QUANTITATIVE RISK ASSESSMENT - QRA

FOR

TOWN GAS COMPANY

PART - II

Pressure Reduction and Odorant Station

at

Greater Cairo

Jan 2006

Report # PS-GZT-TG 001 Rev.0
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1.0 **EXECUTIVE SUMMARY**

Quantitative risk assessment has been performed for a Pressure Reduction Station with odorant as a typical model for Town Gas Company.

This PRS with odorant facilities has been considered as the typical PRS for consequence modelling and risk assessment and representative to all other stations proposed within Greater Cairo Natural Gas Plan.

For the purpose of the analysis it has been assumed that the Pressure Reduction Stations are within restricted entry open area.

For the PRS leak scenario, the release rate has been simulated based on 3-hole sizes.

- 0.25 inch representing instrument fitting failure (pin hole leak).
- 1.0 inch representing small pipe leak (minor leak).
- 4.0 inches leak representing a 4-inch pipe full bore rupture or 4-inch hole size in a larger pipe diameter (major leak or catastrophic failure).

Weather conditions have been selected based on wind speed and stability class. The worst case weather conditions for gas dispersion is the stable weather conditions, represented by wind speed of 1 m/s and stability class “F” representing “very stable” weather conditions, in order to obtain conservative results.
The PRS comprises two types of pressures, the first is the upstream pressure, which is high pressure ranging from 30 to 70 bars, while the second pressure is the downstream pressure which is low pressure ranging from 4 to 7 bars.

- For the purpose of the consequence modelling, the maximum of the two types of pressures have been simulated to represent the worst case and mild case respectively (70 bars as HP and 7 Bars as LP).

- The gas dispersion distances have been calculated in meters in concentration terms of lower Flammability Limits (LFL) and Upper Flammability Limits (UFL) presented in Parts Per Million (PPM) concentrations in order to represent flammability range of release gas cloud; however the extent of damage is presented by LFL only.

- The heat radiation from flash fires will not significantly affect humans, equipment or structures due to the short duration of flash fires.

- Fire consequence analysis has been described in details in fire consequence effects section, which details the hazardous effects from different types of fires.

- The following table presents the generic extent of damage distances as a result from the consequence modelling simulation analysis performed.
Table 1 - Generic Extent of Damage Distances From PRS Leaks in Meters

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Leak Type</th>
<th>Leak Size in Meters</th>
<th>Leak Size in Inches</th>
<th>High Pressure Side 70 Bar</th>
<th>Low Pressure Side 7 Bar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Jet Flame</td>
<td>Gas Cloud</td>
</tr>
<tr>
<td>1</td>
<td>Pin Hole</td>
<td>0.005</td>
<td>0.25</td>
<td>6.5</td>
<td>3.5</td>
</tr>
<tr>
<td>2</td>
<td>Minor Leak</td>
<td>0.025</td>
<td>1.0</td>
<td>25</td>
<td>11.2</td>
</tr>
<tr>
<td>3</td>
<td>Major Leak</td>
<td>0.1</td>
<td>4.0</td>
<td>70</td>
<td>30</td>
</tr>
</tbody>
</table>

The damage distances have been calculated by SHELL’s FRED version (4.0) consequence modelling software with the following conditions:
1- The released gas is Standard Natural Gas.
2- Wind Speed of 1m/sec.
3- Weather stability of “F” representing very stable wind conditions.
4- Damage distances are based on the maximum damage contours.

- From the extent of damage distances calculated, it can be seen that the major or catastrophic equipment failure has the maximum potential extent of damage due to increased leak size. Maximum extent of damage is 70 meters in the worst case conditions.

- The minor leak has a localized extent of damage within the PRS boundary due to medium leak size. Expected extent of damage is 25 meters.

- While the pin hole leak has the minimum localized extent of damage due to small leak size. Minimum extent of damage is 6.5 meters in the mild case conditions.
• But on the other hand the probability of occurrence or failure frequency of major leak or catastrophic equipment failure is deemed to be much lower than a pin hole leak.

• Release from the odorant storage tank, is one of the critical events. A release from the tank pressure relief valve as a result of overfilling or over-pressure was modelled. Dispersion down-wind from the PSV will extend a distance greater than 250m for lower concentration (10 ppm) while the higher concentration (1000 ppm) will extend about 120m.

• The jet flame associated with ignition of the release from the odorant tank PSV would be of 20m in length, and the 12kw/m² heat radiation contour would extend 17m down-wind, while the 25kw/m² contours would extend 13m down-wind.

1.1 **Risk Reduction Measures**

Risk reduction measures (recommendations) have been proposed as points of improvement in order to enhance the PRS safety standards. These risk reduction measures (recommendations) are summarized as follows:

1. There is a need to develop a safe system of work, based on risk assessment for dealing with potential gas leaks.

2. Consideration should be given to the remote actuation of isolation and slam-shut valves by Town Gas for different PRS's as well as the transmission pipelines.
3. There is a need to produce Hazardous Area Classification drawings for all Pressure Reduction Stations.

4. Planned preventive maintenance policy should be in place for the new PRSs.

5. There is a need to produce a 'Station Manual' for each PRS. This manual should include formalized procedures, including precautions and a site scenario specific emergency plan.

6. Site emergency plans must take into account wind direction and stability and should consider interfaces with others, e.g. GASCO as well as the public living nearby.

7. Town Gas needs to consider the security arrangements for all unmanned stations.

8. There is a need that Town Gas should apply risk assessment to all activities and to formalize procedures and permit-to-work systems.

9. The control room inlet door should be located in the upwind direction away from the station (Inlet door should not face the PRS station).

10. Alternatively, the control room should be provided by a secondary means of escape at the back side of the room, which shall be used in case of blockage of the main escape route by jet.

11. Self contained breathing apparatus (2 units at least) to be provided at each PRS for handling odorant releases.
12. It is recommended that a jet fire rated passive fire protection system to be applied to all safety critical shutdown valves ESDVs or Solenoid valves in order to maintain small isolatable inventories. (As applicable)

13. It is recommended to have pipeline marking signs indicating in Arabic and in English "Do Not . Dig" and "High Pressure Pipeline Underneath" in order to prevent such extreme hazardous situation.

14. It is recommended to include the prevailing wind direction on the PRS site plan.

15. It is recommended to have an elevated wind sock installed in the PRS site, which can be seen - from distance and from outside the fence to determine the direction of gas migration in case of major gas leak.

16. The design should fully comply with IGE TD/3 code requirements.
2.0 **BACKGROUND**

Greater Cairo is surrounded by a ring of high pressure main feeders with pressures ranging between 30 bar and 70 bar. These mains are fed from two sources, one from Abu-madi gas field and the second from Abu El Gharadik.

These mains are extending at the outskirts of the town to feed the pressure reduction stations, factories power stations and domestic networks with outlet pressures ranging between 7 bar and 0.025 bar.

Town Gas managing and operated the distribution network, installations and pressure reduction stations to supply natural gas to the domestic, commercial and industrial customers in the greater Cairo Areas.

3.0 **PROJECT DESCRIPTION**

Town Gas established a leadership in transporting and marketing of natural gas for domestic, commercial and industrial customers. A large gas network covering most of Greater Cairo city was laid years ago.

Since this time many vacant areas were developed and requested gas supply. These developments were chosen after a survey and cost evaluation was made to justify expenditure. Accordingly, a natural gas plan was established for greater Cairo areas supply through the installation of more six pressure reduction stations to cover new loads.
These pressure reduction and odorant stations are as follows:

1. El Haram PRS, with a capacity of 40,000 m$^3$/hr.
2. New Cairo city PRS, with a capacity of 60,000 m$^3$/hr.
3. El Mokattam PRS, with a capacity of 20,000 m$^3$/hr.
4. El Tebeen (Domestic) PRS, with a capacity of 10,000 m$^3$/hr.
5. El Shorouk PRS, with a capacity of 20,000 m$^3$/hr.

4.0 **SCOPE OF WORK**

The risk assessment technical proposal is based on the fact that the pressure reduction stations are all identical in design and operating conditions. Accordingly and in addition to the QRA study made before for a pressure reduction station without odorant (Tebeen - Industrial), this study report presents the quantitative risk assessment - QRA study carried out for a typical pressure reduction station and odorant station that can be applied to all other typical ones at greater Cairo City (Cairo / Giza).

4.1 **Objectives**

Town Gas has set out the main objectives of the risk assessment to include the following:

1. To identify, assess and quantify risks to people (the general public, Town Gas operations staffed other associated groups).
2. To identify, assess and quantify risks arising from pressure reduction and odorizing stations.

3. To comprehensively examine the ways in which the identified risks can be eliminated or reduced.

4. To recommended practical risk reduction and control measures for consideration.

4.2 **Terms of Reference**

- Town Gas identified specific parts of the pressure reduction stations for the proposed risk assessment study. These are:
  
  1. The inlet stage
  2. The filtration stage
  3. The heating stage
  4. The reduction stage
  5. The measuring stage
  6. The odorizing stage
  7. The outlet stage

- A risk assessment will be performed to identify the major risk issues and contributors with a best estimate of the associated levels of risk.
• This work will be designed to perform two main functions:

1. To provide town Gas with a clear risk knowledge and awareness such that investment decisions can be well formed.

2. To act as a coherent stage in, and to define the final scope of the full risk assessment.

In general, the work will cover, but not necessarily be limited to the following:

• Review town Gas data provided

• Perform physical survey of the proposed location of each station.

• Define possible accident scenarios and events.

• Conduct a full consequence analysis in relation to gas leaks and fire/explosion.

• Conduct qualitative / quantitative risk assessment.

• Define possible risk elimination / reduction measures.
5.0 **TECHNICAL DEFINITIONS:**

**Confinement**  A qualitative or quantitative measures of the enclosure or partial enclosure areas where vapours 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 vapour cloud explosion.

**EERA**  Escape, Evacuation and Rescue Assessment

**ESD**  Emergency Shut Down

**FRA**  Fire Risk Assessment

**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).

**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.
<table>
<thead>
<tr>
<th><strong>Individual risk</strong></th>
<th>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.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>QRA</strong></td>
<td>Quantitative Risk Assessment</td>
</tr>
<tr>
<td><strong>Risk</strong></td>
<td>Relates to the probability of exposure to a hazard, which could result in harm to personnel, the environment or general 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 or loss.</td>
</tr>
<tr>
<td><strong>Risk Assessment</strong></td>
<td>The identification and analysis, either qualitative or quantitative, of the likelihood and outcome of specific events or scenarios with judgments of probability and consequences.</td>
</tr>
<tr>
<td><strong>Vapour cloud explosion (VCE)</strong></td>
<td>An explosion in air of a flammable material cloud</td>
</tr>
</tbody>
</table>
6.0 **ASSESSMENT OF RISKS**

This part of the study would address the identification, analysis and subsequent assessment of major hazards associated with the relevant gas pressure reduction stations in addition to the associated part of the gas pipeline.

They are categorised, and makes judgement on the tolerability of risks to personnel associated with these hazards. British Gas criteria for risk tolerability are used to base such judgements.

Scenarios that could result in major hazards will be identified and evaluated using semi-quantified and Quantified Risk Assessment 'QRA'. This technique is used to establish the expected frequency of such incidents occurring on each facility and their consequences. Several commercial software tools are available to Petrosafe are available for consequences modelling of dispersion, fire and explosion will be selected for modelling pipeline gas leaks.

Detailed risk profile to different individuals on the facility will be estimated, which in turn becomes an important input in determining the requirements for any remedial work.

This section will be linked to the rest of the proposed study in order to tie together the logic of the arguments and bring the findings into better context. It will encompass:

- Town Gas Policy, Standards and Criteria,
• The sources of hazards,

• Hazardous substances, and their inventories,

• Events which are capable to cause major accidents,

• Analysis of the consequences and their effects on employees, third parties and the public,

• Evaluation of individual and societal risks, using BG Risk Tolerability Criterion,

• Measures to prevent, control or minimise likely consequences,

• Emergency procedures and emergency systems, derived from consideration of the above issues, including evacuation firefighting procedures.

From these studies, risk reduction measures are identified, and improvements to hardware and management systems are considered.

7.0 **METHODOLOGY**

Maximum use should be made of all studies and reports produced for the project so far.

A list of all-relevant studies and reports relevant to all gas facilities should be identified by The Company and made available to the Consultant.
The proposed study will examine the contents of existing documents relating to The Company- HSE Management System. This will cover such documents as:

- The Company HSE Policy.

- Details of the pipeline design, PFD and PlD's.

- Codes and Standards used for the design and construction of the pipeline and relevant stations.

- Fire and gas detection/protection systems and procedures of the facilities in question.

- Operations manuals, procedures and standing orders relating to the pipeline and stations.

- Engineering:

  1. Change control procedures

  2. Relevant stations latest PFDs and PID's

  3. Maintenance philosophy & control

  4. Inspections and planned preventive maintenance

  5. Shut-down and blow-down philosophies

  6. Design and locations of sectionalizing valves

  7. Procedures for pigging operations.
The proposed study will examine the relationship between relevant documents and management procedures to establish that these are adequate to demonstrate that all reasonable steps have been taken to ensure that the design, construction, operation and maintenance of the facility and its equipment are adequate to provide a safe working environment.

Furthermore, the Company should demonstrate that, in the event of an incident, which may escalate and lead to the requirement for personnel to evacuate the facility, such arrangements are in place and are adequate.

8.0 **PROCESS DESCRIPTION:**

The process would include the following stages.

8.1 **Inlet Stage**

The PRS must be completely isolated from the Cathodic system applied to the feeding gas steel pipes, therefore an isolating joint with protection is installed.

The main station valve is installed to shut off the station in case of emergency; this valve has the facility to be close either locally or remotely.

The pressure gauges, temperature indicator, pressure & temperature transmitters shall be exists for local and remote purposes.
8.2 The Filtration Stage

At least 2 Filter & separator are installed to remove dust, rust and other Solid contaminants and any traces of liquids.

The gas goes through filters, cleaned, become nearly dry and free of dust.

This stage is consists of at least two filter lines, each line has full capacity of station. Each filter has the safety devices for safe operation (differential pressure gauge, relief valves, liquid indicator, … etc.)

Each filter has filtration rate 2 - 5 micron for 100 % capacity, for the separator 8 10 micron for 100 % capacity In the operation one filter stream is always on duty, and the other is standby

8.3 The Heating Stage

Due to the high pressure of coming gas, and because the gas lost it s' temperature during reduction stage specially when the range between the inlet and outlet pressure is wide, in this case icing may be formed surrounding the outlet pies after reduction, also to avoid any blocking inside the control pilots may lead to stop the flow of gas, there for the heater should be installed to heat the gas and maintain the temperature after reduction not less than 7 degree centigrade.

It is preferable to install 2 heaters, each 100 % of full capacity for maintenance proposes.
8.4 **The Reduction Stage**

The reduction unit shall be installed in well ventilation-closed area or in open area under protected shelled.

Two reduction streams at least should be installed, each stream has the full capacity of the station.

Each stream consists of slam shut - active & monitors reduce regulators and relief valve Each stream should has the necessary all gauges, indicators and transmitters

8.5 **The Measuring Stage**

After the gas be reduced to adjusted outlet pressure, the quantities must be measured for two reasons, first to know the consumption gas, second for add the suitable amount of odorant which is proportional to the gas flow

For these reasons at least tow measuring line are installed, each line has a measuring device for 100 % of the full capacity

Sometimes when the station at the beginning and due to the low flow because of low number of customers using gas it is better for the accuracy of measuring to install a low flow measuring device ( 20 % of the total capacity)
8.6 **The Odorizing Stage**

After the gas filtered, heated, reduced \( wd \) measured -, odorant is added to give the specific smell

The additional rate for Odorant is normally between 12 - 24 MG/CM

The system is consists of stainless steel storage tank with all necessary safety devices, day tanks, electrical injection pumps and mechanical pump.

Pumps should cover all low flow conditions as well as high flow conditions.

Pumps could be operating automatically or manually.

The control unit is controlled the amount of odour which it should be proportional to the gas flow.

8.7 **The Outlet Stage**

Consist as well as inlet stage from isolating joint, outlet valve gauge, temperature indicator, pressure & temperature transmitters and non return valve to protect the station from the back pressure.
9.0 **OPERATIONS OF THE SYSTEM**

9.1 **Operations and Controls**

The system of operations all Town Gas pressure reduction stations relies on a high degree of flexibility in terms of supply that ensures multiple gas inlet sources and effective monitoring system in accordance with the following:

- These stations operates three shift system/dry reduces gas pressure and adds odorant to the gas.

- The company operates a monitoring and control “SCADA” system that monitors all mains and pressure stations in greater Cairo as well as the main gas transmission lines (30 bar and 70 bar) with the following function:

  - Monitoring of inlet gas pressure for main sources, giving in the case of high and low gas pressures.
  
  - Monitoring of the odourization units in the stations in terms of rate of filling and giving alarms if the storage tanks odorant level and pressure increases or decreases.
  
  - Monitoring of all stations outlet gas pressure and flow rates.
  
  - Monitoring of the effects of gas output on the transmission line pressure.
  
  - Controlling bridges isolation valves remotely in cases of emergency.
- The SCADA system should also remotely control the change-over gas reduction streams to auxiliary lines at all stations in case of emergency or due to failures.

9.2 **Filling The Odorant Main Storage Tank**

- The odorant (spot leak 1009) storage tank is filled when the liquid level drops below the minimum level.

  The liquid level is monitored via two level measuring systems, the first is based on a manometer and the second is electrical device.

- The tank is pressurized by blanket gas to minimize vaporization of the odorant. This gas is used to transfer the odorant from its drum into the storage tank. The odorant vaporizes at about 1-45 bar, so that the blanket gas pressure is increases from 1-5 bar to 1-6bar.

- The pressure inside the tank is equated with atmospheric by means of burning blanket gas saturated with spot-leak through a temporary gas burner. Blanket gas inside the tank forms 20% of the volume above spot-leak level when the tank is full.

9.3 **Gas Odorant (Spot-leak 1009)**

- The odorant is supplied with a safety Data sheet (see appendix-1). The odorant is identified as spot-leak 1009. this is based on aliphatic mercaptan mixtures in clear liquid form that is extremely flammable with the following characteristics:
- Colour | Colourless
- Odour | Stinking
- Boiling Point / Range | 62°C
- Melting Point / range | <-10 (Freezing Point - 45°C)
- Decomposition temperature | 425°C
- Flush point | Closed Cup - 27°C
- Auto-ignition temperature | 245°C
- Vapour pressure | 6.6@37.8°C
- Vapour density (Air = 1) | 3.0
- Specific gravity (water = 1) | 0.812@15-5°C
- Solubility - Water | Insoluble (20°C)
- Solvent | Soluble in Alcohols, Hydrocarbons

- Composition:
  - TERTIOBUTYL MERCAPTAN 77%
  - ISOPROPYL MERCAPTAN 14%
  - N-PROPYL MERCAPTAN 5.5%

* Specific Hazards:  
  - Highly Flammable
  - Irritating to respiratory system
  - May cause sensitization by skin contact
10.0 **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, temperature, humidity and atmospheric stability.

Met oceanographic data gathered for greater Cairo over a period of 5 years. This data included wind-speed and direction, air temperature, as well as current speed.

The general climatic conditions at Cairo are summarized as follows:

- Air temperature °C
  - Minimum recorded: 25.2
  - Yearly average: 28

- Relative humidity %
  - Average Daily maximum: 82%
  - Average Daily Minimum: 54%
  - Annual Average: 78%

The recorded annual wind speeds at Cairo are:

<table>
<thead>
<tr>
<th>Month</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>4.7</td>
<td>5.6</td>
<td>6.3</td>
<td>6.2</td>
<td>5.6</td>
<td>5.2</td>
<td>4.4</td>
<td>3.4</td>
<td>3.6</td>
<td>4.0</td>
<td>3.8</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Average wind speed = 2.44 m/sec.
• Sets of weather conditions initially selected for this study:

<table>
<thead>
<tr>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
<th>Set 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed</td>
<td>Stability</td>
<td>Wind speed</td>
<td>Stability</td>
</tr>
<tr>
<td>3m/S</td>
<td>B</td>
<td>1m/S</td>
<td>D</td>
</tr>
</tbody>
</table>

The wind speed range between 1 to 5m/S was considered to be a reasonable representation of typical conditions of Cairo. This would overcome some of the uncertainty of the meteorological data provided. Wind speed of 8m/s is likely to disperse the cloud over long distances to well below LFL.

The weather set 3 was eventually considered to represent the most likely conditions, however the worst case conditions shall be defined by a sensitivity analysis study.> 

For worst case conditions, Set 4 would be selected for QRA Study Modelling of gas releases and, fire, while Set 3 shall be considered in case of odorant release for conservative results under the most prevailing weather conditions.
11.0 **Generic Release Scenarios**

Events associated with release, dispersion and ignition of flammable releases considered in this study can be summarized in the following figure.

![Diagram](image)

**Figure 11.1 Hazardous events**
These events can be more detailed as follows:

Jet fires
A jet fire will result from an ignited pressurized hydrocarbon gas release. The consequence of jet fires is directional depending on the release orientation. Jet fires typically have flame temperature of about 2,200 °F and can produce high intensity thermal radiation. The high temperature poses a hazard from direct effects of heat on humans and also from possibility of escalation. If a jet flame impinges upon a target such as a vessel, pipe or structural member, it can cause failure of the item to fail within several minutes.

Jet (spray) fire will also result from ignited continuous releases of pressurized flammable liquid. The momentum of the release carries the material forwards in a plume entraining air to give a flammable mixture as gas is released from the plume.

Flash fires
If flammable gas accumulates in an unconfined area and is ignited, then the result will be a flash fire within the flammable limits of the vapour cloud.

Explosions
Ignition of accumulated gas in semi-confined areas may also be accompanied by an explosion; the overpressure generated will depend on the degree of congestion and confinement of the process area, and the gas cloud size.
Pool fires  If a liquid release is ignited after it has time to form a pool, a pool fire results. Because they are less well aerated, pool fires tend to have lower flame temperatures and produce lower levels of thermal radiation than jet fires. They also produce more smoke. Although a pool fire can still lead to structure failure of items within the flame, this would take longer than in a jet fire.

An additional hazard of pool fires is their ability to flow. A burning liquid pool can spread along horizontal surface or run down a vertical surface to give a running fire.

BLEVE  BLEVE stands for Boiling Liquid Expanding Vapour Explosion.

A fire ball can occur if a vessel containing fuel ruptures in the presence of an ignition source (usually a jet or pool fire). A fraction of the liquefied fuel subsequently released will evaporate immediately and take part in a huge fireball, which has the shape of a hemispherical burning cloud or ball of fire. High degree of turbulent mixing and rapid air entrainment allows large quantities of fuel to be consumed in a short period of time.

Structural failure  Loss of structure integrity due to overheating of structure members. The structure shall collapse under much lower load than the designed due to increased temperature.

Safe dispersion  Dilution of the released gases beyond the lower flammability limits (LFL) leading to safe dispersion situation.
12.0 RESULTS OF CONSEQUENCES MODELLING

12.1 High Pressure Release from 100-mm (4-Inch) Leak
Upstream PRS (1A)

General:

This case model considers the scenario of a full bore rupture of 4 inch piping or 4 inch hole in a larger diameter piping, which represents the worst case scenario as the release source is a high pressure major leak.

Gas Cloud / Flash Fire:

The proposed hazardous area resulting from the gas cloud shall be limited by the upper flammability limit (UFL) and the lower flammability limit (LFL), which if ignited results in flash fire.

The following figure represents the side view of the gas cloud (Plume) as a graphical display illustrating the LFL/UFL limits and the maximum plume height.
The following table represents the LFL and UFL limits and heights of the gas cloud (Plume) in figures.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>LFL</th>
<th>UFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contour value (ppm)</td>
<td>47226.4</td>
<td>148597.8</td>
</tr>
<tr>
<td>Downwind distance (m)</td>
<td>32.28</td>
<td>10.12</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>0.8994</td>
<td>0</td>
</tr>
</tbody>
</table>
Jet Fire:

The following figure represents the side view of the jet fire (Torch Flame) as a graphical display illustrating the heat radiation levels.
12.2 High Pressure Release from 25-mm (1-Inch) Leak Upstream PRS (1B)

General:

This case model considers the scenario of a leak of 1 inch hole size in a larger diameter piping, which represents the medium case scenario as the release source is a high pressure minor leak.

Gas Cloud / Flash Fire:

The proposed hazardous area resulting from the gas cloud shall be limited by the upper flammability limit (UFL) and the lower flammability limit (LFL), which if ignited results in flash fire.

The following figure represents the side view of the gas cloud (Plume) as a graphical display illustrating the LFL/UFL limits and the maximum plume height.
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<tbody>
<tr>
<td>Contour value (ppm)</td>
<td>47226.4</td>
<td>148597.8</td>
</tr>
<tr>
<td>Downwind distance (m)</td>
<td>12.08</td>
<td>5.5</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>0</td>
<td>0.7974</td>
</tr>
</tbody>
</table>
Jet Fire:

The following figure represents the side view of the jet fire (Torch Flame) as a graphical display illustrating the heat radiation levels.
12.3 **High Pressure Release from 5-mm (1/4-Inch) Leak**

*Upstream PRS (1C)*

**General:**

This case model considers the scenario of a pin hole leak of 1/4 inch hole size in a larger diameter piping, which represents the mildest case scenario as the release source is from a pin hole leak.

**Gas Cloud / Flash Fire:**

The proposed hazardous area resulting from the gas cloud shall be limited by the upper flammability limit (UFL) and the lower flammability limit (LFL), which if ignited results in flash fire.

The following figure represents the side view of the gas cloud (Plume) as a graphical display illustrating the LFL/UFL limits and the maximum plume height.
The following table represents the LFL and UFL limits and heights of the gas cloud (Plume) in figures.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>LFL</th>
<th>UFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contour value (ppm)</td>
<td>47226.4</td>
<td>148597.8</td>
</tr>
<tr>
<td>Downwind distance (m)</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>0.9443</td>
<td>0.9764</td>
</tr>
</tbody>
</table>
Jet Fire:

The following figure represents the side view of the jet fire (Torch Flame) as a graphical display illustrating the heat radiation levels.
12.4 **Low Pressure Release from 100-mm (4 Inch) Leak**

**Downstream PRS (2A)**

**General:**

This case model considers the scenario of a full bore rupture of 4 inch piping or 4 inch hole in a larger diameter piping, which represents the worst case scenario of the low pressure case downstream the PRS, as the release is from major leak.

**Gas Cloud / Flash Fire:**

The proposed hazardous area resulting from the gas cloud shall be limited by the upper flammability limit (UFL) and the lower flammability limit (LFL), which if ignited results in flash fire.

The following figure represents the side view of the gas cloud (Plume) as a graphical display illustrating the LFL/UFL limits and the maximum plume height.
The following table represents the LFL and UFL limits and heights of the gas cloud (Plume) in figures.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>LFL</th>
<th>UFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contour value (ppm)</td>
<td>47226.4</td>
<td>148597.8</td>
</tr>
<tr>
<td>Downwind distance (m)</td>
<td>12.06</td>
<td>6.001</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>0</td>
<td>0.675</td>
</tr>
</tbody>
</table>
Jet Fire:

The following figure represents the side view of the jet fire (Torch Flame) as a graphical display illustrating the heat radiation levels.
12.5 Low Pressure Release from 25-mm (1-Inch) Leak

Downstream PRS (2B)

General:

This case model considers the scenario of a minor leak from 1 inch hole size in a larger diameter piping, which represents the medium case scenario as the release source is from a minor leak.

Gas Cloud / Flash Fire:

The proposed hazardous area resulting from the gas cloud shall be limited by the upper flammability limit (UFL) and the lower flammability limit (LFL), which if ignited results in flash fire.

The following figure represents the side view of the gas cloud (Plume) as a graphical display illustrating the LFL/UFL limits and the maximum plume height.
The following table represents the LFL and UFL limits and heights of the gas cloud (Plume) in figures.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>LFL</th>
<th>UFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contour value (ppm)</td>
<td>47226.4</td>
<td>148597.8</td>
</tr>
<tr>
<td>Downwind distance (m)</td>
<td>5.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>0.8138</td>
<td>0.9689</td>
</tr>
</tbody>
</table>
Jet Fire:

The following figure represents the side view of the jet fire (Torch Flame) as a graphical display illustrating the heat radiation levels.
12.6 **Low Pressure Release from 5-mm (1/4-Inch) Leak**

**Downstream PRS (2C)**

**General:**

This case model considers the scenario of a pin hole leak of 1/4 inch hole size in a larger diameter piping, which represents the mildest case scenario as the release source is from a pin hole leak.

**Gas Cloud / Flash Fire:**

The proposed hazardous area resulting from the gas cloud shall be limited by the upper flammability limit (UFL) and the lower flammability limit (LFL), which if ignited results in flash fire.

The following figure represents the side view of the gas cloud (Plume) as a graphical display illustrating the LFL/UFL limits and the maximum plume height.
The following table represents the LFL and UFL limits and heights of the gas cloud (Plume) in figures.

<table>
<thead>
<tr>
<th>Concentration</th>
<th>LFL</th>
<th>UFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contour value (ppm)</td>
<td>47226.4</td>
<td>148597.8</td>
</tr>
<tr>
<td>Downwind distance (m)</td>
<td>1.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>0.9803</td>
<td>0.984</td>
</tr>
</tbody>
</table>
Jet Fire:

The following figure represents the side view of the jet fire (Torch Flame) as a graphical display illustrating the heat radiation levels.
12.7 **Release from The Odorant Tank**

Release of vapour from the odorizing storage tank is one of the critical events. This tank is filled about once every two months. A release from the tank pressure relief valve as a result of overfilling or over-pressure was modelled. Fig. 12-A & B show the modelling results.

From the sensitivity analysis, the following parameters have been selected to represent the worst case scenario parameters and utilized to present a conservative approach in case of odorant release:

- Maximum ambient temp. 40 c
- Weather stability 2.4m/s class D
- Source of release PSV vent - 1 inch diameter
- Operating pressure 1.5 to 1.6 Bar g

Fig. 12-A shows the vertical section of the gas/vapour (gas containing 80% spot-leak dispersion down-wind from the PSV. Lower concentration taken as 10ppm will extend a distance greater than 250m, while the higher concentration 1000ppm will extend about 120m. Spot-leak vapour is three times heavier than air.

Fig. 12-B gives the horizontal cross-section of the release.

Fig. 12-C shows the jet flame associated with ignition of the release from the odorant tank PSV. A flame length of 20m would result and 12kw/m² heat radiation contours would extend 17m down-wind, while the 25kw/m² contours would extend 13m down-wind.
FIGURE 12-A Release From Odorant Tank PSV – Side View

Material: Methane with 80% Spotleak

Higher Concentration 0.1000 % vol/vol
Lower Concentration 0.0010 % vol/vol

Release from odorant tank PSV
Vertical Section

Windspeed is 2.4 m/s
Stability is D

FIGURE 12-B Gas Release From Odorant Tank PSV – Top View

Material: Methane with 80% Spotleak

Higher Concentration 0.1000 % vol/vol
Lower Concentration 0.0010 % vol/vol

Release from odorant tank PSV
Horizontal Cross Section

Windspeed is 2.4 m/s
Stability is D
Accidental Release Measures:

- For environmental protection, do not release into the environment. PSV vent should be connected to the flare provided on site.

- In case of spill, destroy the product by oxidation using dilute solutions of Hydrogen peroxide or Sodium Hypochlorite.

- In case of leak, use self-contained breathing apparatus avoid contact with the skin by using PPE.
13.0 **RISK EVALUATION**

The risks assessed shall be evaluated based on the international risk acceptance criteria.

The ALARP principle has been adopted for risk evaluation. The ALARP region is that point at which the time, effort difficulty and cost of further risk reduction become out of proportion compared with the amount of risk reduction achieved.

Risks lower than the ALARP region risks will be considered minor risk and consequently they will not be considered.

Risks higher than the ALARP region risks will be considered major risk and consequently they will be not acceptable and further reduction measures are required.

The international risk acceptance criteria are presented in the following figure.
From the risk assessment and the international risk acceptance criteria the conclusion is presented in the following table.

<table>
<thead>
<tr>
<th>No</th>
<th>Calculated Risk</th>
<th>Acceptable Risk</th>
<th>Area Type</th>
<th>Acceptance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>4.5E-05</td>
<td>1.0E-05</td>
<td>Workers</td>
<td>ALARP</td>
</tr>
<tr>
<td>2.0</td>
<td>9.0E-05</td>
<td>1.0E-05</td>
<td>Public</td>
<td>ALARP</td>
</tr>
</tbody>
</table>
13.1 **Individual Risks ‘IR’ to Workers**

In order to calculate Individual Risk ‘IR’ for workers, there is a need to identify who is exposed to the fire and explosion hazards from all hazards at the PRS station, not just as a result of gas leaks. The proportion of time individuals is exposed to the hazards and their vulnerability should be considered in estimating this risk. Vulnerability is the probability that exposure to the fire/explosion hazards will result in fatality. The following calculations relate to the most vulnerable individuals on site, identified to be workers involved in fire-fighting.

‘IR’ is calculated using the following model:

\[
IR = S \times \text{Vulnerability}
\]

\[
IR \text{ (Workers)} = 1.5 \times 10^{-4} \times 0.3 \times 1.0 = 4.5 \times 10^{-5} \text{ per year}
\]

The major contributory factor for the increased level of ‘IR’ is the potential gas vapour cloud explosion due to the confined conditions of the pressure reduction streams and the Odomatic system.

Evaluation of Individual Risks as shown in FIGURE 22.1 indicates that individual risk to workers at the PRS to be within the ALARP region. This should be reduced to a level that is as low as reasonably practicable, taking cost into account.
FIGURE 13-A Evaluation of IR to Town Gas Workers
13.2 **Individual Risk to the Public**

The general public exposed to major hazards as a result of the PRS activities are road users around the site and residents in buildings nearby. Modelling of the consequences identified gas/odorant releases to affect the public outside the station. The station is surrounded by busy roads, as well as the public buildings.

‘IR’ is calculated using the following model:

\[
IR = S \times \text{Occupancy} \times \text{Vulnerability}
\]

IR (Public) = \(1.5 \times 10^{-4} \times 2 \times 0.3 \times 1.0 = 9.0 \times 10^{-5}\) per year

Evaluation of IR to the public is shown in FIGURE 22.2.

![FIGURE 13-B Evaluation of IR to the public](image-url)
It is therefore concluded that, Individual Risk to the public is also within the ALARP region and should be reduced to a level as low as reasonably practicable.

These risks shall be evaluated against the international risk acceptance criteria.