequence Measure
Jet Fire:	Release rate, jet flame length, Surface Emissive Power (SEP), downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2. In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.
Pool Fire/Sea Pool Fire:	Release rate, pool diameter, SEP, downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2. In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.
Fireball/BLEVE:	Fireball radius, BLEVE radius, downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2. In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.
Bund Fire/Rim Seal Fire/Full Surface Fire	Diameter, SEP, downwind distance to 1.6kW/m2, 4.7kW/m2, 6.3kW/m2, 12.5kW/m2 and 37.5kW/m2. In addition, radiation levels at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.
Flammable Gas Dispersion Results	Distance 0.5 LFL, LFL and UFL. At all points and heights of interest (e.g. HVAC inlet, sources of ignition, EER measures, etc.).
Explosion Overpressure Results	Downwind distance to 30mbar, 70mbar, 100mbar, 200mbar, 300mbar and 500mbar. In addition, explosion overpressure and impulse duration at the various onsite and offsite considered populations (indoor and outdoor) shall be reported.
Toxic Gas Dispersion Results	Distance downwind represents specific adverse health effect, on various considered populations onsite and offsite, from specific concentration of toxic material for various exposure times, Various approaches are used to determine the consequences of toxic gases and have various purpose: • IDLH • ERPG/AEGL • Probit • SLOT & SLOD DTLs For the Risk Calculation, Probit method is recommended to be used as it takes into account both concentration and duration of exposure. (More details are given in 8.4.2., 8.4.2.5., 8.4.4. & 8.4.4.3.).
Smoke:	CO, CO2 concentrations at, downwind distance to various effective concentrations (more details are given in IOGP-14).

Consequence Forms	Consequence Measure
Consequence results height of interest	All consequences effects on people shall be calculated at 1 meter above ground level. For ingress into buildings, the concentration shall be monitored at air intake height, where such information is not available, 3m height to be considered. For multi-story units, heights shall be based on where major equipment is located. All other equipment can be considered at ground level.
Notes	*(1) Justification for the selected SEP shall be furnished/ provided for the pool fire (land/sea) scenarios.* *(2) Bund fire and full surface fire scenarios considering credit for the smoke.* *(3) Radiation levels, flammable concentration and toxic concentration (H2S and SO2) shall be reported at various populations identified for the new facilities and existing facilities (if any).* *(4) Explosion overpressure results along with associated impulse duration shall be reported for the critical buildings, non-critical buildings, and manned/unmanned buildings.*

Table D2 gives the Risk deliverables (Risk Various Indicators)

	LSIR	**Process IRPA**	**PLL**	**F-N Curve (Workers)**	**F-N Curve (Public)**
Onshore	- LSIR Contour for each unit / segment / isolatable section - Cumulative LSIR contour	For each worker group	For each worker group	Gathering places (accommodations / administrative buildings / mess / canteen /rest places / entertainment places...etc.)	For nearby public population
Offshore	LSIR value for each deck	For each worker group	For each worker group	Gathering places (accommodations / mess / canteen /rest places / entertainment places...etc.)	—
Note	*Results illustrated in form of:* *- Contours on geographical maps or plot plan, graphs, curves, and* *- Tables shall be provided to show the Risk values for both indoor and outdoor vulnerabilities (for both onsite and offsite populations).*				

Annex E – Shows the QRA Tolerance Criteria- as per mentioned in the Risk Management Standard EGPC-PSM-ST-001

E- Quantitative Risk Assessment Tolerance Criteria

Quantitative Risk Criteria are standards used to translate numerical Risk estimates, as produced by a Quantitative Risk Assessment (QRA), into value judgements such as 'negligible Risk' (e.g. the Risk value is lower than 10-6 which means lower than 1 fatality every 1 million years), that can then be set against other value judgements such as 'high economic benefit' in the decision-making process.

To define the three bands of Risk (acceptable, Tolerable if ALARP, and unacceptable), two levels of Risk Criteria are required:

- A maximum tolerable Criterion above which the Risk is intolerable,
- A broadly acceptable Criterion below which the Risk is insignificant, and
- Between these two Criteria, the ALARP region is laid

Risks to people may be expressed in two main forms:

- **Individual Risk** – the Risk experienced by a person.
- **Societal (or Group) Risk** – the Risk experienced by the whole group of people exposed to the hazard. Where the people exposed are members of the public, the term Societal Risk is often used. Where workers are isolated and members of the public are unlikely to be affected, the term Group Risk is often used. In this document, the term Societal Risk is used to encompass both Public and Worker Risk.

E-1- Individual Risk Criteria (IRPA)

Individual Risk Criteria are intended to show the frequency at which an individual (worker or public) may be expected to sustain a given level of harm from the realization of specified hazards. It is usually taken to be the Risk of death and usually expressed as a Risk per year.

Individual Risk is calculated by identifying all sources of fatality Risk to a given individual, deriving the contribution from each source and then summing these to give the overall Risk. For typical oil, gas and petrochemical workers the primary sources of Risk as a minimum:

- Transport, e.g., road traffic accidents, air/sea transport accidents.
- Hydrocarbon related, e.g., loss of containment leading to toxic releases, fires or explosions.

(Note: Companies have the choice to consider the Occupational Safety Risks in their Quantitative Risk Assessment, e.g., slips, trips and falls, drowning, dropped objects, lifting, working at heights, etc. within the overall Risk Calculations (which might increase the overall Risk value)).

Individual Risk Criteria are most expressed in the form of Individual Risk Per Annum (IRPA). The IRPA is a representative worker of a given worker groups considering expected occupancy at all the locations he is expected to be present within the hazardous location throughout the year. This includes plants, accommodations, recreational activities, etc. The calculation excludes the duration for which personnel is not present at the site due to reasons such as annual leave, personnel is considered not exposed to facility operations or occupational Risk during this duration. This Criterion is applicable for all COMPANIES belonging to ENTITIES. It is mandatory to demonstrate that Risk levels are within the Criteria given in Figure & Table E1

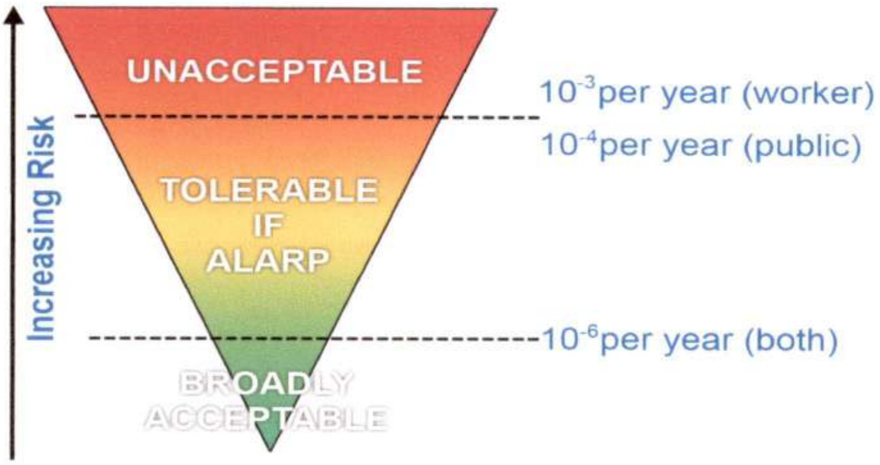

Figure E1: ALARP Demonstration (Ref. UK-HSE - onshore process Individual Risk criteria)

	Workers	Member of public
Maximum Tolerable Criterion	10^{-3} per year	10^{-4} per year
Broadly Acceptable Criterion	10^{-6} per year	

Table E1: Tolerability Criteria

Note (1): Individual Risk Criteria are intended to demonstrate that individual people are not exposed to excessive Risk, assuming all individuals are equally exposed and protected.

Note (2): Individual Risk to workers means Individual Risk to onsite personnel and outside nearby same business' industrial facilities only (i.e. petrochemical, oil and gas facilities), and Individual Risk to public means Individual Risk to offsite personnel.

At the top of the triangle is the unacceptable level, on or above which the Risk is so great or the outcome so unacceptable that it must be reduced immediately.

At the other extreme is the broadly acceptable region, where the Risk is so low that there is no further requirement to undertake additional Risk reduction measures, i.e., the Risk is, or has been made, so small that no further precaution is warranted.

In between these two extremes, lies a wide range of tolerable Risk levels to which the ALARP principle applies, i.e., the Risk must be reduced to the lowest level practicable, bearing in mind the benefits flowing from its acceptance and taking account of the costs of any further reduction. Thus, for the Risks, which fall within the Tolerable region, some weighing of costs and benefits i.e., Cost-Benefit Analysis is necessary to determine compliance with the ALARP principle.

E-2- Societal (Group) Risk Criteria:

Societal Risk evaluation is concerned with the estimation of the chances of more than one individual being harmed simultaneously by an incident. The likelihood of the primary event (an accident at a major hazard plant) is still a factor, but the consequences are assessed in terms of the level of harm and the numbers affected (severity), to provide an idea of the scale of an accident in terms of numbers killed or harmed.

Societal Risk is dependent on the Risks from the substances and processes located on a major hazard installation. A key factor in estimating Societal Risk is the population inside and around the site: in particular, its location and density.

The Criteria may be defined to limit the Risk of major accidents and help target Societal Risk reduction measures (such as restrictions on concurrent activities or land use, enhanced engineered safeguards, and improved building siting or protection).

The concept of the Societal Risk against the Individual Risk is illustrated in the following Figure E2. Where situations *I* and *II* have equal Individual Risk levels, while situation *II* has a larger Societal Risk (SR) because in situation *II* more people are exposed than in situation *I*. Therefore, if the Individual Risk levels are acceptable in both situations, the Societal Risk may not be acceptable for situation *II*.

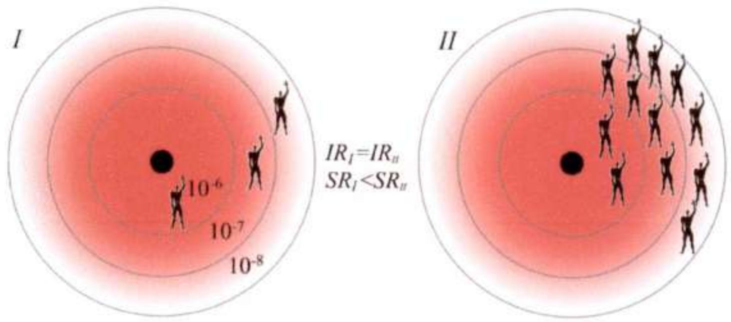

Figure E2: The concept of Societal Risk (Ref. [12]).

E-2-1- FN-diagram

The FN curve is the curve of cumulative frequency versus numbers of fatalities on a logarithmic scale. FN curves are frequency-fatality plots, showing the cumulative frequencies (F) of events involving N or more fatalities. They are derived by sorting the frequency-fatality (FN) pairs from each outcome of each accidental event and summing them to form cumulative frequency-fatality (FN) coordinates for the plot.

A common form of presenting Risk Tolerability Criteria for Societal Risk on an FN diagram is to have two Criteria lines to distinguish three regions: an area where Risk is intolerable, an area where it is broadly acceptable and a region where it requires further assessment and Risk reduction as far as is reasonably practicable. ENTITIES' Criteria for Societal Risk is shown in Figure E3

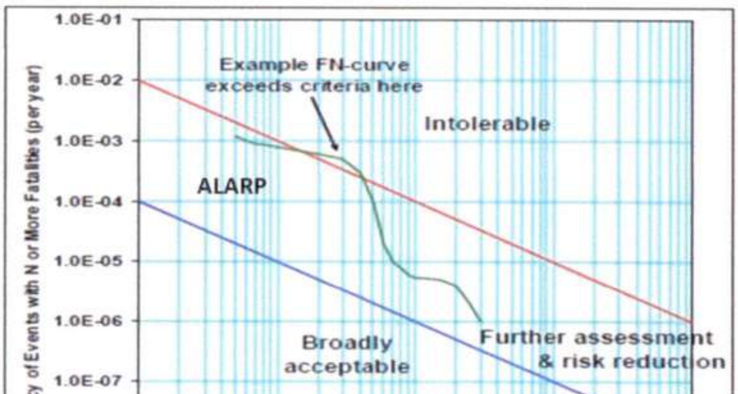

Figure E3: Criteria for Societal Risk (Ref. [2]).

At the top of the curve is the unacceptable level (F = 2.0E-04, for N = 50, and the Slope = -1), on or above which the Risk is so great or the outcome so unacceptable that it must be reduced immediately.

At the other extreme is the broadly acceptable level (F = 2.0E-06, for N = 50, and the Slope = -1), where the Risk is so low that there is no further requirement to undertake additional Risk reduction measures, i.e., the Risk is, or has been made, so small that no further precaution is warranted.

In between these two extremes, lies a wide range of tolerable Risk levels to which the ALARP principle applies, i.e., the Risk must be reduced to the lowest level practicable, bearing in mind the benefits flowing from its acceptance and taking account of the costs of any further reduction.

E-2-2- Potential Loss of Life (PLL)

The other main measure for Societal Risk is the annual fatality rate, where the frequency and number of fatalities are combined into a Potential Loss of Life (PLL), which is a convenient one-dimensional measure of the total number of expected fatalities.

Potential Loss of Life (PLL) is simply the sum of the products of all f-N pairs, (i.e., Potential Loss of Life = ΣFN [people/year])

PLL is well suited for comparing alternative solutions for the same facility is relatively easy to understand for non-Risk specialists and must be calculated to be able to derive the cost-effectiveness of Risk reduction options (Multiplying the annual PLL by the expected lifetime of a facility gives a Lifetime PLL by which the overall number of fatalities incurred by the facility, over its entire operational period, can be estimated), lifetime PLL is how Risk reduction measures should be assessed by using Cost-Benefit Analysis. PLL should be presented as a measure to compare the relative degree of "safety", expressed as potential loss of life for different options or developments. This should be used in conjunction with IRPA levels.

E-3- Risk Contours (LSIR) Criteria for Land Use Planning (LUP)

Risk contours are Iso-Risk contours plot represent the geographical variation of the Risk for a hypothetical individual who is positioned at a particular location for 24 hours per day, 365 days per year. This is also known as Location-Specific Individual Risk (LSIR).

Land Use Planning (LUP) Criteria is a planning tool to advice on new developments, accommodations that are constructed near the existing facility boundary or for siting the facility in the vicinity of the existing occupied building area or master plan updates for existing assets. The purpose of defining LUP zones is to minimize Risk to people around the hazardous facility by specifying how close certain types of facilities can be developed. For example, relatively low occupancy nonindustrial development such as warehouse can be allowed to be relatively close to the facility boundary whereas vulnerable populations, such as schools and hospitals need to be further away from the facility.

The recommended Individual Risk levels to be used, in respect to hazardous substances/sites, are including the Risk contributions from all sources with the inner zone Criteria of LSIR from 10^{-4} to 10^{-5}, middle zone 10^{-5} to 10^{-6} and outer zone beyond 10^{-6} per year. Restrictions are placed on activities or structures within the various zones, as shown in the following Figure and table E3.

Figure E3: Allowable Land Uses (Ref. [9])

Zones	Examples for types of Allowable Land Uses	Location Specific Individual Risk (LSIR)
Zone 0	Process plant/utilities/ industrial facilities are permitted etc.	1E-4
Zone 1	Manufacturing, warehouse, parkland, open space, etc.	1E-4 – 1E-5
Zone 2	Commercial offices and law densities residential	1E-5 – 1E-6
Zone 3	All other uses including institutions, high densities residential etc.	< 1E-6

Table E3: Definition of Zones for Land Use Planning (LUP)

Note 1: The LUP above Criteria shall be used in conjunction with the F-N curve, H2S zones and consequence-based approach for toxic hazards as applicable.

Note 2: The LUP Criteria shall be applied for new oil and gas facilities to be selected at safe distances as much as possible from areas with a different designation, whereas operating facilities and old facilities may be subjected to encroachments and outside activities, unfortunately, the responsible law for preventing such encroachments does not support the LUP Criteria.