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EGAS

The Egyptian Natural Gas Holding Company "EGAS"

Quantitative Risk *Assessment* "QRA" Study For Armant Pressure Reduction Station

Prepared By
Petroleum Safety and Environmental Services Company
PETROSAFE

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This report summarizes the Quantitative Risk Assessment (QRA) analysis study undertaken for the New Natural Gas Pressure Reduction & Metering Station "PRMS" with an Odorant at Armant City – Luxor 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 Armant 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 Armant 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. Four 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.
4. Leak from water bath heater (WBH).

The QRA has been performed using DNV PHAST software (Ver. 8.6) 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 average weather conditions have been selected; represented by wind speed of 2.5 m/s and stability class "D" representing "Neutral" weather conditions, in order to obtain conservative results. The prevailing wind direction is West North West (*WNW*).

Additional scenario was discussed to highlight the effect of different weather conditions "low wind speed", where the differences between the two weather conditions were negligible. Please refer to Annex "1" for additional scenario.

As per results from modeling the consequences of each scenario, the following table summarizes 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 fence.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values will be limited inside the PRMS.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values will be limited inside the PRMS boundary.*
Half Rupture (2") gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas clouds 50 % LFL will extend to reach the southern fence and extend outside. The UFL & LFL 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/m2 will extend outside the PRMS southern fence with no effects outside.*
	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 southern fence.*
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 be limited inside the PRMS.*
	Heat radiation / Jet fire 9.5 kW/m^2	*The modeling shows that the heat radiation values 9.5, 12.5, 25 & 37.5 kW/m2 will extend outside the PRMS southern fence.*

Event	Scenario	Effects
	12.5 kW/m^2	
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.137 & 0.206 bar will extend outside the PRMS southern fence.*
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 kW/m2 effects will be limited inside the PRS boundary with no effects.* *The values of 9.5, 12.5, 25 & 37.5 kW/m2 are not determined by the software due to small leakage.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Half Rupture (3") 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 values of 9.5, 12.5, 25 & 37.5 kW/m2 are limited to the PRMS boundary.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values 0.137 & 0.206 bar will be limited inside the PRMS boundary.*
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.*

Event	Scenario	Effects
	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, 25 & 37.5 kW/m2 will extend outside the PRMS southern fence.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values 0.137 and 0.206 bar will be extend outside the PRMS southern fence.*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 12.5 & 37.5 kW/m2 are limited inside the PRS boundary where 12.5 kW/m2 cover parts of the control room.*
Odorant tank 1" leak		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will extend outside the PRS fence from the south side.* *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/m2 will be limited inside the PRS boundary down and crosswind.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover parts of the PRS and extend outside the PRS boundary .* *The values of 0.137 & 0.206 bar will extend outside the PRS boundary.*
Gas heater (water bath heating system)		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will be limited inside the PRS boundary downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value 9.5, 12.5, 25 & 37.5 kW/m2 effects will be limited inside the PRS boundary.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values will be limited inside the PRMS boundary.*

Event	Scenario	Effects
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 PRMS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values are limited inside PRMS boundary while the 1.6 kW/m2 extend outside the southern fence with no effects outside.* *The values of 9.5, 12.5, 25 & 37.5 kW/m2 are not determined by the software as they are very small values.*
	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 PRMS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 1.6 &4 kW/m2 will extend outside PRMS boundary.* *While the 9.5 kW/m2 will be limited inside PRMS boundary.* *The values of 12.5, 25 & 37.5 kW/m2 are not determined by the software as they are very small values.*
	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.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 1.6, 4 & 9.5 kW/m2 will extend outside PRS boundary.* *The values of 25 & 37.5 kW/m2 are not determined by the software as they are very*

Event	Scenario	Effects
		small values.
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

The previous table shows that there are some of potential hazards with heat radiation (12.5 kW/m2) resulting from jet fire and explosion overpressure waves (0.137 bar) from late explosion events.

These risks (Jet fire, Fireball & overpressure waves) will affect the workers at the PRMS, and reach the surrounding near to the station.

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 the Workers Near to the PRMS

Source of Event	Frequency 1	Heat Radiation (kW/m^2) & Overpressure (Bar)	Vulnerability 2	Time Exposed 3	IR = 1 x 2 x 3
Gas Release from 1"/4" Inlet pipeline	***1.47E-05***	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1] Pers	***4.12E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1] Pers	***1.77E-07***
Gas Release from 1"/3" Heater		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1] Pers	***4.12E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1] Pers	***1.77E-07***
Gas Release from 2"/4" Inlet pipeline	***1.47E-05***	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1] Pers	***4.11E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1] Pers	***1.76E-07***
Gas Release from 3"/6" Outlet pipeline		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1] Pers	***4.11E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1] Pers	***1.76E-07***
Gas Release from 4" Inlet pipeline	***6.45E-07***	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1] Pers	***1.81E-08***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1] Pers	***7.74E-09***
Gas Release from 6" Outlet pipeline		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1] Pers	***1.81E-08***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1] Pers	***7.74E-09***
		Fireball 12.5	**0.1** (Indoor)	**1** [2] Pers	***1.29E-07***
Odorant tank 1" leak	***1.23E-05***	Jet Fire 12.5	**0.3** (Outdoor)	**0.04** [1] Pers	***1.48E-07***
TOTAL Risk for the Workers					***2.68E-06***

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

Source of Event	Frequency 1	Heat Radiation (kW/m^2) & Overpressure (Bar)	Vulnerability 2	Time Exposed 3	IR = 1 x 2 x 3
Gas Release from 2"/4" Inlet pipeline	*1.47E-05*	Jet Fire 12.5	0.7 (Outdoor)	0.04 1 Pers	*4.11E-07*
		Explosion 0.137	0.3 (Outdoor)		*1.76E-07*
Gas Release from 4" Inlet pipeline	*6.45E-07*	Jet Fire 12.5	0.7 (Outdoor)	0.04 1 Pers	*1.81E-08*
		Explosion 0.137	0.3 (Outdoor)		*7.74E-09*
Gas Release from 6" Outlet pipeline		Jet Fire 12.5	0.7 (Outdoor)	0.04 1 Pers	*1.81E-08*
		Explosion 0.137	0.3 (Outdoor)		*7.74E-09*
Odorant tank 1" leak	*1.23E-05*	Explosion 0.137	0.3 (Outdoor)	0.04 1 Pers	*1.48E-07*
TOTAL Risk for the Public (PRMS)					***7.86E-07***

The previous table shows that there are some effects on PRMS workers & surrounding public, it was assumed that:

- One person "as public" is in the neighboring areas around the PRMS for one hour / day light.
- Five Persons "as Workers" are available in the PRS for 24 hrs/ day (two operators in control room & one in admin building + Two persons in the two guard rooms),
- One of the operators will be available around the PRMS components for Maintenance/ Operation for one hour / day light.

The following figure shows the Individual Risk "IR" for Armant PRMS:

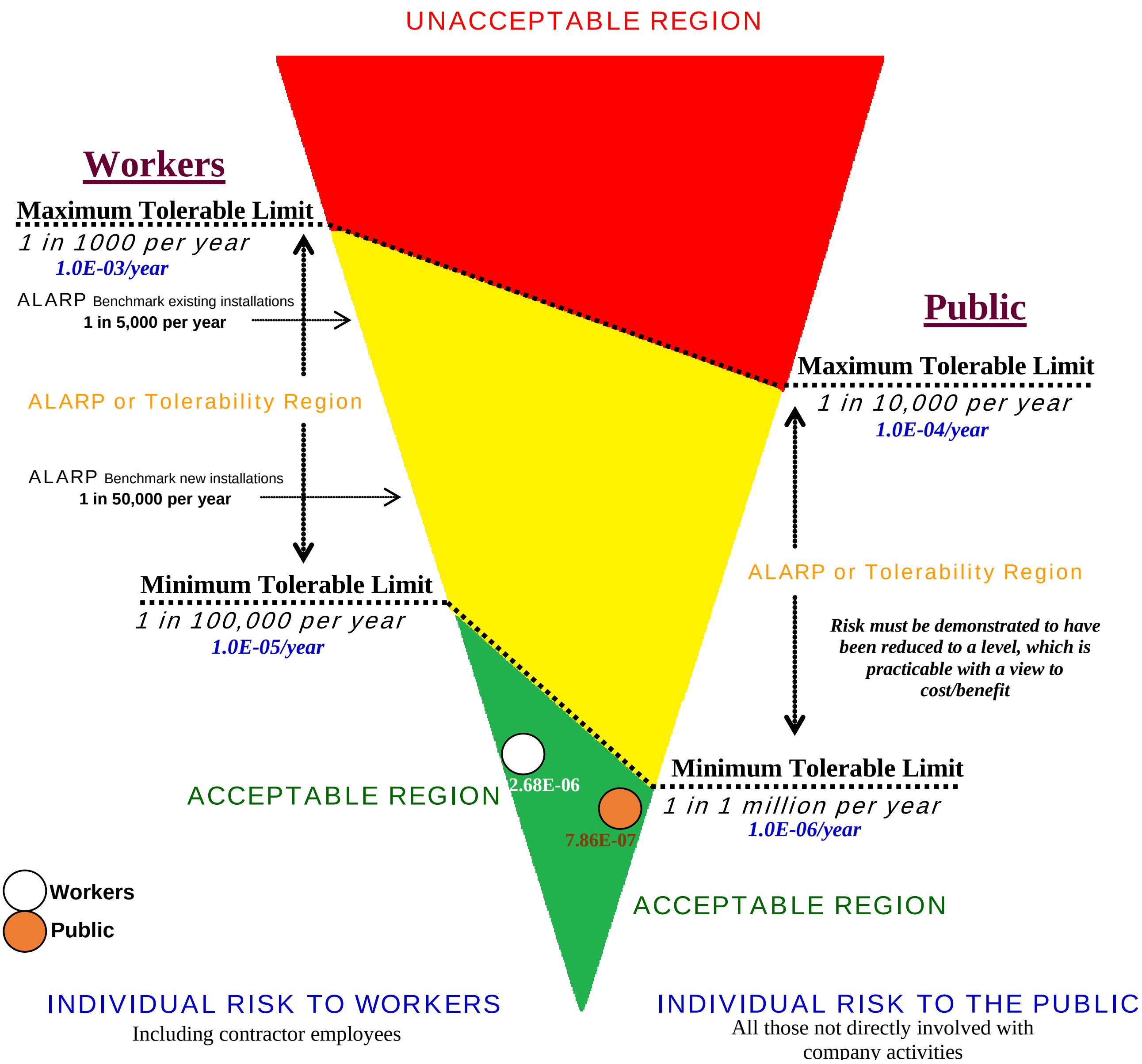


Figure: Evaluation of Individual Risk

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

The level of Individual Risk to the exposed Public at Armant 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 "Natural Gas Pressure Reduction and Odorant Station – PRMS" at **Armant** City – Luxor 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/m² (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. (It means not getting results from the software's calculations)*

N/R	*Not Reached. (It means the resulting consequence doesn't reach the surrounding receptors "if any")*
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 Armant 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 operations of the facilities (e.g. Construction and specific maintenance activities) are excluded from this analysis.

Quantitative Risk Assessment "QRA" Studies

Method of Assessment

1.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.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.

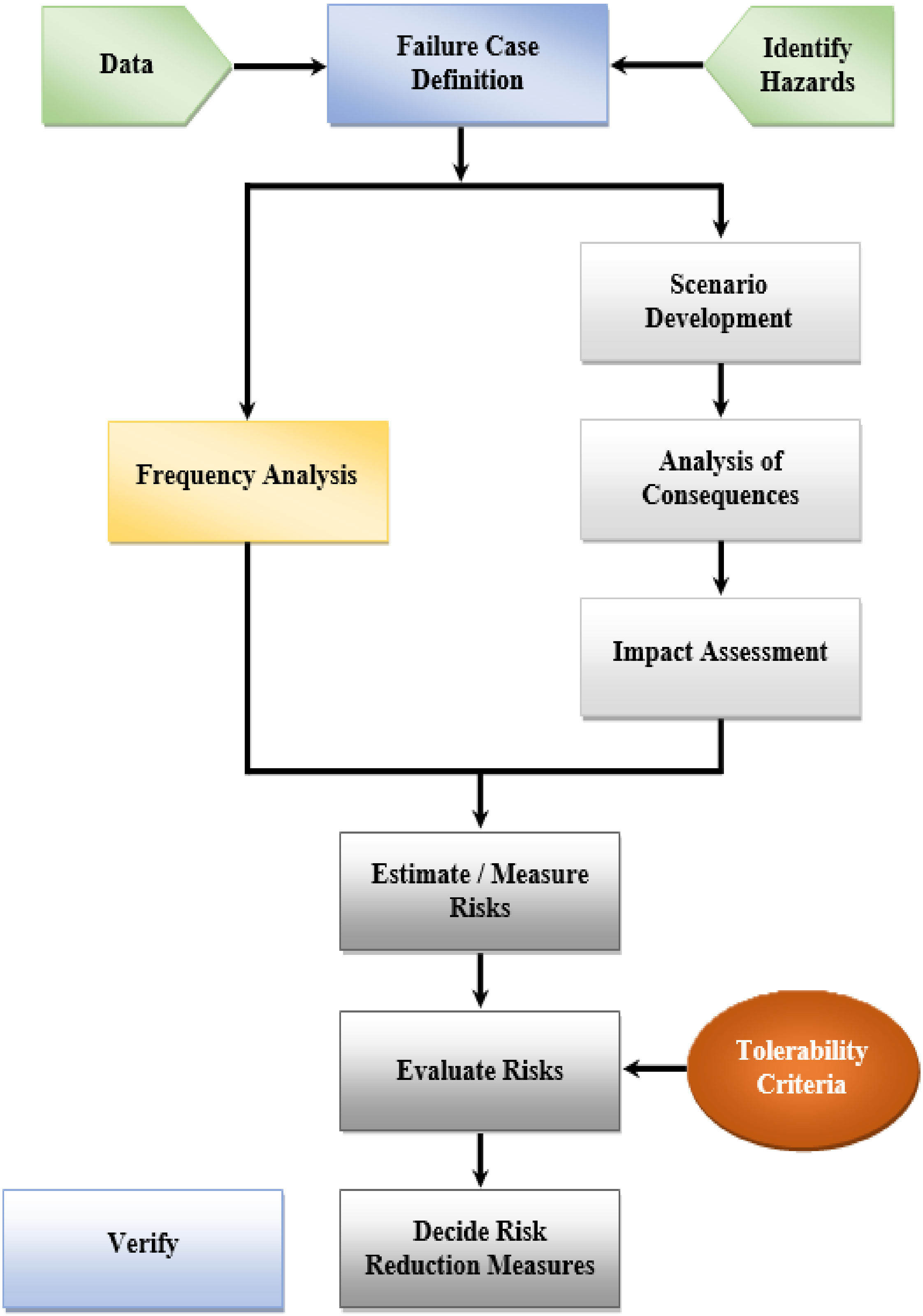


Figure 1 Risk Assessment Framework

Modelling the Consequences

Modelling 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 modelling, 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. 8.6 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 48 to 88)

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).

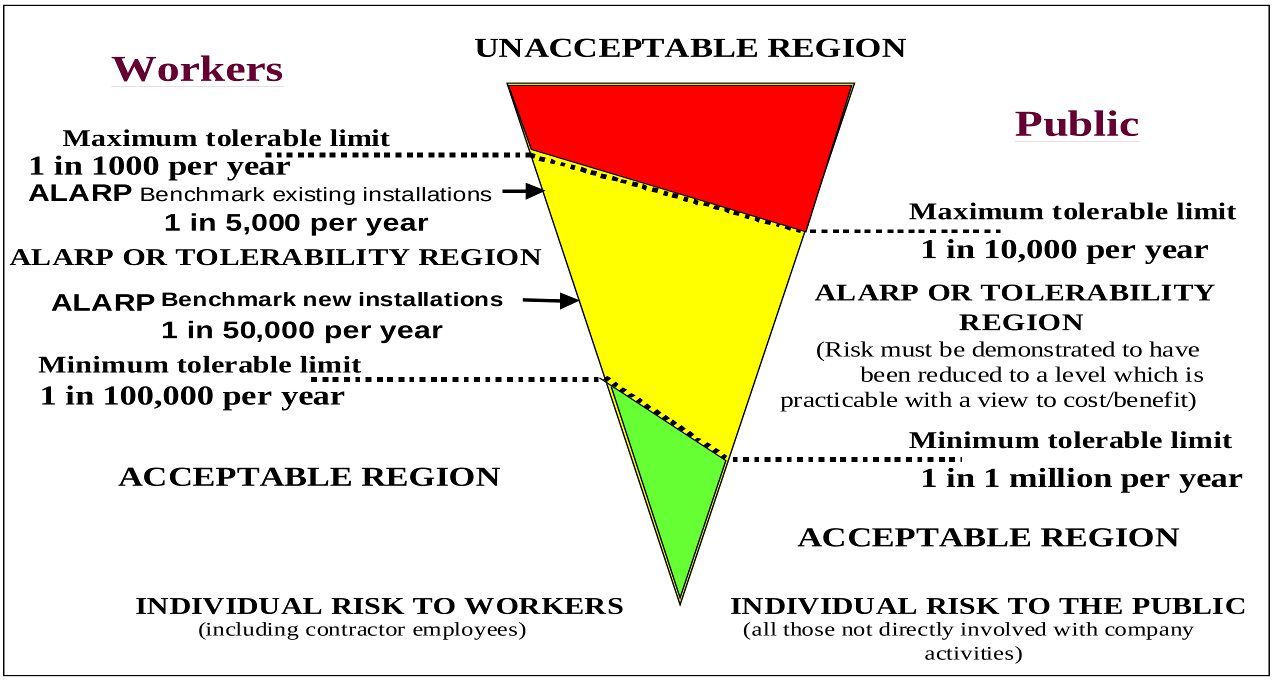


Figure 2. Criteria for Individual Risk Tolerability

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

It should be noted that these 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.*

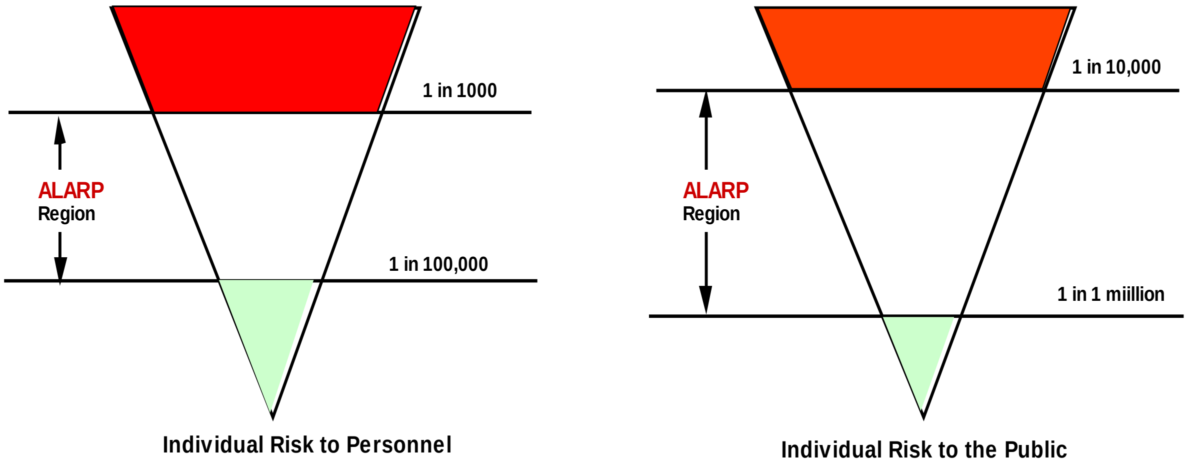


Figure 3. Proposed Individual Risk Criteria

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 uses 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 (International Data 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.

***Ref.1-** *OGP, International Association of Oil & Gas Producers, March 2010.*

***Ref.2-** *API 521.*

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 potential hazard.

Met-oceanographic data gathered from Weather base for Armant Area – Luxor 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 °C**		
	Min. Recorded	**14.0** °C
	Max. Recorded	**32.0** °C
	Annual Average	***25.0** °C*
• **Relative Humidity %**		
	Annual Average Morning	**53.0 %**
	Annual Average Evening	**29.0 %**
	Annual Average	***42.1 %***
• **Wind Speed m/s**		
	Annual Average	*2.5 m / sec.*
• **Wind Direction**		
	Annual Average	***WNW***

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

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

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temp. (c°)	14	16	20	26	30	32	32	32	30	27	20	16

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

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed (m/sec)	2.2	2.5	3.3	3.3	2.5	2.5	2.5	2.5	2.5	1.7	2.2	1.7

Table 10. Mean of Monthly Average Relative Humidity - Armant Area

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Relative Humidity (%)	55	50	40	35	30	30	30	35	40	45	55	60

Figure (4) shows the maximum temperatures diagram for Luxor Governorate (Armant Area)

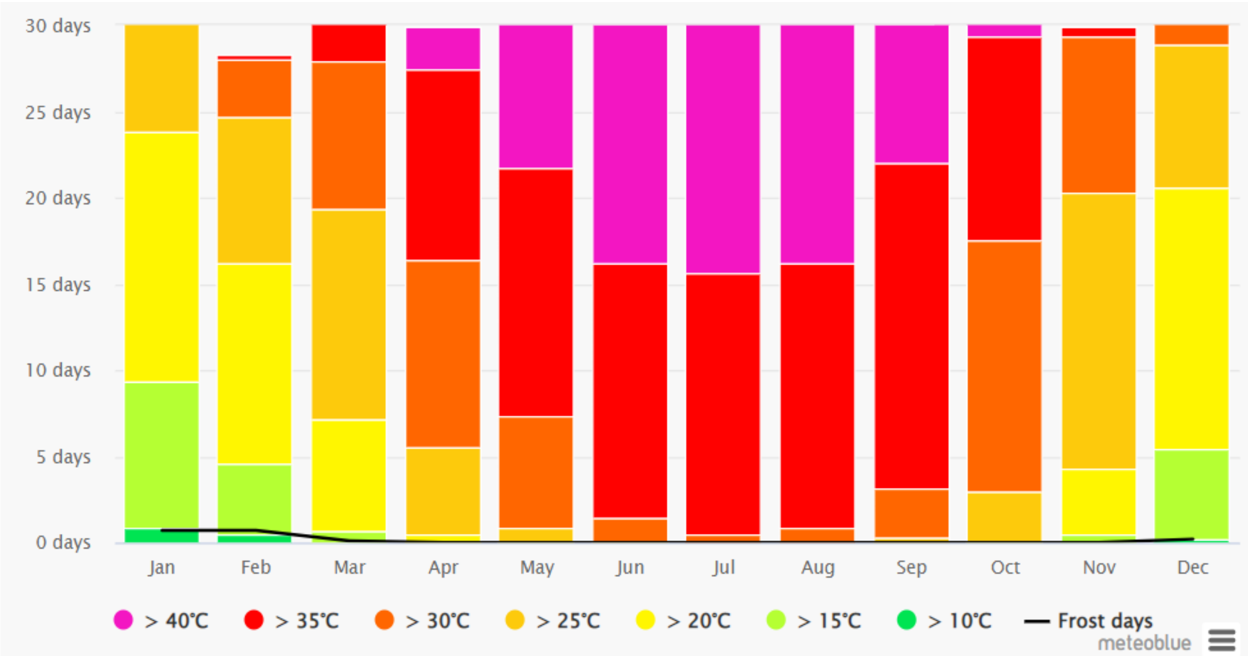


Figure 4. Monthly Variations of the Maximum Temperature for Armant Area

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

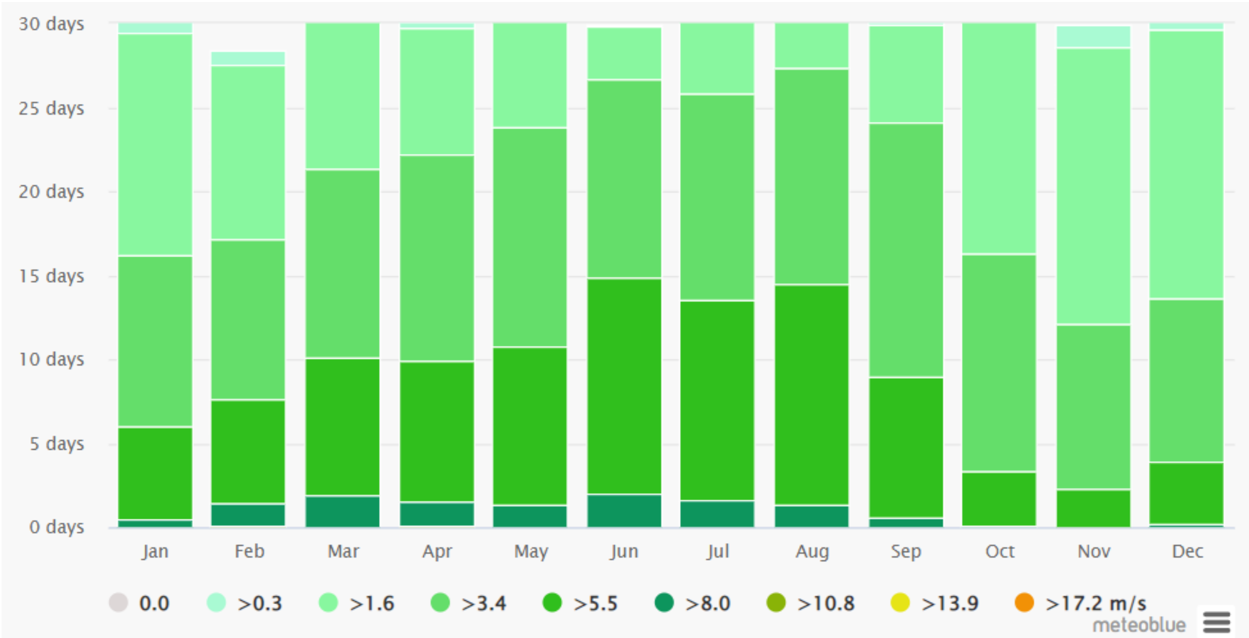


Figure 5. Monthly Variation of the Wind Speed for Armant Area

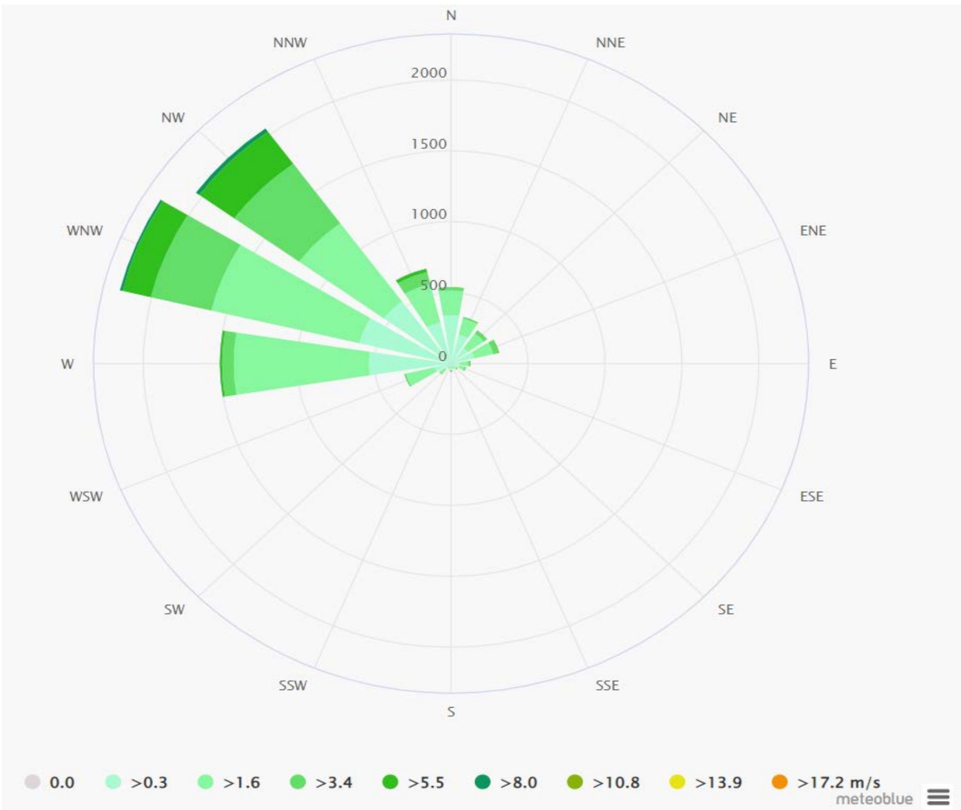


Figure 6. Wind Rose for Armant Area

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

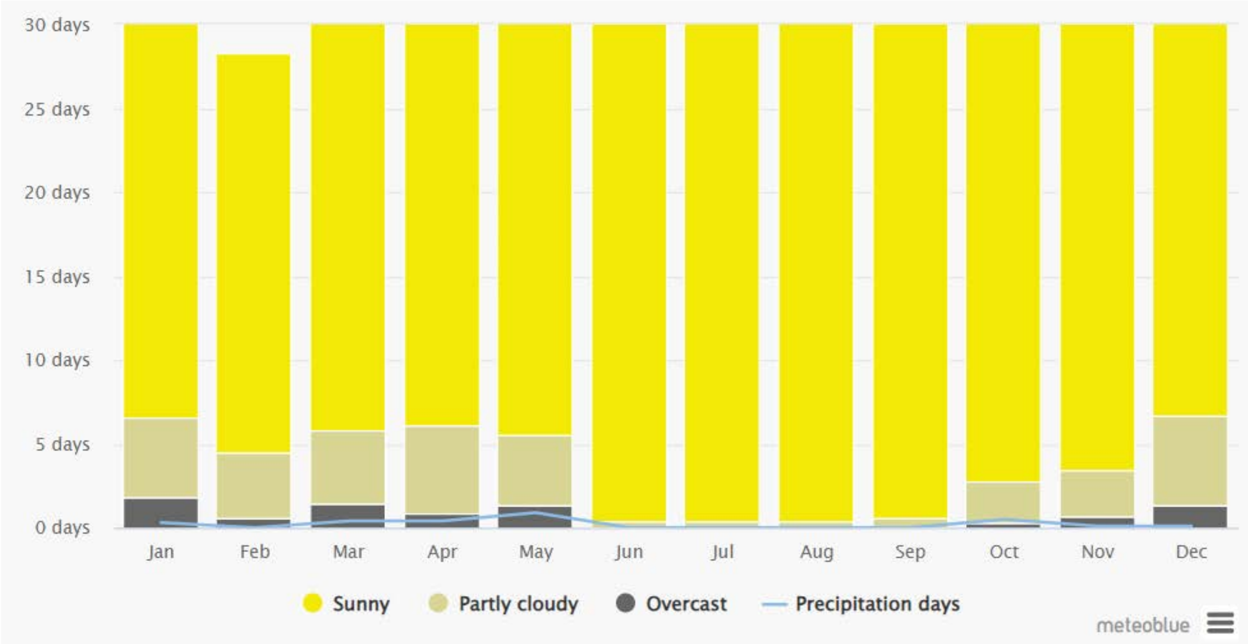


Figure 7. Monthly Variations of the Sunny, Cloudy and Precipitation days for Armant Area

-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 Selected for Current Study

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

Armant PRMS Description

Background

Armant Pressure Reduction and Metering Station is Operated by Egypt Gas Company. It is located at 7.2 km from Armant area and 4 km from Aswan Western Agricultural Road. The PRMS will provide the natural gas to Armant area and surrounding area public housing.

The PRMS feeding will be from the National Gas Pipeline owned by GASCO and the off-take point is located inside to the PRMS boundary. The off-take point pressure will be from 20 to 70 bar, later the pressure is reduced to 7 bar at the PRMS facilities following the adding of odorant. As for the last step of the station, the pipeline is connected to the internal distribution network to public housing at Armant and surrounding areas.

The PRMS Location Coordinates (Egypt Gas Data)

Table 14. Location Coordinates of PRMS

	PRMS	
Point	**North (N)**	**East (E)**
1	25°40'8.33"	32°29'23.12"
2	25°40'10.06"	32°29'25.82"
3	25°40'7.06"	32°29'27.88"
4	25°40'5.32"	32°29'25.13"

PRMS Brief Description and Component list (Egypt Gas Data)

The PRMS will be surrounded by 3 m height fence and mainly consist of the following:

- Inlet module: which contains 4" pipeline #600 RF isolation inlet manual ball valve.
- Filter module: two identical streams each contain required instrumentation and valves + 1m^3 Condensate tank + one future connections with manual ball valve DN4" #600.
- Heating system module: Inlet and outlet header DN3" #600.
- Metering module: two identical existing each with one inlet manual isolation ball valve DN3" #600 + one future connection DN3" #600.
- Regulating module: two identical regulating lines existing each with one inlet manual isolation ball valve DN3" #600 + one future connection DN3" #600 to WBH.

- Outlet module: contains DN6" #150 butterfly valve/ manual ball valve.
- Odorant module: 600 lit. capacity bulk tank / 50 lit. daily usage
- Off-take point: from up-ground room surrounded by 1 m height brick wall fence containing connection pipes and isolation valves with GASCO underground pipeline 24", connected to 4" PRMS feeding pipeline. inside the PRMS boundary.
- Two Guard rooms (one floor)
- Administration office (one floor)
- Firefighting Facilities (Fire Water Tank / Pumps / Fire water Network / Powder Fire Extinguishers)

Armant PRMS Units (Egypt Gas Data)

Table 15. Armant PRMS Units

No	PRMS Units	Capacity	Size
1	***Inlet unit***		
	Inlet valve	5000 scmh	4″
	Inlet valve bypass (ball + plug)		2″
2	***Filter units***		
	Line Fl	5000 scmh	3″ * 2″
	Line F2	5000 scmh	3″ * 2″
	Line F3(only two valves)	5000 scmh	3″ * 2″
3	***Meter unit***		
	Line Ml	5000 scmh	3″ * 4″ * 3″
	Line M2	5000 scmh	3″ * 4″ * 3″
4	***Heater unit***		
	Line Hl (150 kw)	----	----
	Heater bypass Line	----	----
	Line H2 (only two valves)	----	----
5	***Regulator unit***		

	Line Rl	5000 scmh	2″ * 4″
	Line R2	5000 scmh	2″ * 4″
	One extension ball valve on inlet header (future heater)		
6	***Odorant unit***		
	Electrical pumps		
	Lapping system		
7	***Outlet unit***		
	Outlet valve	5000 scmh	6″
	Extension valve (future)		
8	***Monitoring and Control unit***		
9	***Generator (15 KVA)***		
10	***UPS***		

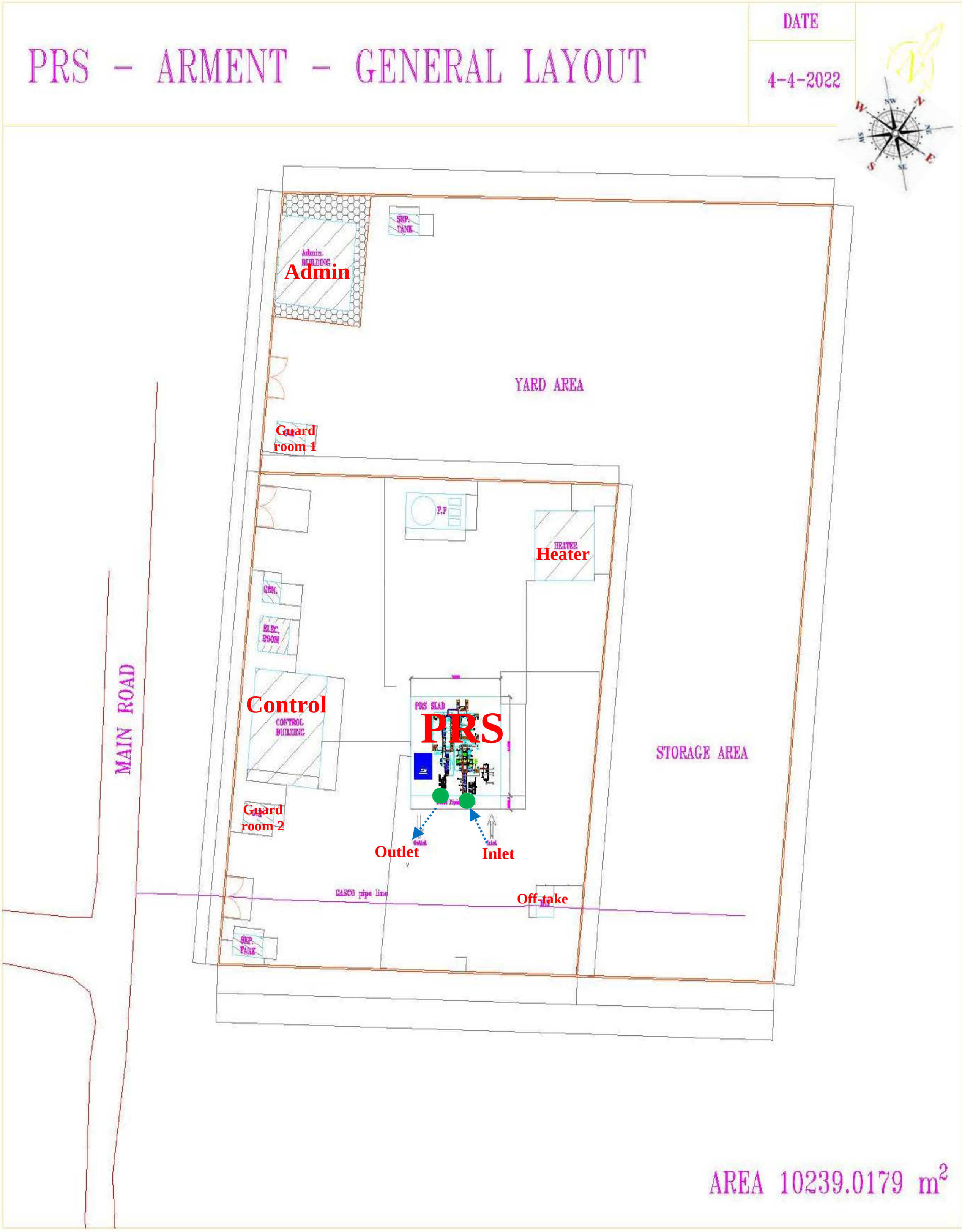


Figure 8. Armant PRMS Layout

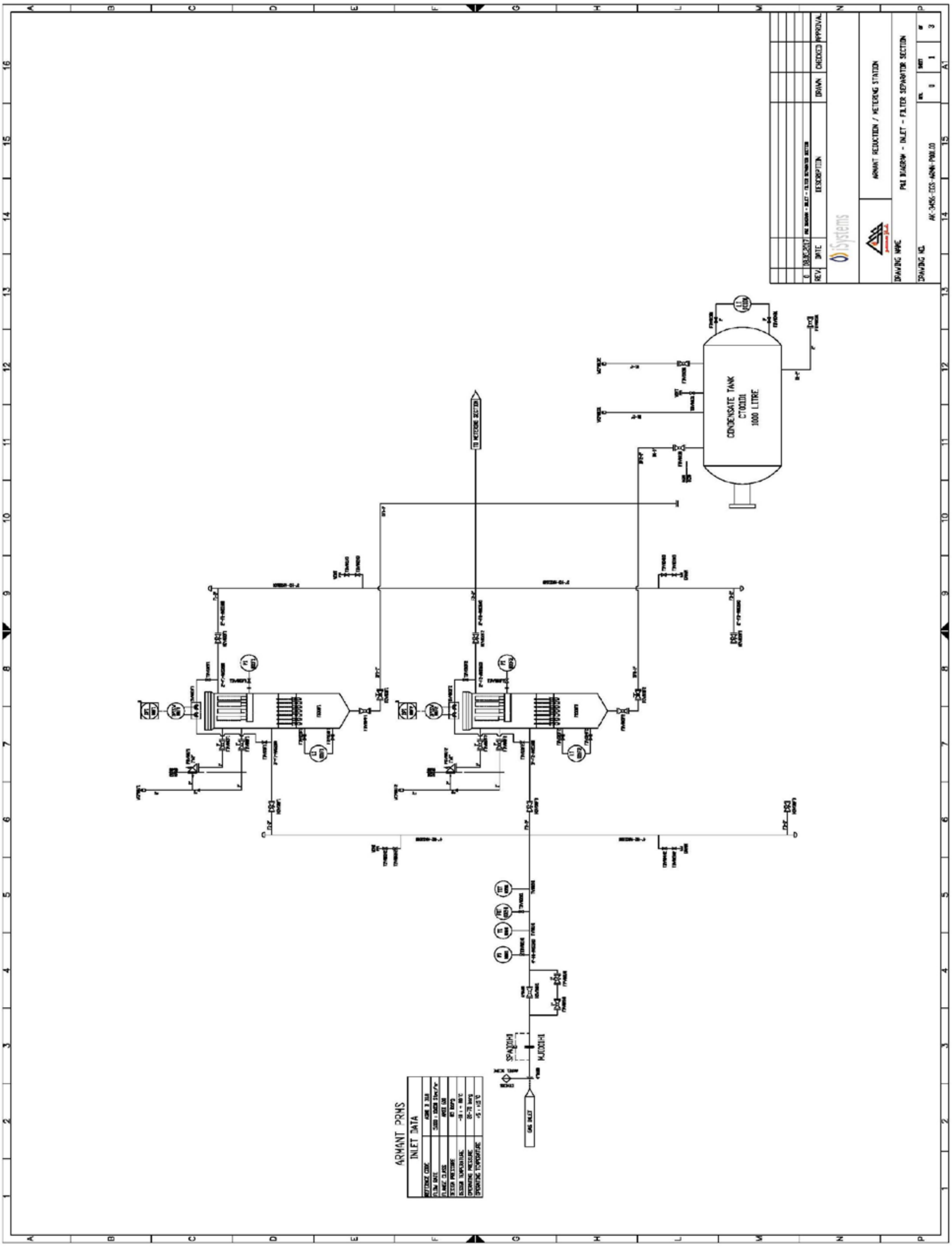


Figure 9. Armant PRMS Piping and Instrumentation Diagram "P&ID" (Inlet and filter section)

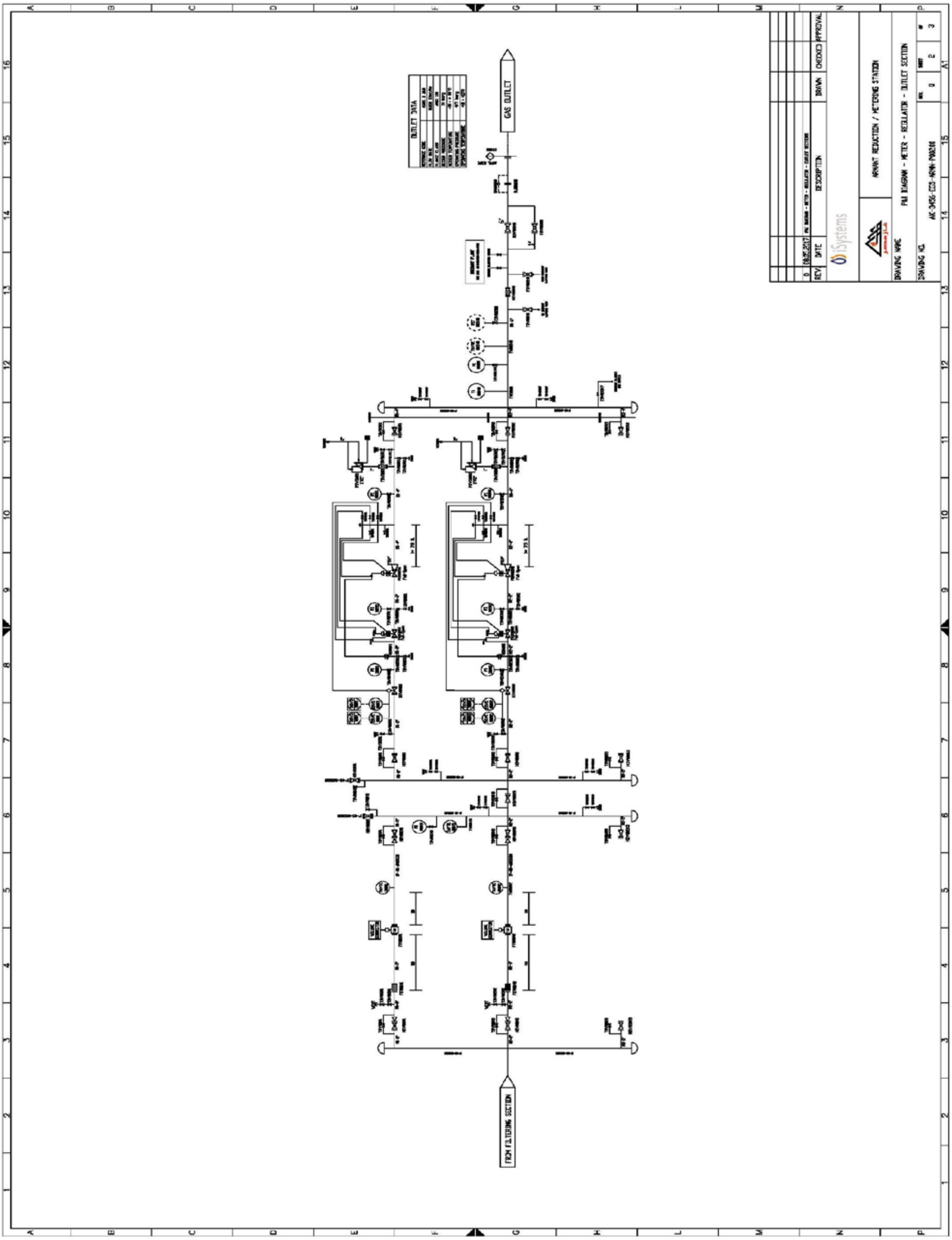


Figure 10. Armant PRMS Piping and Instrumentation Diagram "P&ID" (Metering, Regulating and Outlet section)

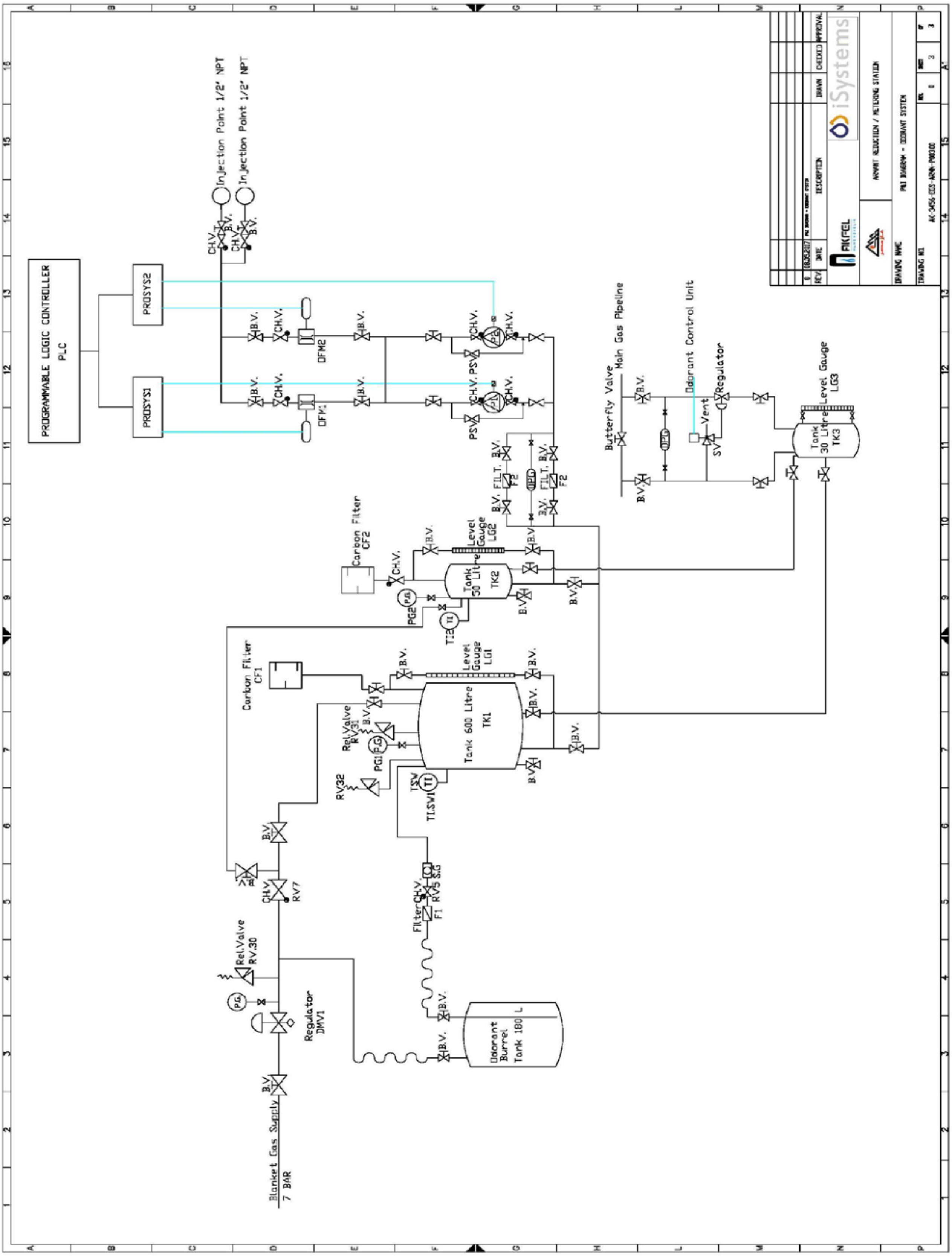


Figure 11. Armant PRMS and Surroundings Plotted on Google Earth Photo

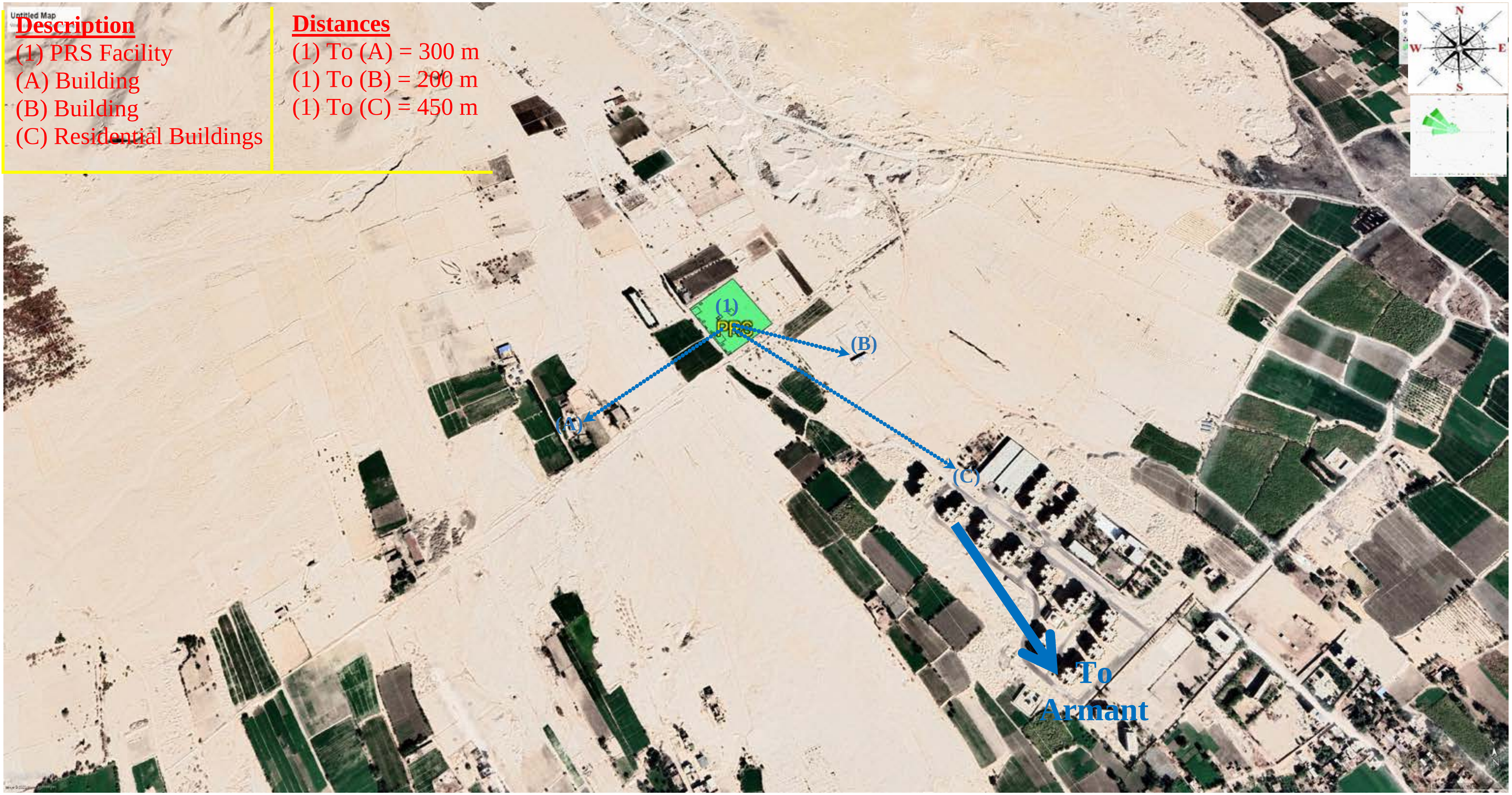


Figure 12. Armant PRMS and Surroundings Plotted on Google Earth Photo

The following *Table 16.* describes the process conditions for Armant PRMS:

Table 16. Process Conditions / Gas Components and Specifications

Process Conditions	
Maximum flow rate scm / hr	10,000
future flow rate scm / hr	20,000
Design pressure bar g	70
Min / Max inlet pressure bar g	70/20
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

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

PEL: 10 PPM according to OSHA, TWA (NIOSH): 0.5 ppm not to be exceeded during any 15 minute work period. "Refer to Annex 5 of PRS ESIA"

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

The PRMS will provided by the following fire protection facilities:

- Firewater tank with a capacity of 40 cubic meters.
- Firewater pumps (1 Electrical & 1 Diesel with capacity of 250 gpm each) + one Jockey pump.
- Firewater main with a diameter of 4 inch.
- Four Firewater hydrants (each with a diameter of 3 inch)
- Firewater monitors.
- Smoke detectors in control rooms according to the area.
- Different sizes of fire extinguishers will be distributed at PRMS site.

Emergency Response Plan “ERP”

There is a general Emergency Response Plan “ERP” for Egypt Gas PRMS, including the following items:

- Calling Plan
- Emergency Cases and Scenarios at Main PRSs
- Emergency Procedures in case of Significant Risks
- Emergency Procedures in case of Normal Risks
- Possible causes of these scenarios and their precaution procedures

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. (17) Shows that:

Table 17. 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)**
2.5 D	UFL	2.2	1.1	0.2 @ 1.4 m
	LFL	7	1.3	0.6 @ 4 m
	50 % LFL	14.2	1.7	1.4 @ 9 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	12.3	1.6	20	13.9	0
		4	16.9	8.7	0
		9.5	14.6	5.2	0
		12.5	14	4.3	20% /60 sec.
		25	12.2	2	80.34
		37.5	10.9	0.7	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	13.6	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	3.5	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	2.7	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

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

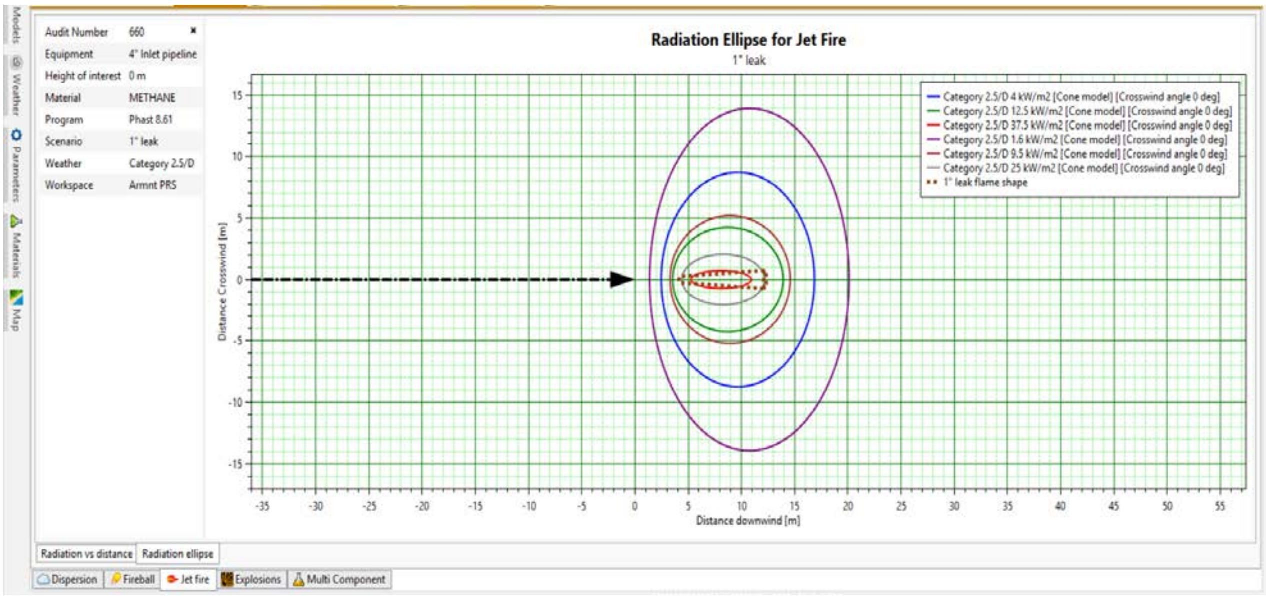


Figure 14. Heat Radiation Contours from Jet Fire (1" hole in 4" Inlet Pipeline

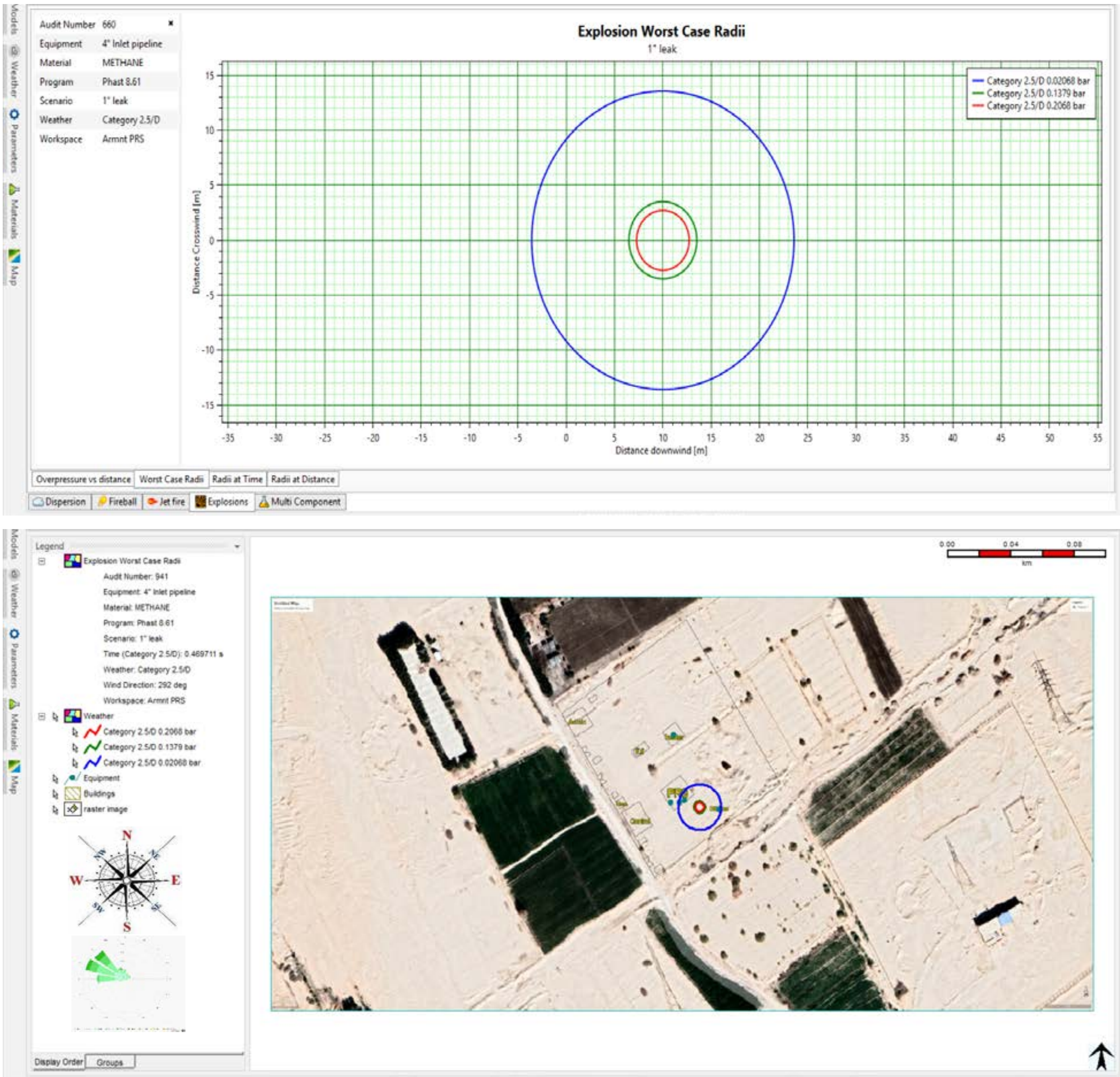


Figure 15 Worst-Case Explosion Overpressure Waves (1” hole in 4” Inlet Pipeline)

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

The following table no. (18) Shows that:

Table 18. 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)**
2.5 D	UFL	5.5	1.2	0.4 @ 3 m
	LFL	18.5	0 – 1.8	1.6 @ 10 m
	50 % LFL	28.5	0 – 2.8	2.8 @ 20 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m²)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	26.7	1.6	54.4	42.9	0
		4	43	27.2	0
		9.5	36.2	17.6	0
		12.5	34.5	15.1	20% /60 sec.
		25	30.5	9.8	80.34
		37.5	27.8	7	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	26	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	6.7	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	5.2	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Figure 16. Gas Cloud Side View (UFL/LFL) (2" hole in 4" Inlet Pipeline

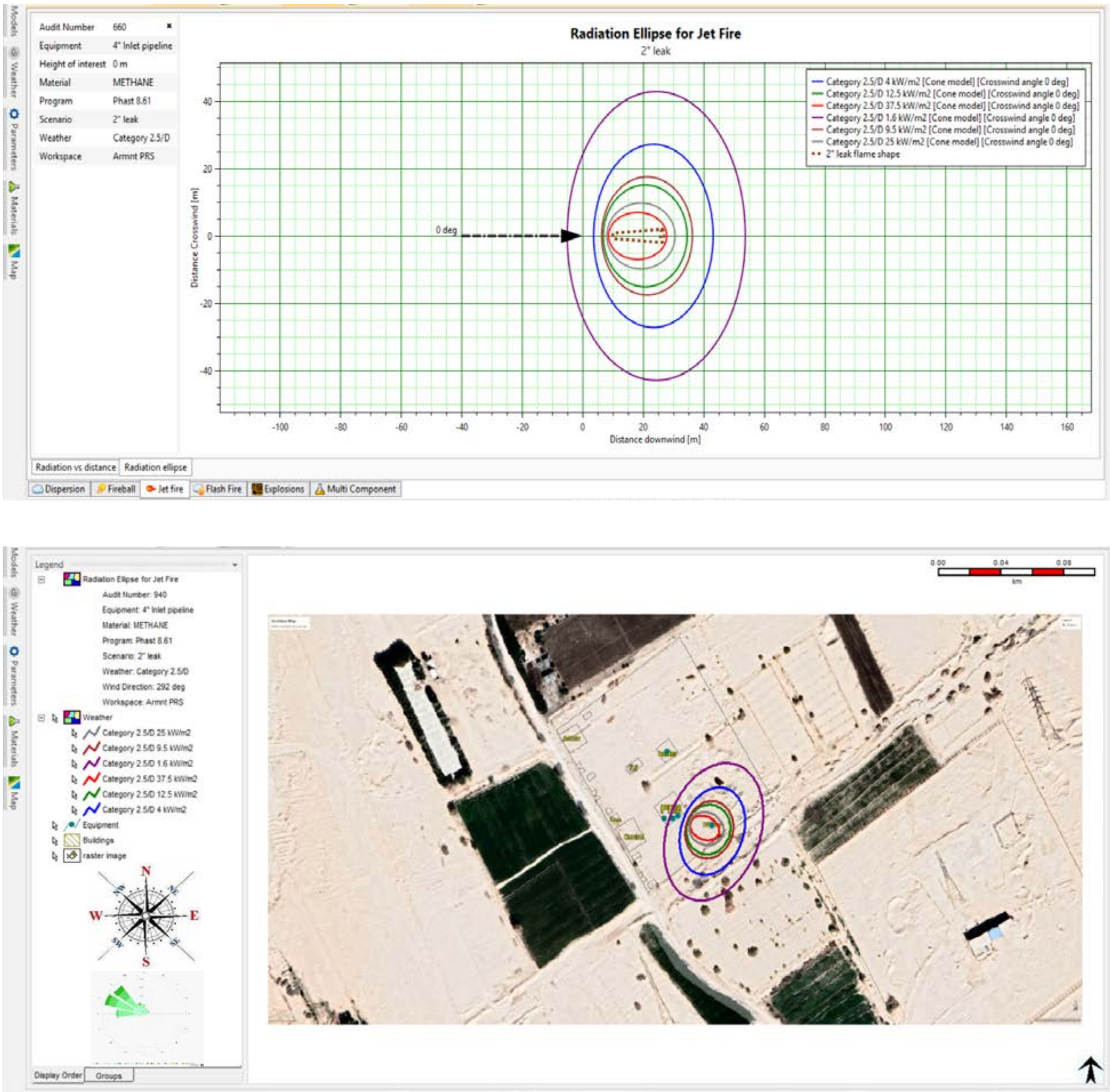


Figure 17. Heat Radiation Contours from Jet Fire (2” hole in 4” Inlet Pipeline)

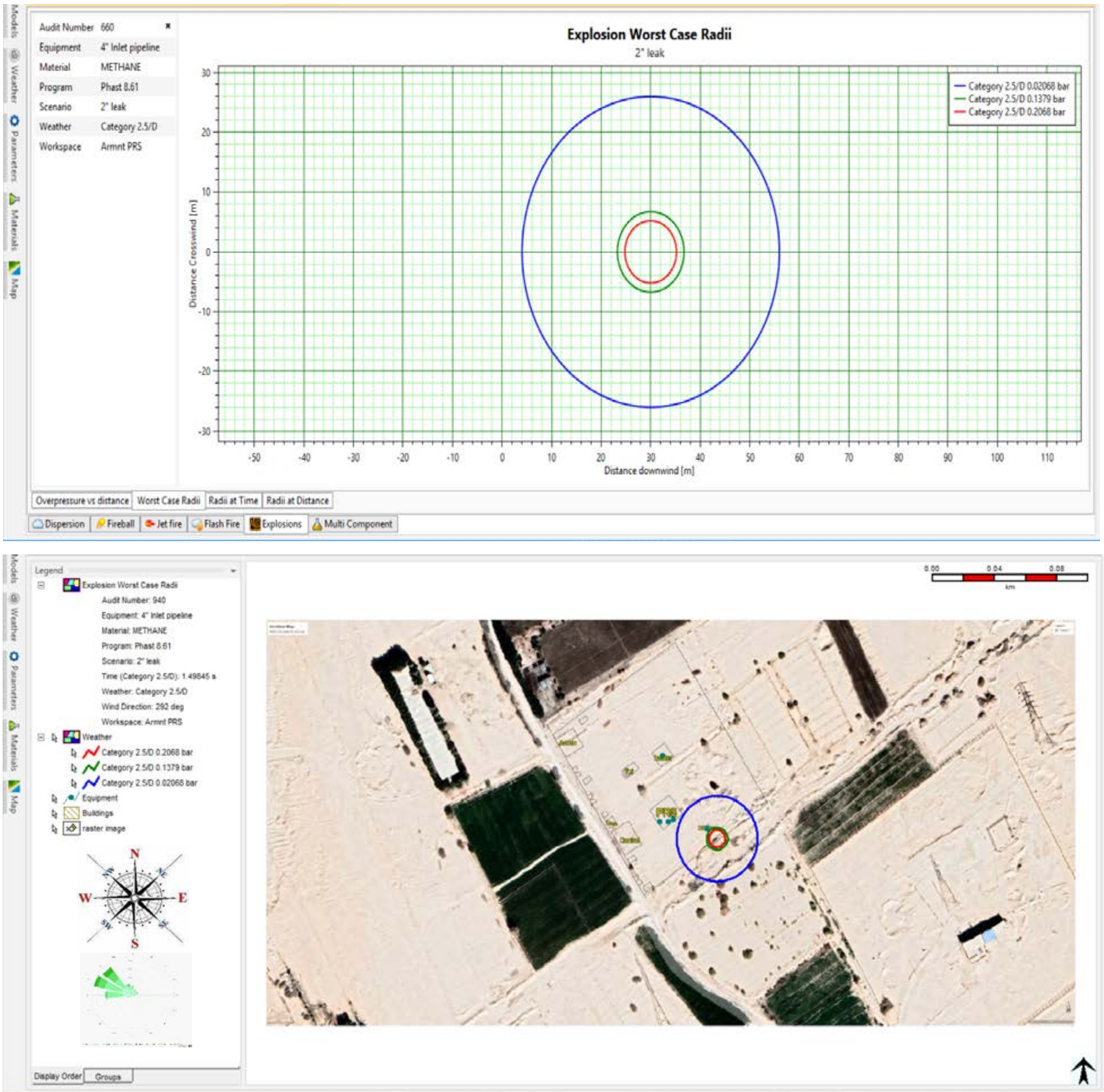


Figure 18. Worst-Case Explosion Overpressure Waves (2" hole in 4" Inlet Pipeline)

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

The following table no. (19) Shows that:

Table 19. Dispersion Modeling for Inlet - 4" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	8	1.4	0.7 @ 4 m
	LFL	18.5	0 – 2.2	2.2 @ 14 m
	50 % LFL	21	0 – 2.9	2.9 @ 16 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	55.9	1.6	131.3	107	0
		4	101.6	68.7	0
		9.5	82.8	44.7	0
		12.5	78	38.8	20 %/60 sec.
		25	67.8	26.3	80.34
		37.5	62	20	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	54.9	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	6.8	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	5.3	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Figure 19. Gas Cloud Side View (UFL/LFL) (4" Inlet Pipeline Full Rupture)

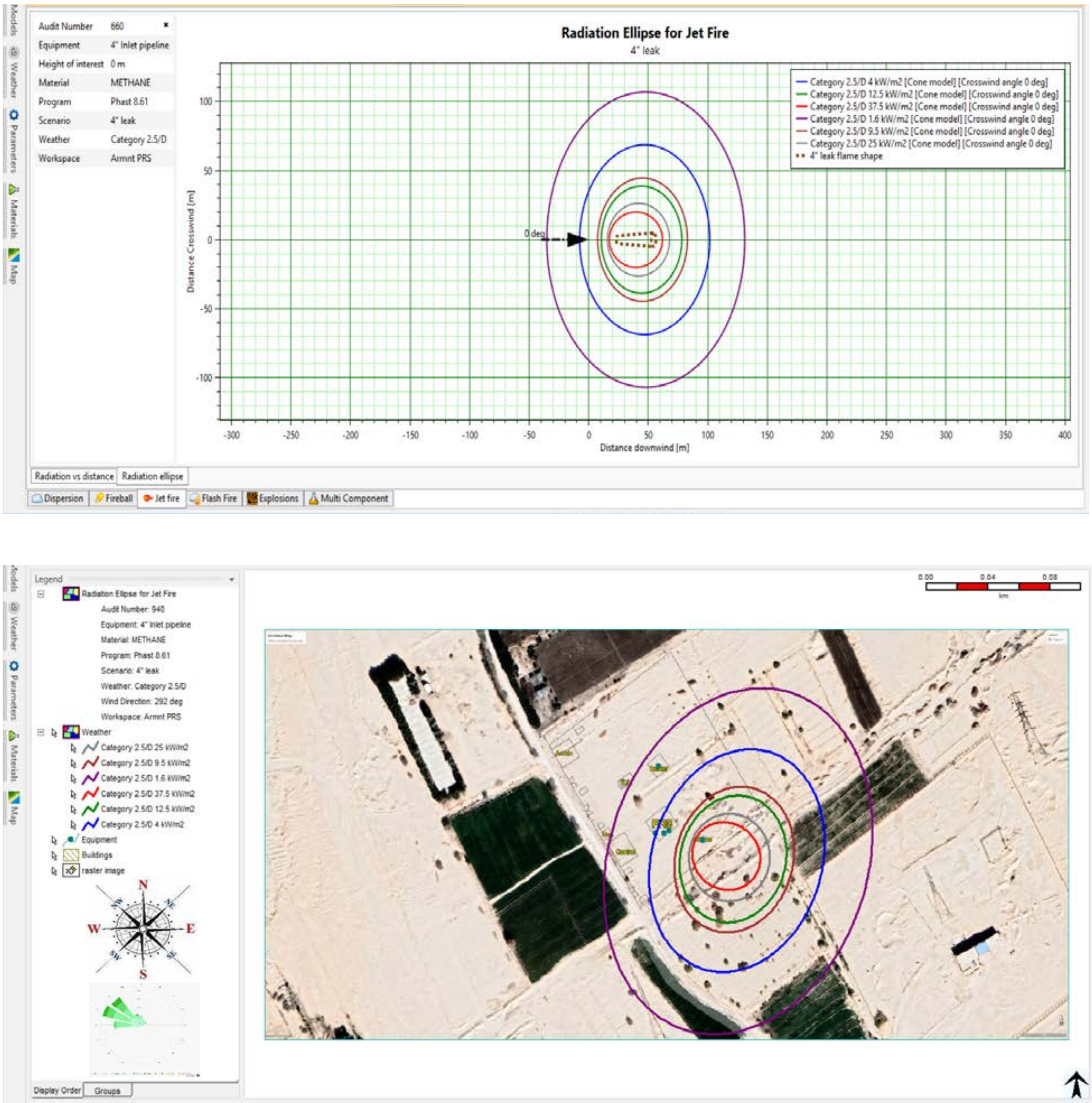


Figure 20. Heat Radiation Contours from Jet Fire (4" Inlet Pipeline Full Rupture

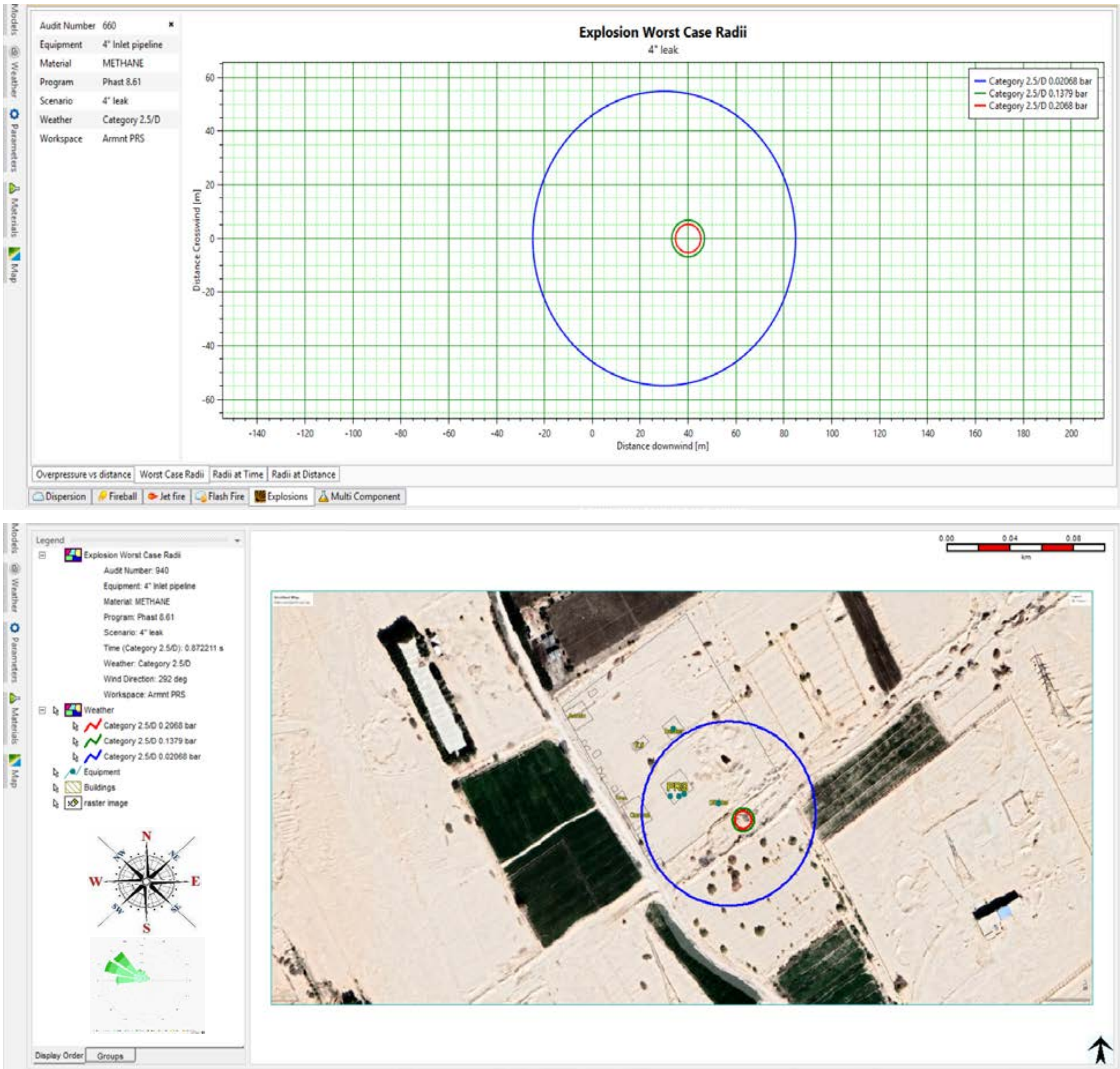


Figure 21. Worst-Case Explosion Overpressure Waves (4" Inlet Pipeline Full Rupture

2.0.Pressure Reduction Station Outlet Pipeline (6 inch)

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

The following table no. (20) Shows that:

Table 20. 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)
2.5 D	UFL	1	1.05	0.07 @ 0.5 m
	LFL	3.1	1.15	0.3 @ 2 m
	50 % LFL	5.5	1.3	0.6 @ 3.5 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	5.7	1.6	7.6	3.9	0
		4	6	2	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)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

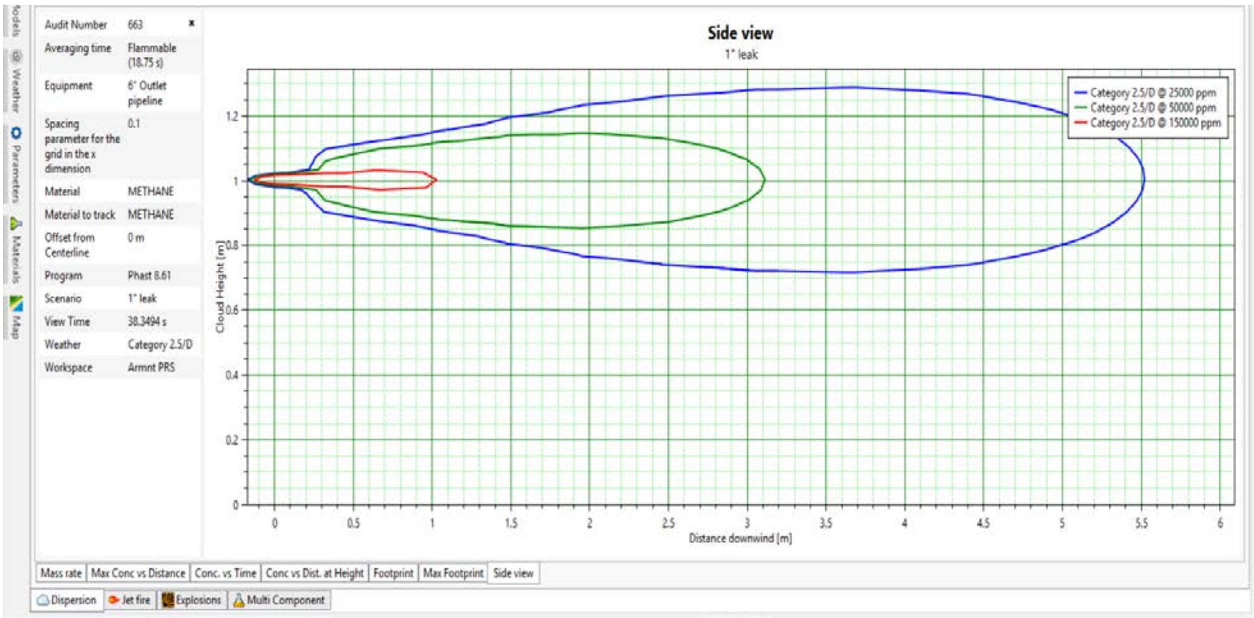


Figure 22. Gas Cloud Side View (UFL/LFL) (1" hole in 6" Outlet Pipeline

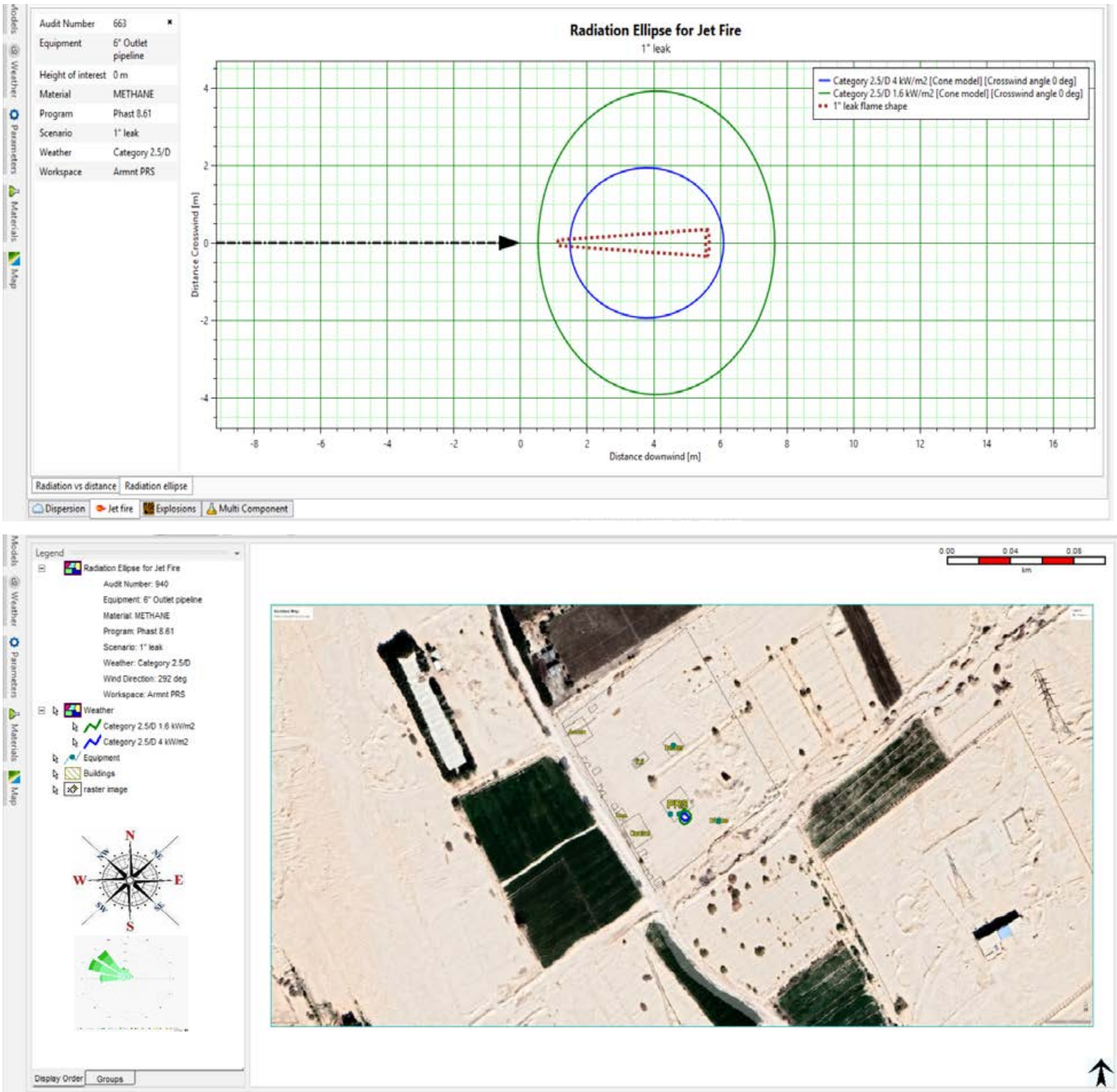


Figure 23. Heat Radiation Contours from Jet Fire (1" hole in 6" Outlet Pipeline)

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

The following table no. (21) Shows that:

Table 21. Dispersion Modeling for Outlet - 3" / 6" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance** (m)	**Height** (m)	**Cloud Width** (m)
2.5 D	UFL	3.5	1.2	0.3 @ 2 m
	LFL	11	1.5	1 @ 6 m
	50 % LFL	25	0 - 2.1	2.1 @ 14 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	18	1.6	33	24.3	0
		4	26.7	15.6	0
		9.5	22.7	9.7	0
		12.5	21.6	8.1	20% /60 sec.
		25	18.5	4.6	80.34
		37.5	17.5	2.8	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	21.5	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	5.6	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	4.3	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

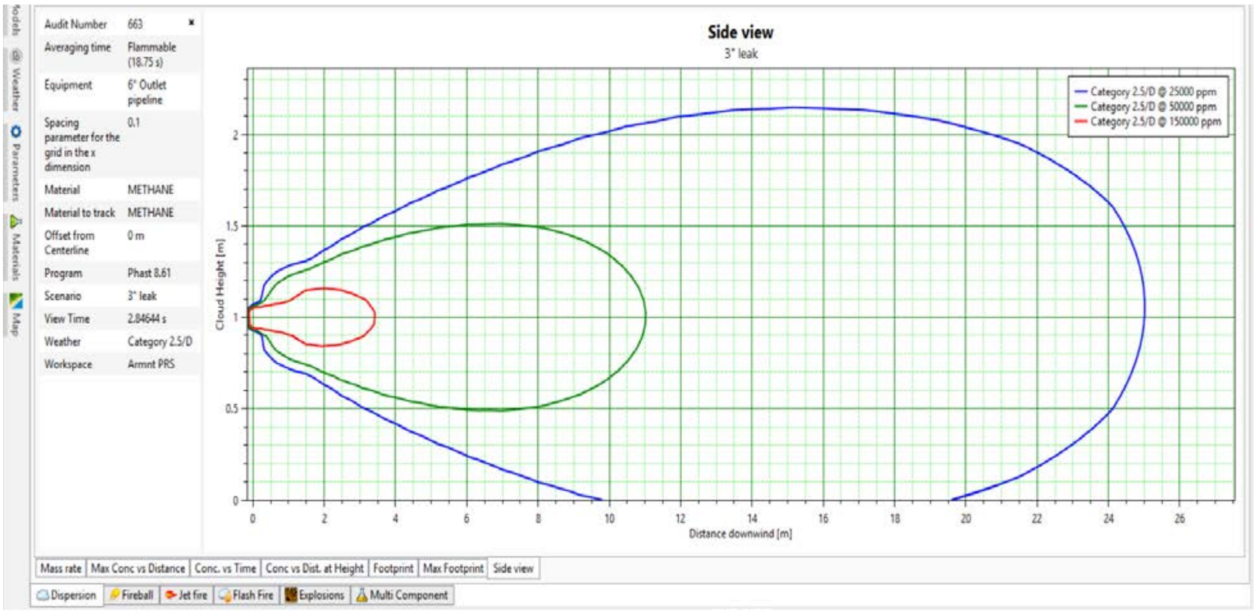


Figure 24. Gas Cloud Side View (UFL/LFL) (3" hole in 6" Outlet Pipeline

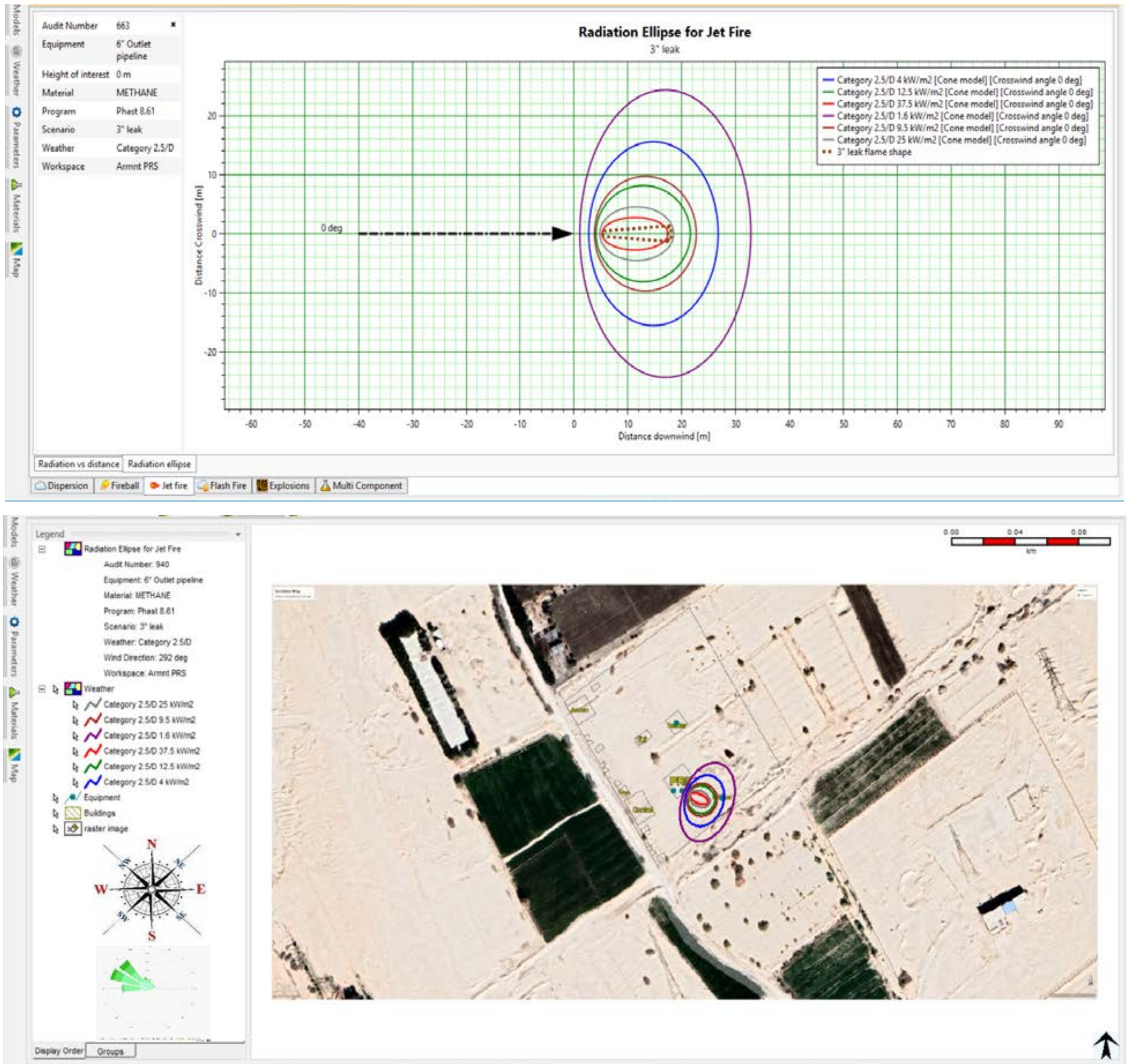


Figure 25. Heat Radiation Contours from Jet Fire (3" hole in 6" Outlet Pipeline)

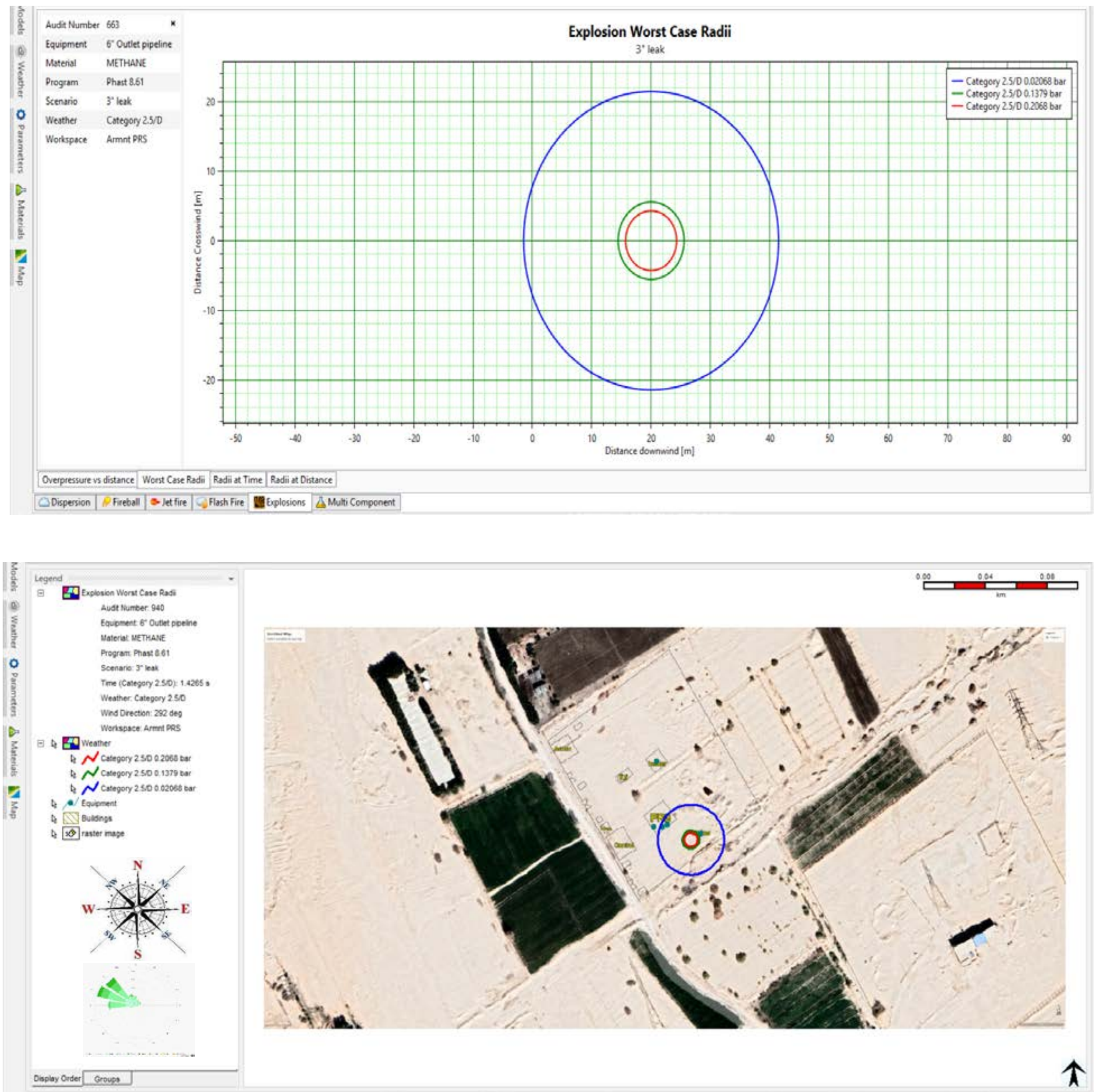


Figure 26. Worst-Case Explosion Overpressure Waves (3" hole in 6" Outlet Pipeline)

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

The following table no. (22) Shows that:

Table 22. Dispersion Modeling for Outlet - 6" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	7	1.4	0.6 @ 4 m
	LFL	22	0 - 2.2	2.2 @ 14 m
	50 % LFL	26	0 - 3.1	3.1 @ 19 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m²)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	37	1.6	80.8	65.4	0
		4	63.1	41.7	0
		9.5	52	26.9	0
		12.5	49.3	23.2	20% /60 sec.
		25	43	15.2	80.34
		37.5	38.8	11	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	44.8	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	11.6	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	9	**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**
2.5 D	4	37.8	**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*
	12.5	21.3	
	37.5	11.6	

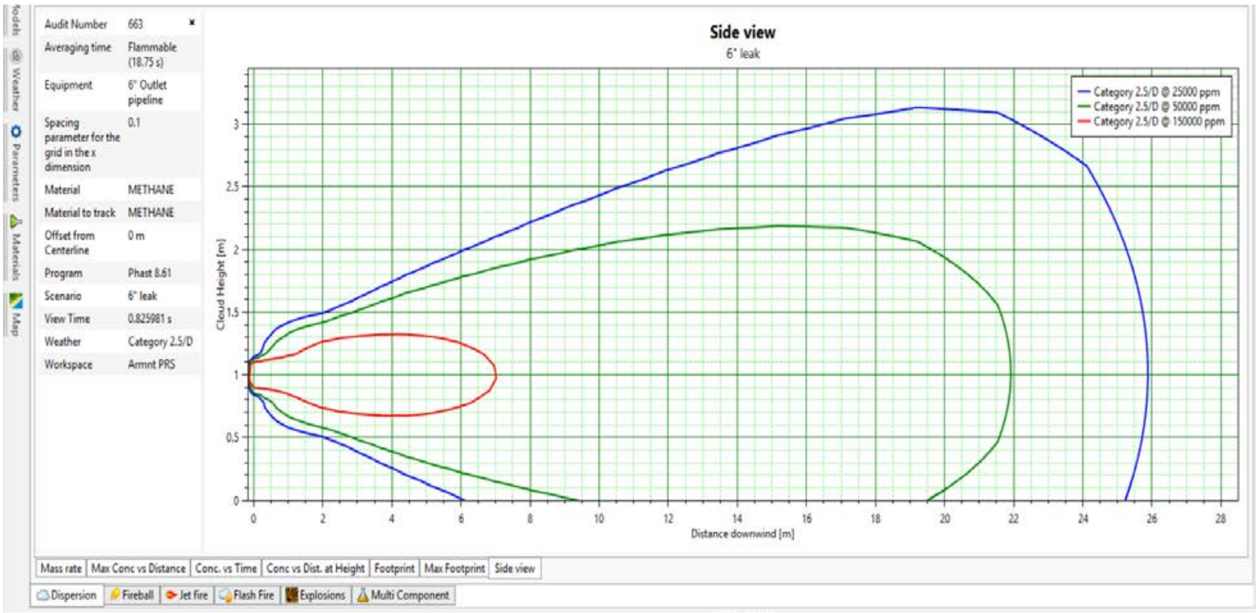


Figure 27. Gas Cloud Side View (UFL/LFL) (6" Outlet Pipeline Full Rupture)

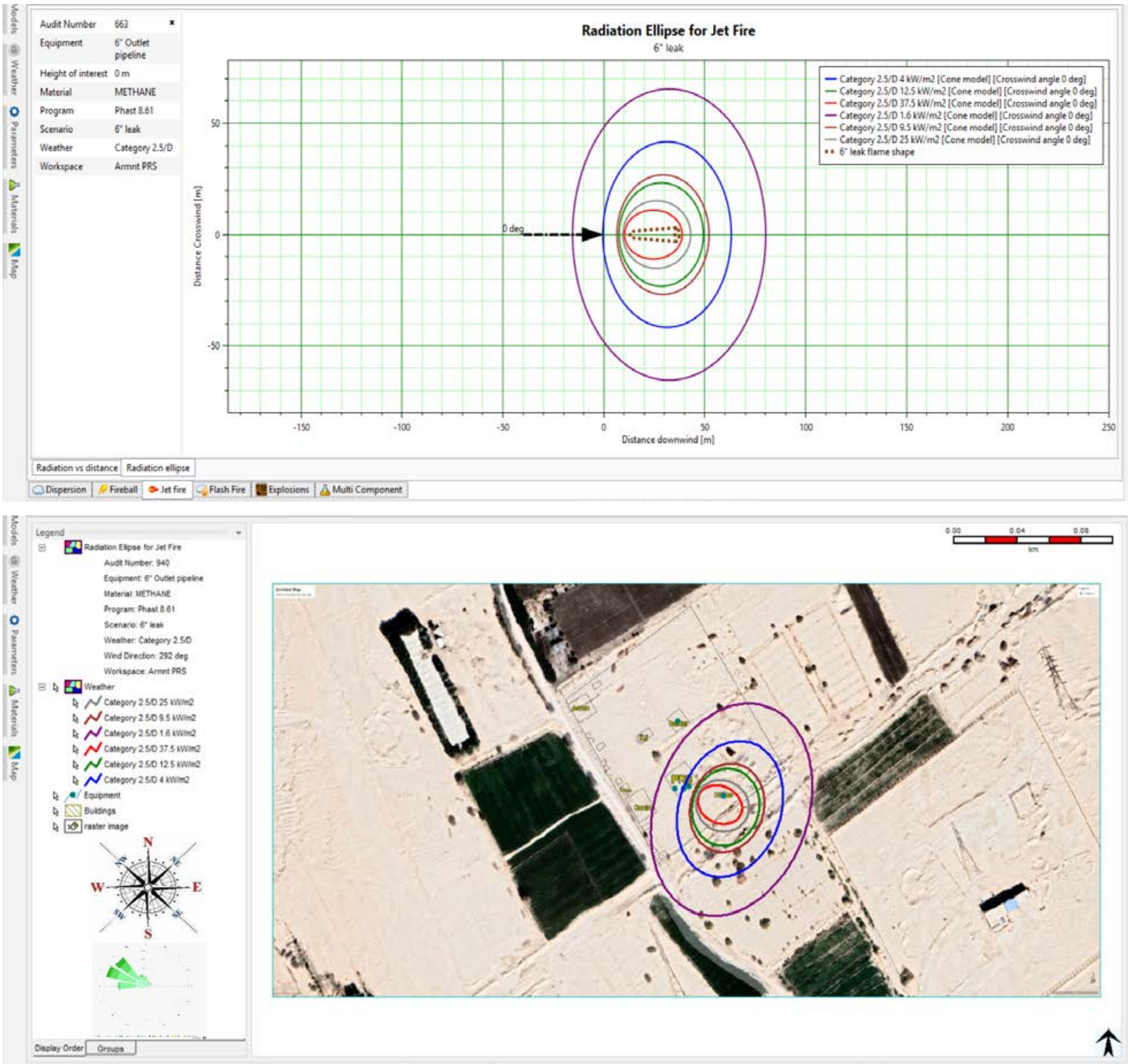


Figure 28. Heat Radiation Contours from Jet Fire (6" Outlet Pipeline Full Rupture)

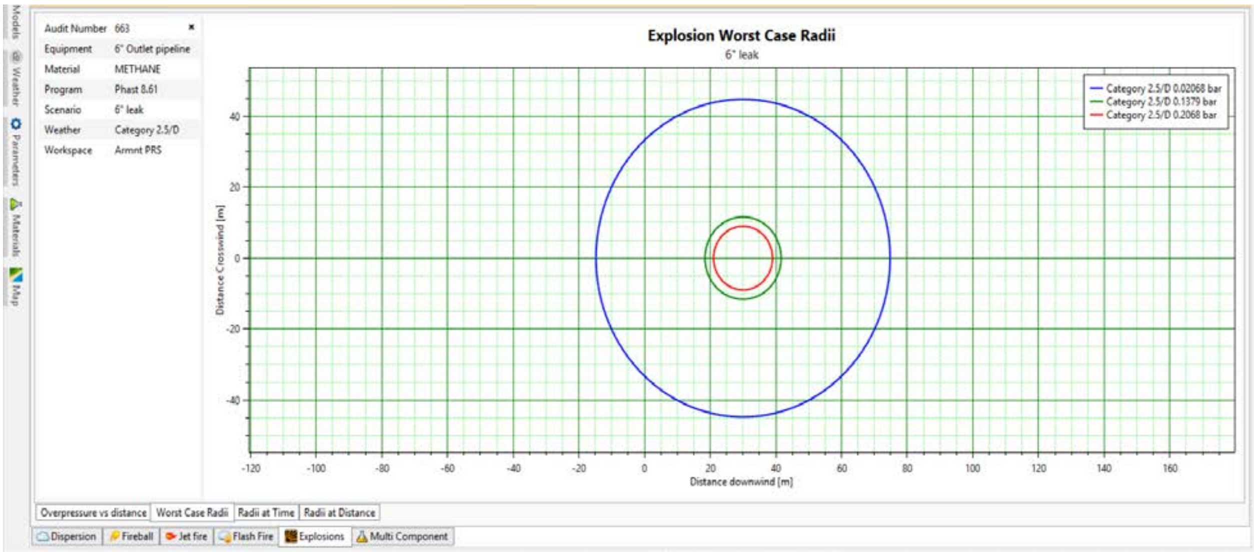


Figure 29. Worst-Case Explosion Overpressure Waves (6" Outlet Pipeline Full Rupture)

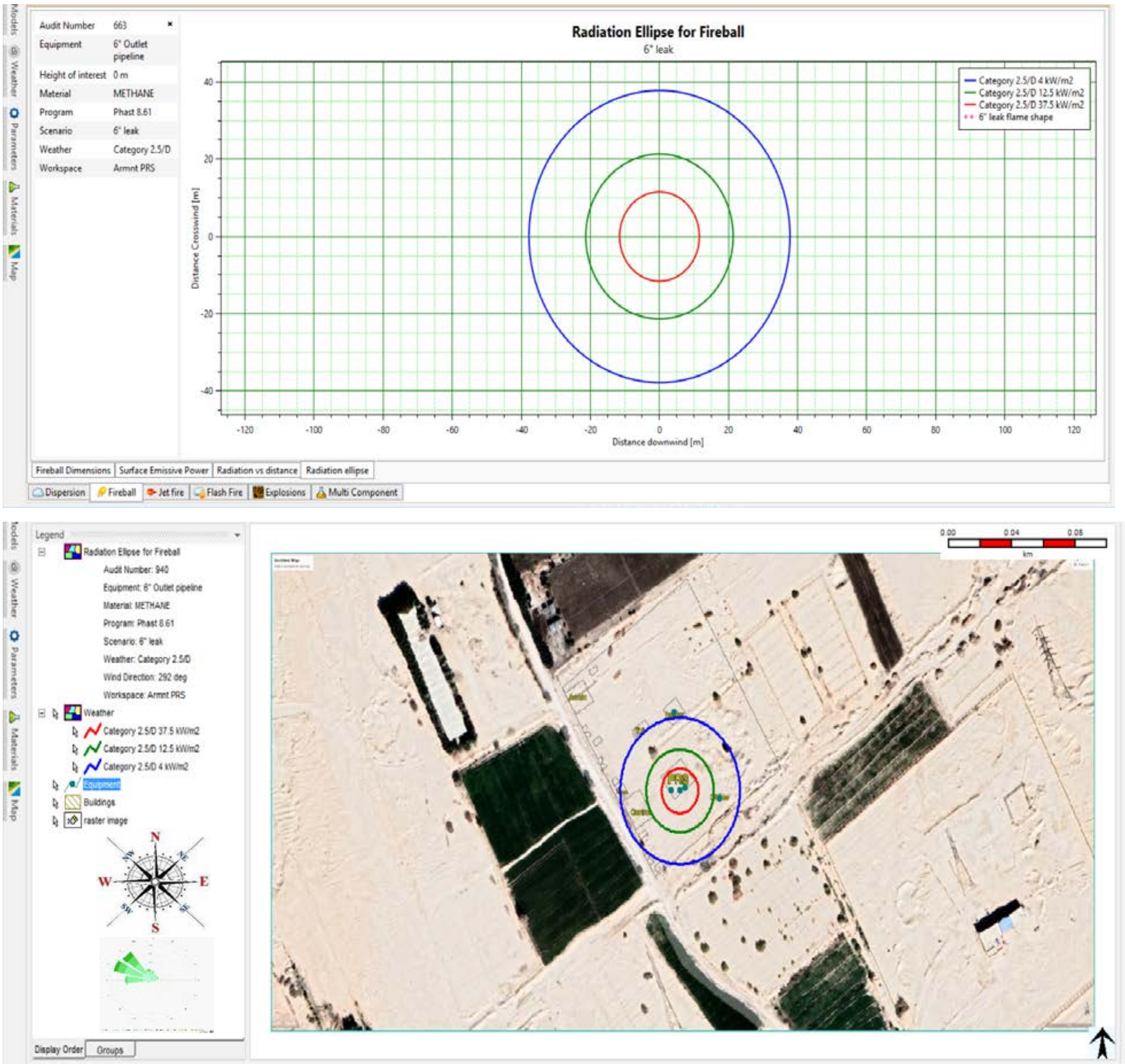


Figure 30. Heat Radiation Contours from Fireball (6" Outlet Pipeline Full Rupture)

3.0.Pressure Reduction Station Odorant Tank (Spotleak)

The following table no. (23) Shows 1" hole leak form odorant Modeling:

Table 23. Dispersion Modeling for Odorant Tank

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	25	0 – 0.2	15
	LFL	65	0 – 0.7	45
	50 % LFL	89	0 – 1	60

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	17.4	1.6	26	26	0
		4	16.8	16.8	0
		9.5	12.2	10.8	0
		12.5	11.3	9.1	20% /60 sec.
		25	9.3	5	80.34
		37.5	8.2	3.2	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	35.5	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	9.2	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	7.1	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

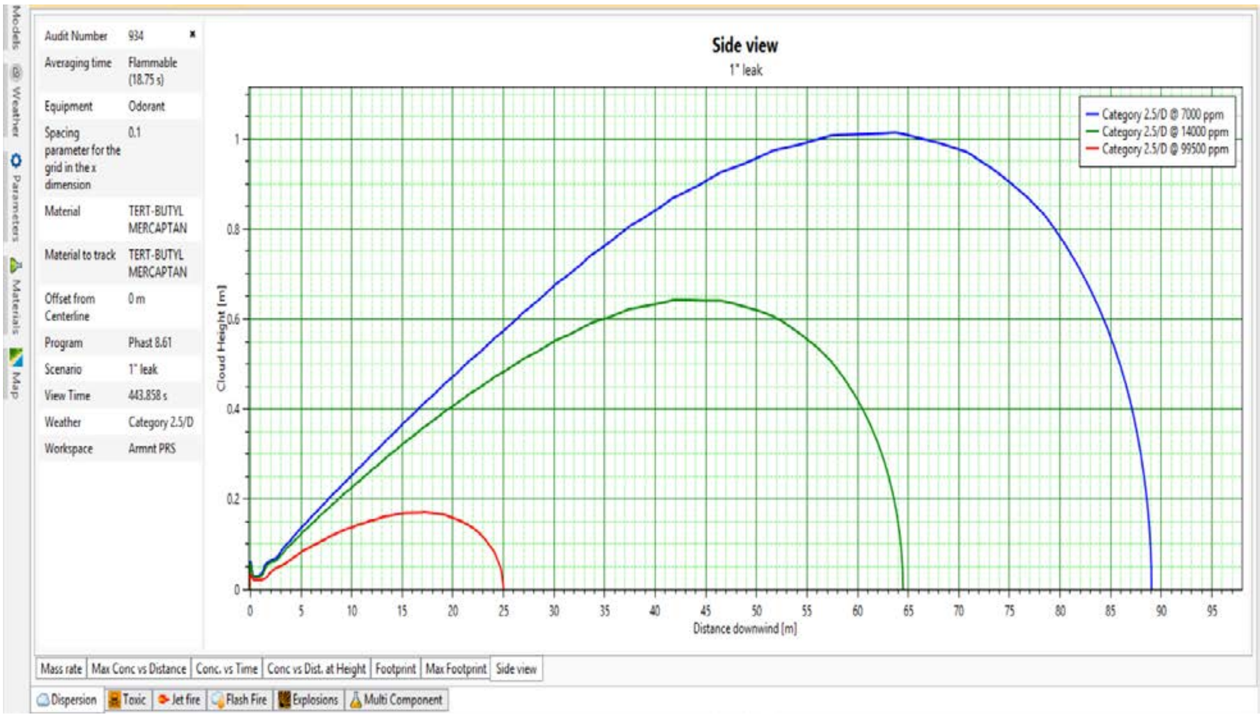


Figure 31. Vapor Cloud (UFL/LFL) Side View Graph (Odorant leak)

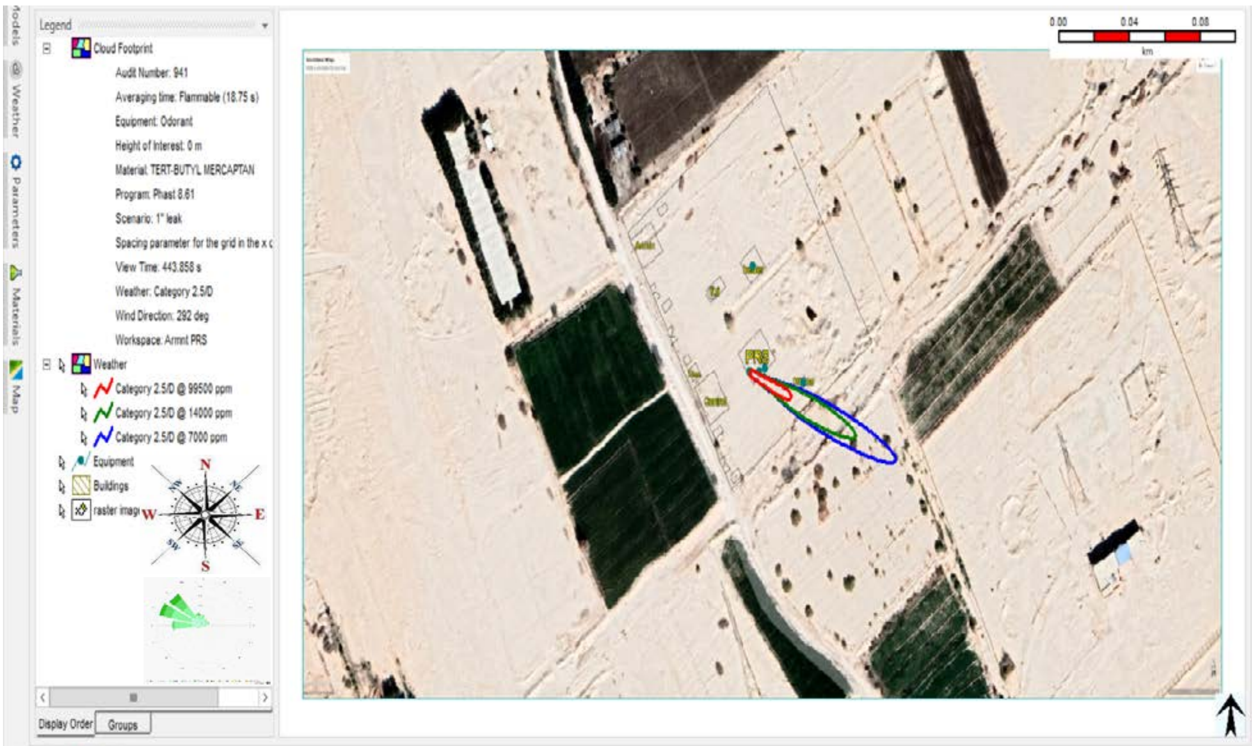


Figure 32. Cloud Footprint (UFL/LFL) on site (Odorant leak

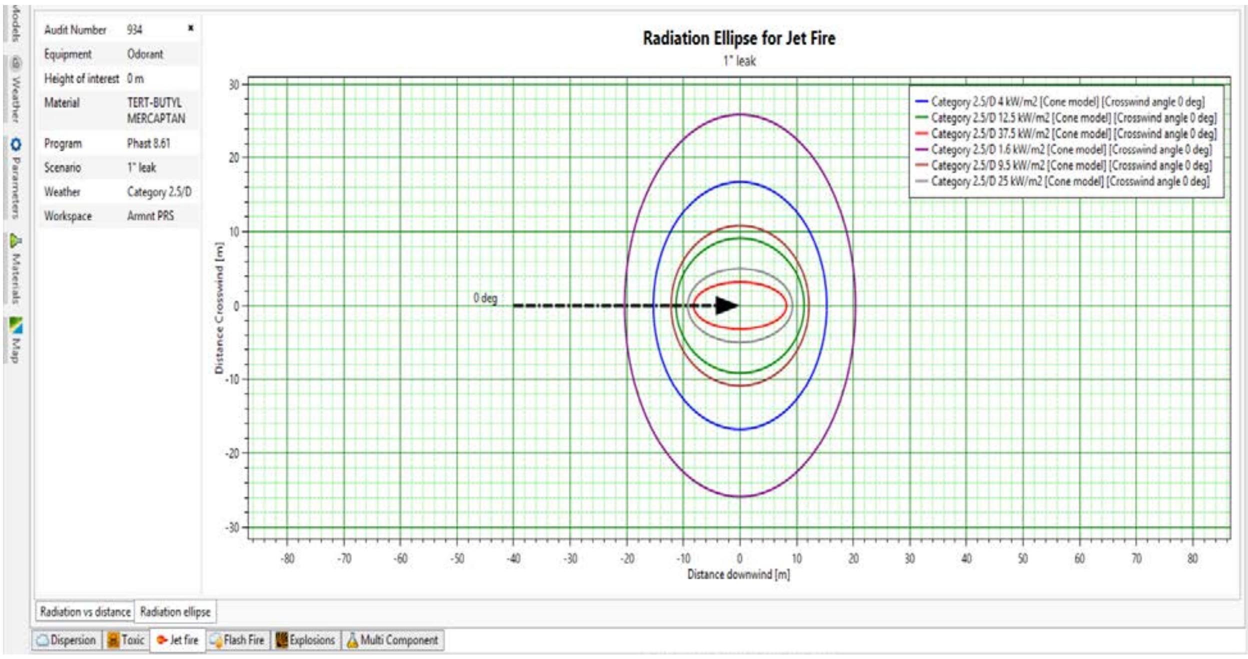


Figure 33. Heat Radiation Contours - Jet Fire Graph (Odorant Leak)

Figure 34. Heat Radiation Contours - Jet Fire on Site (Odorant Leak)

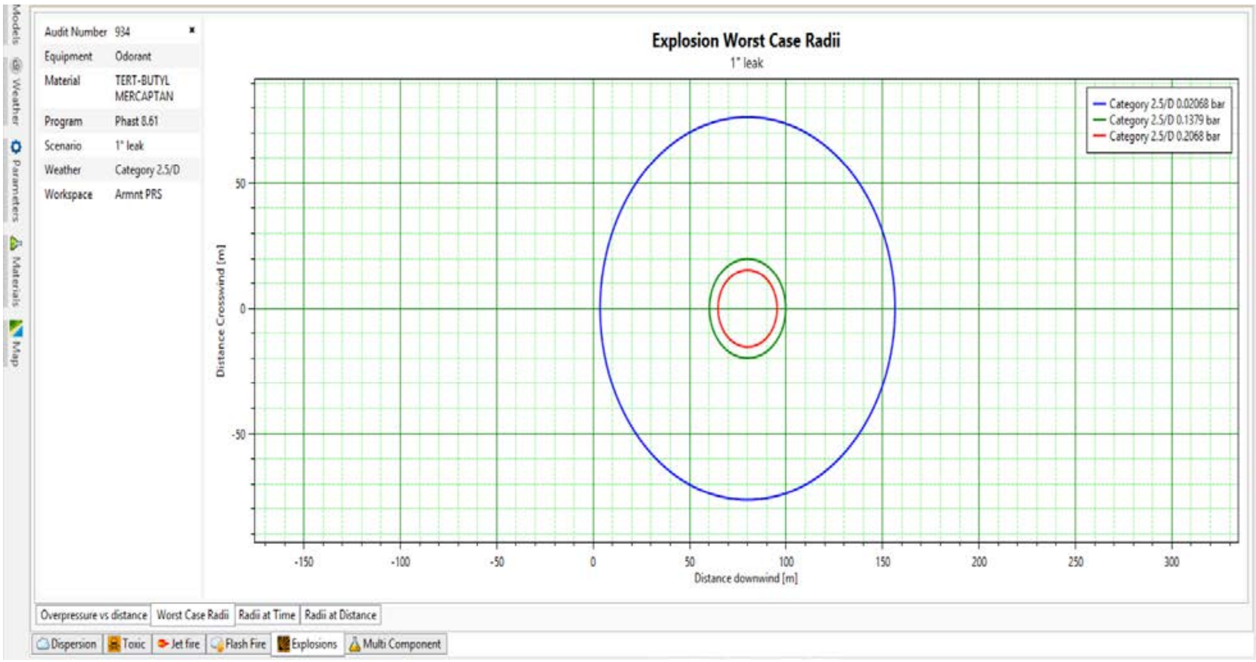


Figure 35. Worst-Case Explosion Overpressure Waves Graph (Odorant Leak

Figure 36. Explosion Overpressure Waves on Site (Odorant Leak)

4.0. Gas Heater (Water Bath Heating System)

The following table no. (24) Shows 1" hole leak from the heater Modeling:

Table 24. Dispersion Modeling for Heater Tank

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	1.8	1.1	0.1 @ 1.4 m
	LFL	5.4	1.3	0.5 @ 3 m
	50 % LFL	10.2	1.5	1 @ 6 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m²)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	9.7	1.6	15	9.7	0
		4	12.7	6	0
		9.5	10.9	3.3	0
		12.5	10.2	2.6	20% /60 sec.
		25	8.8	0.7	80.34
		37.5	Not reached	Not reached	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	10.5	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	2.7	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	2.1	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

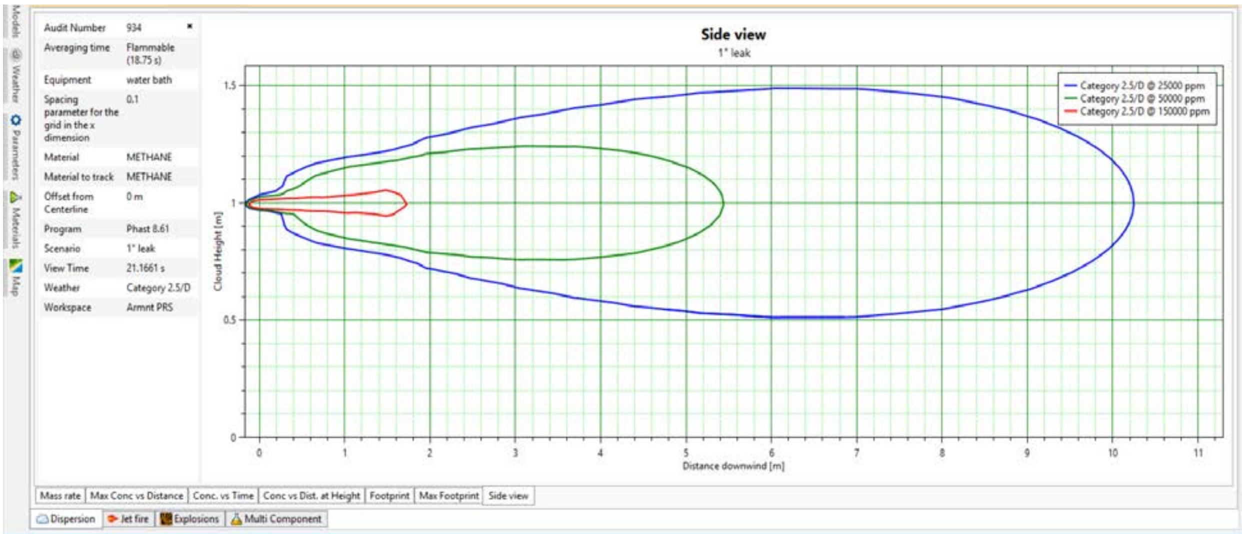


Figure 37. Vapor Cloud (UFL/LFL) Side View Graph (Gas Heater)

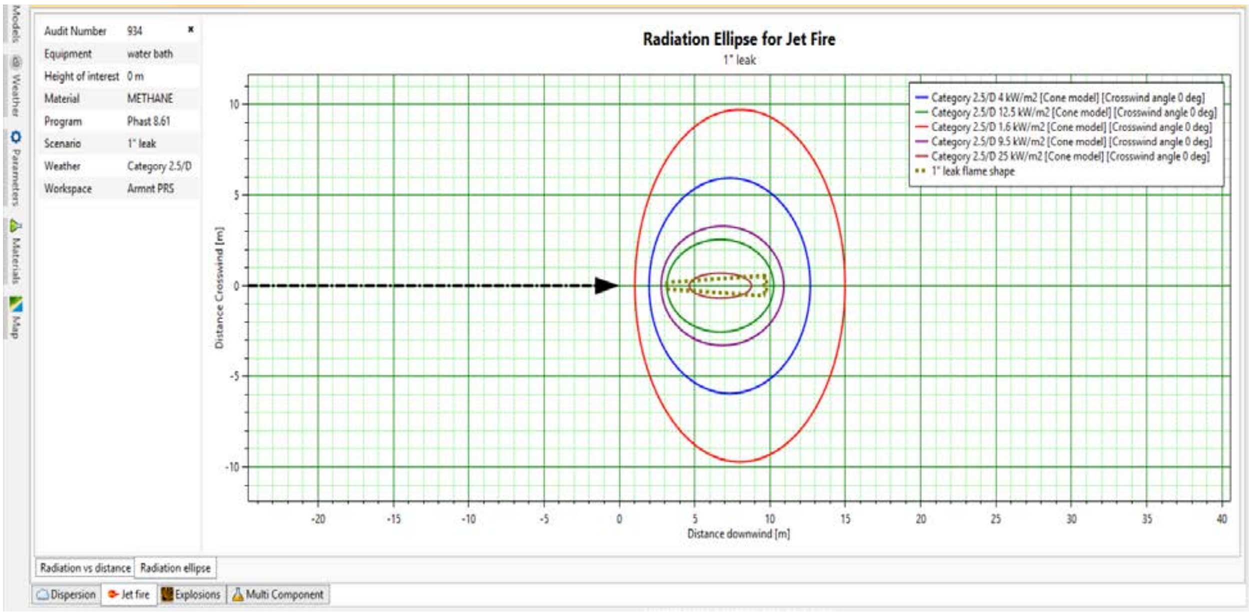


Figure 38. Heat Radiation Contours - Fire Graph (Gas Heater)

Figure 39. Heat Radiation Contours - Fire on Site (Gas Heater)

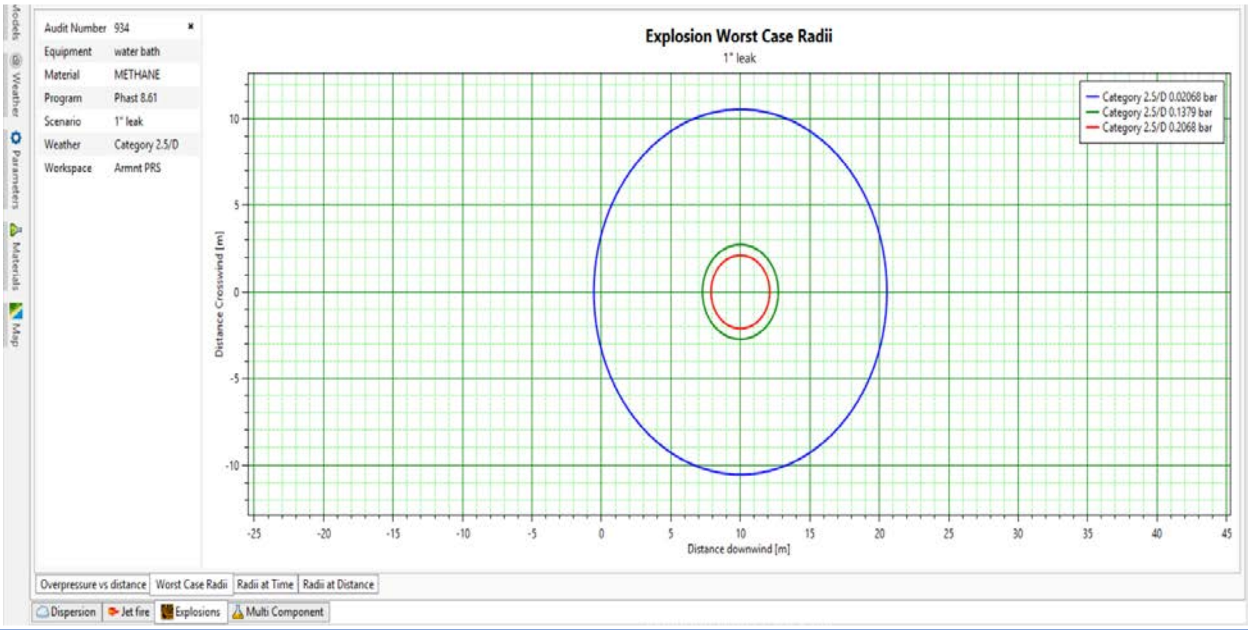


Figure 40. Explosion Overpressure Waves Graph (Gas Heater)

Figure 41. Explosion Overpressure Waves on Site (Gas Heater)

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. (25) Shows that:

Table 25. Dispersion Modeling for Off-take - 1" / 4" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	0.01	1.5	0.1
	LFL	0.4	5.5	0.6
	50 % LFL	1.12	8.5	1.5

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	10.2	1.6	18.5	17.3	0
		4	10	8.7	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)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Figure 42. Gas Cloud Side View (UFL/LFL) (1" hole in 4" off-take Pipeline)

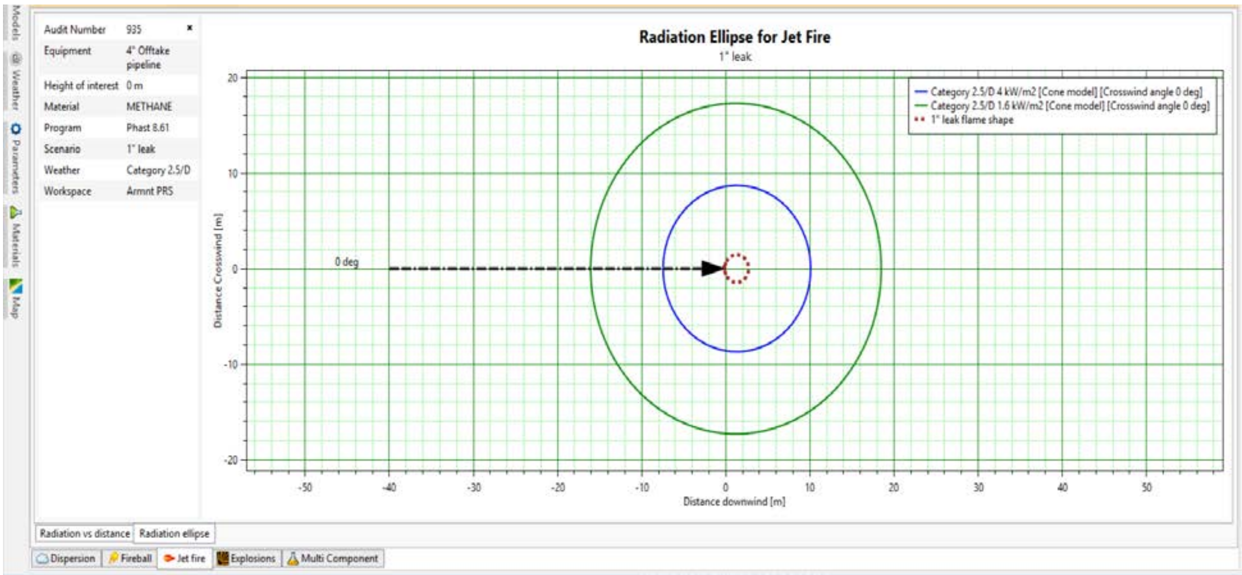


Figure 43. Heat Radiation Contours from Jet Fire (1" hole in 4" off-take Pipeline)

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

The following table no. (26) Shows that:

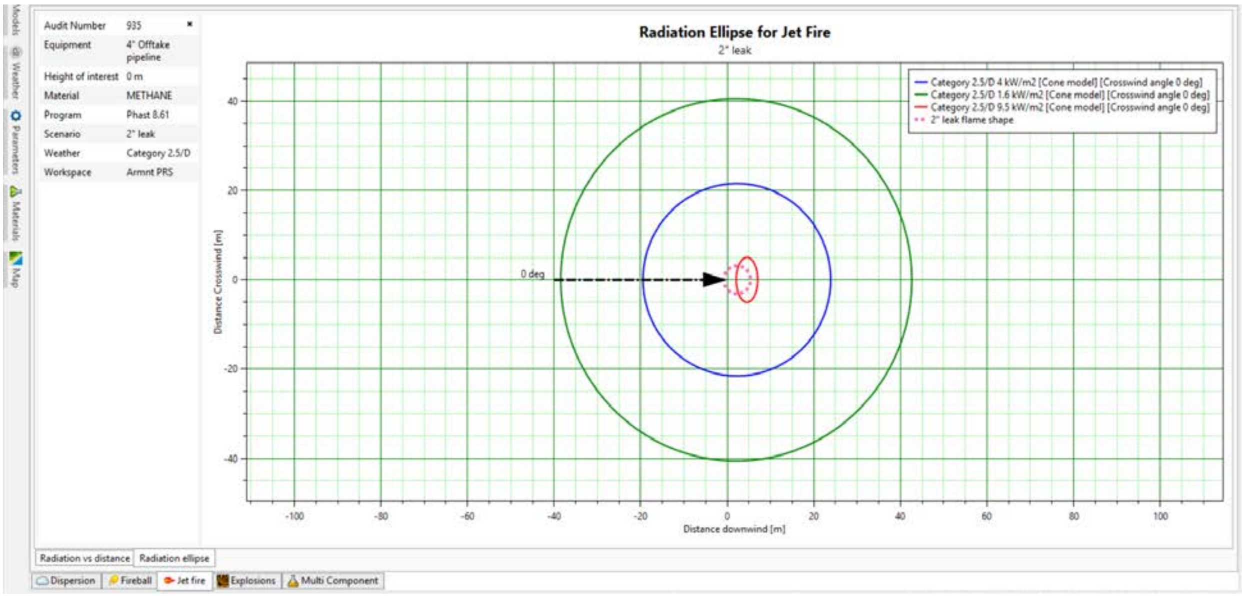
Table 26. Dispersion Modeling for Off-take - 2" / 4" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	0.2	5	0.3
	LFL	1.1	12	1.6
	50 % LFL	2.8	20	3.8

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m²)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	22.3	1.6	42.6	40.6	0
		4	24	21.5	0
		9.5	7.2	5	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)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

Figure 44. Gas Cloud Side View (UFL/LFL) (2" hole in 4" off-take Pipeline)



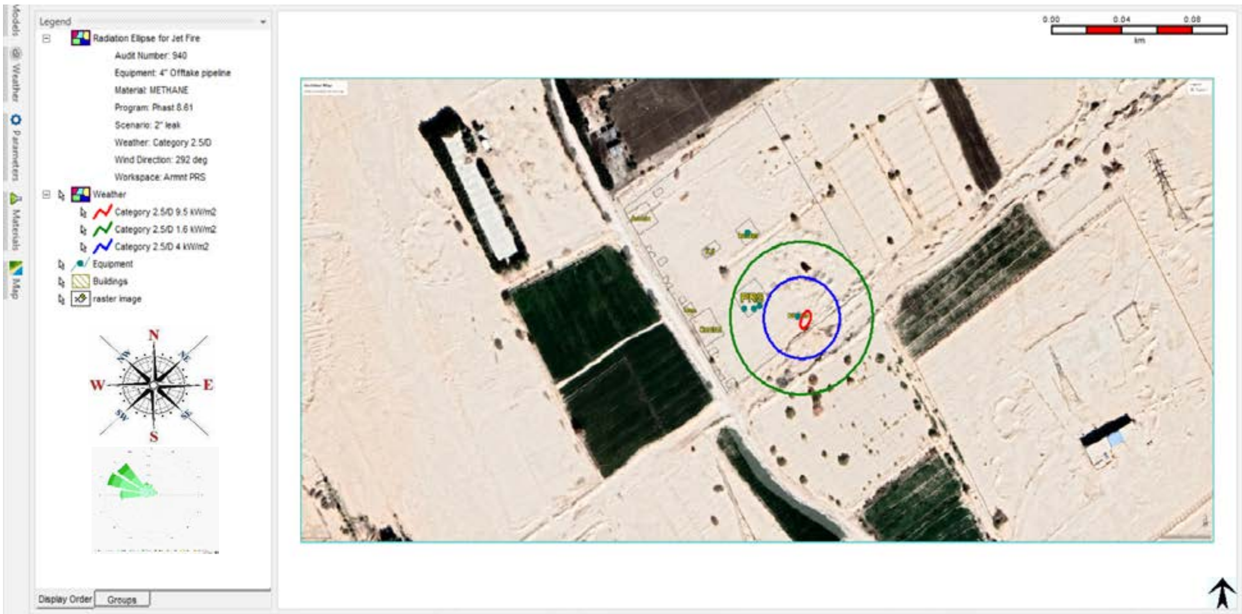


Figure 45. Heat Radiation Contours from Jet Fire (2” hole in 4” off-take Pipeline)

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

The following table no. (27) Shows that:

Table 27. Dispersion Modeling for Off-take - 4" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2.5 D	UFL	0.3	7	0.6
	LFL	1.7	17	2.5
	50 % LFL	3.1	18	4.6

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2.5 D	47.2	1.6	95.8	92.3	0
		4	55	51	0
		9.5	21.2	18.5	0
		12.5	8.6	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)**	**Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2.5 D	0.020	N/D	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	N/D	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	N/D	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

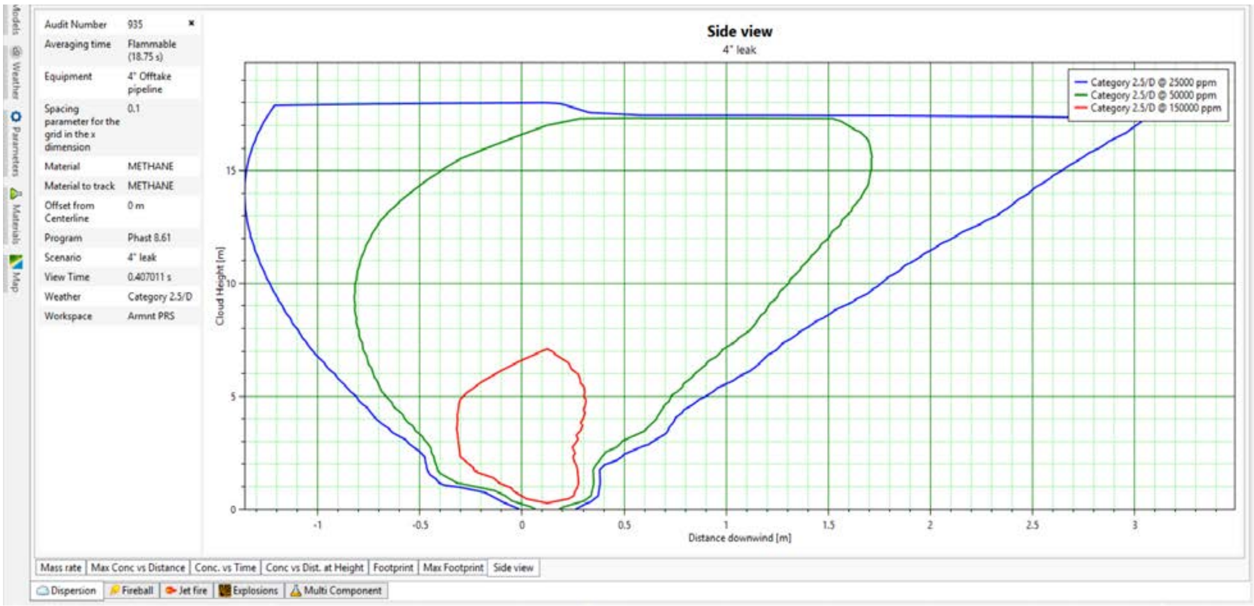


Figure 46. Gas Cloud Side View (UFL/LFL) (4" off-take Pipeline Full Rupture)

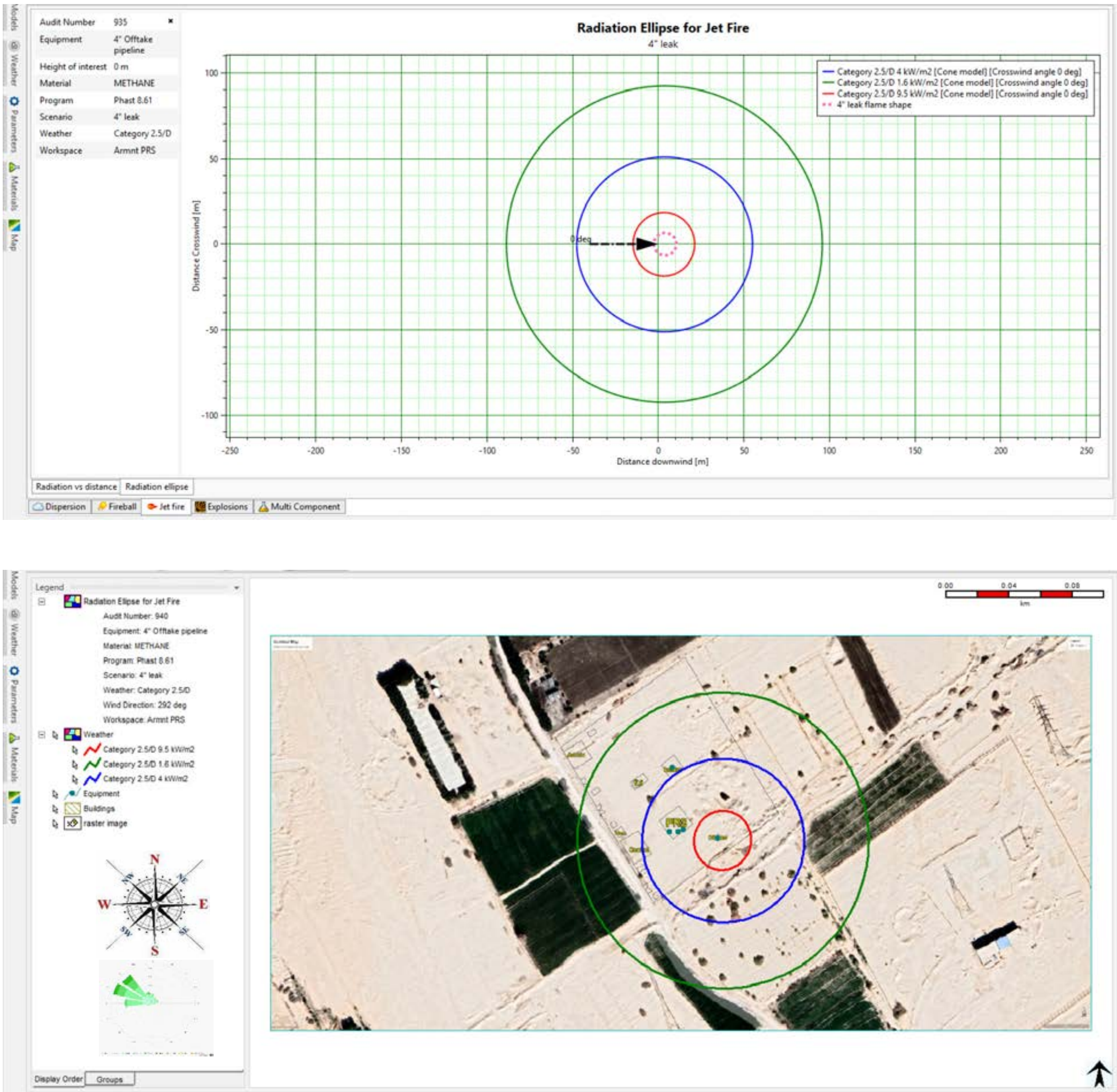


Figure 47. Heat Radiation Contours from Jet Fire (4" off-take Pipeline Full Rupture)

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: 30 & 31) *the vulnerability of people to heat radiation starting from 12.5 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 calculation 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 is decided to use an International Data Bank for major hazardous incident data.

The following table (28) shows the frequency for each failure that can be raised in pressure reduction station operations:

Table 28. Failure Frequency for Each Scenario

Scenario	Release Size	Failure Cause	Failure Rate
Gas Release from 1"/6" & 1"/8" Pipeline & 1"/4" Gas Heater	***Small***	**Failure Cause**	**Failure Rate**
		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 3"/6"& 4"/8" 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 6" & 8" 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 representing "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

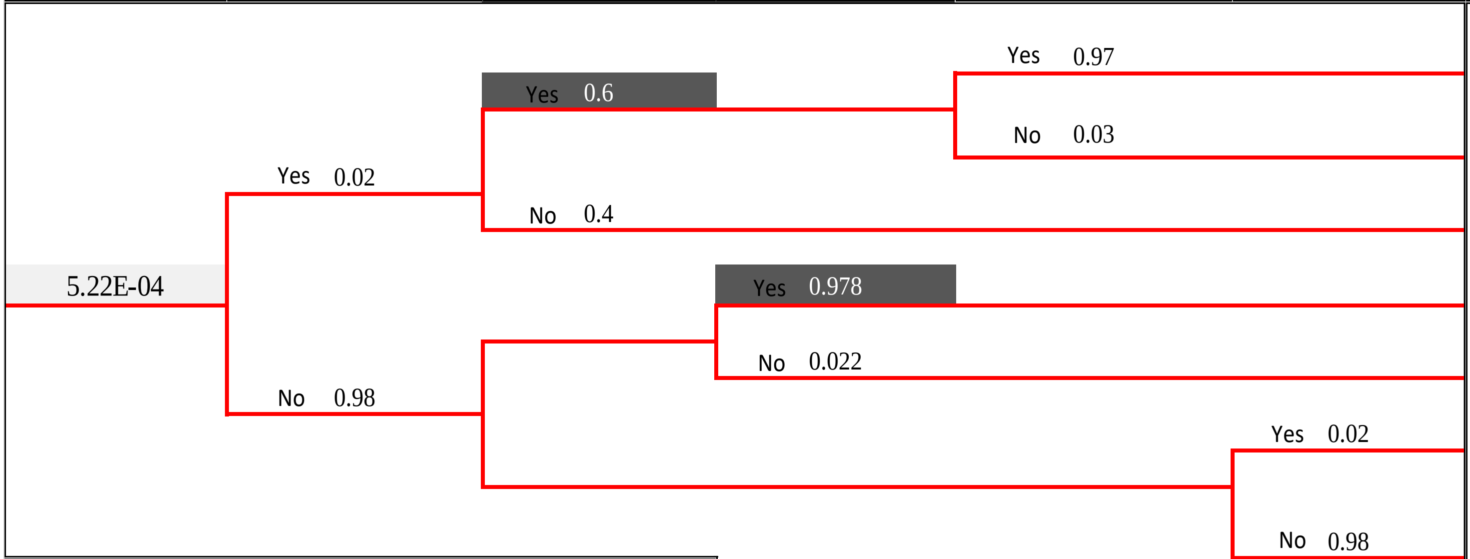
The event tree analysis outcomes can be classified into three main categories as follows:

"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 (29) Inlet 4" / Outlet 6" / Off-Take 4"/ Waterbath 3" Pipeline 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***

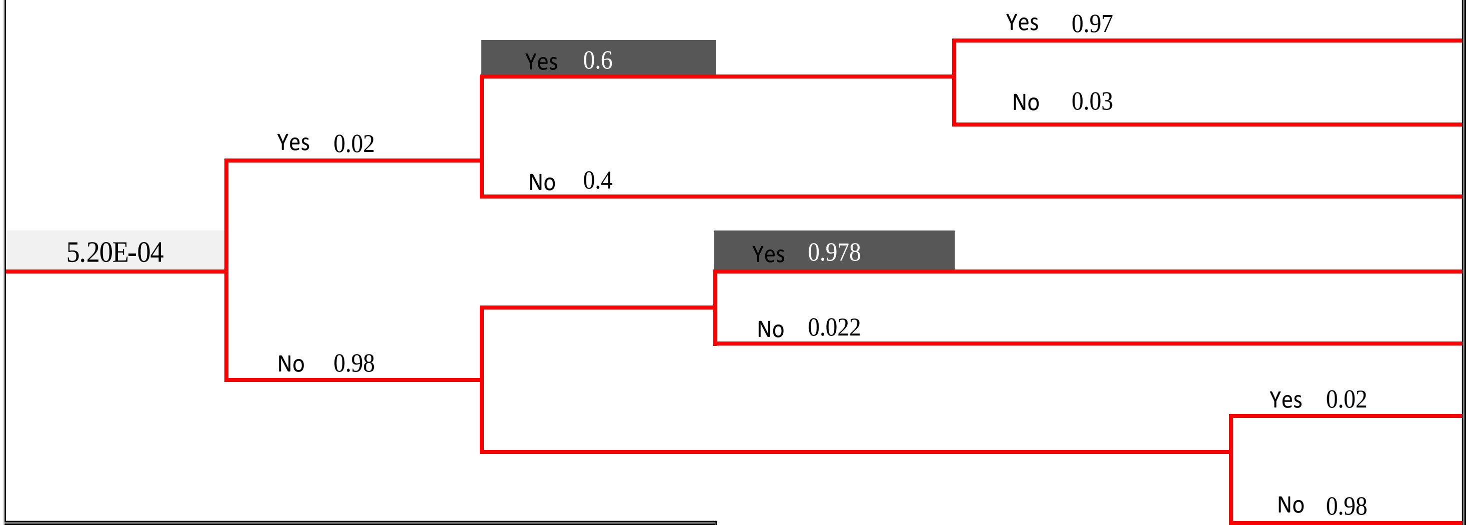
(1) Refer to QRA Study Page 94. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

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

Table (30) Inlet 4" / Off-Take 4" / Outlet 6" 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)	Outcomes	Frequency
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	***1.47E-05***

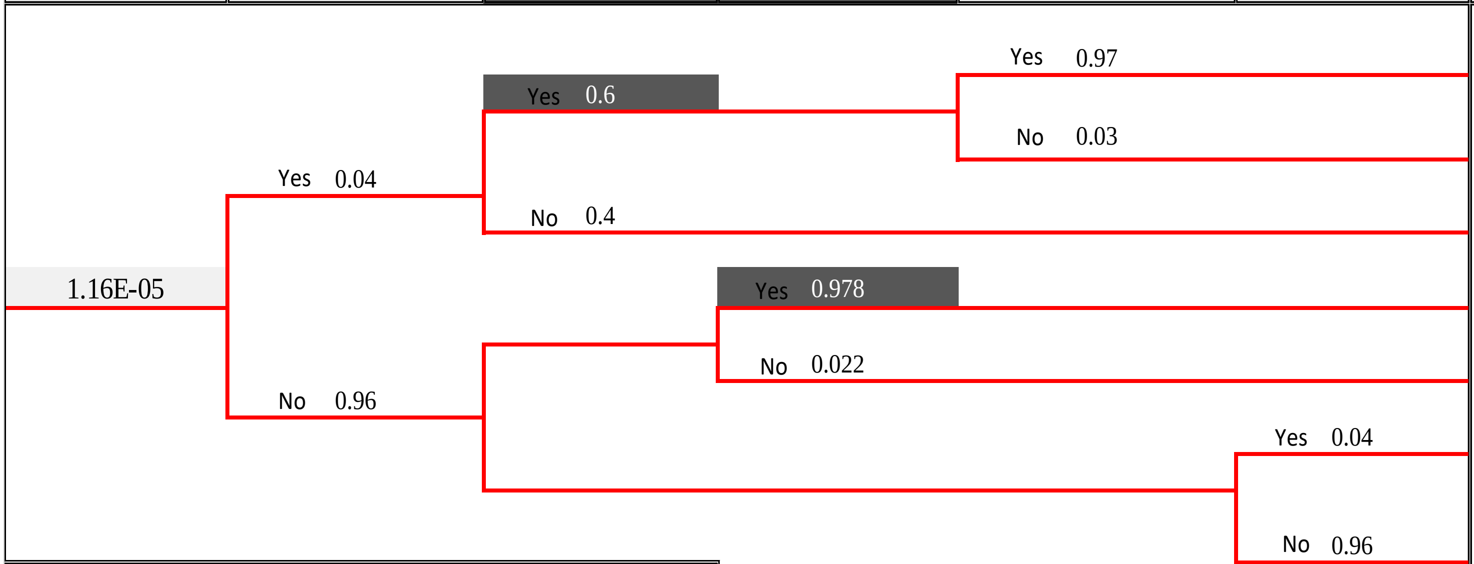
(1) Refer to QRA Study Page 94. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

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

Table (31) Inlet 4" / Off-Take 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		



Outcomes	Frequency
Controlled Jet fire	*4.50E-07*
Not controlled jet fire	*1.39E-08*
Escalated jet fire	*1.86E-07*
Limited release	-------------
Large release	*2.45E-07*
Escalated jet fire	*4.45E-07*
Escalated release	*1.07E-05*
TOTAL	*6.45E-07*

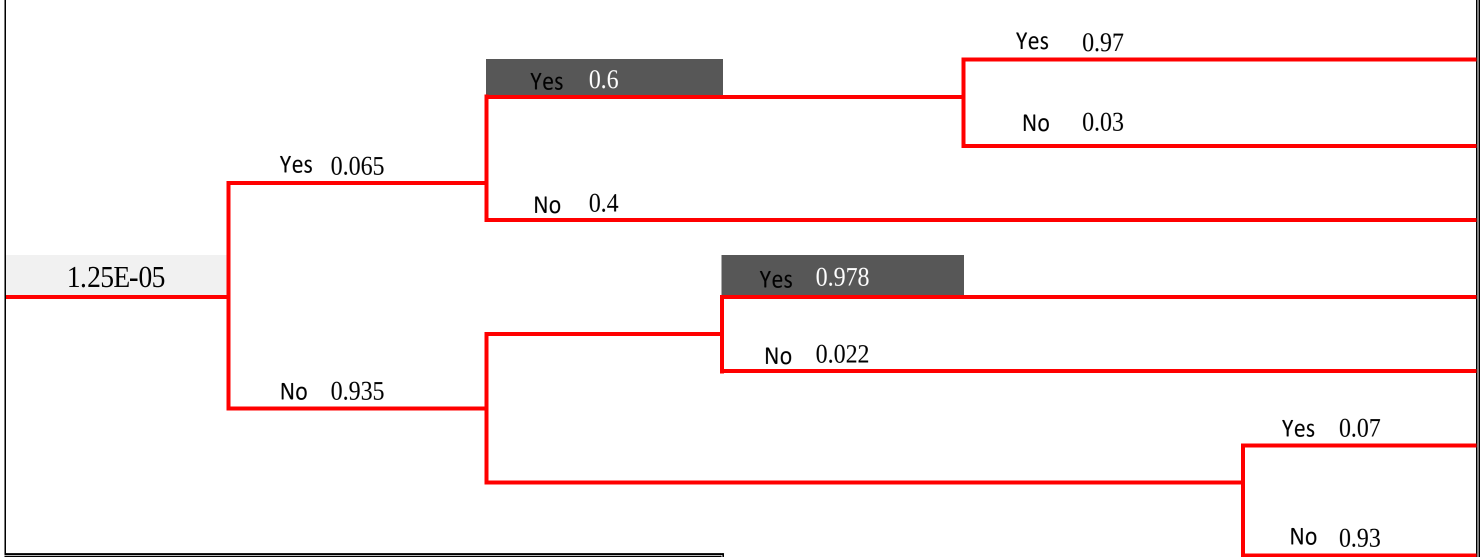
(1) Refer to QRA Study Page 94. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

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

Table (32) 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)
1.25E-05	0.065	0.6	0.978	0.97	0.07



Outcomes	Frequency
Controlled Jet fire	*7.88E-07*
Large fire	*2.44E-08*
Escalated jet fire	*3.25E-07*
Limited leak	-------------
Large leak	*2.57E-07*
Escalated jet fire	*8.18E-07*
Escalated leak	*1.09E-05*
TOTAL	***1.23E-05***

(1) Refer to QRA Study Page 94. (Taylor Associates ApS - 2006)

(2) Ref. Handbook Failure Frequencies 2009.

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

The following table (33) shows the total frequency for each scenario from ETA - Tables (29 to 32):

Table 33. Total Frequencies for Each Scenario

Source of Release	Total Frequency (ETA)
Inlet Pipeline Pin Hole	***1.47E-05***
Off-Take Pipeline Pin Hole	
Outlet Pipeline Pin Hole	
Gas Heater Pin Hole	
Inlet Pipeline Half Rupture	***2.89E-05***
Off-Take Pipeline Half Rupture	
Outlet Pipeline Half Rupture	
Inlet Pipeline Full Rupture	***6.45E-07***
Off-Take Pipeline Full Rupture	
Outlet Pipeline Full Rupture	
Odorant Tank 1" hole Leak	***1.23E-05***

The following table (34) summarize the risk events on workers / public, it will be assumed that:

- One person "as public" is in the neighboring areas around the PRMS for one hour / day light.
- Five Persons "as Workers" are available in the PRS for 24 hrs/ day (two operators in control room & one in admin building + Two persons in the two guard rooms),
- One of the operators will be available around the PRMS components for Maintenance/ Operation for one hour / day light.

Table 34. Summarization of Risk on Workers / Public (Occupancy)

Inlet 4" Pipeline Release Scenarios					
	Event	Jet / Fireball (12.5 kW/m²)		Explosion Overpressure (0.137 bar)	
	Exposure	Workers	Public	Workers	Public
Pin Hole	1"	*1 for 1 h (0.04)*	*None*	*1 for 1 h (0.04)*	*None*
Half Rupture	2"	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*
Full Rupture	4"	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*
Outlet 6" Pipeline Release Scenarios					
Pin Hole	1"	*None*	*None*	*None*	*None*
Half Rupture	3"	*1 for 1 h (0.04)*	*None*	*1 for 1 h (0.04)*	*None*
Full Rupture	6"	*2 for 24 h (2)* *1 for 1 h (0.04)*	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*	*1 for 1 h (0.04)*
Odorant Tank Release Scenario					
Small Leak	1"	*1 for 1 h (0.04)*	*None*	*None*	*1 for 1 h (0.04)*

Gas heater (water bath heating system)					
Pin Hole	1"	*1 for 1 h (0.04)*	*None*	*1 for 1 h (0.04)*	*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*	*None*	*None*	*None*

Therefore, the risk calculation will depend on total risk from these scenarios, and as per the equation page (94):

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-33)

- 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").

(Ref. to Table-34)

- 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 as per the following tables (35 & 36):

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

Source of Event	Frequency 1	Heat Radiation (kW/m^2) & Overpressure (Bar)	Vulnerability 2	Time Exposed 3	IR = 1 x 2 x 3
Gas Release from 1"/4" Inlet pipeline	***1.47E-05***	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1 Pers]	***4.12E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1 Pers]	***1.77E-07***
Gas Release from 1"/3" Heater		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1 Pers]	***4.12E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1 Pers]	***1.77E-07***
Gas Release from 2"/4" Inlet pipeline	***1.47E-05***	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1 Pers]	***4.11E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1 Pers]	***1.76E-07***
Gas Release from 3"/6" Outlet pipeline		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1 Pers]	***4.11E-07***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1 Pers]	***1.76E-07***
Gas Release from 4" Inlet pipeline	***6.45E-07***	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1 Pers]	***1.81E-08***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1 Pers]	***7.74E-09***
Gas Release from 6" Outlet pipeline		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** [1 Pers]	***1.81E-08***
		Explosion 0.137	**0.3** (Outdoor)	**0.04** [1 Pers]	***7.74E-09***
		Fireball 12.5	**0.1** (Indoor)	**1** [2 Pers]	***1.29E-07***
Odorant tank 1" leak	***1.23E-05***	Jet Fire 12.5	**0.3** (Outdoor)	**0.04** [1 Pers]	***1.48E-07***
TOTAL Risk for the Workers					***2.68E-06***

Table 36. Individual Risk (IR) Calculation for the Public Near to the PRMS

Source of Event	Frequency 1	Heat Radiation (kW/m^2) & Overpressure (Bar)	Vulnerability 2	Time Exposed 3	IR = 1 x 2 x 3
Gas Release from 2"/4" Inlet pipeline	*1.47E-05*	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** 1 Pers	*4.11E-07*
		Explosion 0.137	**0.3** (Outdoor)		*1.76E-07*
Gas Release from 4" Inlet pipeline	*6.45E-07*	Jet Fire 12.5	**0.7** (Outdoor)	**0.04** 1 Pers	*1.81E-08*
		Explosion 0.137	**0.3** (Outdoor)		*7.74E-09*
Gas Release from 6" Outlet pipeline		Jet Fire 12.5	**0.7** (Outdoor)	**0.04** 1 Pers	*1.81E-08*
		Explosion 0.137	**0.3** (Outdoor)		*7.74E-09*
Odorant tank 1" leak	*1.23E-05*	Explosion 0.137	**0.3** (Outdoor)	**0.04** 1 Pers	*1.48E-07*
TOTAL Risk for the Public (PRMS)					*7.86E-07*

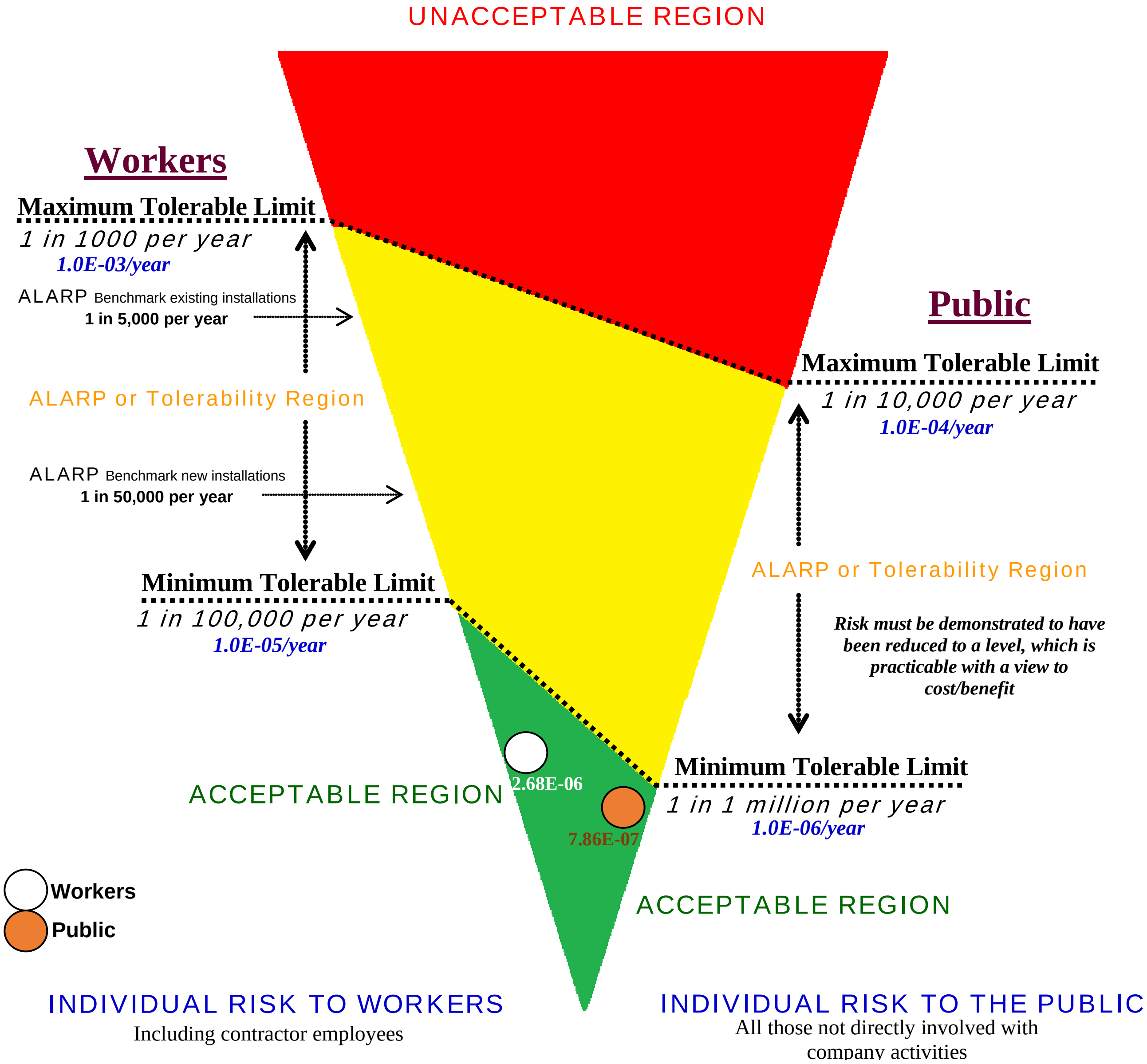


Figure 48 Evaluation of Individual Risk

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

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

Summary of Modelling 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 fence.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values will be limited inside the PRMS.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values will be limited inside the PRMS boundary.*
Half Rupture (2") gas release 4" inlet pipeline		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the gas clouds 50 % LFL will extend to reach the southern fence and extend outside. The UFL & LFL 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/m2 will extend outside the PRMS southern fence with no effects outside.*
	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 southern fence.*
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 be limited inside the PRMS.*
	Heat radiation / Jet	*The modeling shows that the heat radiation*

Event	Scenario	Effects
	fire 9.5 kW/m^2 12.5 kW/m^2	*values 9.5, 12.5, 25 & 37.5 kW/m2 will extend outside the PRMS southern fence.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.137 & 0.206 bar will extend outside the PRMS southern fence.*
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 kW/m2 effects will be limited inside the PRS boundary with no effects.* *The values of 9.5, 12.5, 25 & 37.5 kW/m2 are not determined by the software due to small leakage.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*
Half Rupture (3”) 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 values of 9.5, 12.5, 25 & 37.5 kW/m2 are limited to the PRMS boundary.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values 0.137 & 0.206 bar will be limited inside the PRMS boundary.*
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.*

Event	Scenario	Effects
	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, 25 & 37.5 kW/m2 will extend outside the PRMS southern fence.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values 0.137 and 0.206 bar will be extend outside the PRMS southern fence.*
	Heat radiation / Fireball 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 12.5 & 37.5 kW/m2 are limited inside the PRS boundary where 12.5 kW/m2 cover parts of the control room.*
Odorant tank 1" leak		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will extend outside the PRS fence from the south side.* *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/m2 will be limited inside the PRS boundary down and crosswind.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the value of 0.020 bar will cover parts of the PRS and extend outside the PRS boundary .* *The values of 0.137 & 0.206 bar will extend outside the PRS boundary.*
Gas heater (water bath heating system)		
	Gas cloud UFL LFL 50 % LFL	*The modeling shows that the vapor cloud will be limited inside the PRS boundary downwind.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation value 9.5, 12.5, 25 & 37.5 kW/m2 effects will be limited inside the PRS boundary.*
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*The modeling shows that the overpressure values will be limited inside the PRMS boundary.*

Event	Scenario	Effects
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 PRMS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values are limited inside PRMS boundary while the 1.6 kW/m2 extend outside the southern fence with no effects outside.* *The values of 9.5, 12.5, 25 & 37.5 kW/m2 are not determined by the software as they are very small values.*
	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 PRMS boundary.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 1.6 &4 kW/m2 will extend outside PRMS boundary.* *While the 9.5 kW/m2 will be limited inside PRMS boundary.* *The values of 12.5, 25 & 37.5 kW/m2 are not determined by the software as they are very small values.*
	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.*
	Heat radiation / Jet fire 9.5 kW/m^2 12.5 kW/m^2	*The modeling shows that the heat radiation values of 1.6, 4 & 9.5 kW/m2 will extend outside PRS boundary.* *The values of 25 & 37.5 kW/m2 are not determined by the software as they are very*

Event	Scenario	Effects
		small values.
	Explosion *0.020 bar* *0.137 bar* *0.206 bar*	*N/D*

The previous table shows that there are some of potential hazards with heat radiation (12.5 kW/m2) resulting from jet fire and explosion overpressure waves (0.137 bar) from late explosion events.

These risks (Jet fire, Fireball & overpressure waves) will affect the workers at the PRMS, and reach the surrounding near to the station .

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

Recommendations

Regarding to the modeling scenarios and risk calculations to workers / public which find that the risk to Workers is in the **Acceptable region**, While the risk to Public was found to be in the **Acceptable region**, therefore there are some points need to be considered to maintain the risk tolerability in its region and this will be described 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	
• Updating the emergency response plan for the PRS to include all scenarios in this study and other needs like:	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
- Safe exits in building according to the modeling in this study, and to the PRS from other side beside the designed exit in layout.	Design	
• Provide the site with SCBA "Self-Contained Breathing Apparatus (at least two sets) and arrange training programs for operators.	Operation	
• Cooperation should be done with the concerned parties before planning for housing projects around the PRMS area.	Operation / Design / Construction	
• Update the PRS layout to include the layout scale and the North direction to be compatible with the coordinates and Google Earth North.	Design	

Annex "1"

Results of Consequence Modelling Low Wind Scenario

Results of Consequence Modelling
Low Wind Scenario

1.0.Pressure Reduction Station Inlet Pipeline (4 inch)

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

The following table no. (A.1) Shows that:

Table (A.1) 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)**
2 F	UFL	2.3	1.1	0.2 @ 1.5 m
	LFL	7	1.3	0.7 @ 4 m
	50 % LFL	14.5	1.7	1.4 @ 8 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2 F	12.3	1.6	20.2	14	0
		4	16.9	8.8	0
		9.5	14.6	5.2	0
		12.5	13.9	4.3	20% /60 sec.
		25	12.2	2	80.34
		37.5	10.9	0.7	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Explosion Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2 F	0.020	14.2	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	3.7	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	2.9	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

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

The following table no. (A.2) Shows that:

Table (A.2) 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)**
2 F	UFL	5.4	1.3	0.5 @ 3 m
	LFL	16	1.8	1.7 @ 10 m
	50 % LFL	25	0 – 2.5	2.5 @ 16 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m²)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2 F	26.5	1.6	54.5	43	0
		4	43.1	27.2	0
		9.5	36.2	17.6	0
		12.5	34.4	15.2	20% /60 sec.
		25	30.4	9.8	80.34
		37.5	27.6	7	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Explosion Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2 F	0.020	36.3	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	9.4	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	7.3	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*

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

The following table no. (A.3) Shows that:

Table (A.3) Dispersion Modeling for Inlet - 4" Gas Release

Gas Release				
Wind Category	**Flammability Limits**	**Distance (m)**	**Height (m)**	**Cloud Width (m)**
2 F	UFL	7.5	1.4	0.7 @ 4 m
	LFL	17	0 – 2	2 @ 10 m
	50 % LFL	21.5	0 – 2.5	2.5 @ 13 m

Jet Fire					
Wind Category	**Flame Length (m)**	**Heat Radiation (kW/m^2)**	**Distance Downwind (m)**	**Distance Crosswind (m)**	**Lethality Level (%)**
2 F	55.5	1.6	131.6	107	0
		4	101.7	68.7	0
		9.5	82.6	44.7	0
		12.5	77.9	38.8	20 %/60 sec.
		25	67.4	26.3	80.34
		37.5	61.3	20	98.74

Unconfined Vapor Cloud Explosion - UVCE (Open Air)				
Wind Category	**Pressure Value (bar)**	**Explosion Overpressure Radius (m)**	**Overpressure Waves Effect / Damage**	
2 F	0.020	58.1	**0.021 bar**	*Probability of serious damage beyond this point = 0.05 - 10 % glass broken*
	0.137	15	**0.137 bar**	*Some severe injuries, death unlikely*
	0.206	11.6	**0.206 bar**	*Steel frame buildings distorted / pulled from foundation*