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إحدى شركات قطاع البترول

The Egyptian Natural Gas Holding Company "EGAS"

Quantitative Risk *Assessment* "QRA" Study For

QAHA

Pressure Reduction Station

Prepared By
Petroleum Safety and Environmental Services Company
PETROSAFE

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Executive Summary

This report summarizes the Quantitative Risk Assessment (QRA) analysis study undertaken for the New Natural Gas Pressure Reduction & Metering Station "PRMS" with Odorant at Qaha City – Qalyoubeyia Governorate – Egypt. The PRMS owned by The Egyptian Natural Gas Holding Company "EGAS" and operated by Egypt Gas Company.

The scope of work includes performing frequency assessment, consequence modeling analysis and Quantitative Risk Assessment of Qaha PRMS in order to assess its impacts on the surroundings.

The main objective of the Quantitative Risk Assessment (QRA) study is to demonstrate that Individual Risk "IR" for workers and for public fall within the ALARP region of Risk Acceptance Criteria, and the new Qaha PRMS does not lead to any unacceptable risks to workers or the public.

QRA Study has been undertaken in accordance with the methodology outlined in the UKHSE as well as international regulations and standards.

QRA starts by Hazard Identification (HAZID) study, which determines the Major Accident Hazards (MAH) that requires consequence modelling, frequency analysis, and risk calculation.

In order to perform consequence-modelling analysis of the potential hazardous scenarios resulting from loss of containment, some assumptions and design basis have been proposed. Three scenarios of the release have been proposed:

1. Gas Release from the inlet / outlet pipeline.
2. Gas Release from the off-take point.
3. Leak from odorant tank.

The QRA has been performed using DNV Phast software (Ver. 8.2) for consequence modelling of different types of hazardous consequences.

Weather conditions have been selected based on wind speed and stability class for the area detailed weather statistics.

The worst case weather conditions has been selected represented by wind speed of 3.4 m/s and stability class "D" representing "Neutral" weather conditions, in order to obtain conservative results. The prevailing wind direction is North (N) & North North West (NNW).

As per results from modeling the consequences of each scenario, the following table summarize the study, and as follows:

Event	Scenario	Effects
Pin hole (1") gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRMS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values will extend down and crosswind outside the PRS boundary reaching the off-take point crosswind (1.6 & 4 kW/m^2), with no effects downwind (9.5, 12.5 & 25 kW/m^2)*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Half Rupture (2") gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud (LFL & 50 % LFL) will extend to reach the southern fence and extend about outside. The UFL will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the values of 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the PRS southern fence downwind with no effects. The values of 9.5 & 12.5 kW/m^2 will reach the off-take point crosswind*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020, 0.137 & 0.206 bar will extend outside the PRMS south fence with no effects down or crosswind.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

Event	Scenario	Effects
Full Rupture gas release 4” inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects (LFL & 50 % LFL) will extend over south boundary with no effects outside downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the south fence with no effects downwind and reach the off-take point crosswind.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and off-take point and no effects on site offices.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*N/D*
Pin hole (1”) gas release 6” outlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value 1.6, 4, 9.5 & 12.5 kW/m^2 effects will be limited inside the PRS boundary with no effects.* *The values of 25 & 37.5 kW/m^2 not determined by the software due to small leakage.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

Event	Scenario	Effects
Half Rupture (3") gas release 6" outlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud (LFL & 50% LFL) will be limited inside the PRS boundary reaching the off-take point downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 9.5 & 12.5 kW/m^2 will extend outside the PRS boundary south side with no effects downwind, and covering the off-take point crosswind.* *The values of 25 & 37.5 kW/m^2 will be limited inside the boundary effecting the PRS facilities.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects outside and covering the firefighting facilities and the heater.* *The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and no effects on site offices.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Full Rupture gas release 6" outlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the south fence with no effects downwind and cover the off-take point crosswind.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects outside and covering the firefighting facilities and the heater.* *The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and no effects on site offices.*

Event	Scenario	Effects
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 1.6, 4, 9.5 & 12.5 kW/m^2 will limited inside the PRS boundary effecting the PRS facilities with some extension (1.6 kW/m^2) down and crosswind.*
Odorant tank 1" leak		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will extend inside the PRS boundary reaching the off-take point downwind.* *Consideration should be taken when deal with liquid, vapors and smokes according to the MSDS for the material.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that all values of heat radiation 9.5, 12.5, 25 & 37.5 kW/m^2 will be limited inside the PRS boundary down and crosswind.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover the PRS facilities inside and extend outside from S/E/W sides with no effects.* *The values of 0.137 & 0.206 bar will extend outside the PRS boundary from south side with no effects down or crosswind.*
Gas heater (water bath heating system)		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will extend inside the PRS boundary downwind reaching the PRS facilities.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value 1.6, 4, 9.5 & 12.5 kW/m^2 effects will be limited inside the PRS boundary with no effects.* *The values of 25 & 37.5 kW/m^2 not determined by the software due to small leakage.*

Event	Scenario	Effects
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will extend outside the PRS from all sides covering the area surrounded with no effects outside.* *The value of 0.137 & 0.206 bar will be limited inside the PRS and near to the control room.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Pin hole (1") gas release 4" off-take pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value of 1.6 & 4 kW/m^2 will be limited inside the PRS boundary with some extension outside from south side with no effects.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Half Rupture (2") gas release 4" off-take pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value of 1.6 & 4 kW/m^2 will cover the PRS facilities and off-take point and extend outside the south and east fences down and crosswind with no effects.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

Event	Scenario	Effects
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Full Rupture gas release 4" off-take pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud will be limited inside the PRS boundary with some extension outside from south side downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values will extend outside the PRS south fence downwind with no effects on surrounding area.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*N/D*

The previous table shows that there is no direct effects on PRMS workers or surrounding public, so it will be assumed that one person (as public) works as farmer for 1 hour / day light.

The major hazards that extend over site boundary and/or effect on workers / public were used for Risk Calculations.

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). ETA provides a Probabilistic Risk Assessment (PRA) of the risk associated with each potential outcome. ETA has been used for scenario development.

The following data and assumptions have been considered in the Event tree analysis (ETA):

- Failure frequency data (mainly E&P Forum/OGP),
- Risk reduction factors (if available),
- Ignition probabilities (both immediate and delayed),
- Vulnerability data.

Risks have been assessed for workers / public using International Risk Management Guidelines as a reference.

The resulting risks have been compared with International Risk Acceptance Criteria.

Risk evaluation for Individual Risk "IR" for the major hazards presented in the following tables:

Individual Risk (IR) Calculation for PRMS Workers

Scenario	Event	People	Individual Risk "IR"	Acceptability Criteria
Gas heater (water bath heating system) 3" pipeline	Jet Fire	Indoor	***8.82E-06***	Acceptable (√)
TOTAL Risk for Worker			***8.82E-06***	**Acceptable (√)**

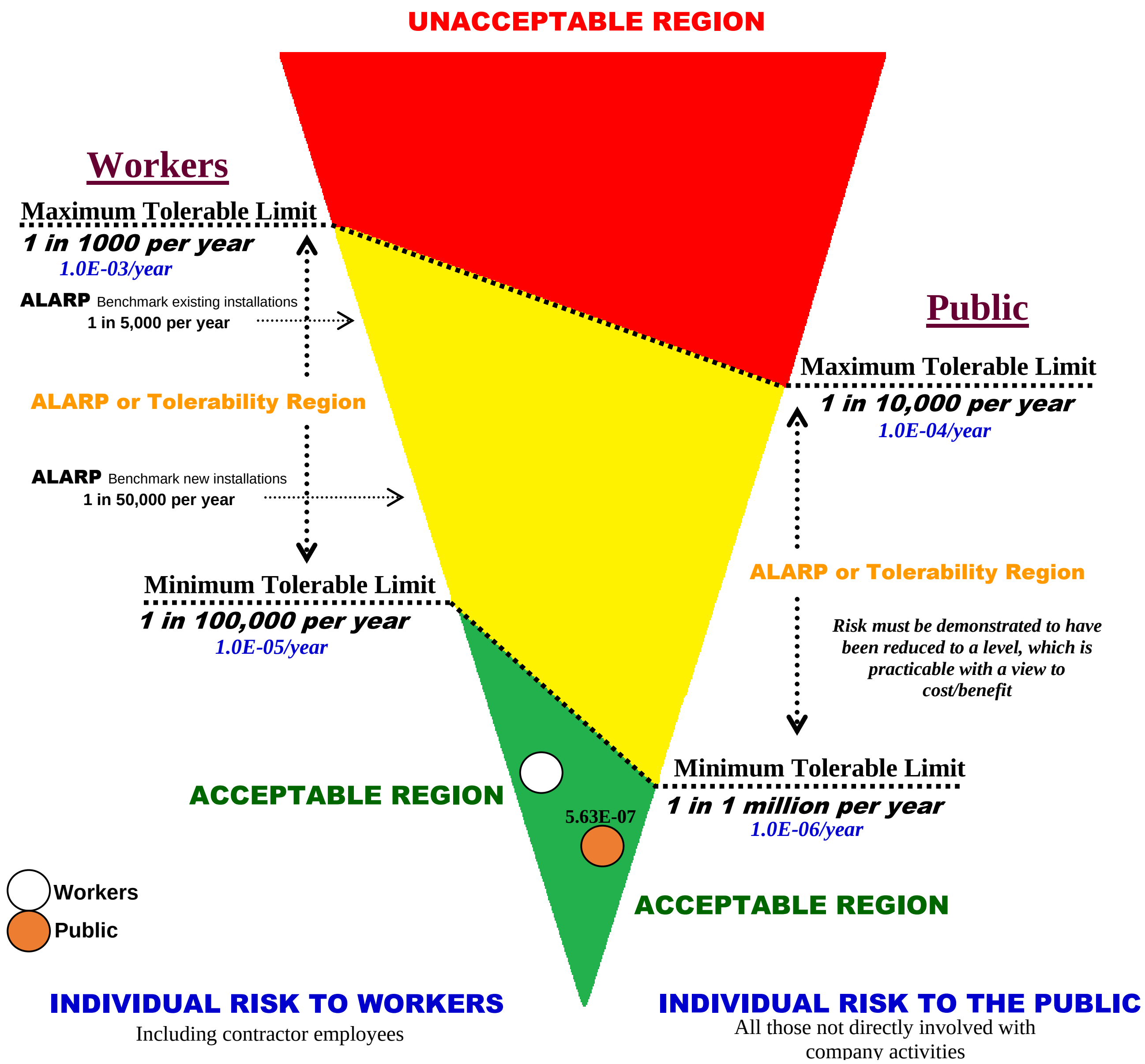
Individual Risk (IR) Calculation for the Public Near to the PRMS

Scenario	Event	People	Individual Risk "IR"	Acceptability Criteria
Gas Release from 2"/4" inlet pipeline	Jet Fire	Outdoor	***4.09E-07***	Acceptable (√)
Gas Release from 4" off-take pipeline	Jet Fire	Outdoor	***1.81E-08***	Acceptable (√)
Gas Release from 4" inlet pipeline				
Gas Release from 6" outlet pipeline				
Odorant tank 1" leak	Explosion	Outdoor	***1.36E-07***	Acceptable (√)
TOTAL Risk for Worker			***5.63E-07***	**Acceptable (√)**

The previous table shows that there is some of direct effects on PRMS workers, and as there is no direct effects on public around the PRMS or the off-take point. Therefore it will be assumed that one person (as public) works as farmer for 1 hour / day light. (Refer to table 35).

Regarding to the results from risk calculations; the risk to PRMS ***Workers and Public found in Acceptable Region,*** so there are some points need to be considered to keep the risk tolerability and this will be describe in the following recommendations.

The following figure shows the Individual Risk "IR" for Qaha PRMS and Off-Take point:



Evaluation of Individual Risk

The level of Individual Risk to the exposed workers at Qaha PRMS, based on the risk tolerability criterion used is ***Acceptable****.*

The level of Individual Risk to the exposed Public at Qaha PRMS area, based on the risk tolerability criterion used is ***Acceptable****.*

Introduction

The Egyptian Natural Gas Holding Company "EGAS" has engaged Petroleum Safety and Environmental Services Company "PETROSAFE" to identify and evaluate hazards generated from the "New Natural Gas Pressure Reduction and Odorant Station – PRMS" at **Qaha** City – Qalyoubeyia Governorate – Egypt. The PRMS operated by Egypt Gas Company in order to advice protective measures for minimizing risk up to acceptable level.

As part of this review, a QRA study conducted for the following objectives:

- Identify hazardous scenarios related to the most critical unexpected event(s).
- Determine the likelihood of the identified scenarios;
- Model the potential consequences of the identified scenarios;
- Determine the Potential risk of fatality resulting from the identified hazardous scenarios.

The proposed study should also identify existing arrangements for the prevention of major accidents and their mitigation. This would involve emergency plan and procedure for dealing with such events.

PETROSAFE selected to carry out this study, as it has the experience in conducting this type of work.

PETROSAFE is also empowered by the Egyptian General Petroleum Corporation "EGPC" to identify and evaluate factors that relate to Occupational Health & Safety and Environmental Protection.

Technical Definitions

ALARP	*Stands for "As Low As Reasonably Practicable", and is a term often used in the milieu of safety-critical and safety-involved systems. The ALARP principle is that the residual risk shall be as low as reasonably practicable.*
API	*American Petroleum Institute.*
Confinement	*A qualitative or quantitative measure of the enclosure or partial enclosure areas where vapors cloud may be contained.*
Congestion	*A qualitative or quantitative measure of the physical layout, spacing, and obstructions within a facility that promote development of a vapor cloud explosion.*
DNV PHAST	*Process Hazard Analysis Software Tool "PHAST" established by Det Norske Veritas "DNV". Phast examines the progress of a potential incident from the initial release to far-field dispersion including modelling of pool spreading and evaporation, and flammable and toxic effects.*
E&P Forum	*Exploration and Production "E&P" Forum is the international association of oil companies and petroleum industry organizations formed in 1974. It was established to represent its members' interests at the specialized agencies of the United Nations, governmental and other international bodies concerned with regulating the exploration and production of oil and gas.*
EGAS	*The Egyptian Natural Gas Holding Company.*
EGPC	*The Egyptian General Petroleum Corporation.*
EX	*Explosion Proof Type Equipment.*
EERA	*Escape, Evacuation and Rescue Assessment.*
ESD	*Emergency Shut Down.*
Explosion	*Explosion is the delayed ignition of gas in a confined or congested area resulting in high overpressure waves.* *Once the explosion occurs, it creates a blast wave that has a very steep pressure rise at the wave front and a blast wind that is a transient flow behind the blast wave. The impact of the blast wave*

	on structure near the explosion known as blast loading. The two important aspects of the blast loading concern are the prediction of the magnitude of the blast and of the pressure loading onto the local structures. Pressure loading predication as result of a blast; resemble a pulse of trapezoidal or triangular shape. They normally have duration of between approximately 40 msec and 400 msec. The time to maximum pressure is typically 20 msec. *Primary damage from an explosion may result from several events:* 1. *Overpressure - the pressure developed between the expanding gas and its surrounding atmosphere.* 2. *Pulse - the differential pressure across a plant as a pressure wave passes might cause collapse or movement, both positive and negative.* 3. *Missiles and Shrapnel - are whole or partial items that are thrown by the blast of expanding gases that might cause damage or event escalation. In general, these "missiles" from atmospheric vapor cloud explosions cause minor impacts to process equipment since insufficient energy is available to lift heavy objects and cause major impacts. Small projectile objects are still a hazard to personnel and may cause injuries and fatalities. Impacts from rupture incidents may produce catastrophic results.*
(ETA) Event Tree Analysis	*Is a forward, bottom up, logical modeling technique for both success and failure that explores responses through a single initiating event and lays a path for assessing probabilities of the outcomes and overall system analysis. This analysis technique used to analyze the effects of functioning or failed systems, given that an event has occurred.*
Failure Rate	*Is the frequency with which an engineered system or component fails, expressed in failures per unit of time. It is highly used in reliability engineering.*
GASCO	*The Egyptian Natural Gas Company.*
Gas Cloud Dispersion	*Gas cloud air dilution naturally reduces the concentration to below the LEL or no longer considered ignitable (typically defined as 50 % of the LEL).*

HSE Policy	*Health, Safety and Environmental Policy.*
Hazard	*An inherent physical or chemical characteristic (flammability, toxicity, corrosively, stored chemical or mechanical energy) or set of conditions that has the potential for causing harm to people, property, or the environment.*
(HAZOP) Hazard And Operability Study	*Is a structured and systematic examination of a planned or existing process or operation in order to identify and evaluate problems that may represent risks to personnel or equipment, or prevent efficient operation. The HAZOP technique is qualitative, and aims to stimulate the imagination of participants to identify potential hazards and operability problems; structure and completeness given by using guideword prompts.*
(HAZID) Hazard Identification Study	*Is a tool for hazard identification, used early in a project as soon as process flow diagrams, draft heat and mass balances, and plot layouts are available. Existing site infrastructure, weather, and Geotechnical data also required, these being a source of external hazards.*
(HAC) Hazardous Area Classification	*When electrical equipment is used in, around, or near an atmosphere that has flammable gases or vapors, flammable liquids, combustible dusts, ignitable fibers or flying's, there is always a possibility or risk that a fire or explosion might occur. Those areas where the possibility or risk of fire or explosion might occur due to an explosive atmosphere and/or mixture is often called a hazardous (or classified) location/area.*
(IR) Individual Risk	*The risk to a single person inside a particular building. Maximum individual risk is the risk to the most-exposed person and assumes that the person is exposed.*
Jet Fire	*A jet fire is a pressurized stream of combustible gas or atomized liquid (such as a high-pressure release from a gas pipe or wellhead blowout event) that is burning. If such a release is ignited soon after it occurs, (i.e., within 2 - 3 minutes), the result is an intense jet flame. This jet fire stabilizes to a point that is close to the source of release, until the release stopped. A jet fire is usually a very localized, but very destructive to anything close to it. This is partly because as well as producing thermal radiation, the jet fire causes considerable convective heating in the region*

	beyond the tip of the flame. The high velocity of the escaping gas entrains air into the gas "jet" causing more efficient combustion to occur than in pool fires. *Consequentially, a much higher heat transfer rate occurs to any object immersed in the flame, i.e., over 200 kW/m^2 (62,500 Btdsq. ft) for a jet fire than in a pool fire flame. Typically, the first 10% of a jet fire length is conservatively considered un-ignited gas, as a result of the exit velocity causing the flame to lift off the gas point of release. This effect has been measured on hydrocarbon facility flares at 20% of the jet length, but a value of 10% is used to account for the extra turbulence around the edges of a real release point as compared to the smooth gas release from a flare tip. Jet flames have a relatively cool core near the source. The greatest heat flux usually occurs at impingement distances beyond 40% of the flame length, from its source. The greatest heat flux is not necessarily on the directly impinged side.*
kW/m^2	*Kilowatt per square meter – unit for measuring the heat radiation (or heat flux).*
LFL / LEL	*Lower Flammable Limit / Lower Explosive Limit - The lowest concentration (percentage) of a gas or a vapor in air capable of producing a flash of fire in presence of an ignition source.*
MSDS	*Material Safety Data Sheet.*
mm Hg	*A millimeter of mercury is a manometeric unit of pressure, formerly defined as the extra pressure generated by a column of mercury one millimeter high.*
MEL	*Maximum Exposure Limit.*
NFPA	*National Fire Protection Association.*
N	*North Direction.*
NE	*Northern East Direction.*
NW	*Northern West Direction.*
N/D	*Not Determined.*

N/R	*Not Reached.*
OGP	*Oil and Gas Producers.*
ppm	*Part Per Million.*
PRMS	*Pressure Reduction and Metering Station.*
P&ID's	*Piping and Instrumentation Diagrams.*
PETROSAFE	*Petroleum Safety and Environmental Services Company.*
QRA	*Quantitative Risk Assessment Study is a formal and systematic approach to estimating the likelihood and consequences of hazardous events, and expressing the results quantitatively as risk to people, the environment or your business.*
Risk	*Relates to the probability of exposure to a hazard, which could result in harm to personnel, the environment or public. Risk is a measure of potential for human injury or economic loss in terms of both the incident likelihood and the magnitude of the injury / loss.*
Risk Assessment	*The identification and analysis, either qualitative or quantitative, of the likelihood and outcome of specific events or scenarios with judgments of probability and consequences.*
scm/hr	*Standard Cubic Meter Per Hour.*
SCBA	*Self-Contained Breathing Apparatus.*
SE	*Southern East Direction.*
SW	*Southern West Direction.*
TWA	*Time Weighted Averages.*
UFL/UEL	*Upper flammable limit, the flammability limit describing the richest flammable mixture of a combustible gas.*
UVCE	*When a flammable vapor is released, its mixture with air will form a flammable vapor cloud. If ignited, the flame speed may accelerate to high velocities and produce significant blast overpressure.*
V	*Volume.*
Vapor Cloud Explosion (VCE)	*An explosion in air of a flammable material cloud.*

Objectives

The objectives of this QRA for the unit facilities are:

- Identify hazardous scenarios related to the facilities based on historical data recorded;
- Determine the likelihood (frequencies) of the identified scenarios;
- Model the potential consequences of the identified scenarios;
- Determine the Potential risk of fatality resulting from the identified hazardous scenarios;
- Evaluate the risk against the acceptable risk level to ensure that it is within *As Low As Reasonably Practicable "ALARP"*, otherwise additional control measures and recommendations will be provided at this study to reduce the Risk, *(ALARP).*

Quantitative Risk Assessment Study Scope

The scope of work of this QRA study is limited to the following:

- Identification of the Most Critical Event$_{(s)}$ or scenarios that may lead to fatal accidents as well as to ensure that the expected risk will not exceed the Acceptable Risk Level as per national and international standards;
- To assess and quantify the risks associated with Qaha PRMS and the off-take point on the neighboring / surrounding community;
- The study determines Frequencies, Consequences (Including Associated Effect Contours) and Potential Risk of Fatality for the identified hazardous scenarios;
- Normal operation of the facilities (e.g. Construction and specific maintenance activities) are excluded from this analysis.

Quantitative Risk Assessment "QRA" Studies

Method of Assessment

1.0- General Method Used

Attention mainly focussed on those accidents where a gross failure of containment could result in the generation of a large vapour cloud of flammable or toxic material. The approach adopted has involved the following stages:

- Identification of hazardous materials,
- Establishment of maximum total inventories and location.

During the site visit by the study team, the overall functioning of the site discussed in some detail and the Companies asked to provide a complete list of holdings of hazardous materials. A preliminary survey notes was issued by the team, as a private communication to the company concerned, and this formed the basis for subsequent more discussion and analysis.

From the PRMS design model provided by the client, it was impractical to examine in depth all possible failure modes for all parts within the time allowed for this study. Instead, only those potential failures, which might contribute, either directly or indirectly, to off-site risks were examined.

2.0- Risk Assessment

As the PRMS designed and prepared for construction, so it was therefore necessary for the study team to identify and analyse the hazards potential from first principles the routes by which a single or multiple accident could affect the community or neighbouring.

The terms of reference required the team to investigate and determine the overall risk to health and safety both from individual installations and then foreseeable interactions.

The assessment of risk in a complex situation is difficult. No method is perfect as all have advantages and limitations.

It was agreed that the quantitative approach was the most meaningful way of comparing and evaluating different risks. The risk assessment framework shown in Figure (1) used for the study.

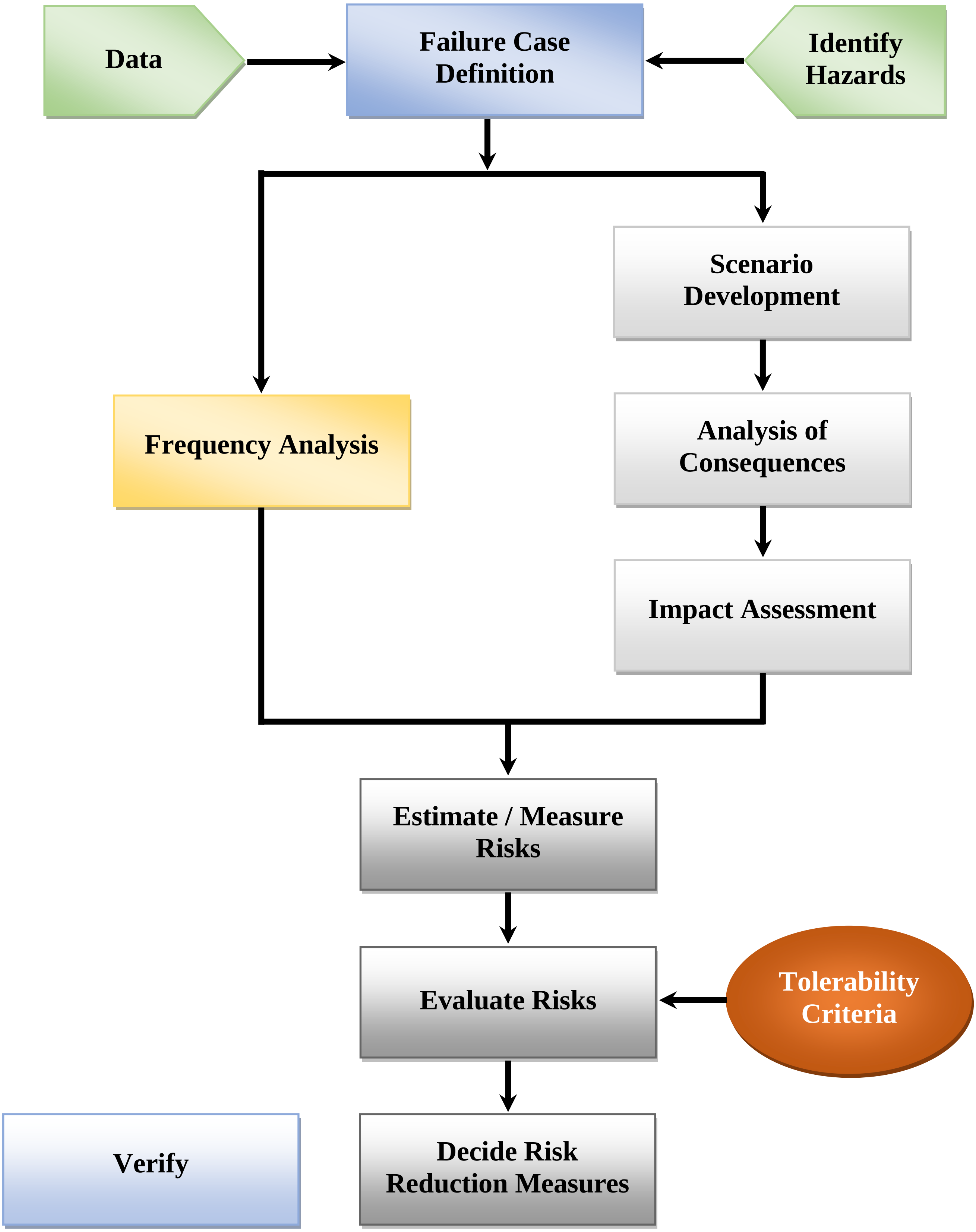


Figure (1) Risk Assessment Framework

Modeling the Consequences

Modeling of the consequences is one of the key steps in Quantitative Risk Assessment "QRA", as it provides the link between hazard identification (in this study Potential Loss of Containment Incidents) and the determination of possible impact of those incidents on People (Worker / Public), Asset and the Environment.

In this study, Natural Gas (Mainly Methane CH_4) was considered. There are several types of consequences to be considered for modelling, these include Gas Dispersion (UFL - LFL - 50 % LFL) / Heat Radiation / Explosion Overpressure modeling, also each of these scenarios described in the following table:

Table (1) Description of Modeling of the Different Scenario

Discharge Modeling	*Modeling of the mass release rate and its variation overtime.*
Radiation Modeling	*Modeling of the Thermal radiation from fires.*
Dispersion Modeling	*Modeling of the Gas and two-phase releases.*
Overpressure	*Associated with explosions or pressure burst.*

Toxic hazards are considered as result of releases / loss of containment for which discharge modeling and gas dispersion modeling are required. The hazard ranges are dependent upon the condition of the release pressure and rate of release.

There are a number of commercial software for modeling gas dispersion, fire, explosion and toxic releases. PETROSAFE select the *DNV PHAST Ver. 8.2 Software package* in modeling scenarios.

The software developed by DNV in order to provide a standard and validated set of consequence models that can be used to predict the effects of a release of hydrocarbon or chemical liquid or vapour. (Results of the modeling presented in pages from 51 to 94)

Criterion for Risk Tolerability

The main function of this phase of the work was to assess the effectiveness of the proposed arrangement for managing risks against performance standards.

In order to do this, we need firstly to define a performance standard and secondly, to be able to analyse the effectiveness of the arrangements in a manner which permits a direct comparison with these standards.

The defining of performance standards undertakes at the following three levels:

- Policy-based
- System
- Technical

Where the present work is mainly concerned with the assessment against the standards associated with the first two levels.

The policy-based performance standard relates to this objective to provide a working environment, where the risk to the individual reduced to a level that is ALARP.

This performance standard is therefore, expressed in the form of individual risk and the arrangements for managing this risk should result in a level of 'Individual Risk', based on a proposed Tolerability Criteria, Figure (2).

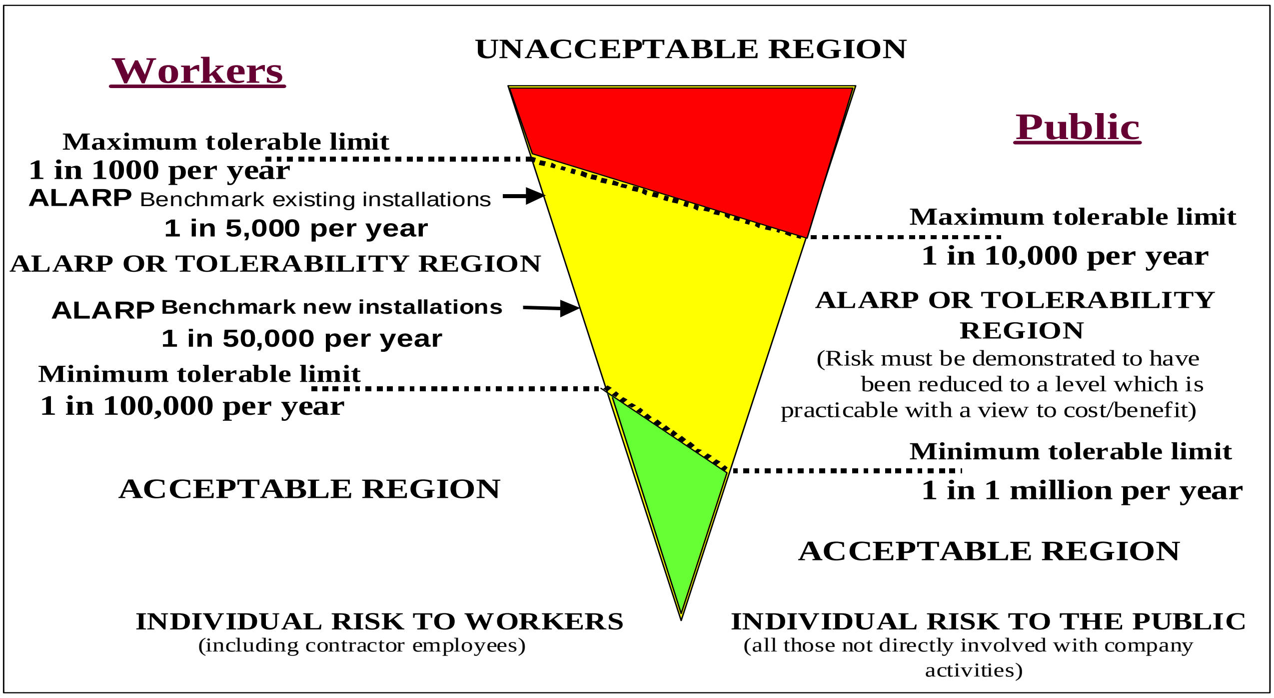


Figure (2) Criteria for Individual Risk Tolerability

The criterion for IR tolerability for workers and to the public outlined in Table (2) and Figure (3).

It should be noted that this criteria proposed only as a guideline. Risk assessment is no substitute to professional judgement.

Table (2) Proposed Individual Risk (IR) Criteria (per person/year)

Risk Level	Workers	Public
Intolerable	*> 10^{-3} per person/yr.*	*> 10^{-4} per person/yr.*
Negligible	*> 10^{-5} per person/yr.*	*> 10^{-6} per person/yr.*

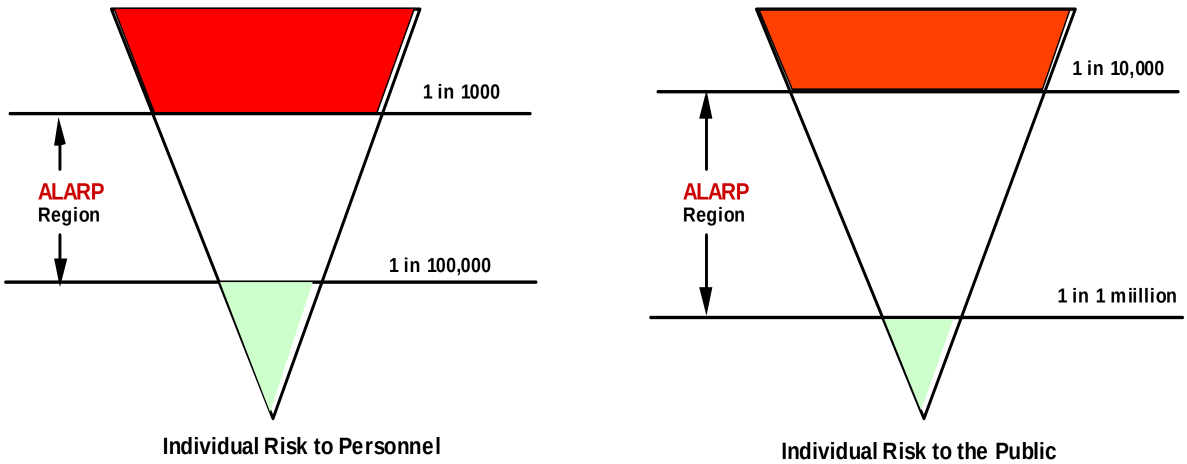


Figure (3) Proposed Individual Risk Criteria

Workers would include the Company employees and contractors. The public includes the public, visitors, and any third party who is not directly involved in the Company work activities.

On this basis, we have chosen to set our level of intolerability at Individual Risk for workers of 1 in 1,000 per year, and we define an individual risk of 1 in 100,000 per year as broadly acceptable. Consequently, our ALARP region is between 1 in 1,000 and 1 in 100,000 per person/year.

It is important to ensure that conflict between these subordinate standards and those stemming from international codes and standards are avoided and that any subordinate standards introduced are at least on a par with or augment those standards, which are associated with compliance with these international requirements. These system level performance standards are included as part of the summaries from the QRA. These used as the basis for assessing the suitability and sufficiency of Egypt Gas Site arrangements for both protecting personnel on site and members of public from major hazards and securing effective response in an emergency. Failure to meet acceptance criteria at this level results in the identification of remedial measures for assessment both qualitatively and quantitatively.

The analytical work use a system analysis approach and divided into a number of distinct phases:

- Data collection, including results from site-based qualitative assessments.
- Definition of arrangements.
- Qualitative evaluation of arrangements against a catalogue of fire and explosion hazards from other major accident hazards.
- Preparing of event tree analysis models.
- Consolidation of list of design events.
- Analysis of the effect of design events on fire, explosion and toxic hazard management and emergency response arrangements.
- Quantification of that impact in terms of individual risk.

The main model would base on a systems approach, and it takes the following form:

- Estimates of incremental individual risk (IIR) per person/yr.
- Is caused-consequences based.
- Uses event tree analysis to calculate the frequency of occurrence.
- Estimates incremental individual risk utilizing event tree analysis, based on modeling the emergency response arrangements from detection through to recovery to a place of safety.

Personnel Vulnerability and Structural Damage

A criterion used in the QRA study for the calculation of personnel vulnerability and structural / asset damage because of fire, explosion and toxic release shown in Table (3).

The criteria shown below provide some assumptions for the impairment effects of hydrocarbon releases on personnel and structures, which based on Health and Safety Executive: Methods of approximation and determination of human vulnerability for offshore major accident hazard assessment.

Table (3) Criteria for Personnel Vulnerability and Structural Damage

Event Type	Threshold of Fatality	Asset/Structural Damage
Jet and Diffusive Fire Impingement	6.3 kW/ m^2 (1) 12.5 kW/m^2 (2)	- Flame impingement 10 minutes. - 300 - 500 kW/m^2 Structural Failure within 20 minutes.
Pool Fire Impingement	6.3 kW/ m^2 (1) 12.5 kW/m^2 (2)	- Flame impingement 20 minutes - 100 - 150 kW/m^2 Structural Failure within 30 minutes.
Smoke	2.3% v/v (3) 15% v/v (4)	
Explosion Overpressure	300 mbar	100 mbar

(1) Fatality within 1 - 2 minutes
(2) Fatal < 1 minute
(3) Above 2.3%, escape possible but difficult
(4) No escape possible, fatal in a few seconds

The effects of exposure to fire expressed in terms of heat radiation (kW/m^2) and overpressure waves shown in Tables (4), (5) and (6).

Table (4) Heat Radiation Effects on Structures (World Bank)

Radiation Level kW/m^2	Observed Effect
37.5	Sufficient to cause damage to process equipment.
25	Minimum energy to ignite wood at indefinitely long exposure (non-piloted).
12.5	Minimum energy required to ignite wood, melting of plastic tubing.

Table (5) Heat Radiation Effects on People

Radiation Level kW/m^2	Effects on People
1.2	Equivalent to heat from sun at midday summer.
1.6	Minimum level at which pain can be sensed.
4 - 6	Pain caused in 15 - 20 seconds, Second Degree burns after 30 seconds.
12	20 % chance of fatality for 60 seconds exposure.
25	100 % chance of fatality for continuous exposure. 50 % chance of fatality for 30 seconds exposure.
40	30 % chance of fatality for 15 seconds exposure.
50	100 % chance of fatality for 20 seconds exposure.

Table (6) Effects of Overpressure

Pressure		Effects / Damage
bar	psig	
0.002	0.03	Occasional breakage of glass windows.
0.006	0.1	Breakage of some small windows.
0.021	0.3	Probability of serious damage beyond this point = 0.05. 10 % glass broken.
0.027	0.4	Minor structural damage of buildings.
0.068	1.0	Partial collapse of walls and roofs, possible injuries.
0.137	2.0	Some severe injuries, death unlikely.
0.206	3.0	Steel frame buildings distorted / pulled from foundation.
0.275	4.0	Oil storage tanks ruptured.
0.344	5.0	Wooden utilities poles snapped / Fatalities.
0.41	6.0	Nearly complete destruction of building.
0.48	7.0	Loaded wagon train overturned.
0.689	10.0	Total destruction of buildings.

Quantification of the Frequency of Occurrence

The probability of a sequence of events leading to a major hazard is dependent on the probability of each event in a sequence occurring; usually these probabilities may be multiplied together to obtain the end event probability or frequency.

The technique of Quantified Risk Assessment 'QRA' requires data in the form of probability or frequency to be estimated for each input event.

Ideally, data relating to hardware failures and human error that are specific to each plant should be obtained from the company's maintenance and historical records.

Unfortunately, records available were not in the form that allows data relevant to this study to be obtained. Therefore, other sources of data were used as a basis for failure/error scenarios. The sources of information and data are shown in the References section of this report.

Identification of Scenarios Leading to Selected Failures

For each selected failure scenario, the potential contributory factors were examined, taking into account any protective features available. Typically, the factors examined included:

- Operator error
- Metallurgical fatigue or ageing of materials
- Internal or external Corrosion
- Loss of process control, e.g. pressure, temperature or flow, etc.
- Overfilling of vessels
- Introduction of impurities
- Fire and/or explosion
- Missiles
- Flooding

Account was taken at this stage of those limited releases, which, although in themselves did not constitute a significant off-site hazard could, under some circumstances, initiate a sequence leading to a larger release, as a knock-on effect.

It was noted that the proposed criterion for risk tolerability was used in Egypt by the following organizations: British Gas / British Petroleum / Shell / Total.

Relevant Weather Data for the Study

- **Weather Data**

The Weather Data relevant to this study consists of a list of weather conditions in the form of different combinations of wind-speed/direction, temperature, humidity and atmospheric stability. Table (7)

The weather conditions are an important input into the dispersion calculations and results for a single set of conditions could give a misleading picture of the hazard potential.

Met-oceanographic data gathered from Weather base for Qaha Area - Qalyoubeyia Governorate over a period of some years.

These data included wind speed, wind direction, air temperature and humidity, as well as current speed, direction and wave height.

Table (7) Annual Average Temperature, Relative Humidity and Wind Speed / Direction

• Air Temperature ºC		
	Min. Recorded	**13.4** ºC
	Max. Recorded	**27.5** ºC
	Annual Average	***21.1 ºC***
• Relative Humidity %		
	Average Daily Min.	**50.1 %**
	Average Daily Max.	**66.1 %**
	Annual Average	***60.3 %***
• Wind Speed m/s		
	Annual Average	***3.4 m / sec.***
• Wind Direction		
	Annual Average	***N / NNW***

The general climatic conditions at Qalyoubeyia Governorate (Qaha Area) are summarized in Tables No. (8, 9 & 10) Below.

Table (8) Mean of Monthly Air Temperature (°C) - Qaha Area

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. (c°)	13.4	14.5	16.7	20.6	23.9	26.7	27.5	27.3	25.9	23.4	18.9	14.9

Table (9) Mean of Monthly Wind Speed (m/sec) - Qaha Area

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (m/sec)	3.2	3.6	3.9	3.8	3.8	3.7	3.3	3.1	3.1	3.3	2.9	3.0

Table (10) Mean of Monthly Average Relative Humidity - Qaha Area

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Relative Humidity (%)	65.2	61.4	58.7	52.5	50.1	52.7	61	64.5	62.9	62.2	66.1	65.7

Figure (4) shows the maximum temperature diagram for Qalyoubeyia Governorate (Qaha Area)

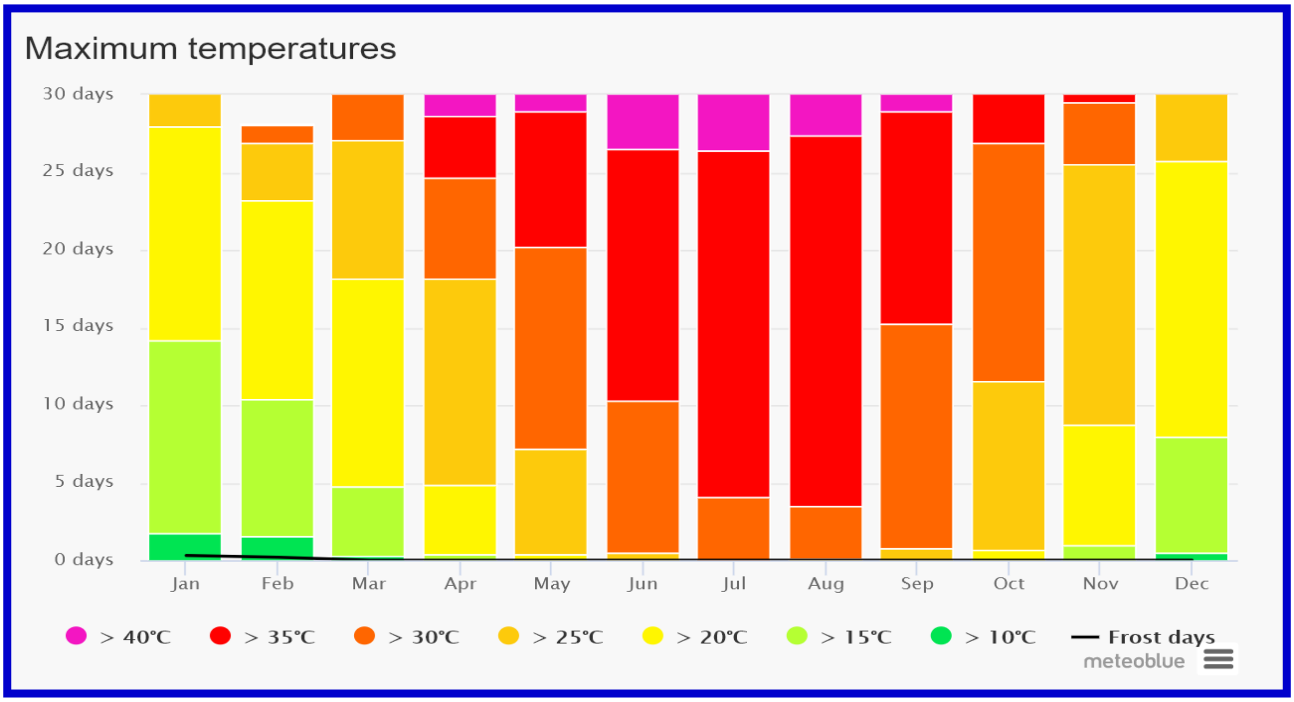


Figure (4) – Monthly Variations of the Maximum Temperature for Qaha Area

Figures (5 & 6) show the monthly variations of the wind speed as well as wind rose for Qalyoubeyia Governorate (Qaha Area) respectively.

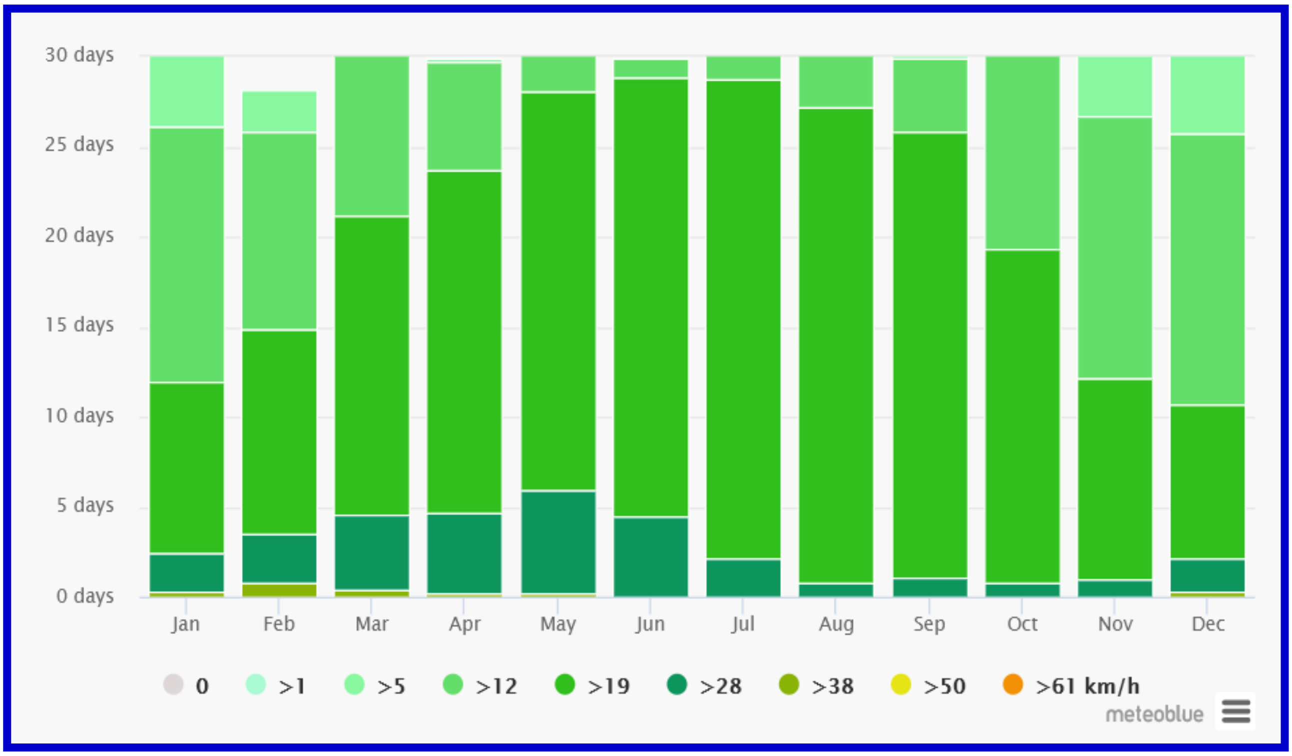


Figure (5) – Monthly Variations of the Wind Speed for Qaha Area

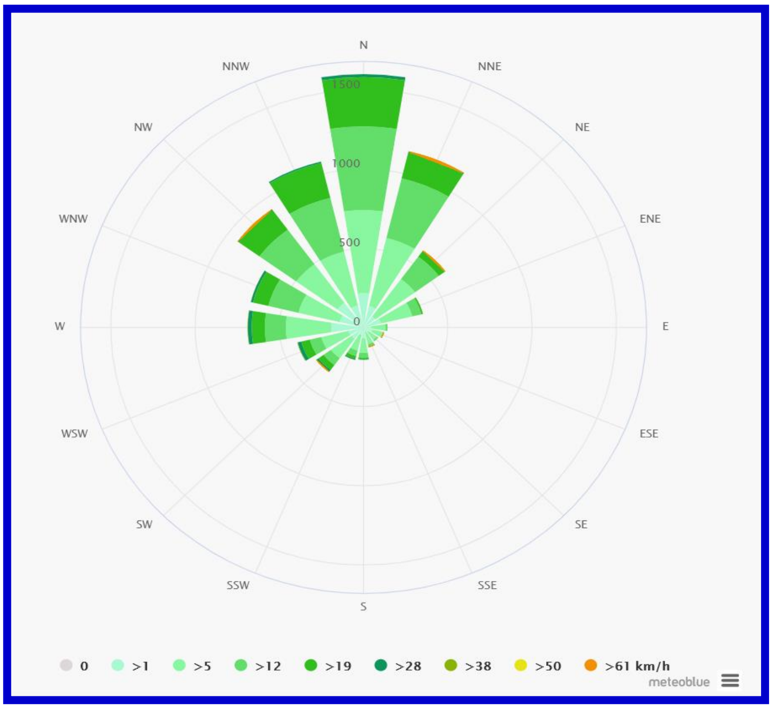


Figure (6) –Wind Rose for Qaha Area

Figure (7) shows the monthly variations of the sunny, cloudy and precipitation days for Qalyoubeyia Governorate (Qaha Area).

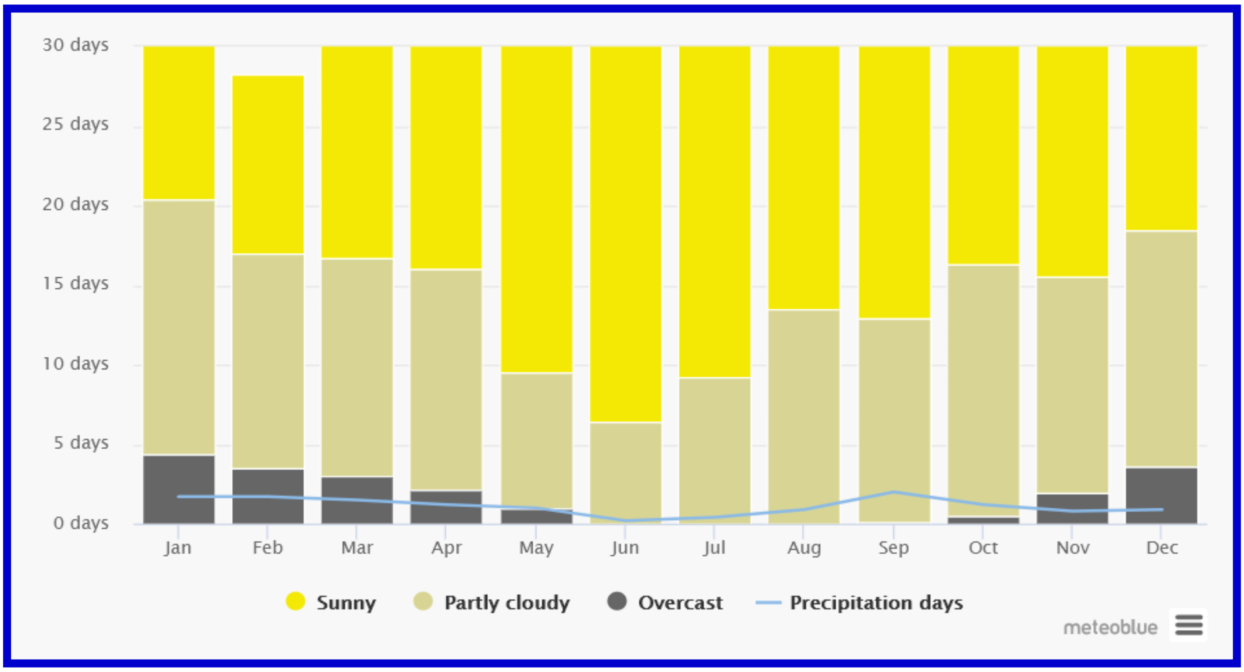


Figure (7) – Monthly Variations of the Sunny, Cloudy and Precipitation days for Qaha Area

- **Stability Categories**

The two most significant variables, which would affect the dispersion calculations, are Wind-speed and atmospheric stability. The stability class is a measure of the atmospheric turbulence caused by thermal gradients. Pasqual Stability identifies six main categories, which shown in the Tables (11 & 12) and summarized in Table (13).

Table (11) Pasqual Stability Categories

A	B	C	D	E	F
Very Unstable	Unstable	Moderately Unstable	Neutral	Moderately Stable	Stable

Neutral conditions correspond to a vertical temperature gradient of about 1° C per 100 m.

Table (12) Relationship between Wind Speed and Stability

Wind speed	Day-time Solar Radiation			Night-time Cloud Cover		
(m/s)	Strong	Medium	Slight	Thin <3/8	Medium >3/8	Overcast >4/5
<2	A	A-B	B	-	-	D
2-3	A-B	B	C	E	F	D
3-5	B	B-C	C	D	E	D
5-6	C	C-D	D	D	D	D
>6	C	D	D	D	D	D

Table (13) Sets of Weather Conditions Initially Selected for this Study

Set for Wind Speed and Stability	
Wind speed	Stability
3.4 m/sec.	D

Qaha PRMS Description

Background

Qaha Pressure Reduction and Metering Station Operated by Egypt Gas Company. It is located about 3.5 km North direction from Qaha City downtown. The PRMS will provide the natural gas to Qaha and surrounding area public housing.

The PRMS feeding will be from the National Gas Pipeline owned by GASCO and the off-take point will be inside the PRS boundary. The off-take point pressure will be from 20 to 70 bar, and then the pressure reduced to 4/7 bar at the PRMS facilities with adding odorant, and then connected to the internal distribution network to public housing at Qaha and surrounding area.

The PRMS & Off-Take Point Location Coordinates (Egypt Gas Data)

	PRMS		Off-take Point	
Point	**North (N)**	**East (E)**	**North (N)**	**East (E)**
1	*30 º 17 ' 53.88 "*	*31 º 12 ' 43.13 "*	*30 º 17 ' 52.20 "*	*31 º 12 ' 42.19 "*
2	*30 º 17 ' 51.82 "*	*31 º 12 ' 42.53 "*	*30 º 17 ' 52.02 "*	*31 º 12 ' 42.13 "*
3	*30 º 17 ' 52.25 "*	*31 º 12 ' 40.76 "*	*30 º 17 ' 52.07 "*	*31 º 12 ' 41.91 "*
4	*30 º 17 ' 54.35 "*	*31 º 12 ' 41.41 "*	*30 º 17 ' 52.25 "*	*31 º 12 ' 41.95 "*

PRMS Brief Description and Components (Egypt Gas Data)

The PRMS will be surround by 3 m height fence and mainly consist of the followings: (Ref. Figures 8, 9, 10 and 11)

- Inlet module: which contains 4" # 600 manual isolation valve.
- Filter module: two identical streams each contain inlet and outlet isolation valves.
- Heating system module: two identical.
- Metering module: two identical.
- Regulating module: two identical regulating lines.
- Outlet module: it contains manual outlet isolation valve.
- Odorant module: 600 lit. capacity bulk tank / 50 lit. daily use.
- Off-take point will be from under-ground room inside the PRS boundary containing connection pipes and isolation valves with GASCO underground pipeline 32", connected to 4" PRMS feeding pipeline.
- Security Office (one floor)
- Administration office (one floor)
- Firefighting Facilities (Fire Water Tank / Pumps / Fire water Network)

Qaha PRMS Units (Egypt Gas Data) - Need to be completed by Egypt Gas

Table (14) Qaha PRMS Units

No	PRMS Units	Capacity	Size
1	***Inlet unit***		
	Inlet valve		
	Inlet valve bypass (ball + plug)		
2	***Filter units***		
	Line Fl		
	Line F2		
	Line F3 (valves only)		
	Line F3 (only blind flange)		
	Line F4 (only blind flange)		
3	***Meter unit***		
	Line Ml		
	Line M2		
	Line M3 (valves only)		
	Line M3 (only blind flange)		
	Line M4 (only blind flange)		
	One extension ball valve on outlet header (future heater)		
	One ball valve full bore for heater bypass		
4	***Regulator unit***		
	Line Rl		
	Line R2		
	Line R3(valves only)		
	Line R3(only blind flange)		

	Line R4(only blind flange)		
	One extension ball valve on inlet header (future heater)		
5	***Odorant unit***		
	Electrical pumps		
	Lapping system		
6	***Outlet unit***		
	Outlet valve		
	Extension valve (future)		
7	***Monitoring and Control unit***		
8	***Generator (15 KVA)***		
9	***UPS***		

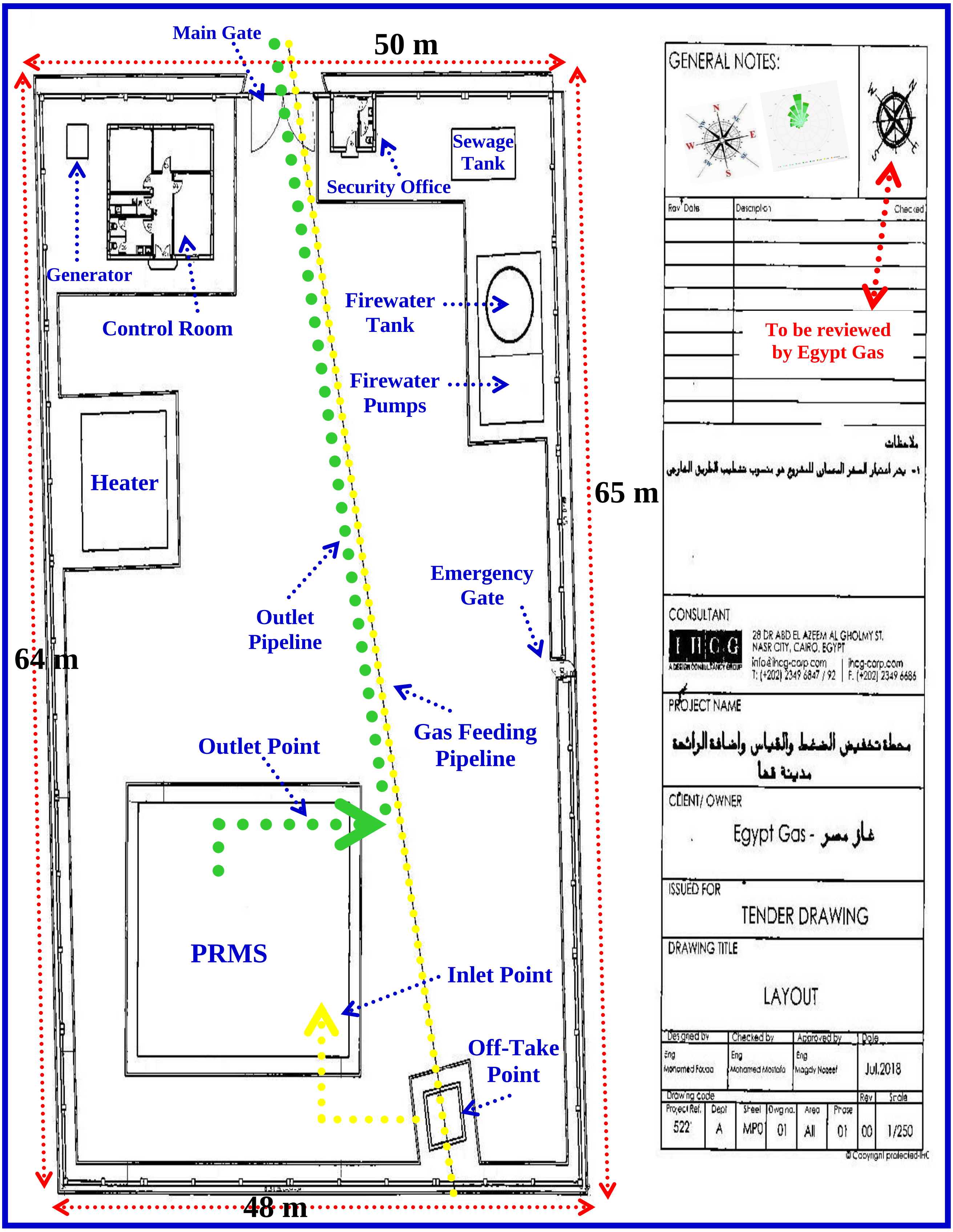


Figure (8) Qaha Pressure Reduction and Metering Station “PRMS” General Layout (Egypt Gas Data)

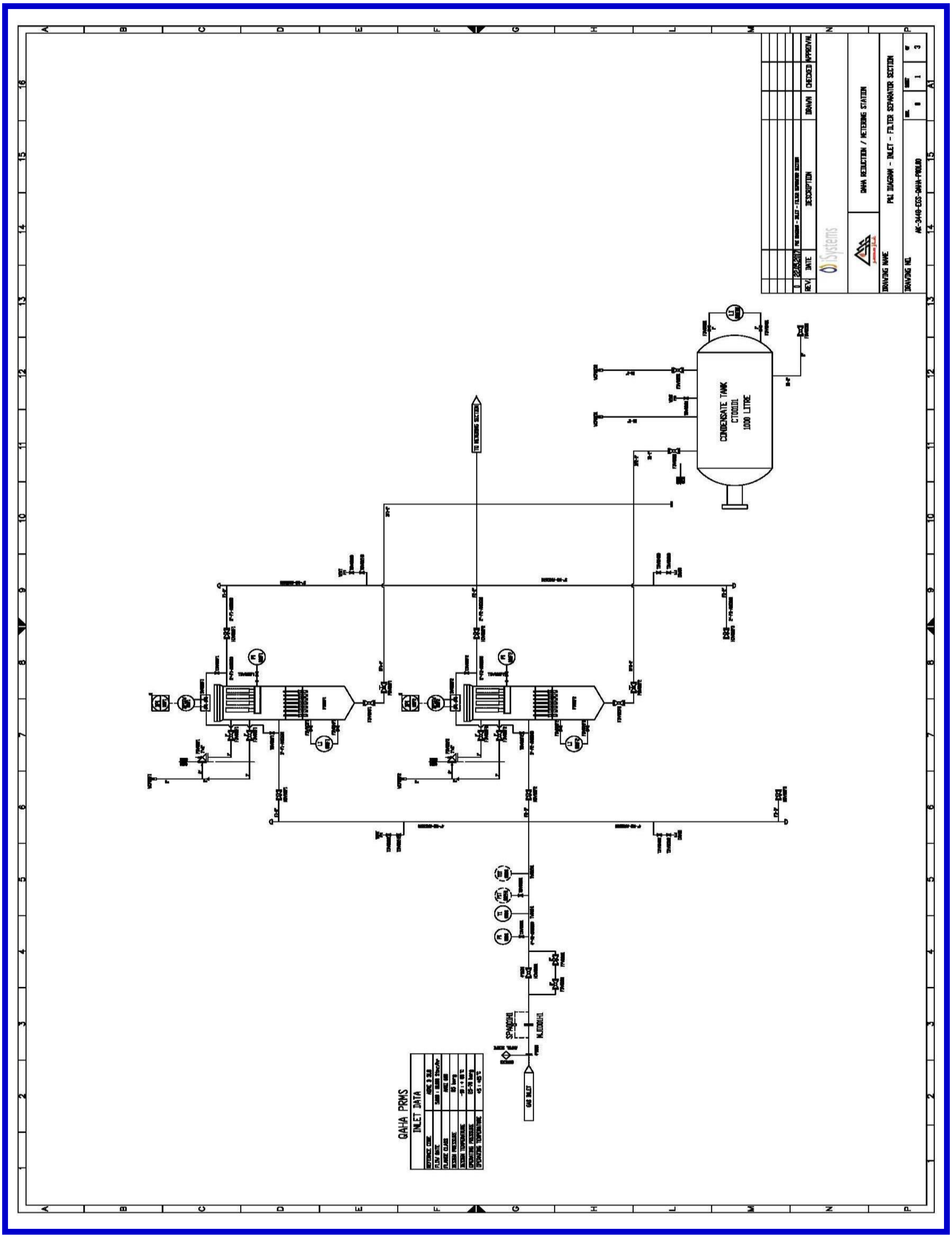


Figure (9) Qaha PRMS Piping and Instrumentation Diagram "P&ID" for Inlet & Filter Separator Section (Egypt Gas Data)

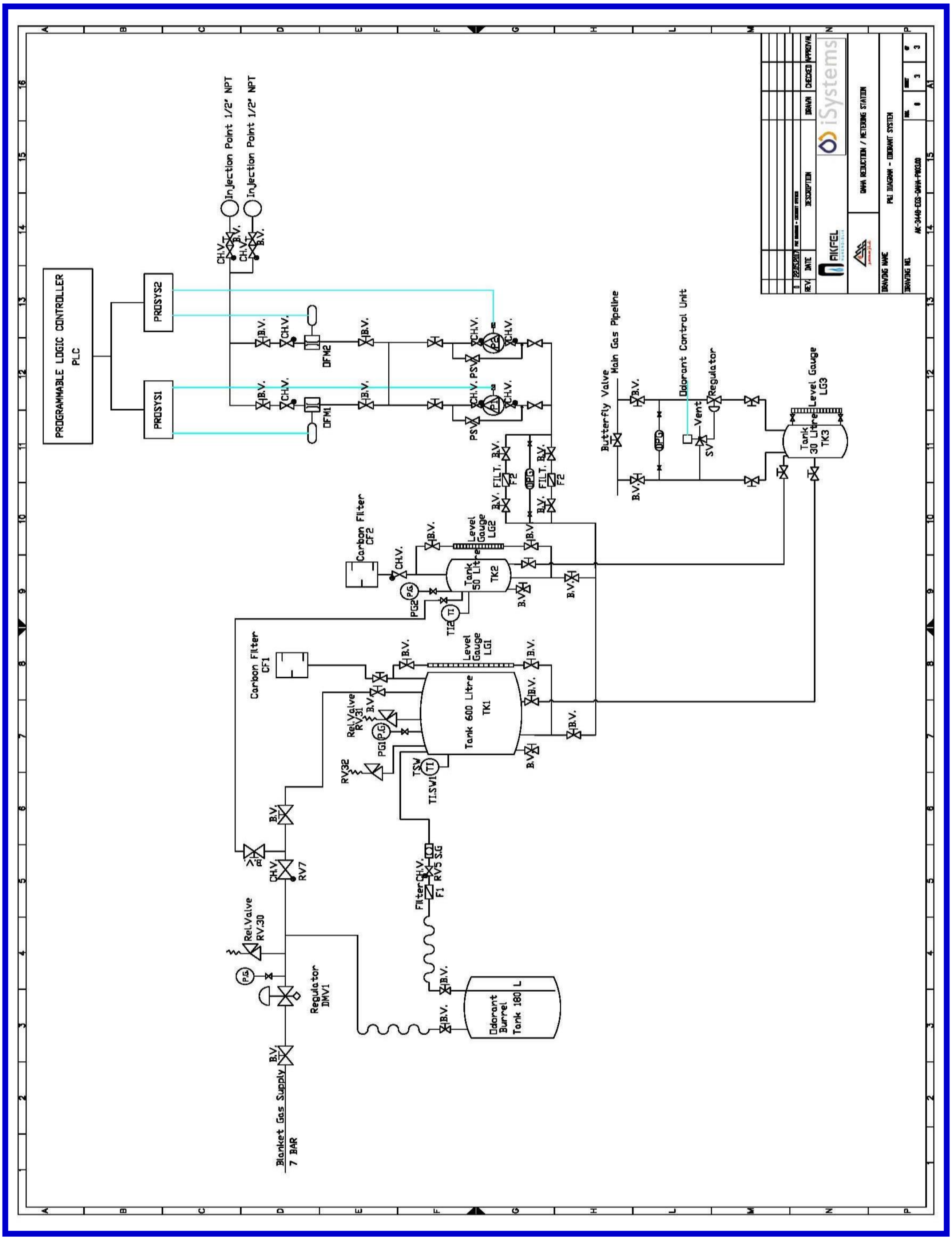


Figure (10) Qaha PRMS Piping and Instrumentation Diagram “P&ID” for Odorant System Section (Egypt Gas Data)

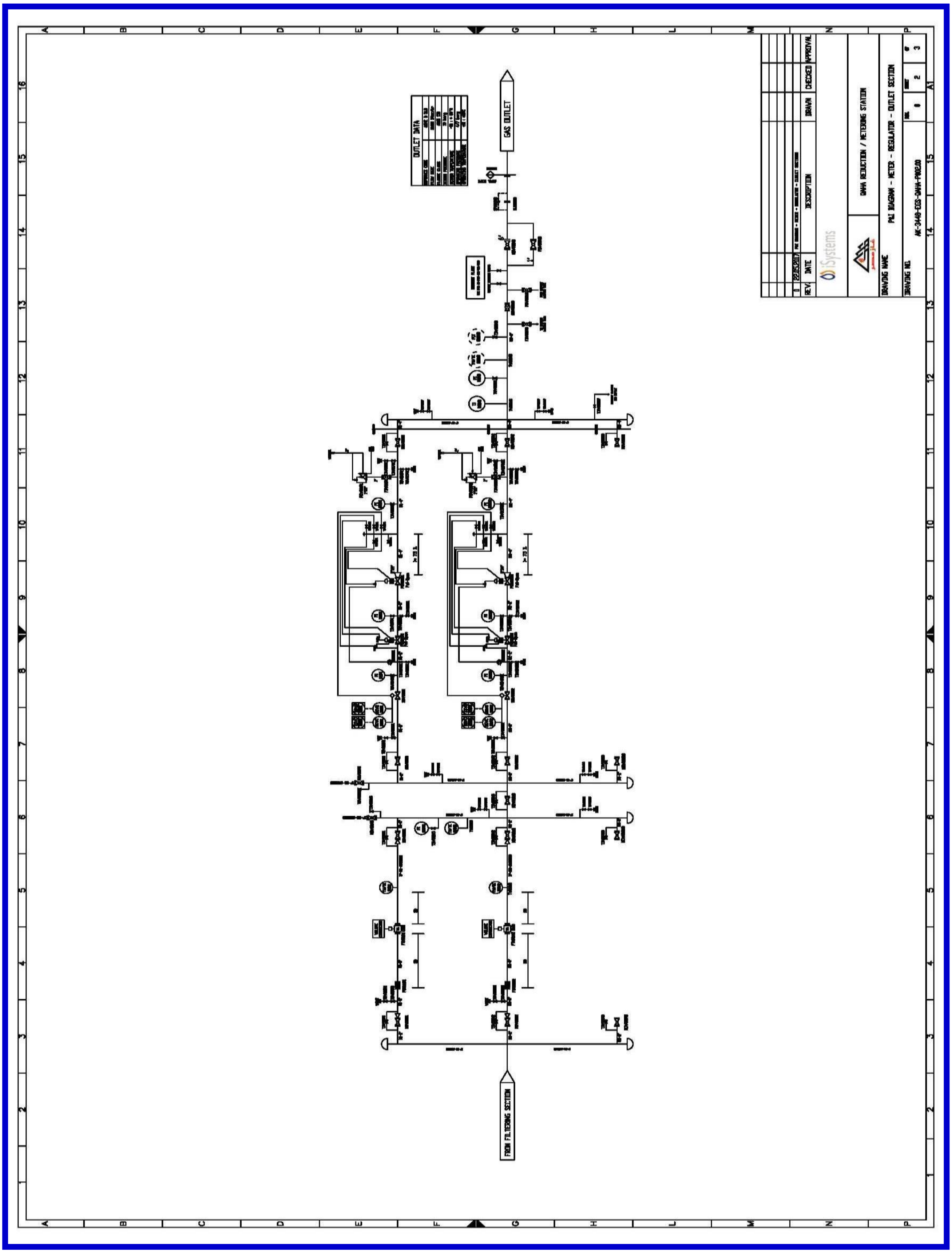


Figure (11) Qaha PRMS Piping and Instrumentation Diagram "P&ID" for Meter, Regulator and Outlet Section (Egypt Gas Data)

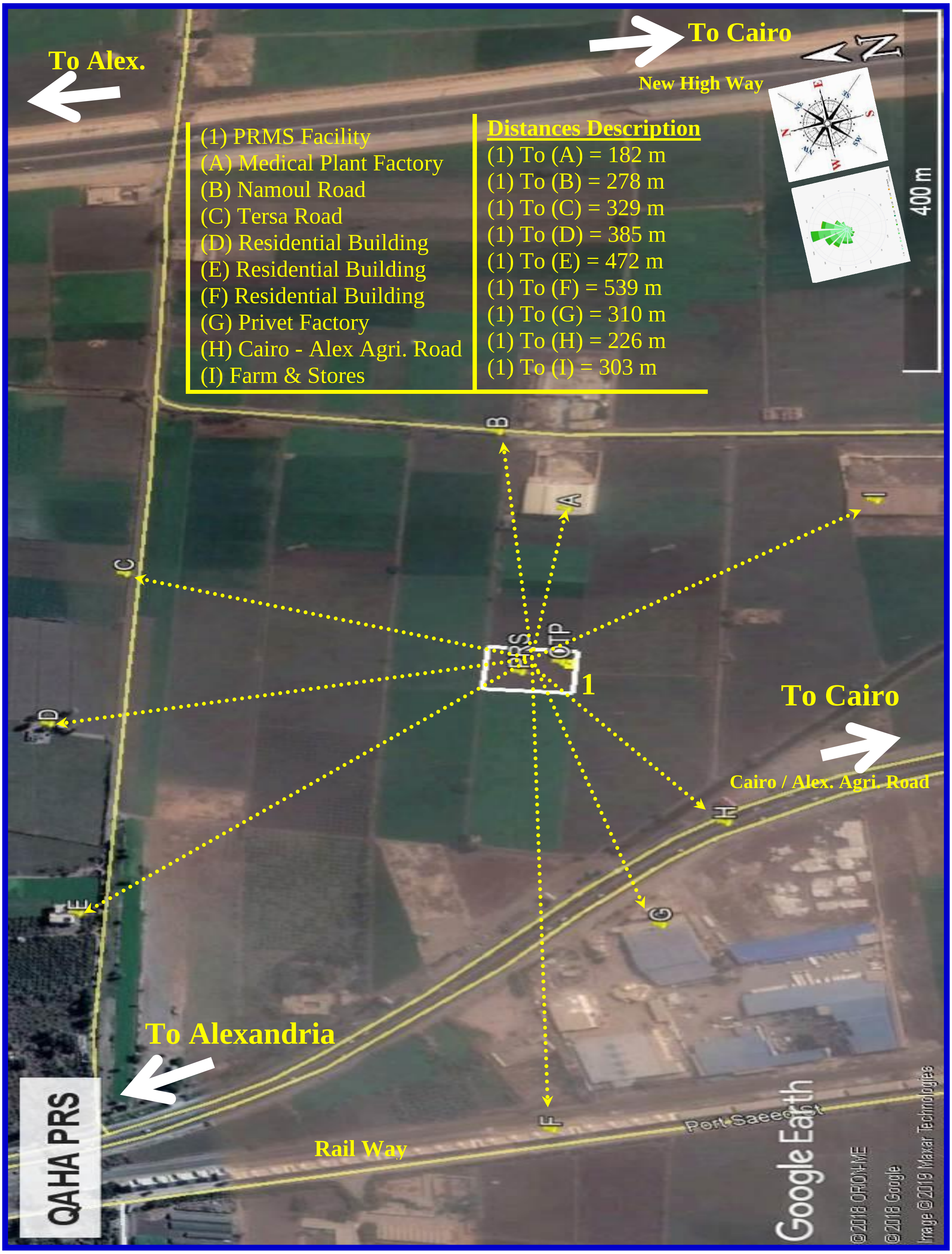


Figure (12) Qaha PRMS and Surroundings Plotted on Google Earth Photo

Process Condition Data (Egypt Gas Company Data)

The following table no (15) describes the process conditions for Qaha PRMS:

Table (15) Process Conditions / Gas Components & Specifications

Process Conditions	
Maximum flow rate scm / hr	10000
future flow rate scm / hr	40000
Design pressure bar g	70
Min / Max inlet pressure bar g	20 – 70
Min / Max outlet pressure bar g	7
Min / Max inlet temperature °C	15 – 25
Outlet temperature °C	Not less than 1

Gas Components	
Gas composition % Mol	
Water	0
H_2S	4 ppm
Nitrogen	0.2 - 0.83
Carbon Dioxide	0.07 - 3
Methane	77.73 - 99.82
Ethane	0.03 - 15.68
Propane	0.01 - 4.39
I-Butane	0.0 - 1.14
N-Butane	0.0 - 1.01
I-Pentane	0.0 - 0.19
N-Butane	0.0 - 0.26
C6+	0.0 - 0.25

Gas Specifications	
Specific gravity	0.5 - 0.69 (air = 1 k/m^3)

Gas Odorant Specifications

The odorant supplied with a Hazard Data Sheet and identified as Spotleak 1009. Spotleak is an aliphatic mixture in clear liquid form that is extremely flammable, with the following characteristics:

− Boiling Range	60-70º C
− Flash Point	-17.8º C
− Freezing Point	-45.5º C
− Density (H_2O = 1)	0.812 @ 15.5º C
− Vapor Density	3.0 (air = 1)
− Vapor Pressure (mm Hg)	6.6 @ 37.8º C

Health Hazards

Spotleak is not carcinogenic, but the major health hazards as a result of exposure to Spotleak include the following:

Inhalation

- Short-term exposure: Irritation and central nervous system effects
- Long-term exposure: Irritation

Skin Contact

- Short-term: Irritation
- Long-term: Dermatitis

Eye Contact

- Short-term: Irritation and tearing
- Long-term: Irritation

Ingestion

- Short-term: nausea, vomiting, central nervous system effects
- Long-term: no effects are known

Hygiene Standards and Limits

Occupational Exposure Limit for Spotleak to all components is 45 ppm, and the long-term "MEL" should be below 12 ppm (8 hrs. "TWA").

Fire and Explosion Hazards

Spotleak is a severe fire hazard. Vapor/air mixtures are explosive. Vapor is 3 times heavier than air. Vapor may ignite at distant ignition sources and flash back.

Thermal decomposition products include oxides of sulphur and hydrogen sulphide.

Fire Fighting and Protection Systems and Facilities

As per minutes of the coordination meeting dated 20/07/2016 with Civil Protection, the PRMS will provided by the following fire protection facilities:

- Firewater tank with a capacity of 40 cum.
- Firewater pumps (1 electrical & 1 diesel with capacity of 250 gpm each).
- Firewater main with a diameter of 4 inch.
- Firewater hydrants 1.5 inch X 1 / each.
- Firewater monitors.
- Smoke detector in all admin rooms & FM200 firefighting system for the control room.
- Heat detectors in buffet rooms.
- Smoke detectors in control rooms according to the area.
- Different sizes of fire extinguishers will be distributed at PRMS site.

Emergency Response Plan "ERP" - Need to be provided by Egypt Gas

The Emergency Response Plan "ERP" for Qaha PRS not provided by Egypt Gas, so it must be prepared (if not) to include all related items including all scenarios has been identified by this QRA study.

Analytical Results of Consequence Modeling

1.0- Pressure Reduction Station Inlet Pipeline (4 inch)

1/1- Consequence Modeling for 1 inch (Pin Hole) Gas Release

The following table no. (16) Show that:

Table (16) Dispersion Modeling for Inlet - 1" / 4" Gas Release

Gas Release (Inlet / PRV "High Pressure")				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
3.4 D	UFL	2.50	1.15	0.30 @ 1.40 m
	LFL	9	1.45	0.90 @ 6.00 m
	50 % LFL	21.20	0 – 2	2.00 @ 12.00 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	14.70	1.6	23.50	15.60	0
		4	19.50	9.60	0
		9.5	16.60	5.30	0
		12.5	15.40	4.10	20% /60 sec.
		25	13.30	1.50	80.34
		37.5	Not Reached	Not Reached	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	N/D	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

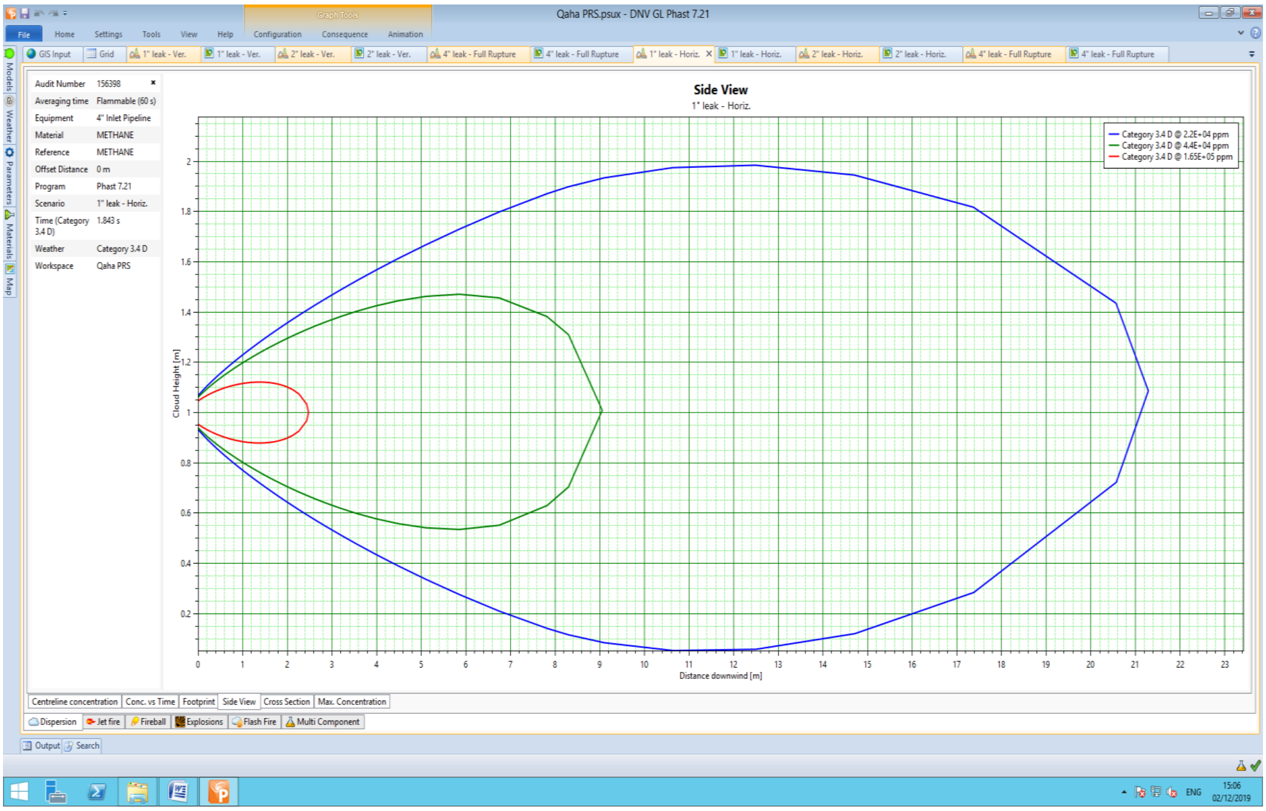


Figure (13) Gas Cloud Side View (UFL/LFL) (1” hole in 4” Inlet Pipeline)

- The previous figure shows that if there is a gas release from 1” hole size without ignition the flammable vapors will reach a distance more than 21 m downwind and from 0 – 2 m height.
- The UFL will reach a distance of about 2.50 m downwind with a height of 1.15 m. The cloud large width will be 0.30 m crosswind at a distance of 1.40 m from the source.
- The LFL will reach a distance of about 9 m downwind with a height of 1.45 m. The cloud large width will be 0.90 m crosswind at a distance of 6 m from the source.
- The 50 % LFL will reach a distance of about 21.20 m downwind with a height from 0 to 2 m. The cloud large width will be 2 m crosswind at a distance of 12 m from the source.

The modeling shows that the gas cloud effects will be limited inside the PRMS boundary.

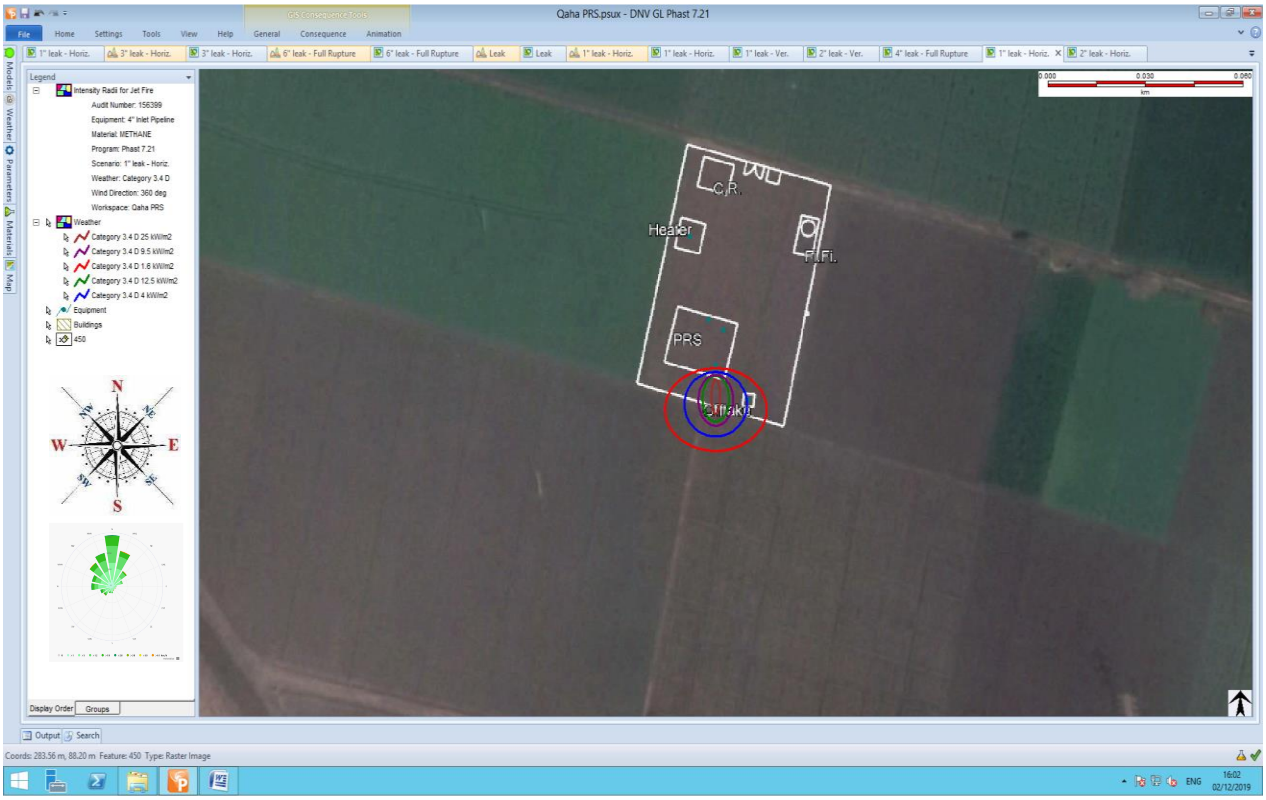


Figure (14) Heat Radiation Contours from Jet Fire (1" hole in 4" Inlet Pipeline)

- The previous figure show that if there is a gas release from 1" hole size and ignited the expected flame length is about 14.70 meters downwind.
- The 9.5 kW/m^2 heat radiation contours extend about 16.60 meters downwind 5.30 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 15.40 meters downwind and 4.10 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 13.30 meters downwind and 1.50 meters crosswind.
- The 37.5 kW/m^2 heat radiation not reached.

The modeling shows that the heat radiation values will extend down and crosswind outside the PRS boundary reaching the off-take point crosswind (1.6 & 4 kW/m^2), with no effects downwind (9.5, 12.5 & 25 kW/m^2)

1/2- Consequence Modeling for 2 inch (Half Rup.) Gas Release

The following table no. (17) Show that:

Table (17) Dispersion Modeling for Inlet - 2" / 4" Gas Release

Gas Release (Inlet / PRV "High Pressure")				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
3.4 D	UFL	5.80	1	0.60 @ 2.80 m
	LFL	24.70	0 – 2.30	2.30 @ 17.00 m
	50 % LFL	24.80	0 – 3.10	3.10 @ 24.80 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	31	1.6	52.70	36	0
		4	43	22.50	0
		9.5	36	13.30	0
		12.5	34	10.70	20% /60 sec.
		25	30	5	80.34
		37.5	23	2.60	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	64	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	17	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	13	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

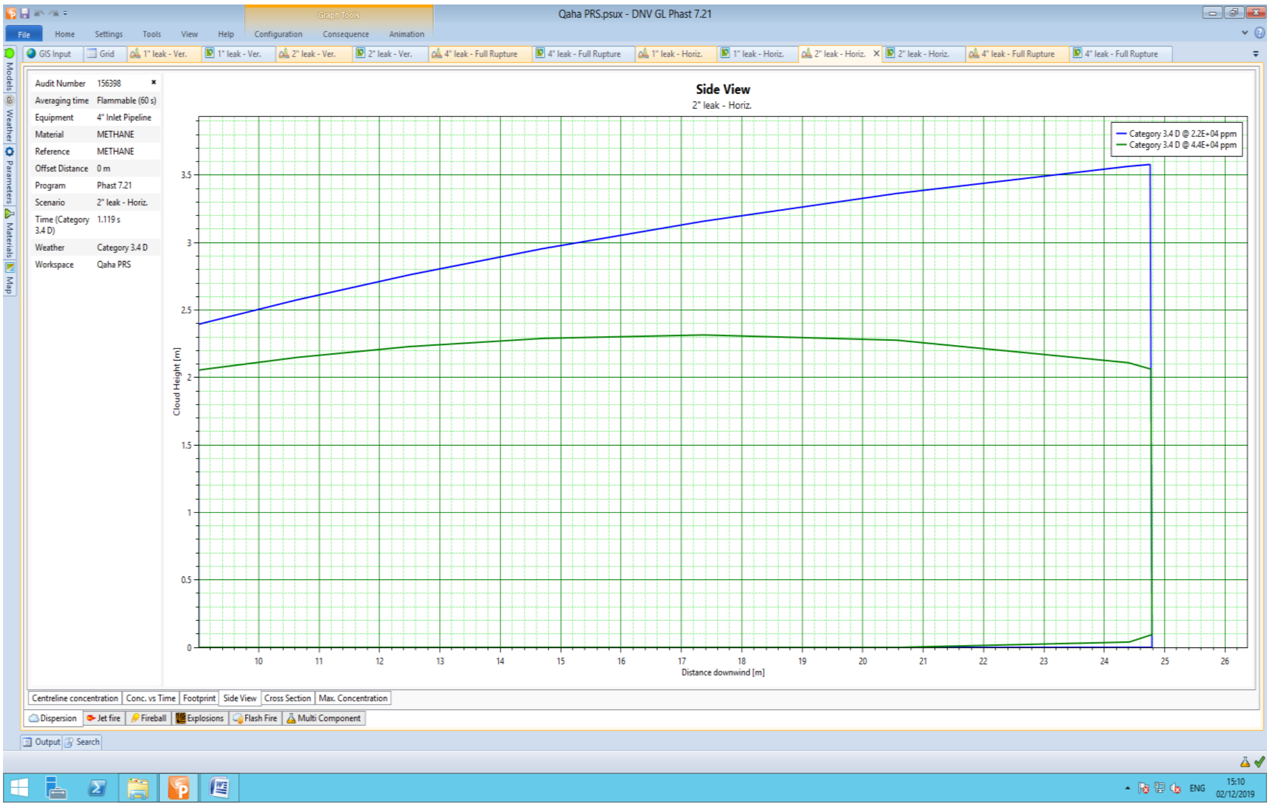


Figure (15) Gas Cloud Side View (UFL/LFL) (2" hole in 4" Inlet Pipeline)

- The previous figure shows that if there is a gas release from 2" hole size without ignition the flammable vapors will reach a distance about 24 m downwind and from 0 to 3.10 m height.
- The UFL will reach a distance of about 5.80 m downwind with a height of 1 m. The cloud large width will be 0.60 m crosswind at a distance of 2.80 m from the source.
- The LFL will reach a distance of about 24.70 m downwind with a height from 0 to 2.30 m. The cloud large width will be 2.30 m crosswind at a distance of 17 m from the source.
- The 50 % LFL will reach a distance of about 24.80 m downwind with a height from 0 to 3.10 m. The cloud large width will be 3.10 m crosswind at a distance of 24.80 m from the source.

The modeling shows that the gas cloud (LFL & 50 % LFL) will extend to reach the southern fence and extend about outside. The UFL will be limited inside the PRS boundary.

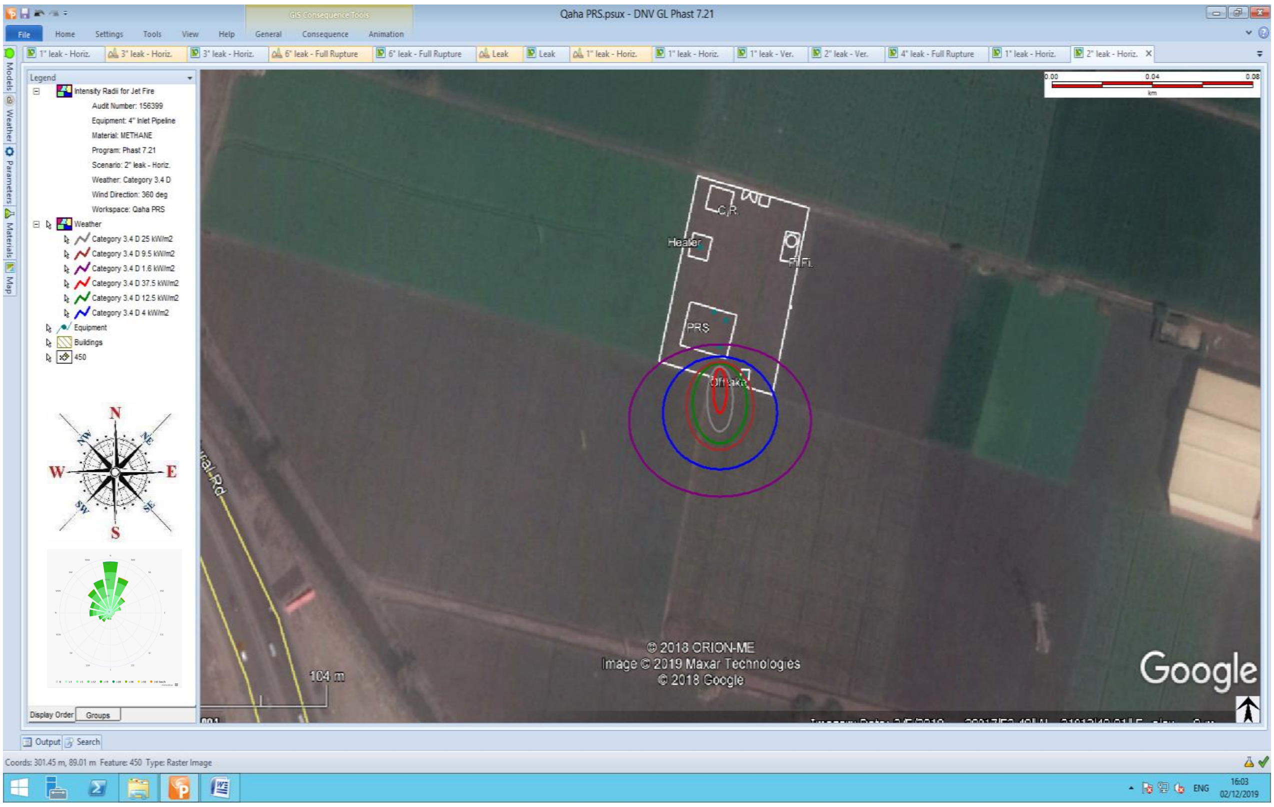


Figure (16) Heat Radiation Contours from Jet Fire (2” hole in 4” Inlet Pipeline)

- The previous figure shows that if there is a gas release from 2” hole size and ignited the expected flame length is about 31 meters downwind.
- The 9.5 kW/m^2 heat radiation contours extend about 36 meters downwind and 13.30 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 34 meters downwind and 10.70 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 30 meters downwind and 5 meters crosswind.
- The 37.5 kW/m^2 heat radiation contours extend about 23 meters downwind and 2.60 meters crosswind.

The modeling shows that the values of 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the PRS southern fence downwind with no effects. The values of 9.5 & 12.5 kW/m^2 will reach the off-take point crosswind

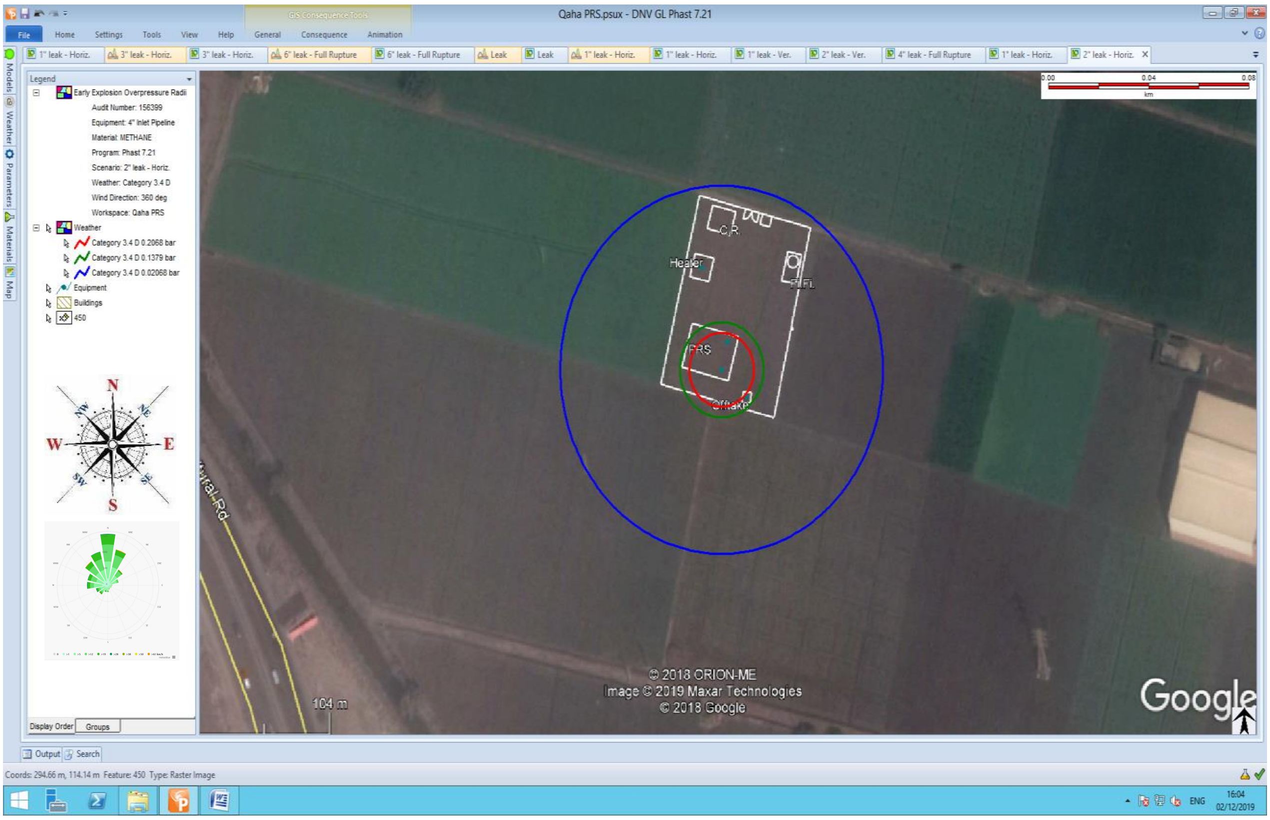


Figure (17) Early Explosion Overpressure Waves (2" hole in 4" Inlet Pipeline)

- The previous figure shows that if there is a gas release from 2" hole size and late ignited this will give an explosion with different values of overpressure waves.
- The 0.020 bar overpressure waves will extend about 64 meters downwind.
- The 0.137 bar overpressure waves will extend about 17 meters downwind.
- The 0.206 bar overpressure waves will extend about 13 meters downwind.

The modeling shows that the value of 0.020, 0.137 & 0.206 bar will extend outside the PRMS south fence with no effects down or crosswind.

1/3- Consequence Modeling for 4 inch (Full Rupture) Gas Release

The following table no. (18) Show that:

Table (18) Dispersion Modeling for Inlet - 4" Gas Release

Gas Release

Wind Category	Flammability Limits	Distance (m)	Height (m)	Cloud Width (m)
3.4 D	UFL	14.66	1.30	0.60 @ 13.60 m
	LFL	19.60	0 – 3.60	3.60 @ 19.60 m
	50 % LFL	19.70	0 – 4.40	4.40 @ 19.70 m

Jet Fire

Wind Category	Flame Length (m)	Heat Radiation (kW/m^2)	Distance Downwind (m)	Distance Crosswind (m)	Lethality Level (%)
3.4 D	58.27	1.6	120	73	0
		4	84	46	0
		9.5	68	27.80	0
		12.5	63	22.70	20 %/60 sec.
		25	55	12	80.34
		37.5	45	8	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)

Wind Category	Pressure Value (bar)	Over Pressure Radius (m)		Overpressure Waves Effect / Damage	
		Early	Late		
3.4 D	0.020	64	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	17	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	13	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Fireball

Wind Category	Heat Radiation (kW/m^2)	Distance (m)	Heat Radiation (kW/m^2) Effects on People & Structures
3.4 D	1.6	Not Determined	**12.5** *20 % Chance of fatality for 60 sec exposure* **25** *100 % Chance of fatality for continuous exposure* *50 % Chance of fatality for 30 sec exposure* **37.5** *Sufficient of cause process equipment damage*
	4	Not Determined	
	9.5	Not Determined	
	12.5	Not Determined	
	25	Not Determined	
	37.5	Not Determined	

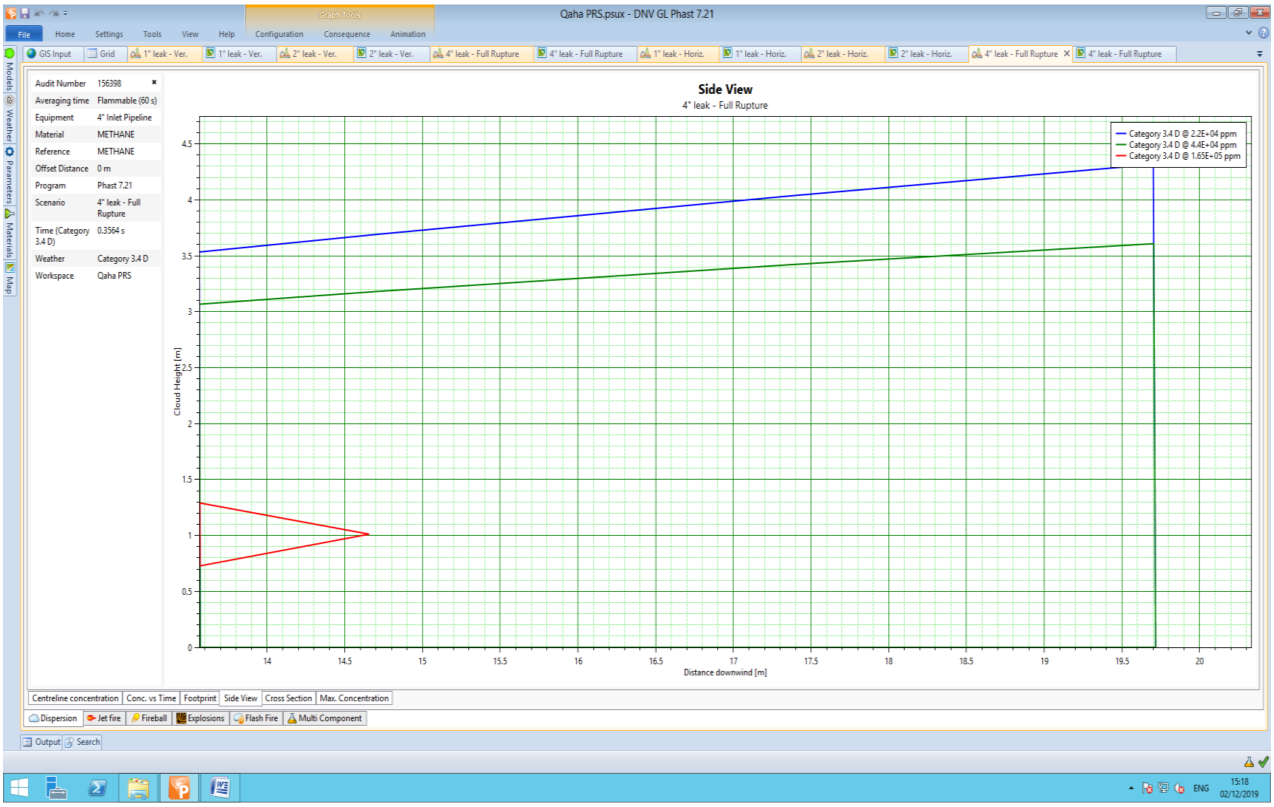


Figure (18) Gas Cloud Side View (UFL/LFL) (4" Inlet Pipeline Full Rupture)

- The previous figure shows that if there is a gas release from 4" pipeline full rupture without ignition, the flammable vapors will reach a distance more than 19 m downwind and over 4 m height.
- The UFL will reach a distance of about 14.66 downwind with a height of 1.30 m. The cloud large width will be 0.60 m crosswind at a distance of 13.60 m from the source.
- The LFL will reach a distance of about 19.60 m downwind with a height from 0 to 3.60 m. The cloud large width will be 3.60 m crosswind at a distance of 19.60 m from the source.
- The 50 % LFL will reach a distance of about 19.70 m downwind with a height from 0 to 4.40 m. The large width will be 4.40 m crosswind at a distance of 19.70 m from the source.

The modeling shows that the gas cloud effects (LFL & 50 % LFL) will extend over south boundary with no effects outside downwind.

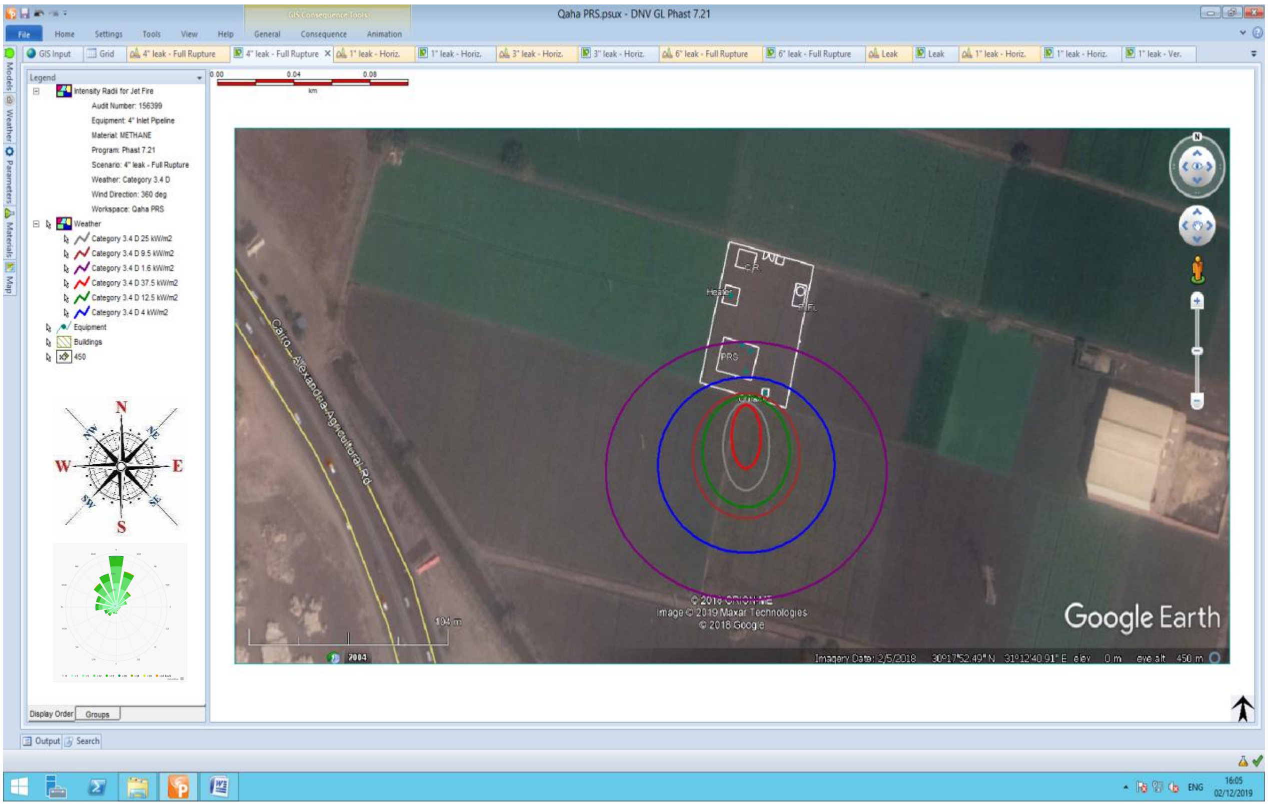


Figure (19) Heat Radiation Contours from Jet Fire (4" Inlet Pipeline Full Rupture)

- The previous figure show that if there is a gas release from 4" pipeline full rupture and ignited the expected flame length is about 58 meters downwind.
- The 9.5 kW/m^2 heat radiation contours extend about 68 meters downwind and 27.80 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 63 meters downwind and 22.70 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 55 meters downwind and 12 meters crosswind.
- The 37.5 kW/m^2 heat radiation contours extend about 45 meters downwind and 8 meters *crosswind.*

The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the south fence with no effects downwind and reach the off-take point crosswind.

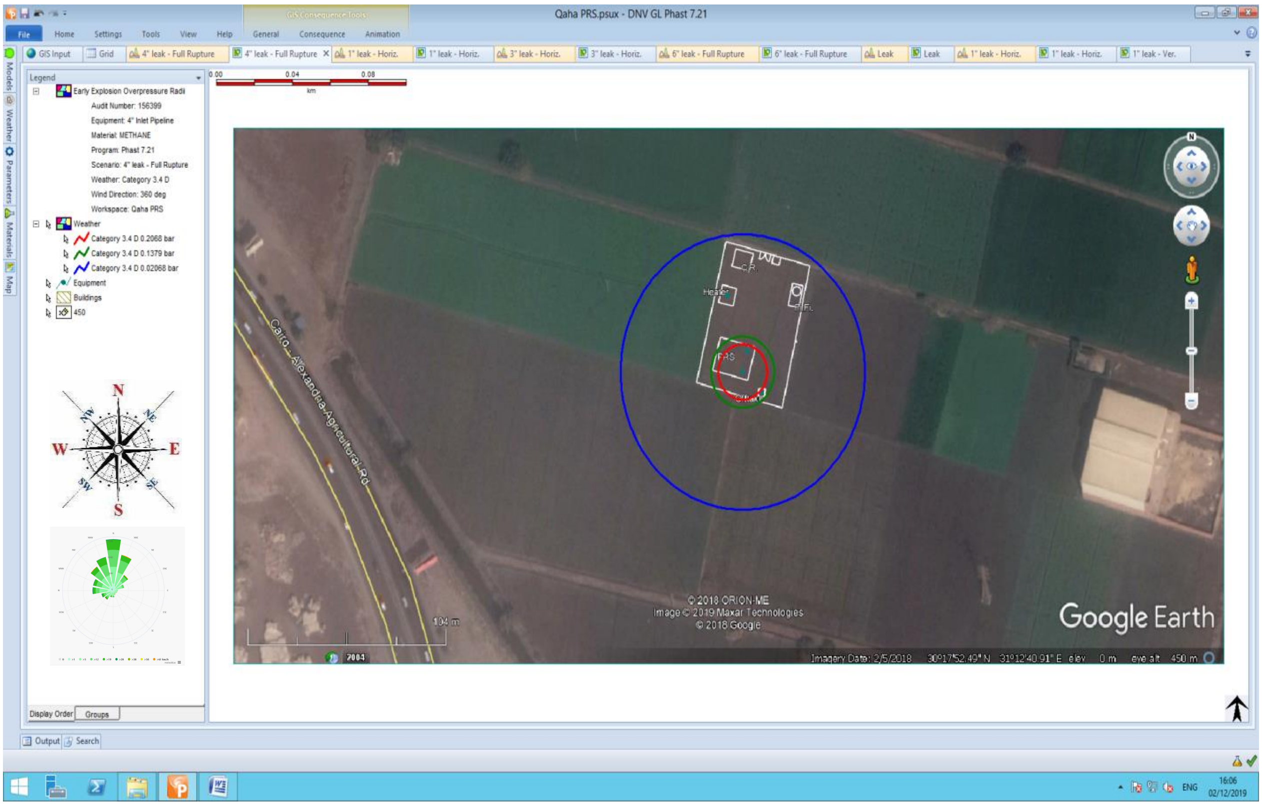


Figure (20) Early Explosion Overpressure Waves (4" Inlet Pipeline Full Rupture)

- The previous figure shows that if there is gas release from 4" pipeline full rupture and late ignited this will give an explosion with different values of overpressure waves.
- The 0.020 bar overpressure waves will extend about 64 meters radius.
- The 0.137 bar overpressure waves will extend about 17 meters radius.
- The 0.206 bar overpressure waves will extend about 13 meters radius.

The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects.

The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and off-take point and no effects on site offices.

2.0- Pressure Reduction Station Outlet Pipeline (6 inch)

2/1- Consequence Modeling for 1 inch (Pin Hole) Gas Release

The following table no. (19) Show that:

Table (19) Dispersion Modeling for Outlet - 1" / 6" Gas Release

Gas Release (Outlet / PRV "Low Pressure")				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
3.4 D	UFL	1.20	1.06	0.12 @ 0.60 m
	LFL	4.35	1.20	0.40 @ 2.70 m
	50 % LFL	7.20	0 – 1.40	1.40 @ 4.50 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m²)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	7.15	1.6	10	5.70	0
		4	8.50	3.20	0
		9.5	7	1.20	0
		12.5	6	0.50	20% /60 sec.
		25	Not Reached	Not Reached	80.34
		37.5	Not Reached	Not Reached	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	N/D	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

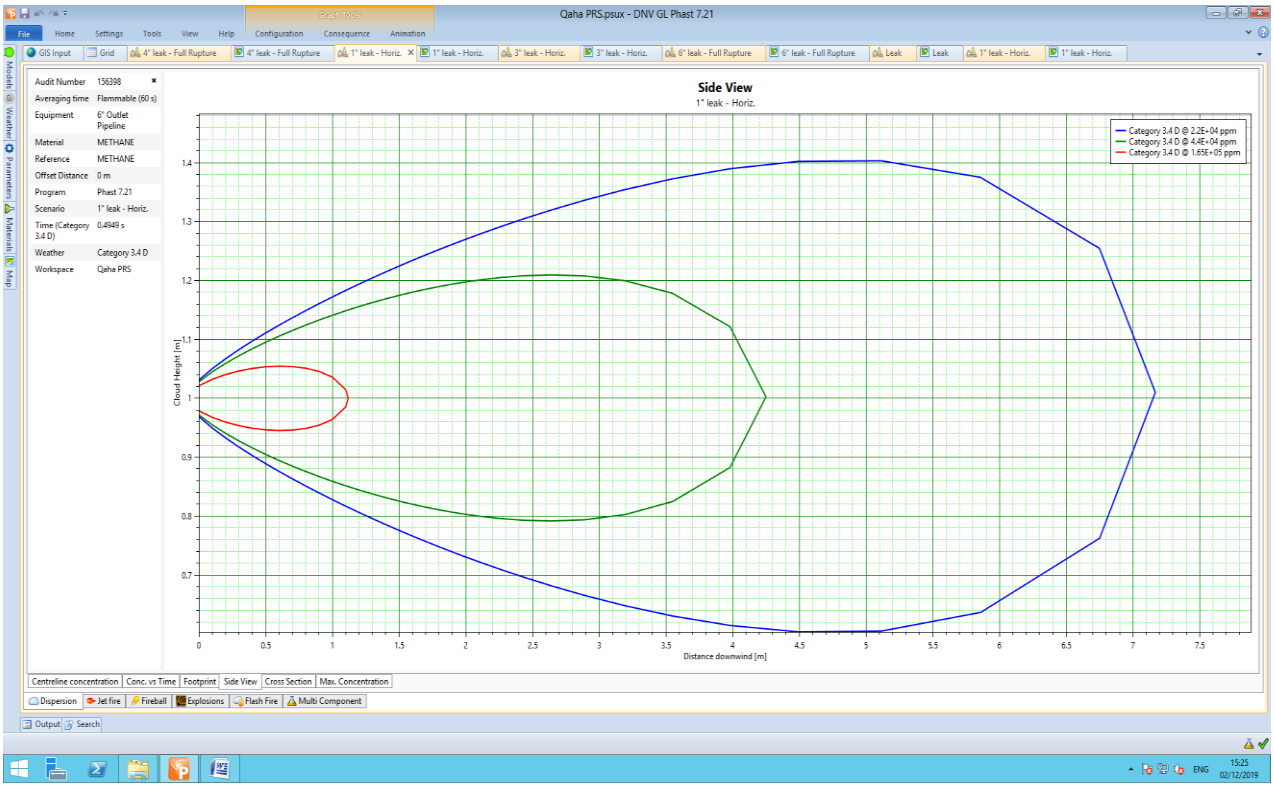


Figure (21) Gas Cloud Side View (UFL/LFL) (1" hole in 6" Outlet Pipeline)

- The previous figure show that if there is a gas release from 1" hole size without ignition the flammable vapors will reach a distance more than 7 m downwind and over 1 m height.
- The UFL will reach a distance of about 1.20 m downwind with a height of 1.06 m. The cloud large width will be 0.12 m crosswind at a distance of 0.60 m from the source.
- The LFL will reach a distance of about 4.35 m downwind with a height of 1.20 m. The cloud large width will be 0.40 m crosswind at a distance of 2.70 m from the source.
- The 50 % LFL will reach a distance of about 7.20 m downwind with a height of from 0 to 1.40 m. The cloud large width will be 1.40 m crosswind at a distance of 4.50 m from the source.

The modeling shows that the gas cloud will be limited inside the PRS boundary.

Figure (22) Heat Radiation Contours from Jet Fire (1" hole in 6" Outlet Pipeline)

- The previous figure shows that if there is a gas release from 1" hole size and ignited the expected flame length is about 7.15 meters downwind.
- The 1.6 kW/m^2 heat radiation contours extend about 10 meters downwind and 5.70 meters crosswind.
- The 4 kW/m^2 heat radiation contours extend about 8.50 meters downwind and 3.20 meters crosswind.
- The 9.5 kW/m^2 heat radiation contours extend about 7 meters downwind and 1.20 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 6 meters downwind and 0.50 meters crosswind.
- The 25 kW/m^2 heat radiation not reached.
- The 37.5 kW/m^2 heat radiation not reached.

The modeling shows that the heat radiation value 1.6, 4, 9.5 & 12.5 kW/m^2 effects will be limited inside the PRS boundary with no effects.

The values of 25 & 37.5 kW/m^2 not determined by the software due to small leakage.

2/2- Consequence Modeling for 3 inch (Half Rup.) Gas Release

The following table no. (20) Show that:

Table (20) Dispersion Modeling for Outlet - 3" / 6" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance** (m)	**Height** (m)	**Cloud Width** (m)
3.4 D	UFL	4.20	1	0.60 @ 2.90 m
	LFL	17.40	0 – 1.90	1.80 @ 11.50 m
	50 % LFL	17.50	0 – 2.80	2.80 @ 17.50 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	23.80	1.6	38	26.40	0
		4	29.40	16.50	0
		9.5	23	9.50	0
		12.5	21	7.60	20% /60 sec.
		25	17	3.40	80.34
		37.5	9.60	1.40	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	40	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	11	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	8	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

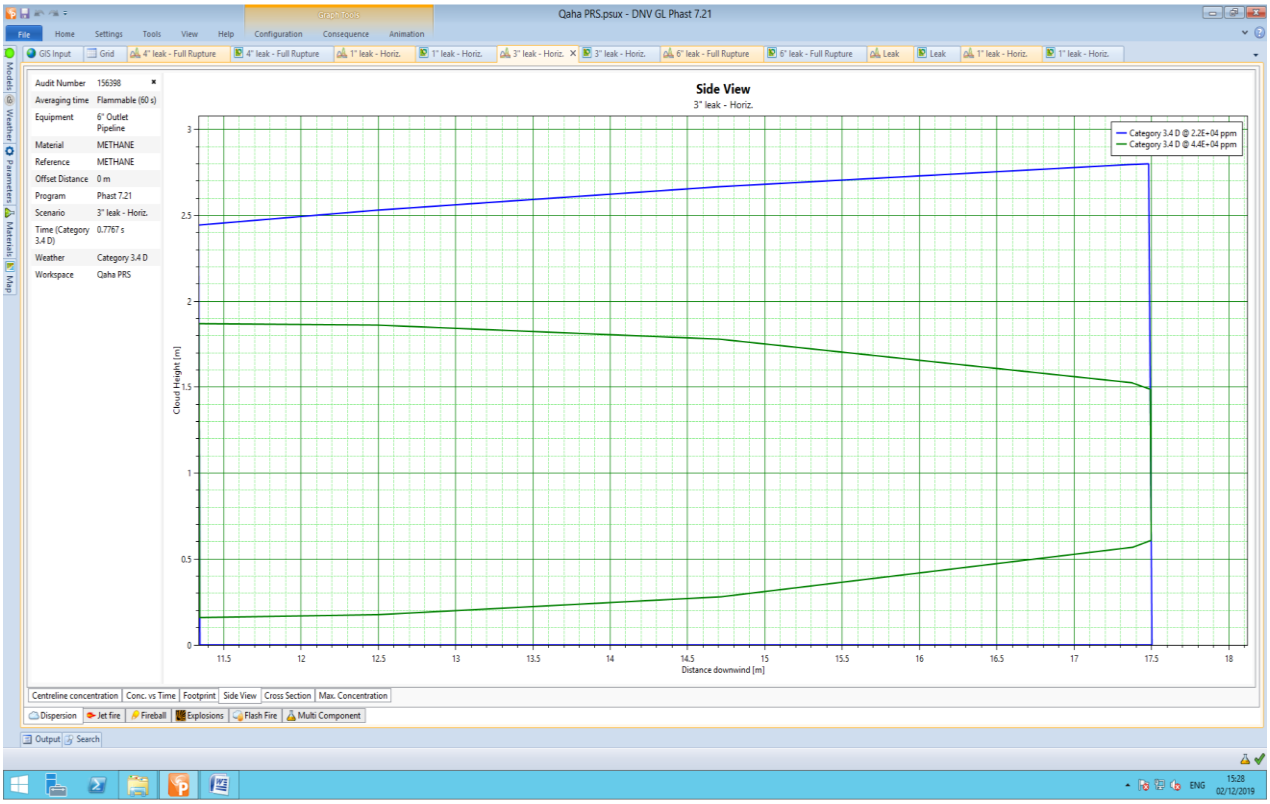


Figure (23) Gas Cloud Side View (UFL/LFL) (3" hole in 6" Outlet Pipeline)

- The previous figure shows that if there is a gas release from 3" hole size without ignition the flammable vapors will reach a distance more than 17 m downwind and 2.80 m height.
- The UFL will reach a distance of about 4.20 m downwind with a height of 1 m. The cloud large width will be 0.60 m crosswind at a distance of 2.90 m from the source.
- The LFL will reach a distance of about 17.40 m downwind with a height from 0 to 1.90 m. The cloud large width will be 1.80 m crosswind at a distance of 11.50 m from the source.
- The 50 % LFL will reach a distance of about 17.50 m downwind with a height from 0 to 2.80 m. The cloud large width will be 2.80 m crosswind at a distance of 17.50 m from the source.

The modeling shows that the gas cloud (LFL & 50% LFL) will be limited inside the PRS boundary reaching the off-take point downwind.

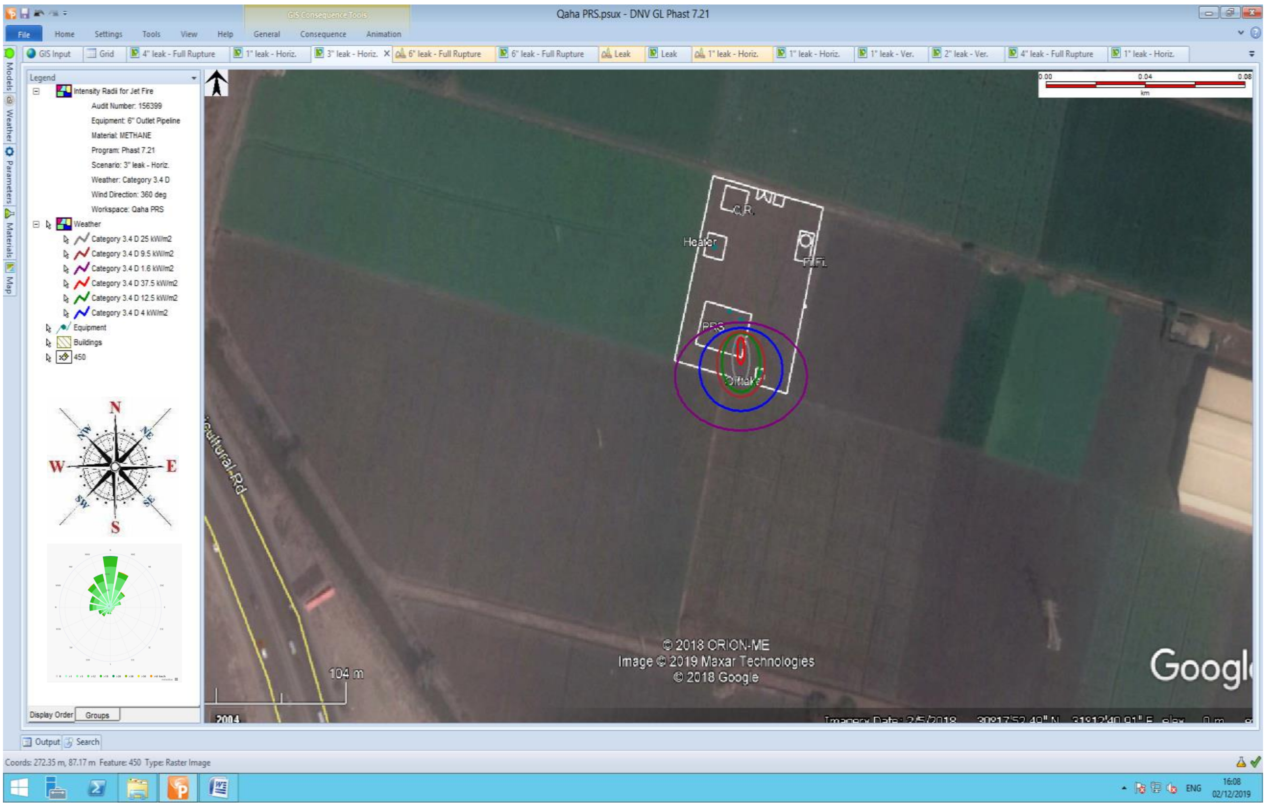


Figure (24) Heat Radiation Contours from Jet Fire (3" hole in 6" Outlet Pipeline)

- The previous figure shows that if there is a gas release from 3" hole size and ignited the expected flame length is about 23.80 meters downwind.
- The 9.5 kW/m^2 heat radiation contours extend about 23 meters downwind and 9.50 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 21 meters downwind and 7.60 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 17 meters downwind and 3.40 meters crosswind.
- The 37.5 kW/m^2 heat radiation contours extend about 9.60 meters downwind and 1.40 meters crosswind.

The modeling shows that the heat radiation values of 9.5 & 12.5 kW/m^2 will extend outside the PRS boundary south side with no effects downwind, and covering the off-take point crosswind.

The values of 25 & 37.5 kW/m^2 will be limited inside the boundary effecting the PRS facilities.

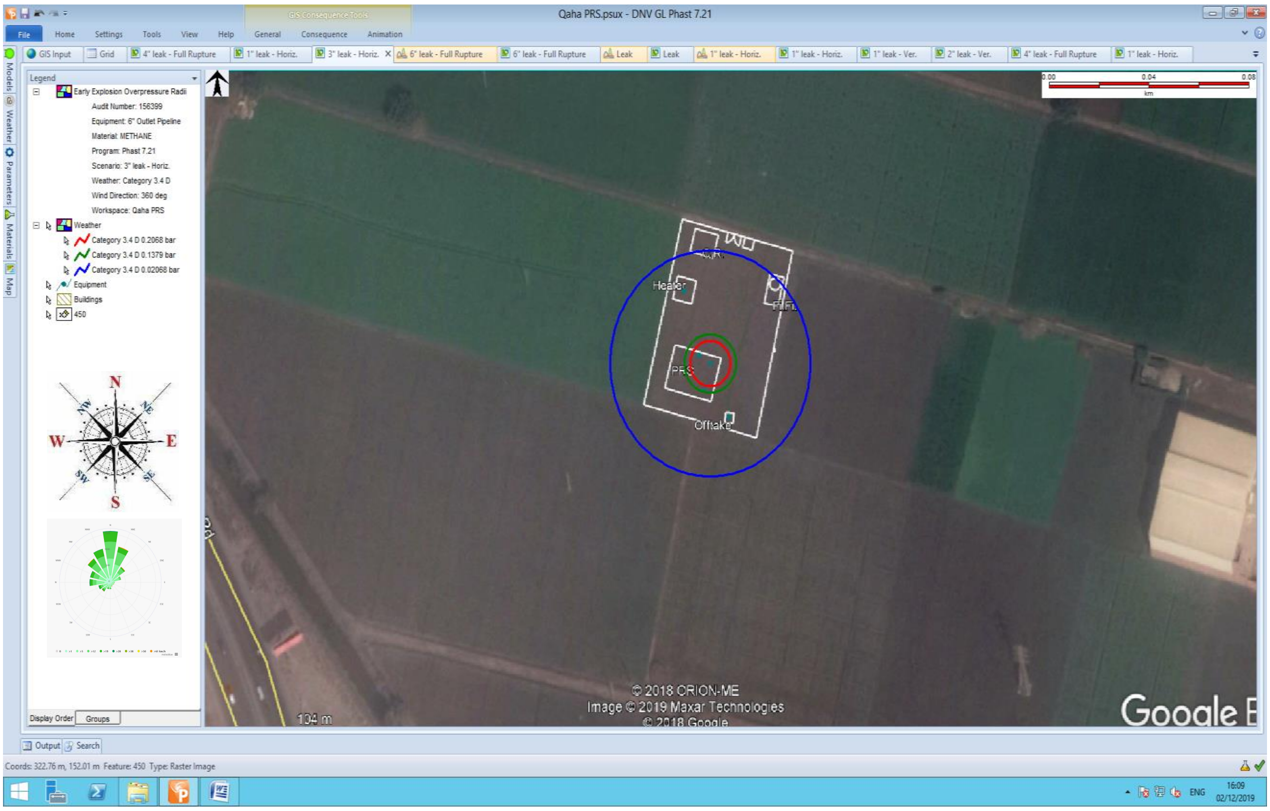


Figure (25) Early Explosion Overpressure Waves (3" hole in 6" Outlet Pipeline)

- The previous figure show that if there is a gas release from 3" hole size and early ignited this will give an explosion with different values of overpressure waves.
- The 0.020 bar overpressure waves will extend about 40 meters radius.
- The 0.137 bar overpressure waves will extend about 11 meters radius.
- The 0.206 bar overpressure waves will extend about 8 meters radius.

The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects outside and covering the firefighting facilities and the heater.

The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and no effects on site offices.

2/3- Consequence Modeling for 6 inch (Full Rup.) Gas Release

The following table no. (21) Show that:

Table (21) Dispersion Modeling for Outlet - 6" Gas Release

Gas Release

Wind Category	Flammability Limits	Distance (m)	Height (m)	Cloud Width (m)
3.4 D	UFL	9.40	1.65	1.25 @ 8.70 m
	LFL	11.80	0 – 2.60	2.60 @ 11.80 m
	50 % LFL	11.90	0 – 3.10	3.10 @ 11.90 m

Jet Fire

Wind Category	Flame Length (m)	Heat Radiation (kW/m²)	Distance Downwind (m)	Distance Crosswind (m)	Lethality Level (%)
3.4 D	45.40	1.6	86	54	0
		4	60	35	0
		9.5	45	21	0
		12.5	41	17	20% /60 sec.
		25	33	9	80.34
		37.5	23	5	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)

Wind Category	Pressure Value (bar)	Over Pressure Radius (m)		Overpressure Waves Effect / Damage	
		Early	Late		
3.4 D	0.020	40	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	11	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	8	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Fireball

Wind Category	Heat Radiation (kW/m²)	Distance (m)	Heat Radiation (kW/m²) Effects on People & Structures
3.4 D	1.6	50	**12.5** *20 % Chance of fatality for 60 sec exposure* **25** *100 % Chance of fatality for continuous exposure* *50 % Chance of fatality for 30 sec exposure* **37.5** *Sufficient of cause process equipment damage*
	4	30	
	9.5	17	
	12.5	13	
	25	Not Reached	
	37.5	Not Reached	

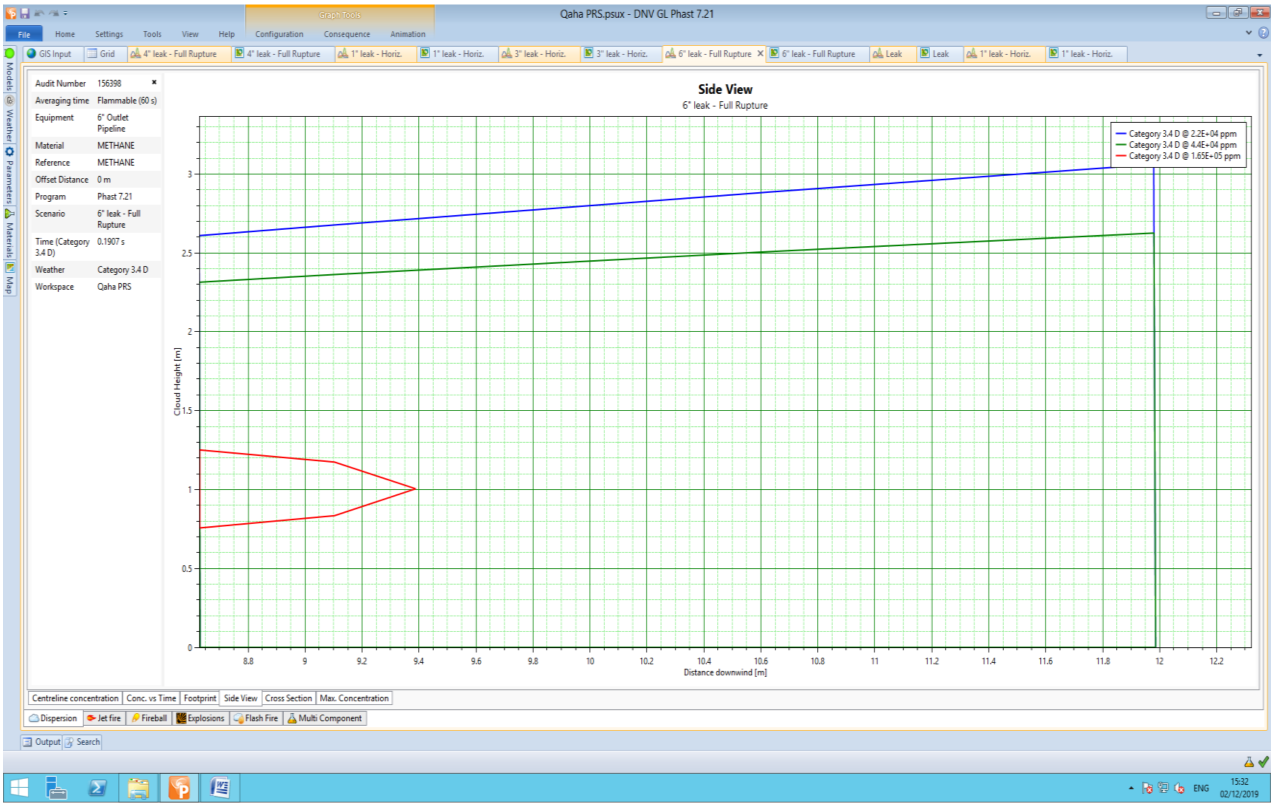


Figure (26) Gas Cloud Side View (UFL/LFL) (6" Outlet Pipeline Full Rupture)

- The previous figure shows that if there is a gas release from 6" pipeline full rupture without ignition the flammable vapors will reach a distance more than 11 m downwind and from 0 to 3 m height.
- The UFL will reach a distance of about 9.40 m downwind with a height of 1.65 m. The cloud large width will be 1.25 m crosswind.
- The LFL will reach a distance of about 11.80 m downwind with a height from 0 to 2.60 m. The cloud large width will be 2.60 m crosswind.
- The 50 % LFL will reach a distance of about 11.90 m downwind with a height from 0 to 3.10 m. The cloud large width will be 3.10 m crosswind.

The modeling shows that the gas cloud effects will be limited inside the PRS boundary.

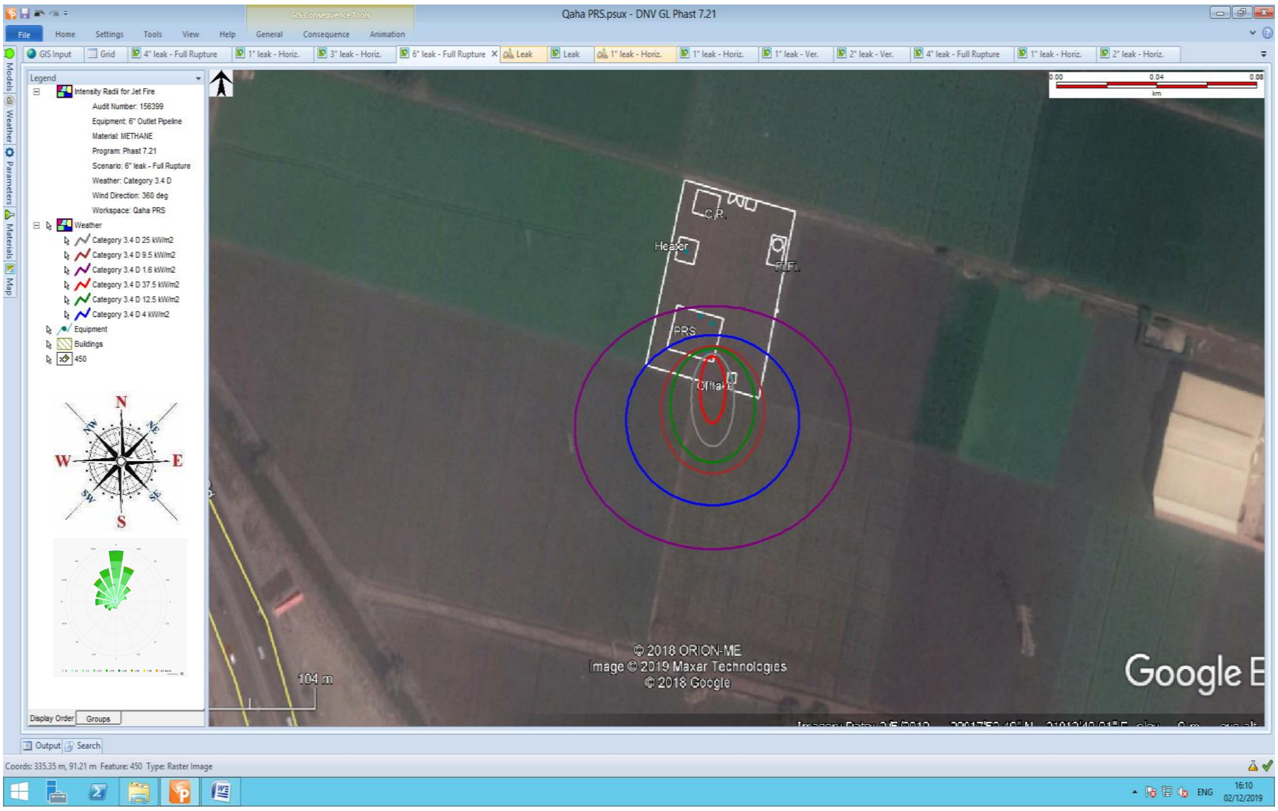


Figure (27) Heat Radiation Contours from Jet Fire (6" Outlet Pipeline Full Rupture)

- The previous figure show that if there is a gas release from 6" pipeline full rupture and ignited the expected flame length is about 35 meters downwind.
- The 9.5 kW/m^2 heat radiation contours extend about 45 meters downwind and 21 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 41 meters downwind and 17 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 33 meters downwind and 9 meters crosswind.
- The 37.5 kW/m^2 heat radiation contours extend about 23 meters downwind and 5 meters crosswind.

The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the south fence with no effects downwind and cover the off-take point crosswind.

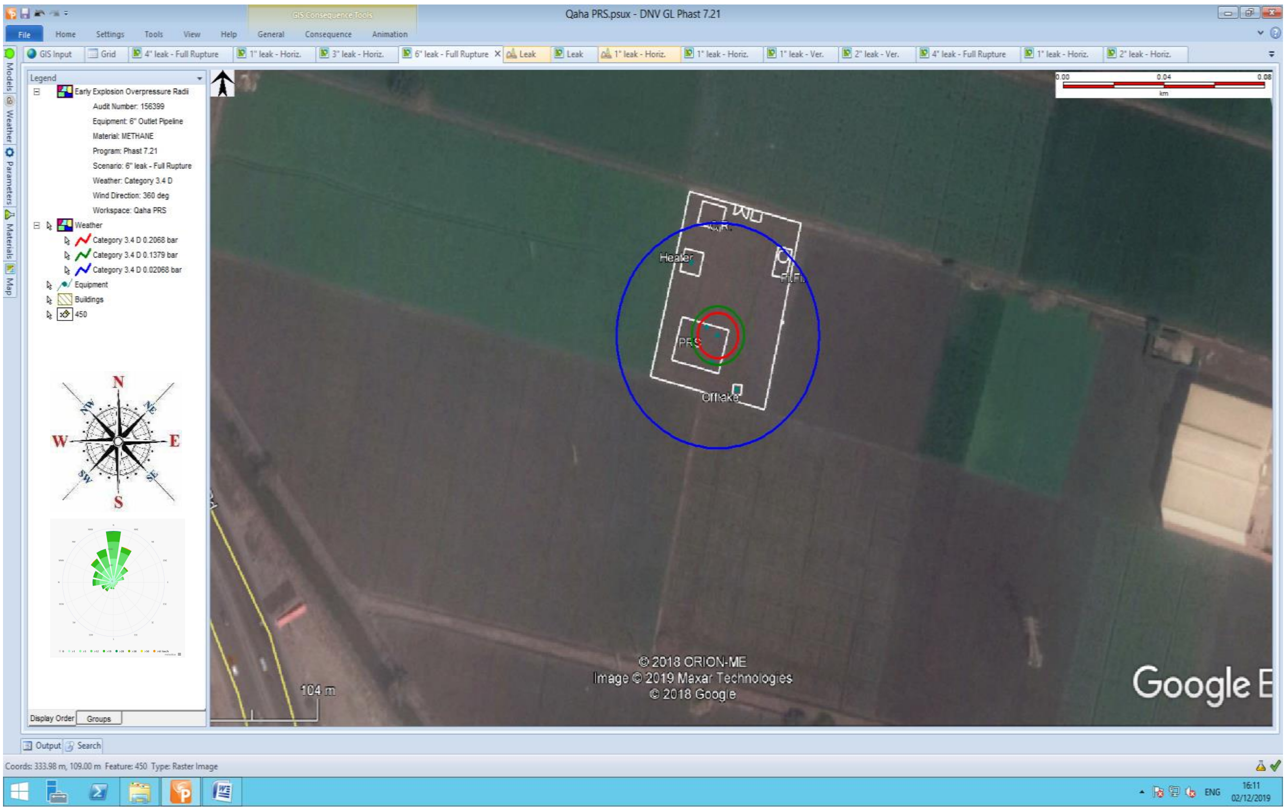


Figure (28) Early Explosion Overpressure Waves (6" Outlet Pipeline Full Rupture)

- The previous figure show that if there is a gas release from 6" hole size and early ignited this will give an explosion with different values of overpressure waves.
- The 0.020 bar overpressure waves will extend about 40 meters radius.
- The 0.137 bar overpressure waves will extend about 11 meters radius.
- The 0.206 bar overpressure waves will extend about 8 meters radius.

The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects outside and covering the firefighting facilities and the heater.

The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and no effects on site offices.

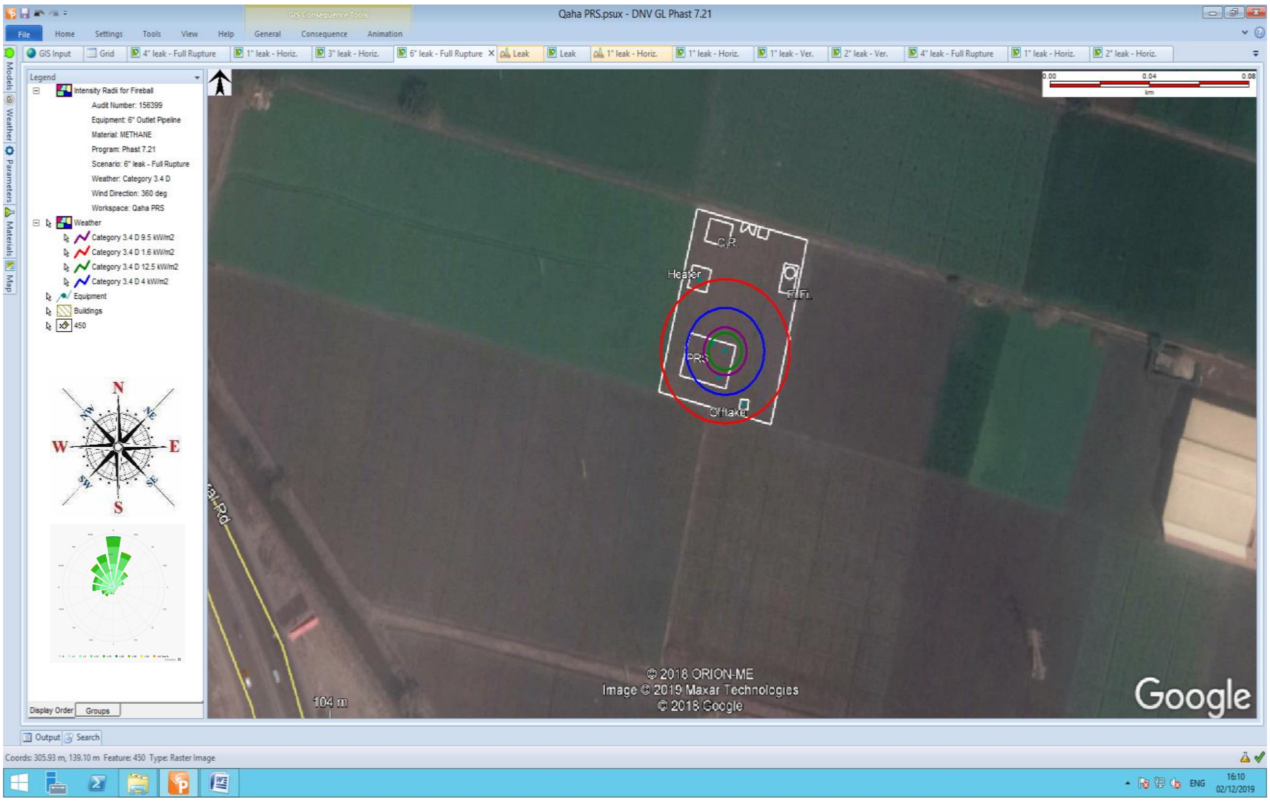


Figure (29) Heat Radiation Contours from Fireball (6" Outlet Pipeline Full Rupture)

- The previous figure show that if there is a gas release from 6" pipeline full rupture and ignited forming fireball this will gives a heat radiation with different values and contours and will extend in four dimensions.
- The 1.6 kW/m^2 heat radiation contours extend about 50 meters radius.
- The 4 kW/m^2 heat radiation contours extend about 30 meters radius.
- The 9.5 kW/m^2 heat radiation contours extend about 17 meters radius.
- The 12.5 kW/m^2 heat radiation contours extend about 13 meters radius.
- The 25 kW/m^2 heat radiation not reached.
- The 37.5 kW/m^2 heat radiation not reached.

The modeling shows that the heat radiation values of 1.6, 4, 9.5 & 12.5 kW/m^2 will limited inside the PRS boundary effecting the PRS facilities with some extension (1.6 kW/m^2) down and crosswind.

3.0- Pressure Reduction Station Odorant Tank (Spotleak)

The following table no. (22) Show 1" hole leak form odorant Modeling:

Table (22) Dispersion Modeling for Odorant Tank

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
3.4 D	UFL	27	0 – 0.32	18
	LFL	33.50	0 – 0.49	22
	50 % LFL	44	0 – 0.68	38

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	18.96	1.6	55	34	0
		4	39	22	0
		9.5	31	14	0
		12.5	28	12	20% /60 sec.
		25	24	8	80.34
		37.5	21	6	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	N/D	45	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	19	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	17	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

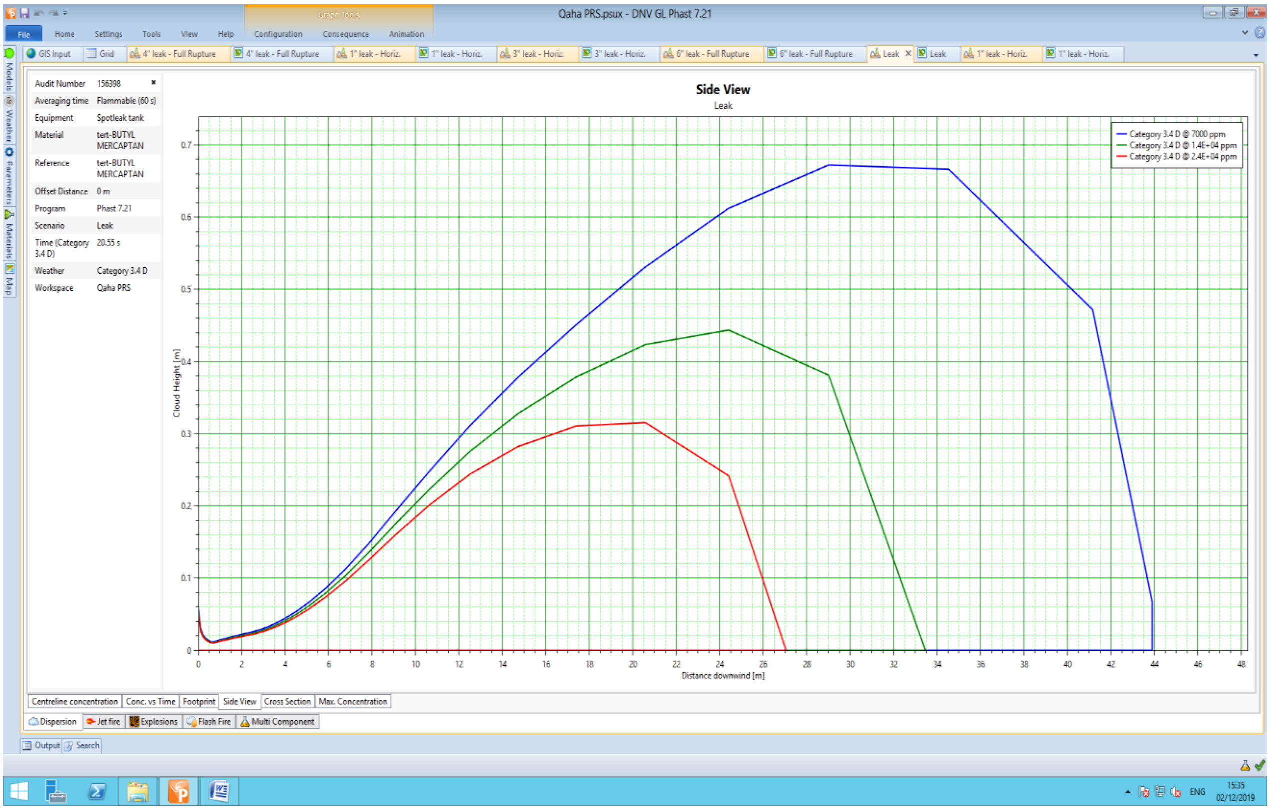


Figure (30) Vapor Cloud (UFL/LFL) Side View Graph (Odorant leak)

- The previous figures show that if there is a leak from odorant tank without ignition the flammable vapors will reach a distance more than 44 m downwind and from 0 to 0.68 m height (the vapors heavier than air).
- The UFL (2.1E+04 ppm) will reach a distance of about 27 m downwind with a height from 0 to 0.32 m. The cloud large width will be 18 m crosswind.
- The LFL (1.4E+04 ppm) will reach a distance of about 33.50 m downwind with a height from 0 to 0.49 m. The cloud large width will be 22 m crosswind.
- The 50 % LFL (7000 ppm) will reach a distance of about 44 m downwind with a height from 0 to 0.68 m. The cloud large width will be 38 m crosswind.

The modeling shows that the vapor cloud will extend inside the PRS boundary reaching the off-take point downwind.

Consideration should be taken when deal with liquid, vapors and smokes according to the MSDS for the material.

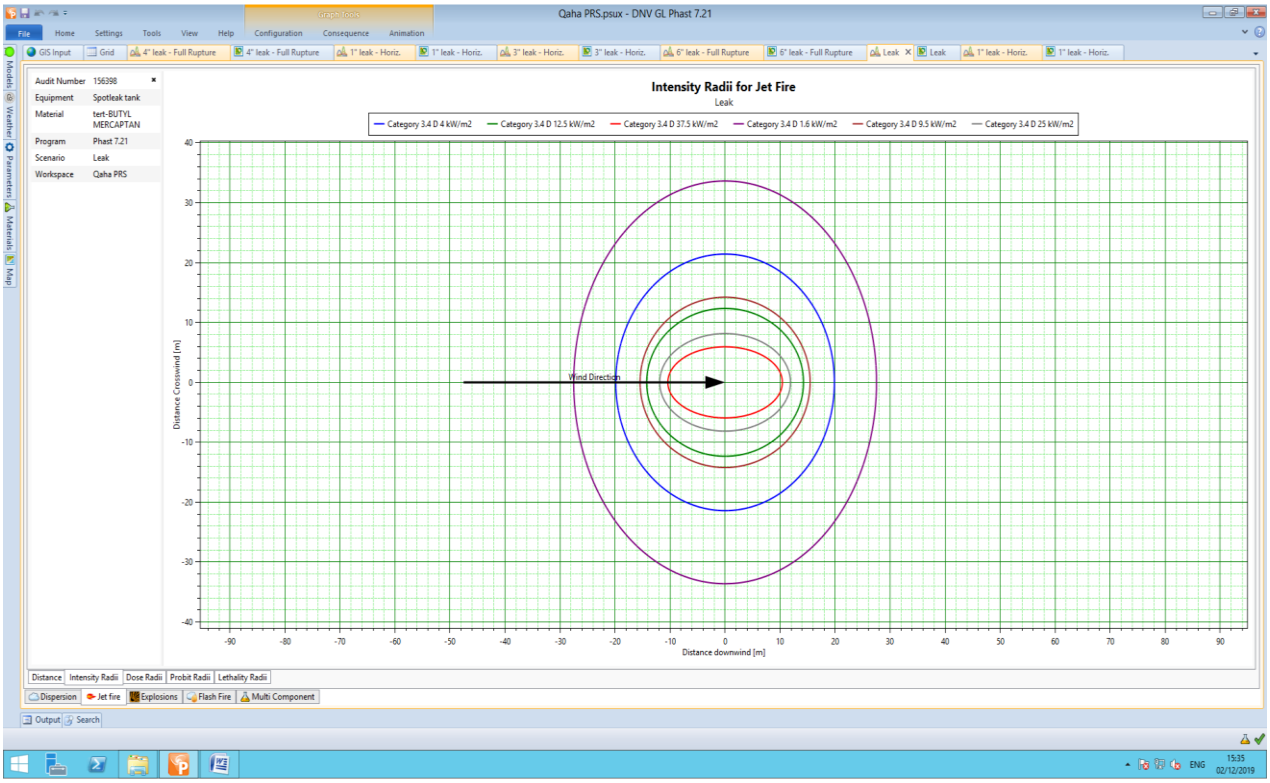


Figure (31) Heat Radiation Contours - Jet Fire Graph (Odorant Leak)

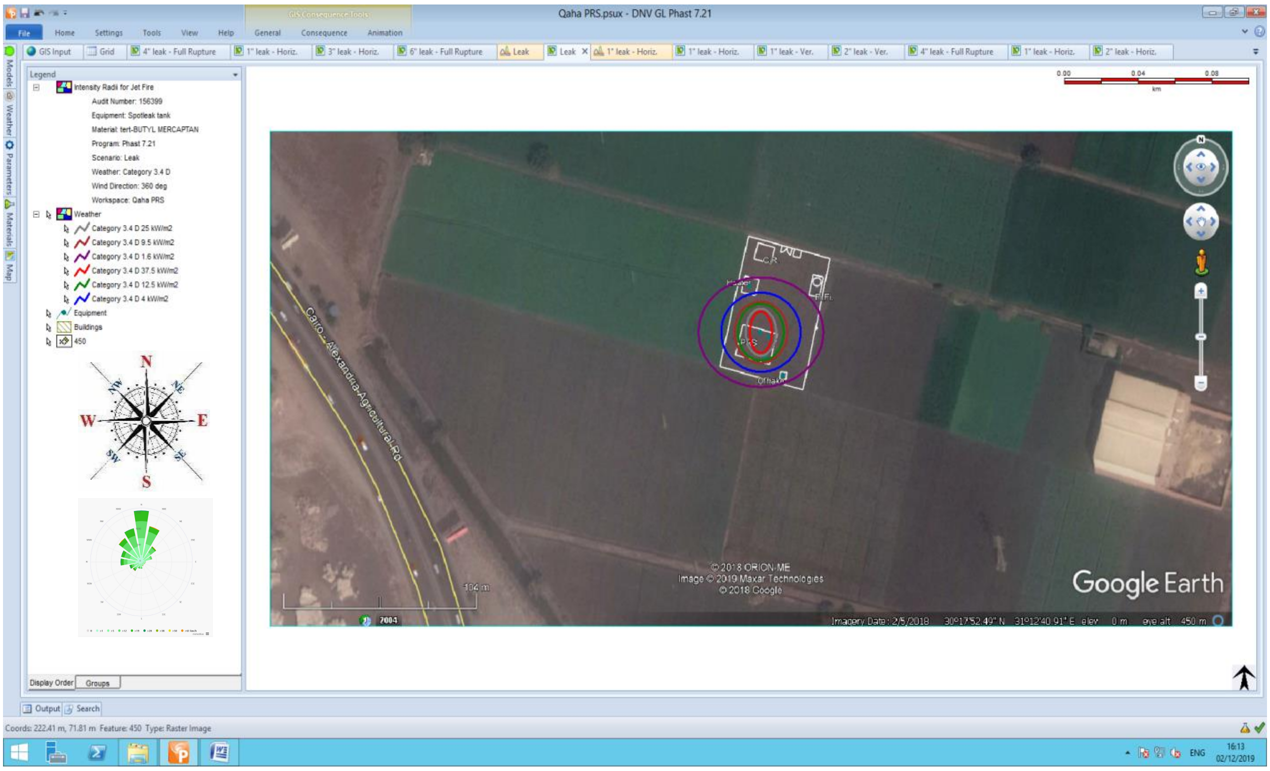


Figure (32) Heat Radiation Contours - Jet Fire on Site (Odorant Leak)

- The previous figure show that if there is a leak from the odorant tank and ignited the expected flame length is about 19 meters downwind.
- The 9.5 kW/m^2 heat radiation contours extend about 31 meters downwind and 14 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 28 meters downwind and 12 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 24 meters downwind and 8 meters crosswind.
- The 37.5 kW/m^2 heat radiation contours extend about 21 meters downwind and 6 meters crosswind.

The modeling shows that all values of heat radiation 9.5, 12.5, 25 & 37.5 kW/m^2 will be limited inside the PRS boundary down and crosswind.

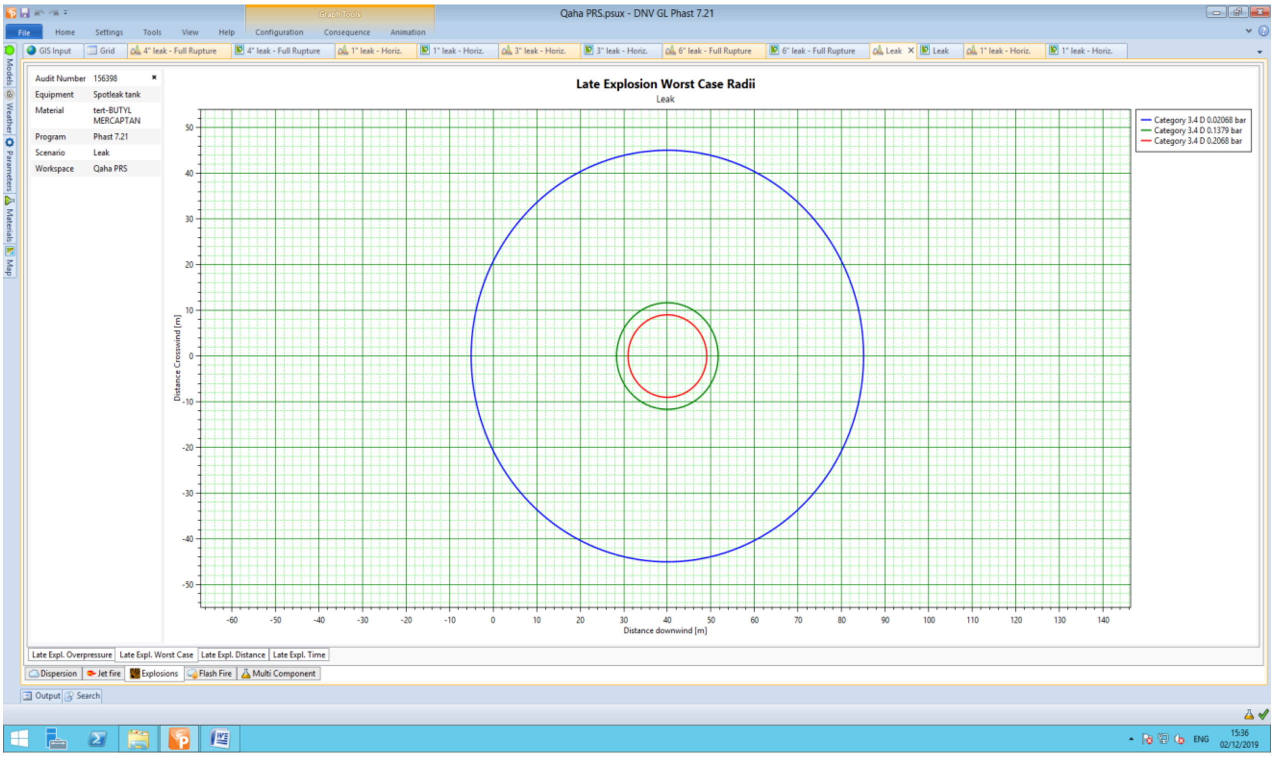


Figure (33) Late Explosion Overpressure Waves Graph (Odorant Leak)

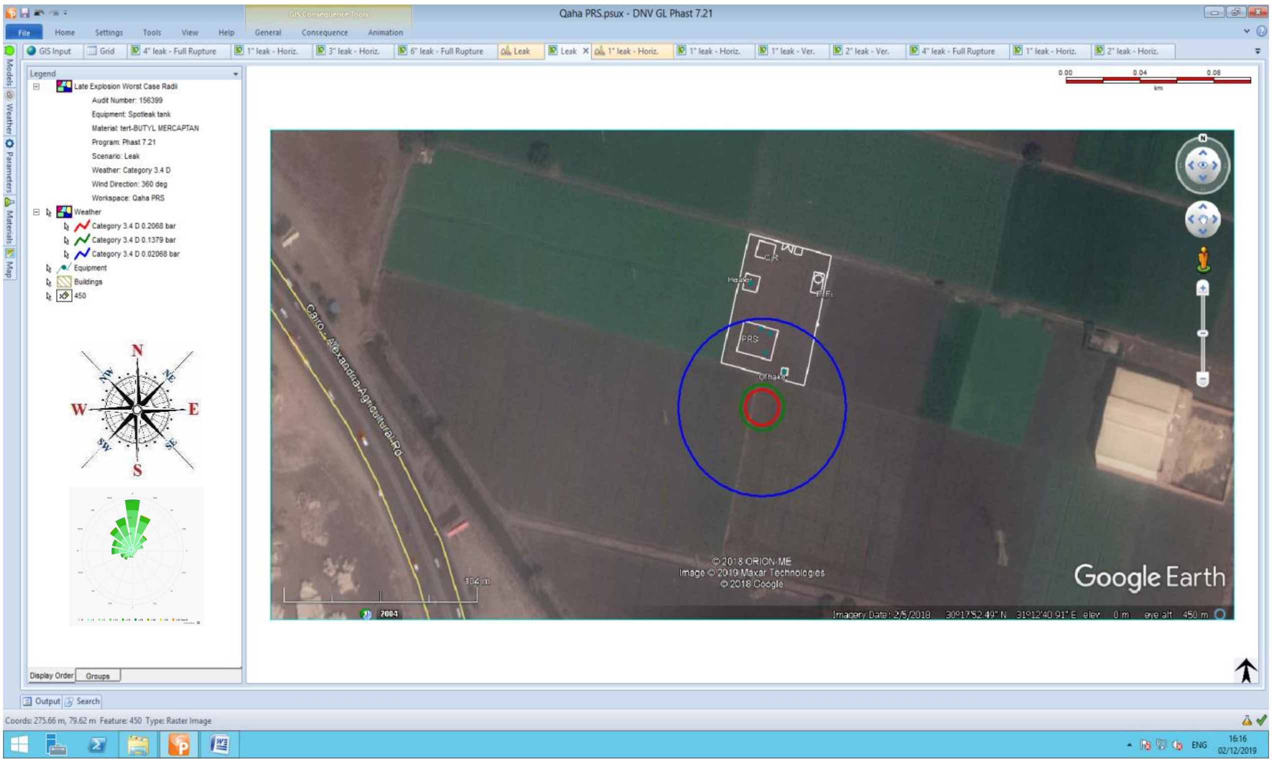


Figure (34) Late Explosion Overpressure Waves on Site (Odorant Leak)

- The previous figure show that if there is a leak from the odorant tank and late ignited this will give an explosion with different values of overpressure waves.
- The 0.020 bar overpressure waves will extend about 45 meters radius.
- The 0.137 bar overpressure waves will extend about 19 meters radius.
- The 0.206 bar overpressure waves will extend about 17 meters radius.

The modeling shows that the value of 0.020 bar will cover the PRS facilities inside and extend outside from S/E/W sides with no effects.

The values of 0.137 & 0.206 bar will extend outside the PRS boundary from south side with no effects down or crosswind.

4.0- Gas Heater (Water Bath Heating System)

The following table no. (23) Show 1" hole leak form the heater Modeling:

Table (23) Dispersion Modeling for Heater Tank

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
3.4 D	UFL	2.15	1.90	0.20 @ 1.00 m
	LFL	7.90	2.20	0.80 @ 5.00 m
	50 % LFL	13.40	0 – 2.55	2.55 @ 9.00 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	13	1.6	19	13	0
		4	15	8	0
		9.5	9	4	0
		12.5	8	3	20% /60 sec.
		25	Not Reached	Not Reached	80.34
		37.5	Not Reached	Not Reached	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	66	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	17	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	13	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

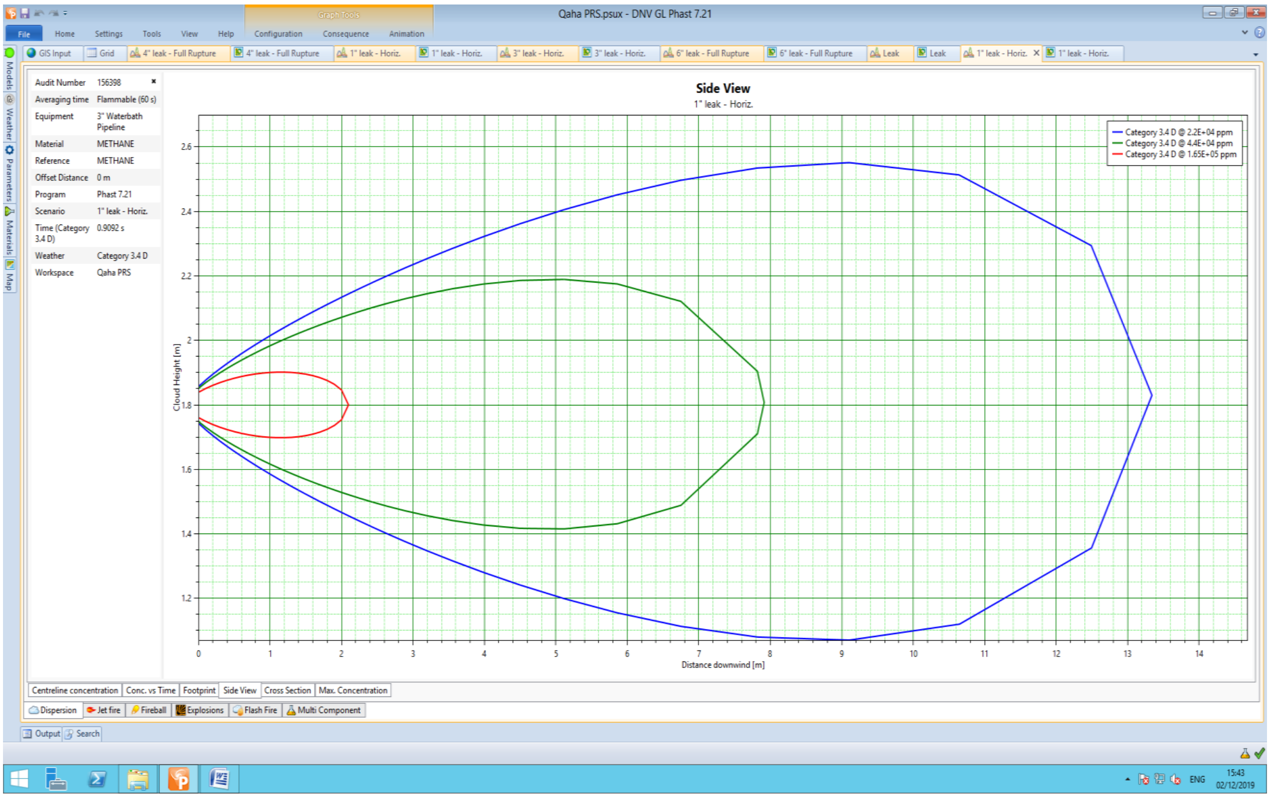


Figure (35) Vapor Cloud (UFL/LFL) Side View Graph (Gas Heater)

- The previous figure shows that if there is a gas release from heater pipe without ignition the flammable vapors will reach a distance about 13 m downwind and from 0 to 2.55 m height.
- The UFL will reach a distance of about 2.15 m downwind with a height of 1.90 m. The cloud large width will be 0.20 m.
- The LFL will reach a distance of about 7.90 m downwind with a height of 2.20 m. The cloud large width will be 0.80 m.
- The 50 % LFL will reach a distance of about 13.40 m downwind with a height from 0 to 2.55 m. The cloud large width will be 2.55 m.

The modeling shows that the vapor cloud will extend inside the PRS boundary downwind reaching the PRS facilities.

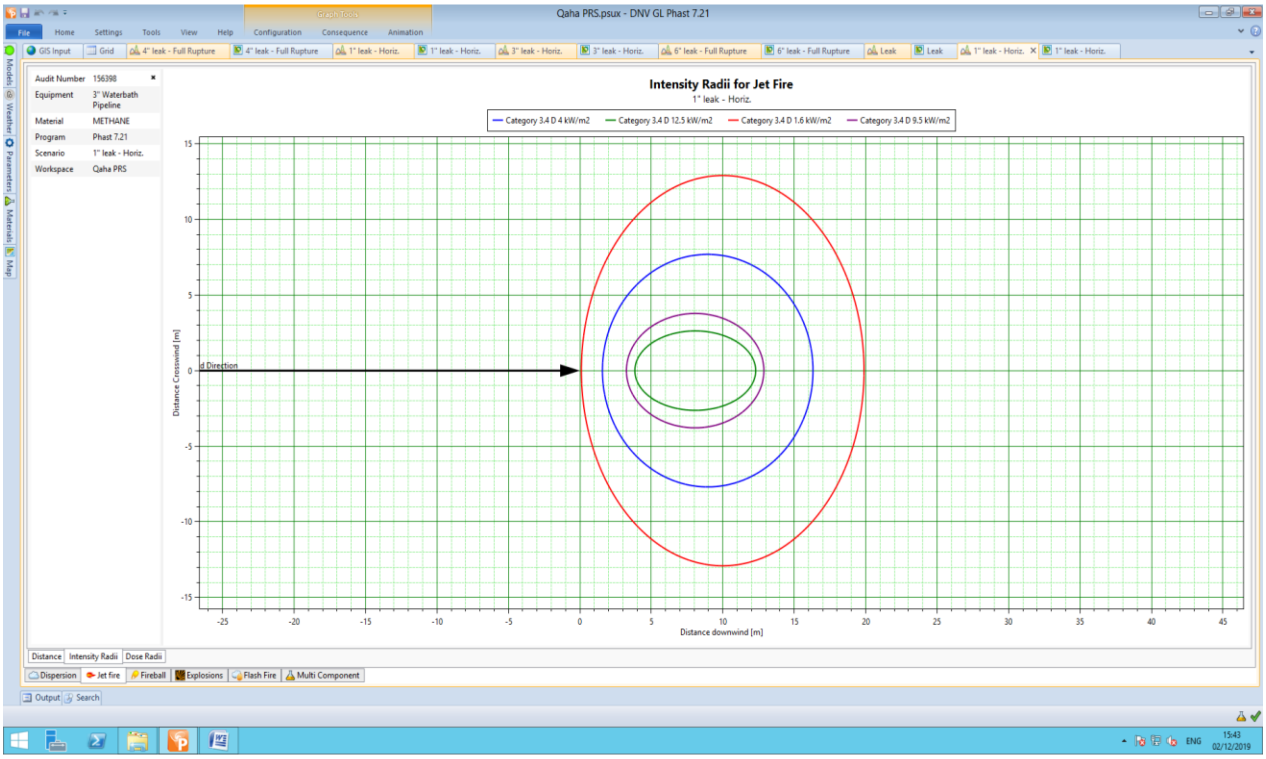


Figure (36) Heat Radiation Contours - Fire Graph (Gas Heater)

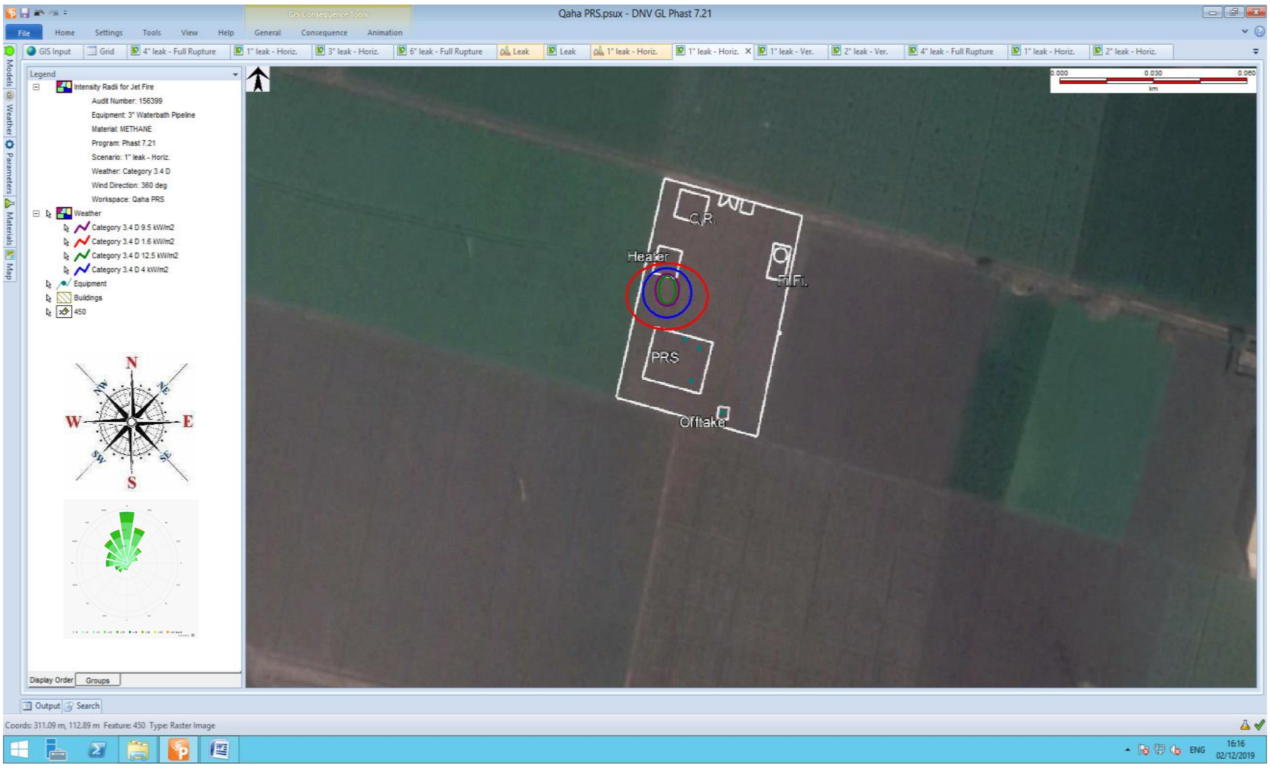


Figure (37) Heat Radiation Contours - Fire on Site (Gas Heater)

- The previous figure show that if there is a leak from the heater and ignited the expected flame length is about 13 meters downwind.
- The 1.6 kW/m^2 heat radiation contours extend about 19 meters downwind and 13 meters crosswind.
- The 4 kW/m^2 heat radiation contours extend about 15 meters downwind and 8 meters crosswind.
- The 9.5 kW/m^2 heat radiation contours extend about 9 meters downwind and 4 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 8 meters downwind and 3 meters crosswind.
- The 25 kW/m^2 heat radiation not reached.
- The 37.5 kW/m^2 heat radiation not reached.

The modeling shows that the heat radiation value 1.6, 4, 9.5 & 12.5 kW/m^2 effects will be limited inside the PRS boundary with no effects.
The values of 25 & 37.5 kW/m^2 not determined by the software due to small leakage.

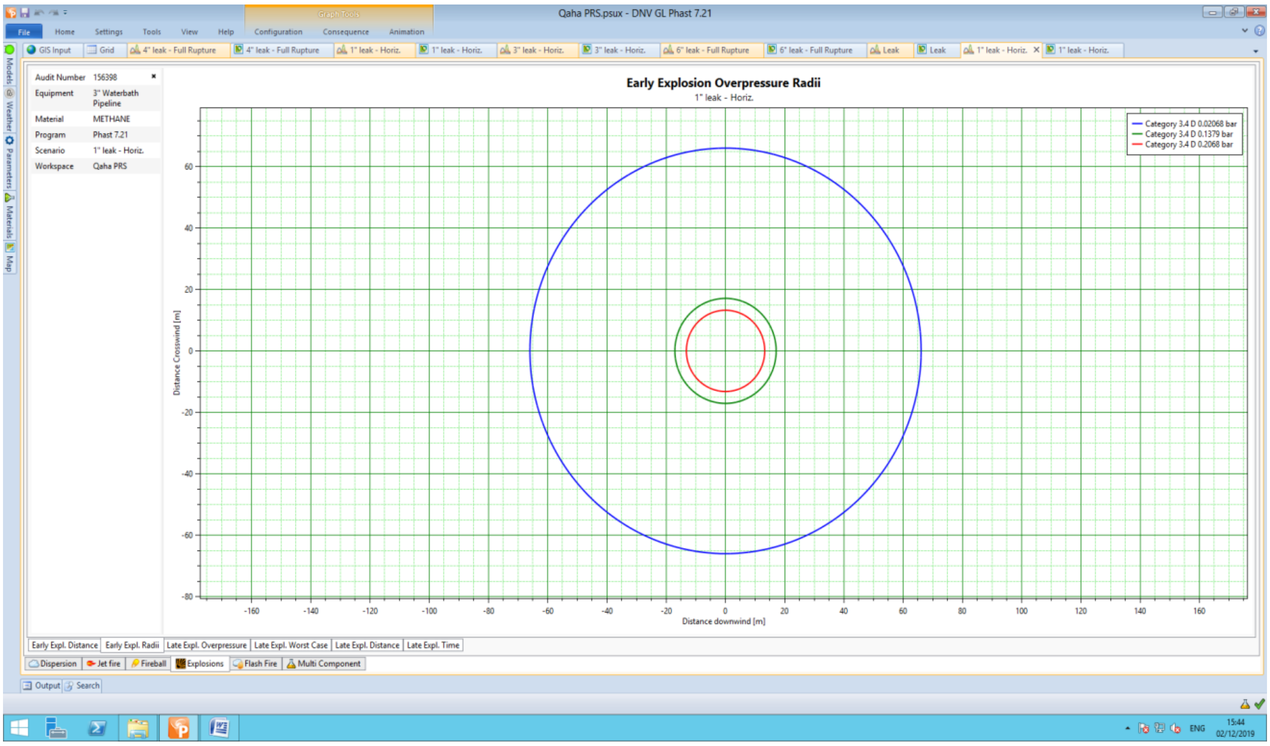


Figure (38) Early Explosion Overpressure Waves Graph (Gas Heater)

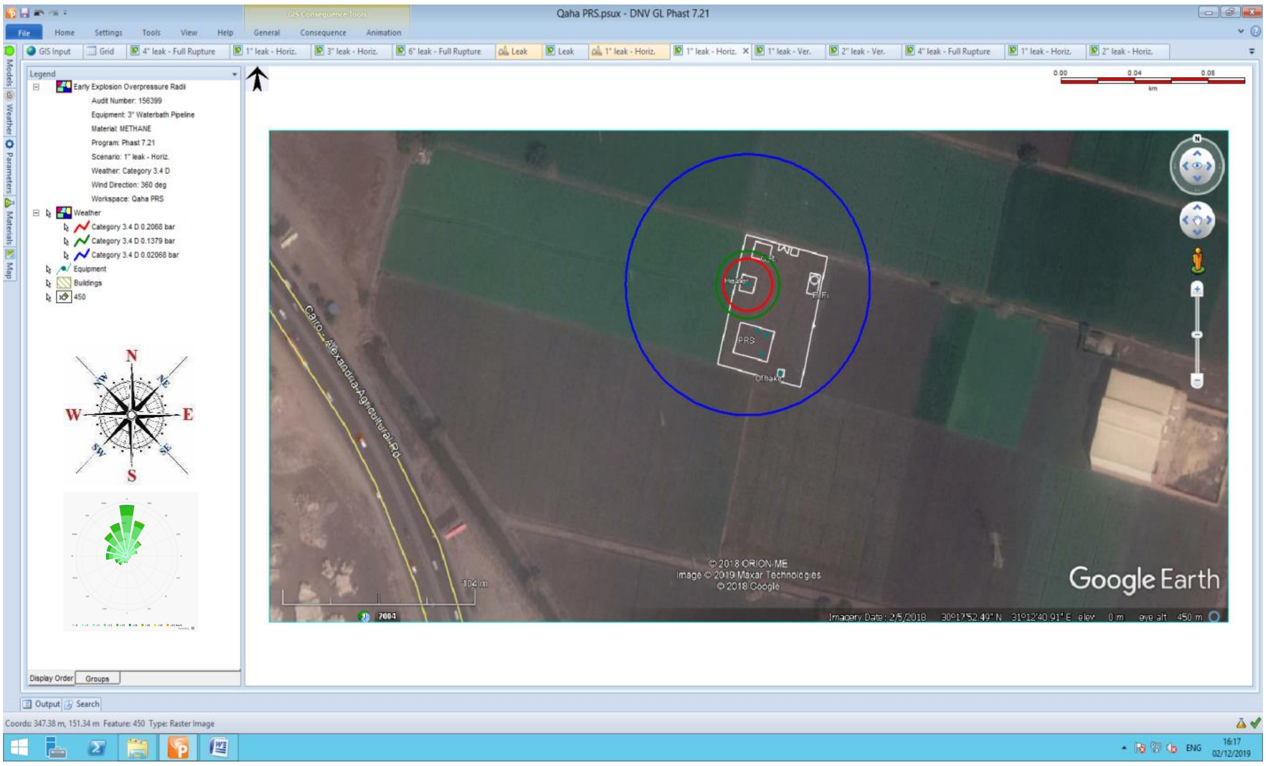


Figure (39) Early Explosion Overpressure Waves on Site (Gas Heater)

- The previous figure show that if there is a leak from the heater and early ignited this will give an explosion with different values of overpressure waves.
- The 0.020 bar overpressure waves will extend about 66 meters radius.
- The 0.137 bar overpressure waves will extend about 17 meters radius.
- The 0.206 bar overpressure waves will extend about 13 meters radius.

The modeling shows that the value of 0.020 bar will extend outside the PRS from all sides covering the area surrounded with no effects outside.

The value of 0.137 & 0.206 bar will be limited inside the PRS and near to the control room.

5.0- Pressure Reduction Station Off-Take Pipeline (4 inch)

5/1- Consequence Modeling for 1 inch (Pin Hole) Gas Release

The following table no. (24) Show that:

Table (24) Dispersion Modeling for Off-take - 1" / 4" Gas Release

Gas Release

Wind Category	Flammability Limits	Distance (m)	Height (m)	Cloud Width (m)
3.4 D	UFL	0.13	0.84	0.24
	LFL	0.20	0.85	0.40
	50 % LFL	0.23	0.86	0.46

Jet Fire

Wind Category	Flame Length (m)	Heat Radiation (kW/m^2)	Distance Downwind (m)	Distance Crosswind (m)	Lethality Level (%)
3.4 D	10.80	1.6	30	16	0
		4	14	7	0
		9.5	Not Reached	Not Reached	0
		12.5	Not Reached	Not Reached	20% /60 sec.
		25	Not Reached	Not Reached	80.34
		37.5	Not Reached	Not Reached	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)

Wind Category	Pressure Value (bar)	Over Pressure Radius (m)		Overpressure Waves Effect / Damage	
		Early	Late		
3.4 D	0.020	N/D	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

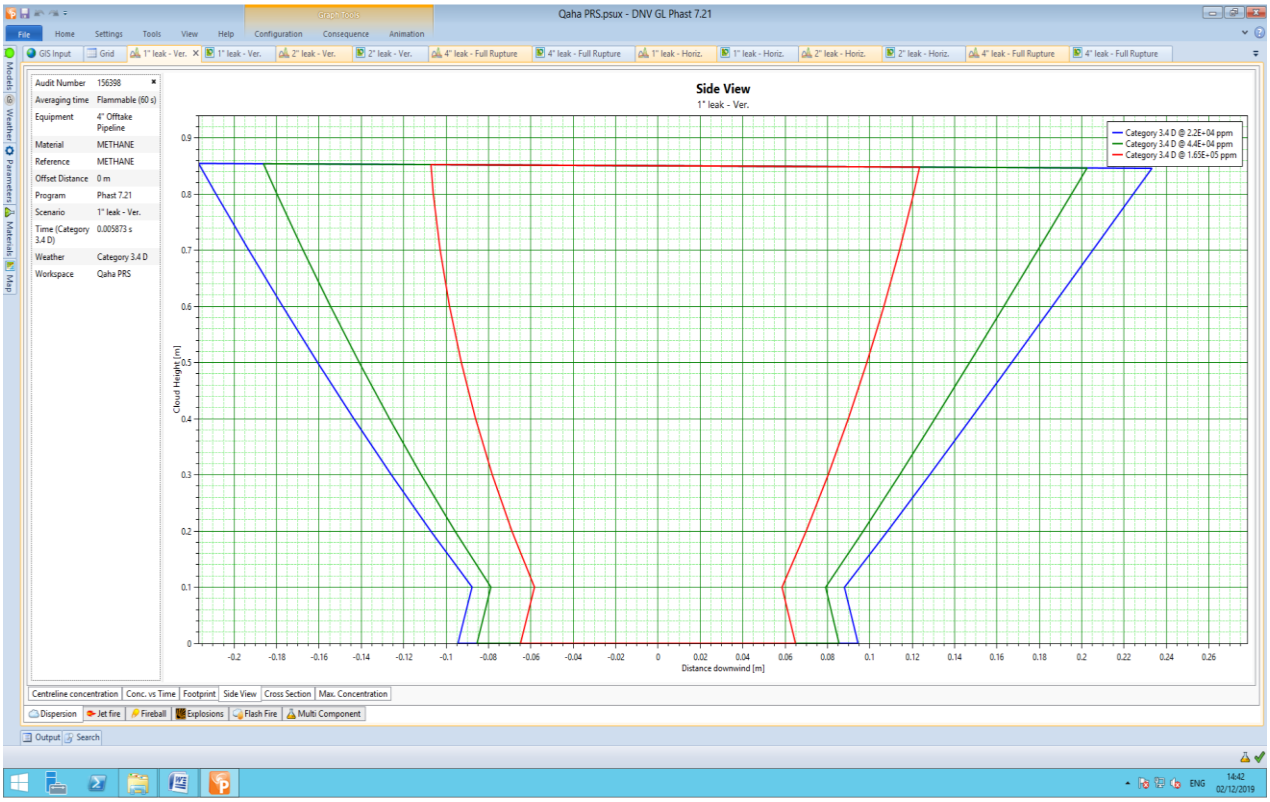


Figure (40) Gas Cloud Side View (UFL/LFL) (1" hole in 4" off-take Pipeline)

- The previous figure shows that if there is a gas release from 1" hole size without ignition the flammable vapors will reach a distance about 0.23 m downwind and 0.86 m height above ground (the tie-in point is under ground with about 5 meters).
- The UFL will reach a distance of about 0.13 m downwind with a height of 0.84 m. The cloud large width will be 0.24 m.
- The LFL will reach a distance of about 0.20 m downwind with a height of 0.85 m. The cloud large width will be 0.40 m.
- The 50 % LFL will reach a distance of about 0.23 m downwind with a height 0.86 m. The cloud large width will be 0.46 m.

The modeling shows that the gas cloud effects will be limited inside the PRS boundary.

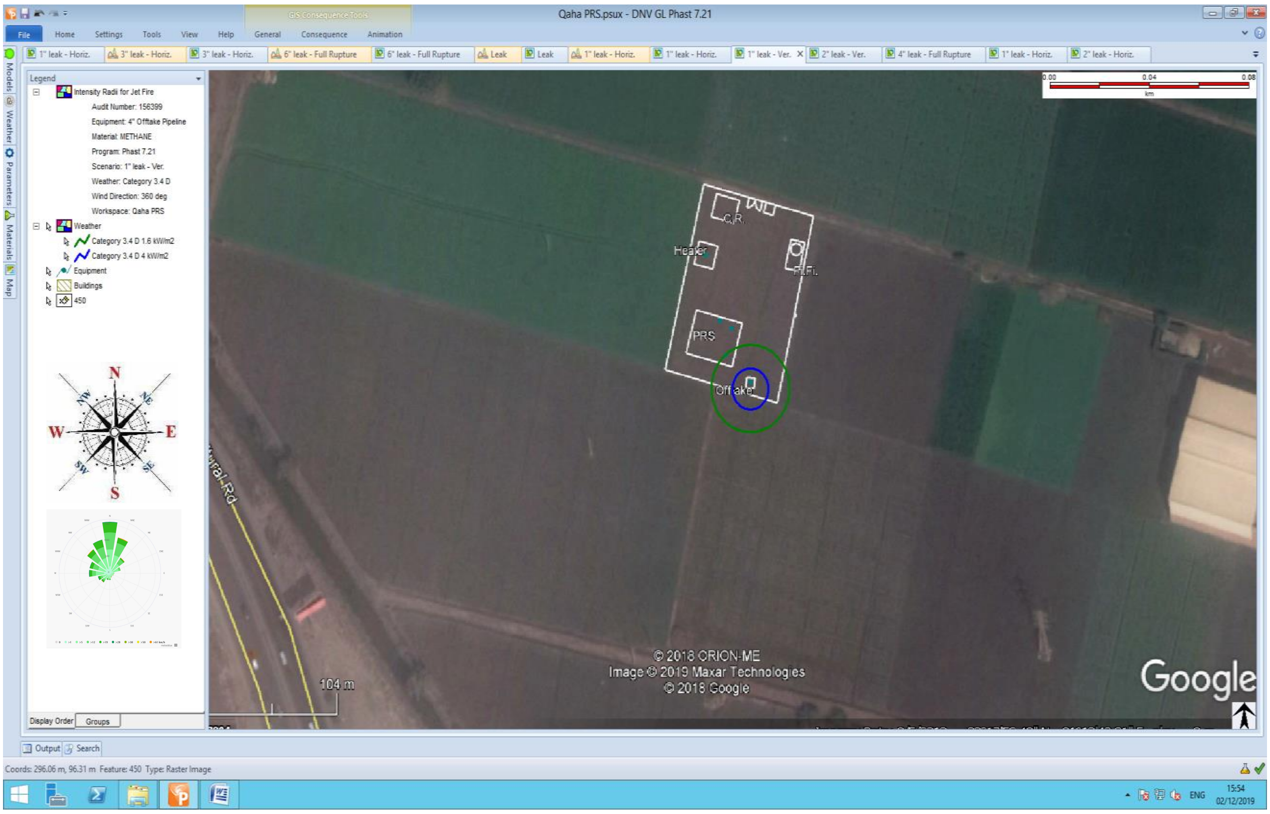


Figure (41) Heat Radiation Contours from Jet Fire (1" hole in 4" off-take Pipeline)

- The previous figure show that if there is a gas release from 1" hole size and ignited the expected flame length is about 10 meters height.
- The 1.6 kW/m^2 heat radiation contours extend about 30 meters downwind and 16 meters crosswind.
- The 4 kW/m^2 heat radiation contours extend about 14 meters downwind and 7 meters crosswind.
- The 9.5 kW/m^2 heat radiation not determined.
- The 12.5 kW/m^2 heat radiation not determined.
- The 25 kW/m^2 heat radiation not determined.
- The 37.5 kW/m^2 heat radiation not determined.

The modeling shows that the heat radiation value of 1.6 & 4 kW/m^2 will be limited inside the PRS boundary with some extension outside from south side with no effects.

5/2- Consequence Modeling for 2 inch (Half Rup.) Gas Release

The following table no. (25) Show that:

Table (25) Dispersion Modeling for Off-take - 2" / 4" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
3.4 D	UFL	0.32	2.43	0.66
	LFL	0.56	2.44	1.10
	50 % LFL	0.64	2.45	1.30

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
3.4 D	23.30	1.6	65	33	0
		4	30	15	0
		9.5	Not Reached	Not Reached	0.72
		12.5	Not Reached	Not Reached	20% /60 sec.
		25	Not Reached	Not Reached	80.34
		37.5	Not Reached	Not Reached	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)					
Wind Category	**Pressure Value (bar)**	**Over Pressure Radius (m)**		**Overpressure Waves Effect / Damage**	
		Early	**Late**		
3.4 D	0.020	N/D	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

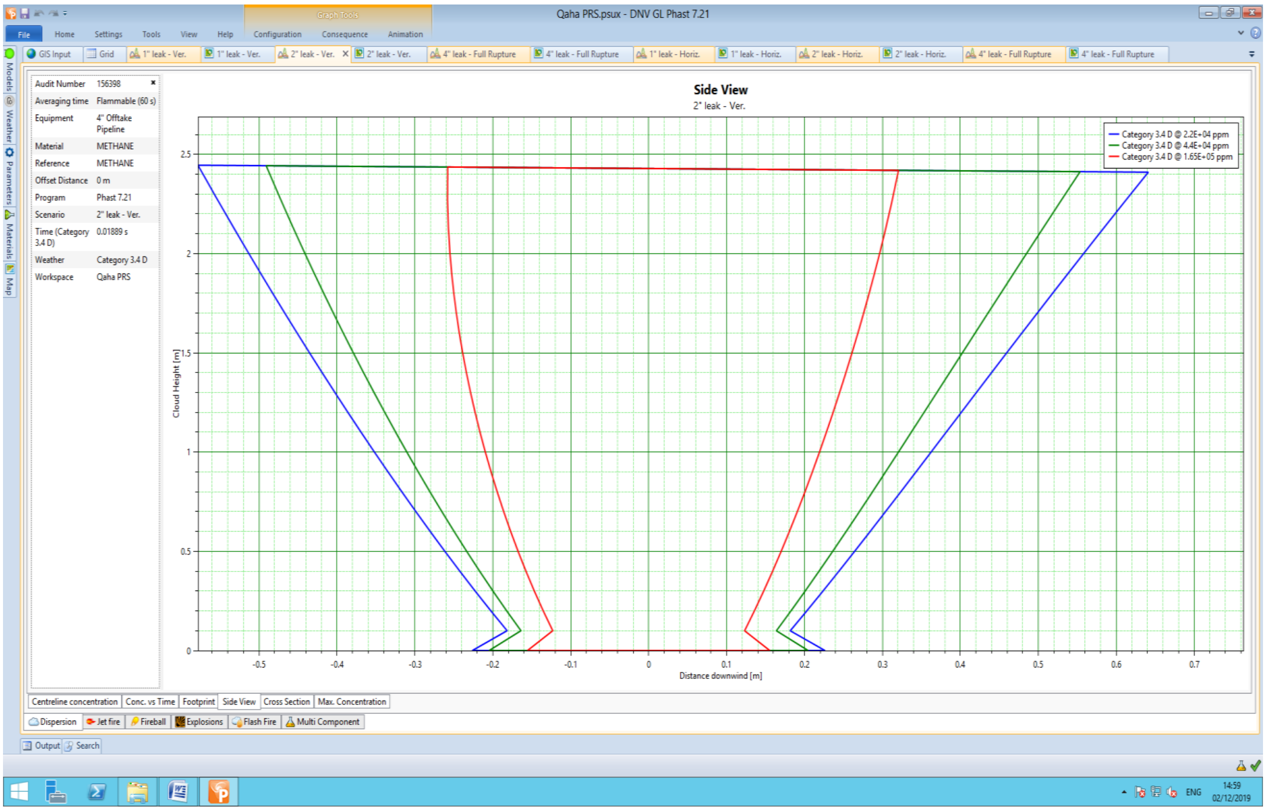


Figure (42) Gas Cloud Side View (UFL/LFL) (2" hole in 4" off-take Pipeline)

- The previous figure shows that if there is a gas release from 2" hole size without ignition the flammable vapors will reach a distance about 0.64 m downwind and 2.45 m height above ground (the tie-in point is under ground with about 5 meters).
- The UFL will reach a distance of about 0.32 m downwind with a height of 2.43 m. The cloud large width will be 0.66 m.
- The LFL will reach a distance of about 0.56 m downwind with a height of 2.44 m. The cloud large width will be 1.10 m.
- The 50 % LFL will reach a distance of about 0.64 m downwind with a height 2.45 m. The cloud large width will be 1.30 m.

The modeling shows that the gas cloud effects will be limited inside the PRS boundary.

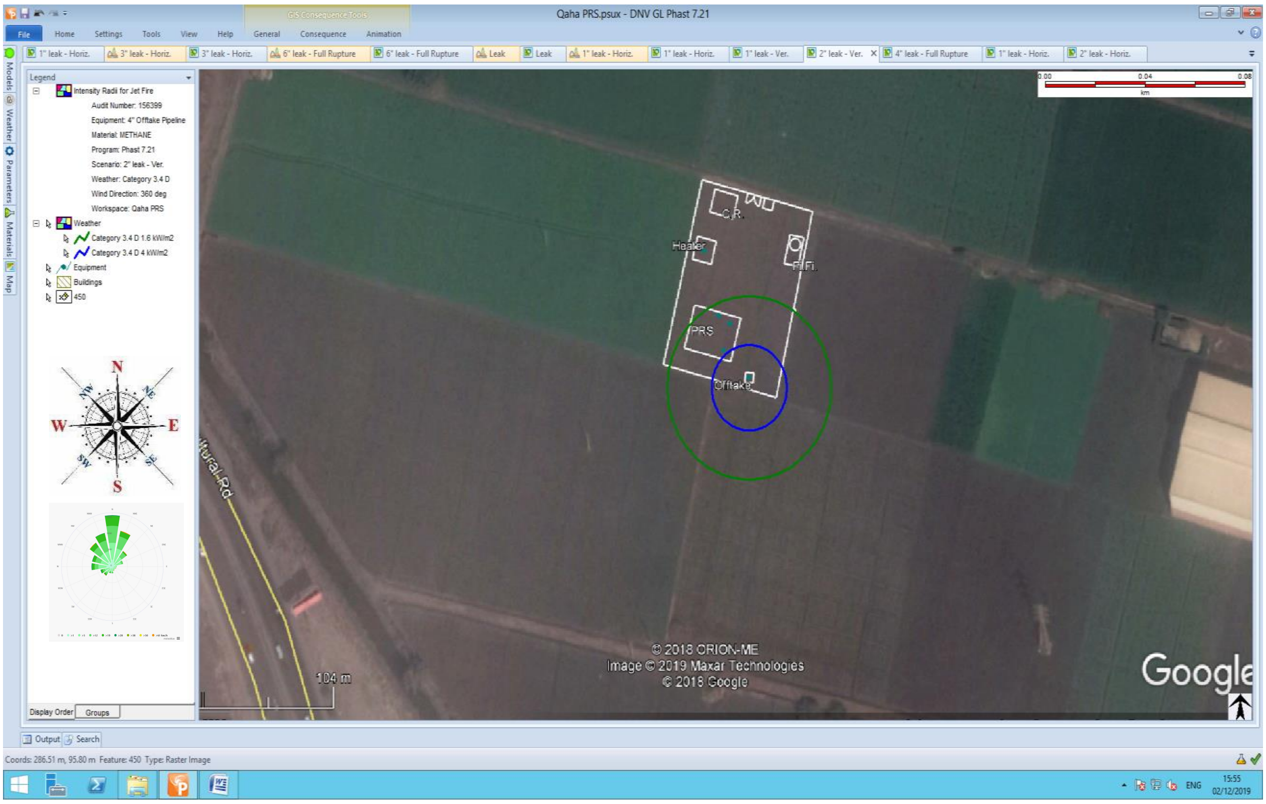


Figure (43) Heat Radiation Contours from Jet Fire (2" hole in 4" off-take Pipeline)

- The previous figure show that if there is a gas release from 2" hole size and ignited the expected flame length is about 23.30 meters height.
- The 1.6 kW/m^2 heat radiation contours extend about 65 meters downwind and 33 meters crosswind.
- The 4 kW/m^2 heat radiation contours extend about 30 meters downwind and 15 meters crosswind.
- The 9.5 kW/m^2 heat radiation not determined.
- The 12.5 kW/m^2 heat radiation not determined.
- The 25 kW/m^2 heat radiation not determined.
- The 37.5 kW/m^2 heat radiation not determined.

The modeling shows that the heat radiation value of 1.6 & 4 kW/m^2 will cover the PRS facilities and off-take point and extend outside the south and east fences down and crosswind with no effects.

5/3- Consequence Modeling for 4 inch (Full Rup.) Gas Release

The following table no. (26) Show that:

Table (26) Dispersion Modeling for Off-take - 4" Gas Release

Gas Release

Wind Category	Flammability Limits	Distance (m)	Height (m)	Cloud Width (m)
3.4 D	UFL	0.85	10.50	1.40
	LFL	2.50	11.50	4
	50 % LFL	3	12	5.10

Jet Fire

Wind Category	Flame Length (m)	Heat Radiation (kW/m^2)	Distance Downwind (m)	Distance Crosswind (m)	Lethality Level (%)
3.4 D	58.30	1.6	121	74	0
		4	82	46	0
		9.5	58	28	0
		12.5	51	23	20% /60 sec.
		25	42	13	80.34
		37.5	32	8	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)

Wind Category	Pressure Value (bar)	Over Pressure Radius (m)		Overpressure Waves Effect / Damage	
		Early	Late		
3.4 D	0.020	N/D	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Fireball

Wind Category	Heat Radiation (kW/m^2)	Distance (m)	Heat Radiation (kW/m^2) Effects on People & Structures
3.4 D	1.6	Not Determined	**12.5** *20 % Chance of fatality for 60 sec exposure* **25** *100 % Chance of fatality for continuous exposure* *50 % Chance of fatality for 30 sec exposure* **37.5** *Sufficient of cause process equipment damage*
	4	Not Determined	
	9.5	Not Determined	
	12.5	Not Determined	
	25	Not Determined	
	37.5	Not Determined	

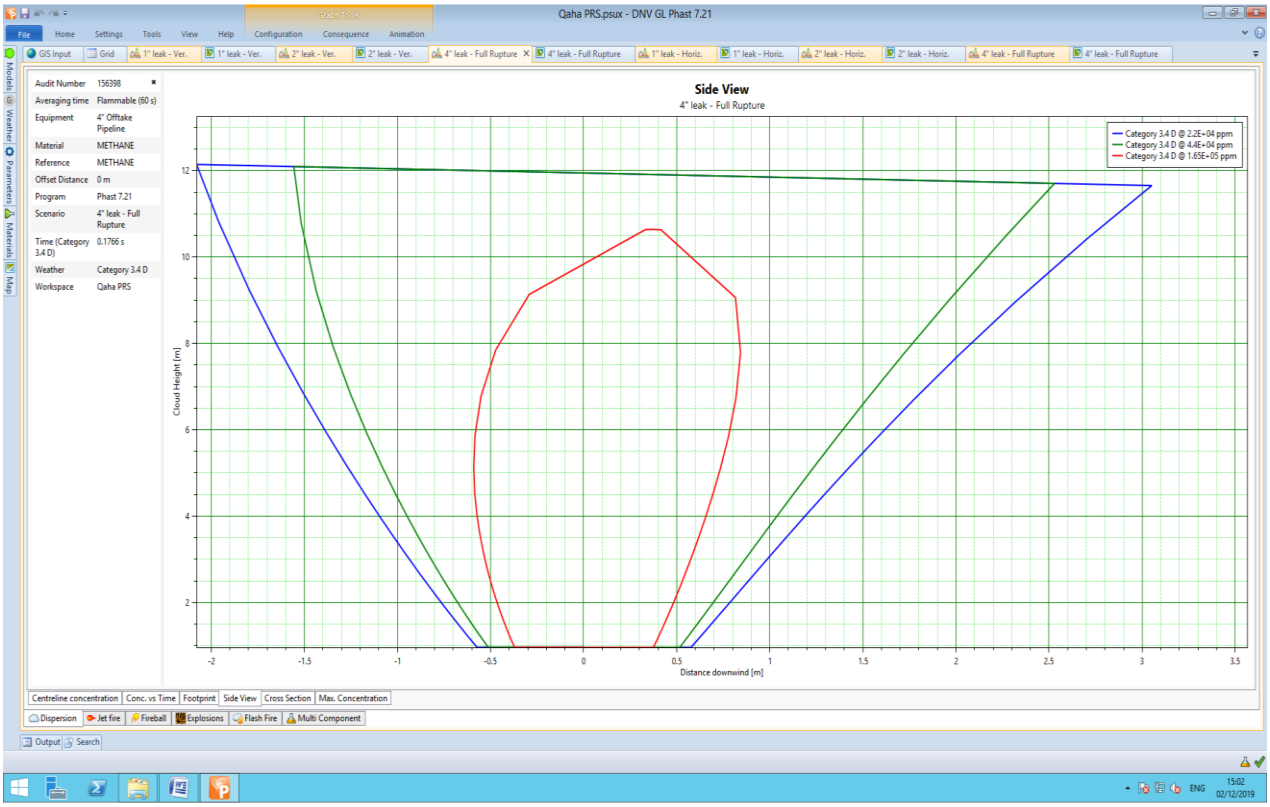


Figure (44) Gas Cloud Side View (UFL/LFL) (4" off-take Pipeline Full Rupture)

- The previous figure show that if there is a gas release from 4" pipeline full rupture without ignition the flammable vapors will reach a distance more than 0.85 m downwind and over 12 m height above ground (the tie-in point is under ground with about 5 meters).
- The UFL will reach a distance of about 0.85 m downwind with a height of 10.50 m. The cloud large width will be 1.40 m.
- The LFL will reach a distance of about 2.50 m downwind with a height of 11.50 m. The cloud large width will be 4 m.
- The 50 % LFL will reach a distance of about 3 m downwind with a height of 12 m. The cloud large width will be 5.10 m.

The modeling shows that the gas cloud will be limited inside the PRS boundary with some extension outside from south side downwind.

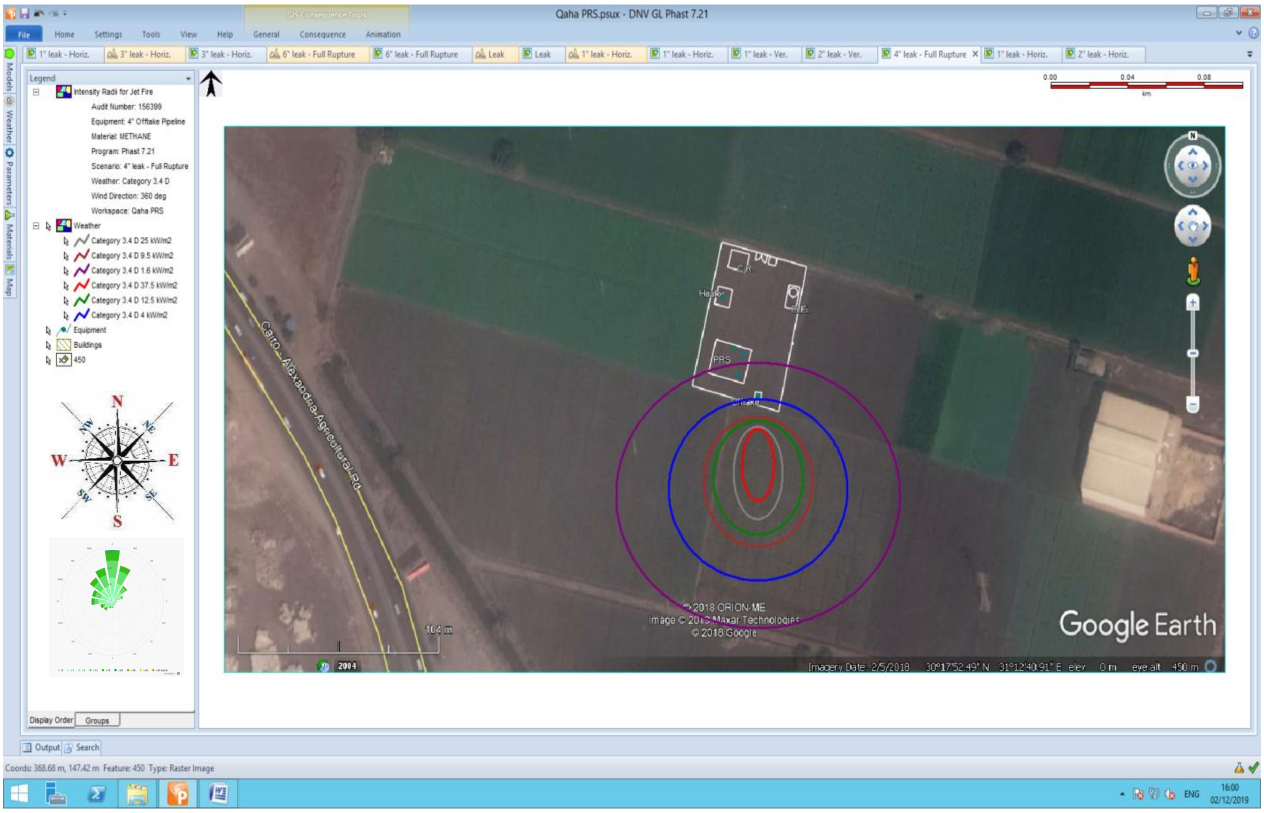


Figure (45) Heat Radiation Contours from Jet Fire (4" off-take Pipeline Full Rupture)

- The previous figure show that if there is a gas release from 4" pipeline full rupture and ignited the expected flame length is about 58 meters height.
- The 9.5 kW/m^2 heat radiation contours extend about 58 meters downwind and 28 meters crosswind.
- The 12.5 kW/m^2 heat radiation contours extend about 51 meters downwind and 23 meters crosswind.
- The 25 kW/m^2 heat radiation contours extend about 42 meters downwind and 13 meters crosswind.
- The 37.5 kW/m^2 heat radiation contours extend about 32 meters downwind and 8 meters crosswind.

The modeling shows that the heat radiation values will extend outside the PRS south fence downwind with no effects on surrounding area.

Individual Risk Evaluation

- **Risk Calculation**

All identified hazards should be subject to an evaluation for risk potential. This means analyzing the hazard for its probability to actually progress to loss event, as well as likely consequences of this event.

There are four steps to calculate risk, which determined as follows:

1- *Identify failure frequency (International Data Base)*

2- *Calculating the frequency against control measures at site by using Event Tree Analysis "ETA".*

3- *Identify scenarios probability.*

4- *Calculated risk to people regarding to the vulnerability of life loses.*

Basically, risk will be calculated as presented in the following equation:

Risk to people (Individual Risk – IR) =

Total Risk (Σ Frequency of fire/explosion) x Occupancy x Vulnerability

Where:

- *Total risk* — *Is the sum of contributions from all hazards exposed to (fire / explosion).*
- *Occupancy* — *Is the proportion of time exposed to work hazards. (Expected that x man the most exposed person to fire/explosion hazards on site. He works 8 hours shift/day)*
- *Vulnerability* — *Is the probability that exposure to the hazard will result in fatality.*

As shown in tables (5 & 6) – (Page: 32 & 33) *the vulnerability of people to heat radiation starting from 12 kW/m^2 will lead to fatality accident for 60 sec. Exposure and for explosion over pressure starting from 0.137 bar.*

The modeling of the different scenarios shows that the heat radiation and explosion overpressure waves would be a result from release scenarios for all sizes of crack and according to the space size for the PRMS, all of the sequence will be determined for three values release (small, medium and large).

Calculating frequencies needs a very comprehensive calculations which needs a lot of data collecting related to failure of equipment’s and accident reporting with detailed investigation to know the failure frequency rates in order to calculate risks from scenarios.

In this study, it decided that to use an International Data Bank for major hazardous incident data.

The following table (27) show frequency for each failure can be raised in pressure reduction station operations:

Table (27) Failure Frequency for Each Scenario

Scenario	Release Size	Failure Cause	Failure Rate
Gas Release from 1"/4"-6" Pipeline / 3" Gas Heater	***Small***	Internal Corrosion	*1.19E-05*
		External Corrosion	*3.55E-06*
		Maintenance Error	*2.28E-05*
		Corrosive Liquid or Gas	*4.84E-04*
		Total	***5.22E-04***
Gas Release from 2"/4"&3"/6" Pipeline	***Medium***	**Failure Cause**	**Failure Rate**
		Internal Corrosion	*2.71E-05*
		External Corrosion	*8.24E-06*
		Erosion	*4.85E-04*
		Total	***5.20E-04***
Gas Release from 4" / 6" Pipeline Full Rupture	***Large***	**Failure Cause**	**Failure Rate**
		Internal Corrosion	*5.53E-06*
		External Corrosion	*1.61E-06*
		Weld Crack	*4.34E-06*
		Earthquake	*1.33E-07*
		Total	***1.16E-05***
Spotleak (Odorant Tank)	***Medium***	*As a package*	**Failure Rate**
			1.25E-05

Reference: Taylor Associates ApS - 2006
(Hazardous Materials Release and Accident Frequencies for Process Plant - Volume II / Process Unit Release Frequencies - Version 1 Issue 7)

- **Event Tree Analysis**

An event tree is a graphical way of showing the possible outcomes of a hazardous event, such as a failure of equipment or human error.

An ETA involves determining the responses of systems and operators to the hazardous event in order to determine all possible alternative outcomes.

The result of the ETA is a series of scenarios arising from different sets of failures or errors.

These scenarios describe the possible accident outcomes in terms of the sequence of events (successes or failures of safety functions) that follow the initial hazardous event.

Event trees shall be used to identify the various escalation paths that can occur in the process. After these escalation paths are identified, the specific combinations of failures that can lead to defined outcomes can then be determined.

This allows identification of additional barriers to reduce the likelihood of such escalation.

The results of an ETA are the event tree models and the safety system successes or failures that lead to each defined outcome.

Accident sequences represents in an event tree represent logical and combinations of events; thus, these sequences can be put into the form of a fault tree model for further qualitative analysis.

These results may be used to identify design and procedural weaknesses, and normally to provide recommendations for reducing the likelihood and/or consequences of the analyzed potential accidents.

Using ETA requires knowledge of potential initiating events (that is, equipment failures or system upsets that can potentially cause an accident), and knowledge of safety system functions or emergency procedures that potentially mitigate the effects of each initiating event.

The equipment failures, system upsets and safety system functions shall be extracted from the likelihood data presented before.

In the case of hydrocarbon release, the event tree first branch is typically represents "Early Ignition". These events are represented in the risk analysis as jet fire events.

This is because sufficient time is unlikely to elapse before ignition for a gas/air mixture to accumulate and cause either a flash fire or a gas hazard.

Subsequent branches for these events represent gas detection, fire detection, inventory isolation (or ESD) or deluge activation.

Delayed ignitions are typically represented by the fifth branch event. This is because, in the time taken for an ignition to occur, sufficient time is more likely to elapse for gas detection and inventory isolation.

The scenario development shall be performed for the following cases**:**

- Without any control measures
- With control measures

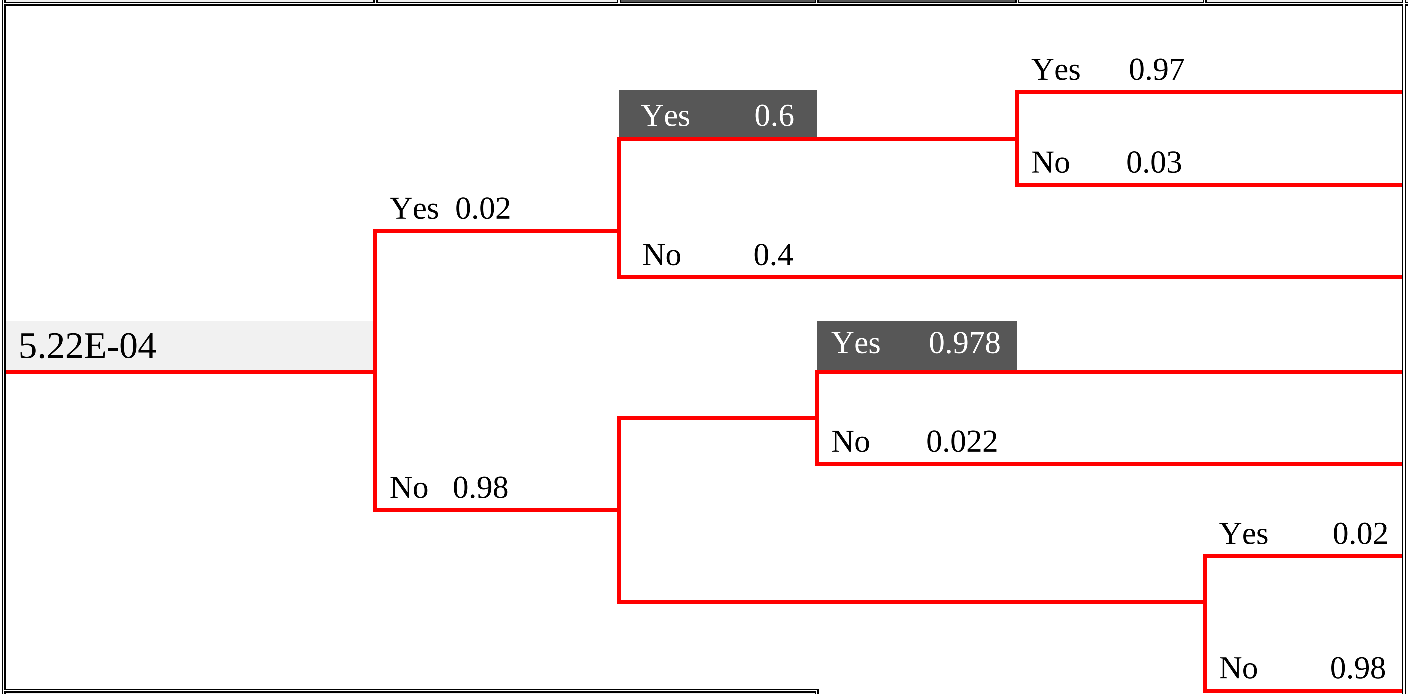
The event tree analysis outcomes can be classified into three main categories as follows:

"Limited Consequence"	*Indicates that the release has been detected and the inventory source has been isolated automatically.*
"Controlled Consequence"	*Indicates that the release has been detected but the source has not been isolated automatically. [Needs human intervention].*
"Escalated Consequence"	*Indicates that the release has not been detected and consequently the source has not been isolated.*

The event trees analysis for each scenario are presented in the below pages:

Table (28) Inlet 4" / Outlet 6" / Off-Take 4" / Pipeline & Gas Heater Scenarios (Pin Hole Crack – 1" Release) – Event Tree Analysis

Release of Flammable Materials [1]	Immediate Ignition [2]	Fire Detection [3]	ESD System [3]	Fire Protec. [3]	Delayed Ignition [2]	Outcomes	Frequency
5.22E-04	**0.02**	**0.6**	**0.978**	**0.97**	**0.02**		



Outcomes	Frequency
Controlled Jet fire	***1.01E-05***
Not controlled jet fire	***3.13E-07***
Escalated jet fire	***4.18E-06***
Limited release	-------------
Large release	***1.13E-05***
Escalated jet fire	***1.02E-05***
Escalated release	***5.01E-04***
TOTAL	***1.47E-05***

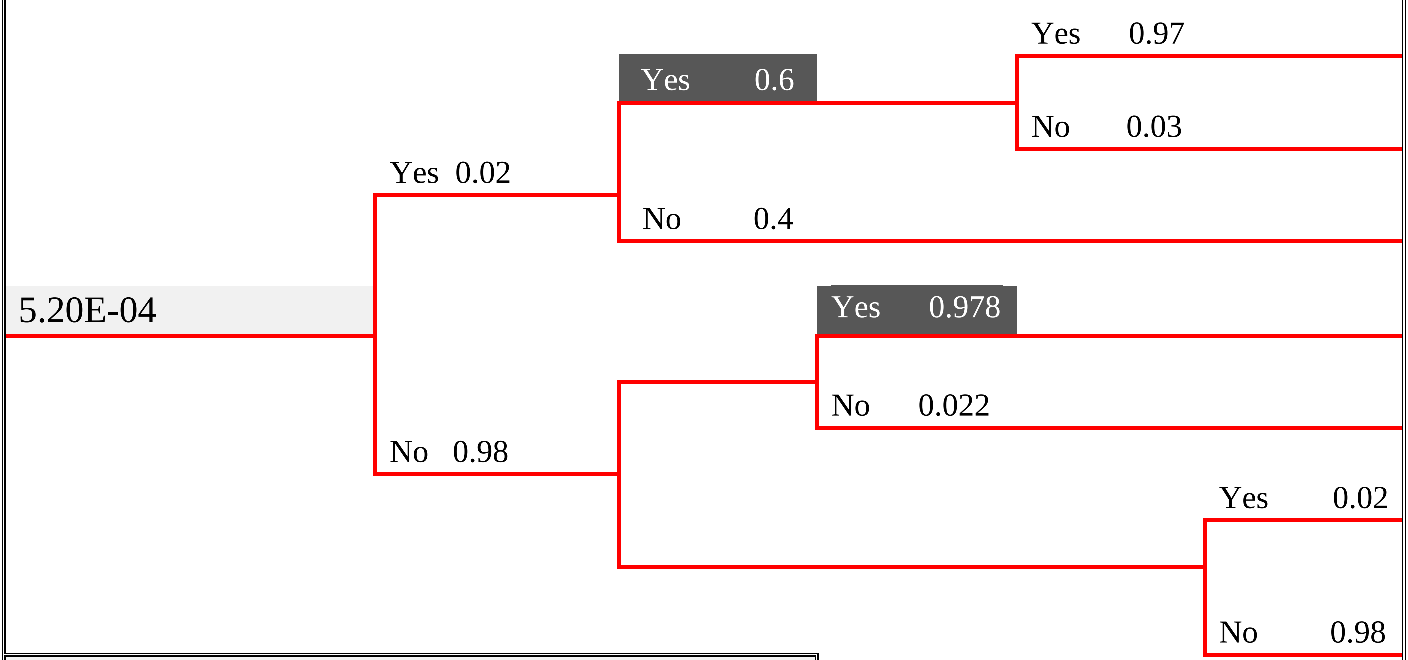
(1) Refer to QRA Study Page 97. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

(3) Ref. OGP – Report No. 434 – A1 / 2010.

Table (29) Inlet 4" / Outlet 6" / Off-Take 4" Pipeline Scenarios (Half Rupture Release) – Event Tree Analysis

Release of Flammable Materials (1)	Immediate Ignition (2)	Fire Detection (3)	ESD System (3)	Fire Protec. (3)	Delayed Ignition (2)
5.20E-04	0.02	0.6	0.978	0.97	0.02



Outcomes	Frequency
Controlled Jet fire	***1.01E-05***
Not controlled jet fire	***3.12E-07***
Escalated jet fire	***4.16E-06***
Limited release	-------------
Large release	***1.12E-05***
Escalated jet fire	***1.02E-05***
Escalated release	***4.99E-04***
TOTAL	***1.46E-05***

(1) Refer to QRA Study Page 97. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

(3) Ref. OGP – Report No. 434 – A1 / 2010.

Table (30) Off-Take 4" / Inlet 4" / Outlet 6" Pipeline Scenarios (Full Rupture Release) – Event Tree Analysis

Release of Flammable Materials (1)	Immediate Ignition (2)	Fire Detection (3)	ESD System (3)	Fire Protec. (3)	Delayed Ignition (2)	Outcomes	Frequency
1.16E-05	0.04	0.6	0.978	0.97	0.04		
1.16E-05	Yes 0.04	Yes 0.6		Yes 0.97		Controlled Jet fire	***4.50E-07***
				No 0.03		Not controlled jet fire	***1.39E-08***
		No 0.4				Escalated jet fire	***1.86E-07***
	No 0.96		Yes 0.978			Limited release	-------------
			No 0.022			Large release	***2.45E-07***
					Yes 0.04	Escalated jet fire	***4.45E-07***
					No 0.96	Escalated release	***1.07E-05***
						TOTAL	***6.45E-07***

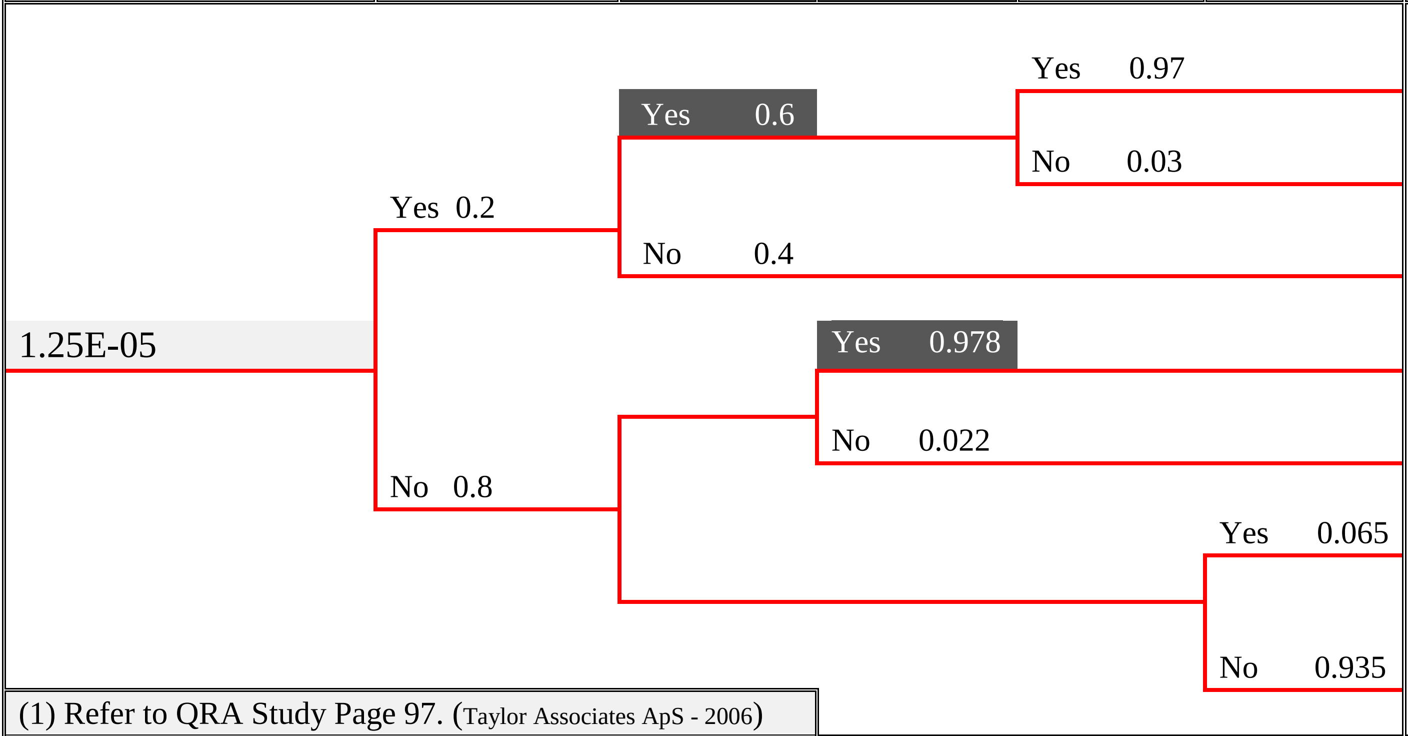
(1) Refer to QRA Study Page 97. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

(3) Ref. OGP – Report No. 434 – A1 / 2010.

Table (31) Odorant Tank Release – Event Tree Analysis

Release of Flammable Materials [1]	Immediate Ignition [2]	Fire Detection [3]	ESD System [3]	Fire Protec. [3]	Delayed Ignition [2]	Outcomes	Frequency
1.25E-05	0.2	0.6	0.978	0.97	0.065		



Outcomes	Frequency
Controlled fire	***2.43E-06***
Large fire	***7.50E-08***
Escalated fire	***1.00E-06***
Limited leak	-------------
Large leak	***2.20E-07***
Escalated fire	***6.50E-07***
Escalated leak	***9.35E-06***
TOTAL	***1.13E-05***

(1) Refer to QRA Study Page 97. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

(3) Ref. OGP – Report No. 434 – A1 / 2010.

The following table (32) show the total frequency for each scenario from ETA - Tables (28 to 31):

Table (32) Total Frequencies for Each Scenario

Source of Release	Total Frequency (ETA)
1" / 4" Inlet Pipeline Pin Hole	***1.47E-05***
1" / 4" Outlet Pipeline Pin Hole	
1" / 6" Off-Take Pipeline Pin Hole	
1" / 3" Gas Heater Pin Hole	
2" / 4" Inlet Pipeline Half Rupture	***1.46E-05***
2" / 4" Outlet Pipeline Half Rupture	
3" / 6" Off-Take Pipeline Half Rupture	
4" Inlet Pipeline Full Rupture	***6.45E-07***
4" Off-Take Pipeline Full Rupture	
6" Outlet Pipeline Full Rupture	
Odorant Tank 1" hole Leak	***1.13E-05***

The following table (33) summarize the risk events on workers / public, and as there is no direct effects on public from any of the scenarios it will be assume that one person (as public) works as farmer for 1 hour / day light.

Table No. (33) Summarize the Risk on Workers / Public (Occupancy)

	Event	Jet / Pool Fire (12.5 kW/m^2)		Explosion Overpressure (0.137 bar)	
	Exposure	Workers	Public	Workers	Public
Inlet 4" Pipeline Release Scenarios					
Pin Hole	1"	*None*	*None*	*None*	*None*
Half Rupture	2"	*None*	*1 for 1 h (0.04)*	*None*	*None*
Full Rupture	4"	*None*	*1 for 1 h (0.04)*	*None*	*None*
Outlet 6" Pipeline Release Scenarios					
Pin Hole	1"	*None*	*None*	*None*	*None*
Half Rupture	3"	*None*	*None*	*None*	*None*
Full Rupture	6"	*None*	*1 for 1 h (0.04)*	*None*	*None*
Odorant Tank Release Scenario					
Small Leak	1"	*None*	*None*	*None*	*1 for 1 h (0.04)*
Gas heater (water bath heating system)					
Pin Hole	1"	*None*	*None*	*2 for 24 h (2)*	*None*
Off-Take 4" Pipeline Release Scenarios					
Pin Hole	1"	*None*	*None*	*None*	*None*
Half Rupture	2"	*None*	*None*	*None*	*None*
Full Rupture	4"	*None*	*1 for 1 h (0.04)*	*None*	*None*

Therefore, the risk calculation will depend on total risk from these scenarios, and as per the equation page (95):

Risk to People (Individual Risk – IR) =

Total Risk (Σ Frequency of fire/explosion) x Occupancy x Vulnerability

Where:

- Total risk - is the sum of contributions from all hazards exposed to (fire / explosion).

(Frequencies of Scenarios from Table-32)

- Occupancy - is the proportion of time exposed to work hazards. (Expected that X man the most exposed person to fire/explosion hazards on site. He works 8 hours "shift/day").

(as per Egypt Gas data, Qaha PRMS occupied by 3 persons for 24 hours, and as there is no direct effects on public from any of the scenarios it will be assumed that one person "as public around the PRMS and Off-Take Point" works as farmer for 1 hour / day light "Ref. to Table 33")

- Vulnerability - is the probability that exposure to the hazard will result in fatality.

(Reference: Report No./DNV Reg. No.: 2013-4091/1/17 TLT 29-6 – Rev. 1)

As per modeling, the IR will be calculated for the workers and the public around the PRMS and Off-Take Point (farmers around the PRS) as per the following tables (34 & 35):

Table (34) Individual Risk (IR) Calculation for PRMS Workers

Source of Event	Frequency 1	Heat Radiation kW/m^2 & Overpressure	Vulnerability 2	Time Exposed 3	IR = 1 x 2 x 3
Gas heater (water bath heating system) 3" pipeline	1.47E-05	Explosion 0.137	0.3 (Indoor)	2 [2 Pers.]	*8.82E-06*
TOTAL Risk for Worker					***8.82E-06***

Table (35) Individual Risk (IR) Calculation for the Public Near to the PRMS

Source of Event	Frequency 1	Heat Radiation kW/m^2 & Overpressure	Vulnerability 2	Time Exposed 3	IR = 1 x 2 x 3
Gas Release from 2"/4" inlet pipeline	1.46E-05	Jet Fire 12.5	0.7 (Outdoor)	0.04 [1 Pers.]	*4.09E-07*
Gas Release from 4" off-take pipeline	6.45E-07	Jet Fire 12.5	0.7 (Outdoor)	0.04 [1 Pers.]	*1.81E-08*
Gas Release from 4" inlet pipeline					
Gas Release from 6" outlet pipeline					
Odorant tank 1" leak	1.13E-05	Explosion 0.137	0.3 (Outdoor)	0.04 [1 Pers.]	*1.36E-07*
TOTAL Risk for the Public (PRMS)					***5.63E-07***

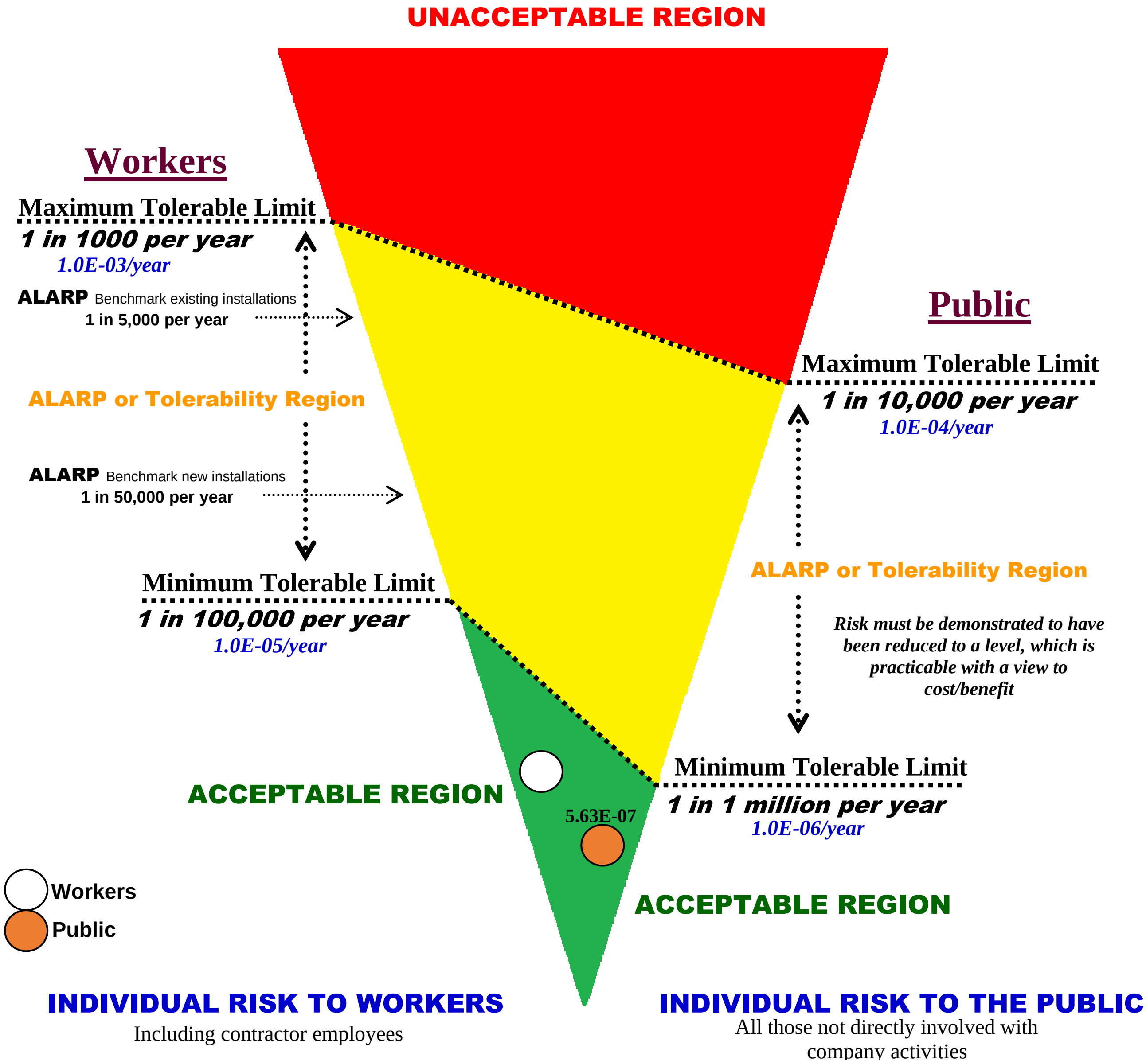


Figure (46) Evaluation of Individual Risk

*The level of Individual Risk to the exposed workers at Qaha PRMS, based on the risk tolerability criterion used is **Acceptable**.*

*The level of Individual Risk to the exposed Public at Qaha PRMS area, based on the risk tolerability criterion used is **Low ALARP**.*

Summary of Modeling Results and Conclusion

As per results from modeling the consequences of each scenario, the following table summarize the study, and as follows:

Event	Scenario	Effects
Pin hole (1") gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRMS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values will extend down and crosswind outside the PRS boundary reaching the off-take point crosswind (1.6 & 4 kW/m^2), with no effects downwind (9.5, 12.5 & 25 kW/m^2)*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Half Rupture (2") gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud (LFL & 50 % LFL) will extend to reach the southern fence and extend about outside. The UFL will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the values of 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the PRS southern fence downwind with no effects. The values of 9.5 & 12.5 kW/m^2 will reach the off-take point crosswind*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020, 0.137 & 0.206 bar will extend outside the PRMS south fence with no effects down or crosswind.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

Event	Scenario	Effects
Full Rupture gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects (LFL & 50 % LFL) will extend over south boundary with no effects outside downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the south fence with no effects downwind and reach the off-take point crosswind.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and off-take point and no effects on site offices.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*N/D*
Pin hole (1") gas release 6" outlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value 1.6, 4, 9.5 & 12.5 kW/m^2 effects will be limited inside the PRS boundary with no effects.* *The values of 25 & 37.5 kW/m^2 not determined by the software due to small leakage.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

Event	Scenario	Effects
Half Rupture (3") gas release 6" outlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud (LFL & 50% LFL) will be limited inside the PRS boundary reaching the off-take point downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 9.5 & 12.5 kW/m^2 will extend outside the PRS boundary south side with no effects downwind, and covering the off-take point crosswind.* *The values of 25 & 37.5 kW/m^2 will be limited inside the boundary effecting the PRS facilities.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects outside and covering the firefighting facilities and the heater.* *The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and no effects on site offices.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Full Rupture gas release 6" outlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m^2 will extend outside the south fence with no effects downwind and cover the off-take point crosswind.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover the PRS and extend outside the PRS boundary with no effects outside and covering the firefighting facilities and the heater.* *The values of 0.137 & 0.206 bar will be limited inside the PRS boundary effecting the PRS facilities and no effects on site offices.*

Event	Scenario	Effects
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 1.6, 4, 9.5 & 12.5 kW/m^2 will limited inside the PRS boundary effecting the PRS facilities with some extension (1.6 kW/m^2) down and crosswind.*
Odorant tank 1" leak		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will extend inside the PRS boundary reaching the off-take point downwind. Consideration should be taken when deal with liquid, vapors and smokes according to the MSDS for the material.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that all values of heat radiation 9.5, 12.5, 25 & 37.5 kW/m^2 will be limited inside the PRS boundary down and crosswind.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover the PRS facilities inside and extend outside from S/E/W sides with no effects.* *The values of 0.137 & 0.206 bar will extend outside the PRS boundary from south side with no effects down or crosswind.*
Gas heater (water bath heating system)		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will extend inside the PRS boundary downwind reaching the PRS facilities.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value 1.6, 4, 9.5 & 12.5 kW/m^2 effects will be limited inside the PRS boundary with no effects.* *The values of 25 & 37.5 kW/m^2 not determined by the software due to small leakage.*

Event	Scenario	Effects
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will extend outside the PRS from all sides covering the area surrounded with no effects outside.* *The value of 0.137 & 0.206 bar will be limited inside the PRS and near to the control room.*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Pin hole (1") gas release 4" off-take pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m² 12.5 kW/m²	*The modeling shows that the heat radiation value of 1.6 & 4 kW/m² will be limited inside the PRS boundary with some extension outside from south side with no effects.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Half Rupture (2") gas release 4" off-take pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud effects will be limited inside the PRS boundary.*
	Heat radiation / Jet fire 9.5 kW/m² 12.5 kW/m²	*The modeling shows that the heat radiation value of 1.6 & 4 kW/m² will cover the PRS facilities and off-take point and extend outside the south and east fences down and crosswind with no effects.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

Event	Scenario	Effects
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Full Rupture gas release 4” off-take pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas cloud will be limited inside the PRS boundary with some extension outside from south side downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values will extend outside the PRS south fence downwind with no effects on surrounding area.*
	Early explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Late explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*N/D*

The previous table shows that there is some of direct effects on PRMS workers, and as there is no direct effects on public around the PRMS or the off-take point. Therefore it will be assumed that one person (as public) works as farmer for 1 hour / day light. (Refer to table 33).

Regarding to the results from risk calculations; the risk to PRMS ***WorkersAND Public found in Acceptable Region,*** so there are some points need to be considered to keep the risk tolerability and this will be describe in the following recommendations.

Recommendations

Regarding to the modeling scenarios and risk calculations to workers / public which found in Acceptable region (workers and public), therefore there are some points need to be considered to maintain the risk tolerability in its region and this will be describe in the following recommendations:

Recommendation	Timeline Phases	Egypt Gas Remarks
• Ensure that		
- All PRMS facilities specifications referred to the national and international codes and standards.	Design	
- Inspection and maintenance plans and programs are according to the manufacturers guidelines to keep all facility parts in a good condition.	Operation	
- All operations are according to standard operating procedures for the PRMS operations and training programs in-place for operators.	Operation	
- Emergency shutdown detailed procedure including emergency gas isolation points at the PRMS and Off-Take Point in place.	Operation	
- Surface drainage system is suitable for containment any odorant spillage.	Design	
• Considering that all electrical equipment, facilities and connections are according to the hazardous area classification for natural gas facilities.	Design	
• Preparing an emergency response plan and for the PRS including all scenarios in this study and other needs like: (Not Provided by EG)	Operation	
- Firefighting brigades, mutual aids, emergency communications and fire detection / protection systems.	Operation	
- Dealing with the external road in case of major fires.	Operation	

Recommendation	Timeline Phases	Egypt Gas Remarks
- First aid including dealing with the odorant according to the MSDS for it, with respect of means of water supply for emergency showers, eye washers and cleaning.	Operation	
- Safe exits in building according to the modeling in this study, and to the PRS from other side beside the designed exit in layout provided.	Design	
• Provide the site with SCBA "Self-Contained Breathing Apparatus (at least two sets) and arrange training programs for operators.	Operation	
• Provide a suitable tool for wind direction (Windsock) to be installed in a suitable place to determine the wind direction **(the PRMS lay-out need to be reviewed for correction of the North direction)**	Construction	
• Cooperation should be done with the concerned parties before planning for housing projects around the PRMS area.	Operation / Design / Construction	