Annex A

Quantitative Risk Assessment

Sembcorp Industries Limited

QRA Study for Fuel Gas Pipeline from MOGE Gas Station to a green-field Combined Cycle Gas Turbine Power Plant in Myingyan, Myanmar: QRA Report

September 2015

Reference: 0284993

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QRA REPORT

Sembcorp Industries Limited

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September 2015

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Revision 2	1/9/2015	Issue for Approval	AAY/TW	KT	HB
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EXECUTIVE SUMMARY

Environmental Resources Management (ERM) has been commissioned by **Sembcorp Industries Limited** (**Sembcorp)** to carry out a Quantitative Risk Assessment (QRA) study to assess the risks posed by the Fuel Gas Pipeline from the MOGE Gas Station to a newly constructed green-field Combined Cycle Gas Turbine Power Plant in Myingyan, Myanmar.

The objective of the QRA Study is to demonstrate the risks generated by the Fuel Gas Pipeline from the MOGE Gas Station to a newly constructed green-field Combined Cycle Gas Turbine Power Plant (CCGTP) in Myingyan, Myanmar are confined to the "As Low As Reasonably Practicable" (ALARP) region.

The scope of work for the QRA Study:

- 1 km Fuel Gas Pipeline
- Operating pressure: 30 barg
- Pipeline Nominal Diameter: 300 mm

The main hazard associated with Fuel Gas Pipeline is loss of containment leading to an accidental gas leak. The gas is flammable and explosive due to the presence of methane and other trace hydrocarbons.

The Fuel Gas consists of light hydrocarbons with methane (>99.5 mol%) as the major component. The Fuel Gas is considered non-toxic and pure methane was assessed for consequence modelling in this QRA study.

The failure rates based on application of the EGIG data and US data to the Fuel Gas pipeline show that failure rates are 2.70 x 10-4 and 1.69 x 10^{-4} per km per year respectively. Both EGIG and US failure rates data are at the same order of magnitude of 1x10^{-4}.

As the gas pipelines concerned are new pipelines with no historical failure record. Therefore, a conservative approach is adopted with the application of the pipeline failure frequency from the EGIG data is considered in this assessment. So the failure frequency for Fuel Gas pipelines used in this report is 2.70 x 10^{-4} per km-year.

DNV Phast Risk v6.7 was used to model the gas dispersion consequence due to various failure scenarios as well as modelling of risk summation of the consequence and failure frequencies.

International risk criteria UK HSE and BS PD 8010 Part 3 were adopted in this study for evaluating the individual risks and societal risks associated with Fuel Gas Pipeline. The individual risk criteria of 1 x 10^{-6} was adopted to ensure the risks to off-site population is broadly acceptable accordingly to UK HSE Risk Framework.

Two cases, base case and comparison case, have been analysed for assessment of societal risks associated with the Fuel Gas Pipeline.:

- Base Case applied the average population density of Myanmar
- Comparison Case assumes the population density of an urban area. The population density of Yangon was selected as a representative.

The purpose of modelling 2 different cases is to understand the impact of population growth on the societal risks associated with the Fuel Gas Pipeline.

It is found that:

1) The maximum individual risk contour generated by both Base Case and Comparison Case is 1×10^{-7} per year which is broadly acceptable and compliant with the UK HSE Risk Criteria.

2) **Base Case** (Year 2017, Average Population Density for Myanmar):

   The societal risk is confined within the "Acceptable" region based on BS PD 8010 Part 3.

   Comparison Case (Year 2017, Urban Population Density)

   The societal risk is confined within the "Acceptable" region based on BS PD 8010 Part 3.

Therefore, it could be concluded that the Individual Risk and the Societal Risk associated with the Fuel Gas Pipeline is compliant with the risk criteria determined in UK HSE Risk Guidelines and BS PD 8010 Part 3 respectively [10].

1 *INTRODUCTION*

Environmental Resources Management (ERM) has been commissioned by **Sembcorp Industries Limited** (**Sembcorp)** to carry out a Quantitative Risk Assessment (QRA) study to assess the impact of the risks of the Fuel Gas Pipeline which starts from the MOGE Gas Station to a newly constructed green-field Combined Cycle Gas Turbine Power Plant in Myingyan, Myanmar.

1.1 *SCOPE OF WORK AND OBJECTIVES*

The objective of the QRA Study is to demonstrate the risks generated by the Fuel Gas Pipeline from the MOGE Gas Station to a newly constructed green-field Combined Cycle Gas Turbine Power Plant (CCGTP) in Myingyan, Myanmar are confined to the "As Low As Reasonably Practicable" (ALARP) region.

The scope of work for the QRA Study:

- 1 km Fuel Gas Pipeline;
- Operating pressure: 30 barg;
- Pipeline Nominal Diameter: 300 mm;
- The detailed tasks include:
    - To identify all potential hazards to the off-site public associated with the Fuel Gas Pipeline;
    - To carry out a QRA study expressing population risks in terms of both Individual Risk and Societal Risk;
    - To compare Individual and Societal Risks with UK HSE Risk Framework and BS PD 8010 Code of practice for pipelines Part 3 [10]; and
    - To identify and assess practicable and cost effective risk mitigation measures, if required, to comply with the "As Low As Reasonably Practicable (ALARP)" principle used in the UK HSE Risk Framework and BS PD 8010 Code of practice for pipelines Part [10].

1.2 TERMS OF DEFINITIONS

ALARP	As Low As Reasonably Practicable
CCGTP	Combined Cycle Gas Turbine Power Plant
CO_2	Carbon Dioxide
ERM	Environmental Resources Management
FN	F-N
IR	Individual Risk
LFL	Lower Flammability Limit
MOGE	Myanma Oil and Gas Enterprise
PIR	Personal Individual Risk
PLL	Potential Loss of Life
QRA	Quantitative Risk Assessment
UK HSE	United Kingdom Health and Safety Executive

2 PROJECT DESCRIPTION

2.1 FUEL GAS PIPELINE

The Fuel Gas Pipeline from the MOGE Gas Station to a newly constructed green-field Combined Cycle Gas Turbine Power Plant in Myingyan, Myanmar was assessed in this QRA Study.

As per BS PD 8010 Code of practice for pipelines Part 3 [10], the highest risk 1 km section of Fuel Gas Pipeline should be selected to compare with the PD 8010 Part 3 F-N criterion envelope. The Fuel Gas Pipeline running from the MOGE Gas Station to a newly constructed green-field Combined Cycle Gas Turbine Power Plant (CCGTP) in Myingyan, Myanmar with a total pipeline length of 1 km was selected for analysis in the QRA Study.

Figure 2.1 shows the section of the proposed pipeline alignment.

Figure 2.1 Proposed Pipeline Alignment (Fuel Gas Source)

2.2 PHYSICAL PROPERTIES

2.2.1 *Physical Properties of Fuel Gas Pipelines*

The pipeline network is designed to supply the newly constructed green-field CCGTP with Fuel Gas. The composition of Fuel Gas and other physical properties is given in *Table 2.1* and *Table 2.2*.

Table 2.1 Gas Composition & Other Physical Property Data of Fuel Gas

Component	Mole Percent	BTU Gross	Relative Density
C6 + 47/35/17	0.0199	1.05	0.0007
Propane	0.0297	0.75	0.0005
i-Butane	0.0109	0.36	0.0002
n-Butane	32.2 ppm	0.11	0.0001
i-Pentane	49.7 ppm	0.20	0.0001
n-Pentane	0.0000	0.00	0.0000
Nitrogen	0.2218	0.00	0.0021
Methane	99.5529	1007.81	0.5514
Carbon Dioxide	0.0491	0.00	0.0007
Ethane	0.1073	0.00	0.0011
TOTAL	100.0000	1012.18	0.5570

Table 2.2 Fuel Gas Pipeline Parameters

Component	Descriptions
Gas flow range	33068 kg/h
Pressure range	30 barg
Pipe Diameter (Nominal)	300 mm
Temperature range	20 Degree Celsius

2.3 POPULATION CONSIDERED

The risk of residential population surrounding Fuel Gas Pipeline considered in this study from Myingyan Power Plant was assessed.

2.3.1 *Study Zone*

The study zone for Fuel Gas Pipeline is defined as 300 m from the pipeline alignment based on 1% fatality thermal radiation distance. The approach to determine the study zone is consistent with IGEM/TD/2 [7] and PD 8010 Part 3 [10].

The population data within the study zone was estimated based on population density.

2.3.2 *Land and Building Population*

The population within the study zone was based on the following data:

- Local Population Data.

Population within or extended partly into the study zone were included in the assessment. The analysis was performed for population density based on averages Myanmar population projected to year 2017 [9].

Population Density of Residential Population

As there are no local population data available for the region, the average population density of Myanmar and the average population density of the major city Yangon [9][11] were applied in the Base Case and Comparison Case respectively. The population density applied in this study has been summarised in Table 2.3.

Table 2.3 Local Population Density Assessed in the Study

Case	Population Density (persons / km^2)	Notes
Base Case	101	The population density for base case is obtained from the average Myanmar population density projected to year 2017 [9].
Comparison Case	723	The population density in the comparison case is the population density of Yangon obtained from the Population and Housing Census of Myanmar [11]. The purpose of the comparison case was to evaluate the worst case scenario of the risks associated with the fuel gas pipeline for a case of Urban population density.

2.4 *METEOROLOGICAL DATA*

Wind speed, wind stability and direction data received from Lakes Environmental were used for the QRA Study.

Probability of each weather state for each direction during the day and night are shown in *Table 2.4*. Estimated based on raw data provided by Lakes Environmental was used for this study.

The wind speeds are quoted in units of meters per second, (m/s). The atmospheric stability classes refer to:

A – Turbulent

B – Very Unstable

C – Unstable

D – Neutral

E – Stable

F – Very Stable

Atmospheric stability suppresses or enhances the vertical element of turbulent motion. The vertical element of turbulent motion is a function of the vertical temperature profile in the atmosphere. The greater the rate of decrease in temperature with height, the greater the level of turbulent motion. Category D is neutral and neither enhances nor suppresses turbulence.

Table 2.4 Table of Meteorological Data

In consistency with other sections of the ESIA Report, wind speed, wind direction, daytime incoming solar radiation and night time cloud cover were obtained from Lakes Environmental. The daytime incoming solar radiation and night time cloud cover have been further analysed and converted into the Pasquill stability class.

Day	**N**	**NNE**	**ENE**	**E**	**ESE**	**SSE**	**S**	**SSW**	**WSW**	**W**	**WNW**	**NNW**	**Total**
1.5B	18.365	5.673	2.950	2.024	2.974	4.729	5.934	7.573	7.071	5.717	6.681	15.483	**85.173**
2D	0.077	0.034	0.019	0.034	0.058	0.149	0.212	0.193	0.130	0.053	0.043	0.063	**1.065**
4D	1.012	0.328	0.193	0.202	0.713	2.381	3.172	2.400	1.215	0.434	0.255	0.569	**12.875**
7D	0.000	0.000	0.000	0.000	0.010	0.039	0.415	0.304	0.087	0.034	0.000	0.000	**0.887**
3.5E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
1.5F	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
Total	**19.454**	**6.035**	**3.162**	**2.261**	**3.755**	**7.298**	**9.732**	**10.469**	**8.503**	**6.237**	**6.980**	**16.114**	**100.0**

Night	**N**	**NNE**	**ENE**	**E**	**ESE**	**SSE**	**S**	**SSW**	**WSW**	**W**	**WNW**	**NNW**	**Total**
1.5B	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
2D	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.000**
4D	0.132	0.033	0.070	0.113	0.559	1.297	0.959	1.838	0.606	0.141	0.042	0.047	**5.837**
7D	0.005	0.000	0.000	0.000	0.019	0.061	0.038	0.108	0.028	0.014	0.009	0.014	**0.296**
3.5E	1.448	0.484	0.357	0.503	1.570	5.306	9.226	15.035	5.687	1.100	0.409	1.382	**42.506**
1.5F	3.816	3.412	2.834	3.064	4.080	7.139	7.839	6.279	3.722	2.298	2.632	4.244	**51.361**
Total	**5.400**	**3.929**	**3.262**	**3.680**	**6.227**	**13.804**	**18.062**	**23.260**	**10.044**	**3.553**	**3.093**	**5.687**	**100.0**

3 HAZARD IDENTIFICATION

3.1 MAIN HAZARDS FROM FUEL GAS PIPELINE

The main hazard associated with Fuel Gas Pipeline is loss of containment leading to an accidental gas leak. The gas is flammable and explosive due to the presence of methane and other trace hydrocarbons.

3.2 FLAMMABLE & TOXIC EFFECTS OF FUEL GAS

3.2.1 Flammable effects

Fuel Gas consists of light hydrocarbons with methane (>99.5mol %) as the major component. The lower flammability limits (LFL) for methane is given below:

LFL for methane : 5.3% (vol)

As methane is the major flammable component in Fuel Gas, pure methane was assessed for consequence modelling in this QRA study.

Consequence considered: Jet Fire, Flash Fire, Fireball, and Vapour Cloud Explosion

It is noted that while Vapour Cloud Explosion (VCE) is a possible scenario of a gas release, the event of accidental leak of Fuel Gas trapped and accumulated in a congested area in vicinity of the Fuel Gas Pipeline leading to a VCE scenario is very unlikely according to the plot plan of the pipeline and surrounding areas. Therefore, VCE was not considered as a possible scenario in this QRA study.

3.2.2 Toxicity

Carbon dioxide is usually considered as a simple asphyxiant, although it is also a potent stimulus to respiration and both a depressant and excitant of the central nervous system. Only under high concentrations of 20 to 30% carbon dioxide would result in unconsciousness and convulsions within 1 minute of exposure [1].

As the carbon dioxide concentration in Fuel Gas is around 5% of the total gas, Fuel Gas is therefore considered as non-toxic gas.

4 FREQUENCY ANALYSIS

Approach to frequency analysis was based on the application of world-wide historical data for similar systems modified suitably to reflect local factors.

4.1 CAUSES OF LOSS OF CONTAINMENT

4.1.1 *Fuel Gas Pipeline*

The principal causes for loss of containment of pipeline, based on an analysis of wide incident database, are:

- Corrosion – internal and external;
- Third party interference during road construction, due to work on other underground utilities, construction work on adjoining areas, etc;
- Material defect;
- Construction defect;
- Improper operations;
- Defect caused by pressure cycling; and
- External – flooding, subsidence, etc.

The contributions of the above causes have been included in the overall failure frequency. The assumptions made in this study have been summarised in Annex A.

4.2 REVIEW OF PIPELINE INCIDENTS AND FAILURE RATE FOR FUEL GAS PIPELINE

The Consultants undertook a review of major international failure/accident databases to identify past incidents involving transmission gas pipelines. The databases review included:

- US Gas Pipeline Incident Database, 1984 to 2013 [3]; and
- European Gas Pipeline Incident database, EGIG 1970 to 2013 [4].

The operating km-years for US gas transmission pipeline between 1984 to 2013 is 14.0 million km-years while for European gas pipelines between 1970 to 2013, it is 3.98 million-km years. These databases are based on the operating experience world-wide and therefore are more representative in terms of inclusion of various possible failure modes.

The Consultants have conducted an extensive review and analysis of these databases to derive failure rates appropriate to the Fuel Gas pipeline under study. A brief description of the databases is included in the following paragraphs.

4.2.1 *Analysis of US Gas Failure Data*

The US Department of Transportation Research and Special Administration maintain databases for pipelines incidents (reportable) in the United States and pipeline mileage data. Under the reporting requirements, events involving a gas release that causes death, injury or damage in excess of US$50,000 needs to be reported. Due to the nature of reporting, it is possible that minor incidents of leaks are underrepresented.

The US gas database has been filtered to consider only onshore transmission pipelines and only those failures involving the body of the pipeline. There have been 2359 incidents involving loss of containment during the period 1984 to 2013. The total pipeline km-years during this period is 1.4 x 10^7. This gives a failure rate of 1.69 x 10^{-4} per km per year.

A breakdown of the 2,359 pipeline incidents according to cause of failure is given in *Table 4.1.*

Table 4.1 ***Summary of US Gas Onshore Transmission Pipeline Incidents by Cause 1984-2013***

Cause of Failure	Description of Cause	No. of Incidents	%
1 EXTERNAL FORCE		**918**	**38.9%**
1.1 Weather		188	8.0%
1.1.1 Earth Movement	Subsidence, landslides, earthquake	109	4.6%
1.1.2 Temperature		11	0.5%
1.1.3 Heavy Rain/Flood		34	1.4%
1.1.4 Lightning		19	0.8%
1.1.5 High Wind		11	0.5%
1.1.6 Cold Weather	Thermal stress, frozen components, frost heave	4	0.2%
1.2 Excavation Damage		613	26.0%
1.3 Other forces damage	Previous damaged pipe, vandalism, Damage by fire/explosion, vehicle not engaged in excavation, previous mechanical and intentional damage	117	5.0%
2 CORROSION		**453**	**19.2%**
2.1 External	Failure of coating/ CP	273	11.6%
2.2 Internal		180	7.6%
3 WELDS, MATERIALS & EQUIPMENT FAILURE	Environment-cracking related, body of pipe, pipe seam, butt & fillet weld, joint, fitting or component, malfunction of control/relief equipment, threaded connection or coupling failure, non-threaded connection failure	**529**	**22.4%**

4 INCORRECT OPERATIONS	Includes incorrect valve position	**47**	**2.0%**
5 OTHER	Miscellaneous and unknowns	**412**	**17.5%**
TOTAL		**2359**	**100%**

4.2.2 *Analysis of EGIG Data*

The EGIG is an industry group of nine companies comprising all of the major gas transmission system operators in Western Europe.

The EGIG database for the period 1970 to 2013 includes 1,309 incidents against the total exposure of 3.98 x 10^6 km-years [4].

Table 4.2 EGIG Incidents Breakdown by Causes

Cause	**Proportion (1970 to 2013)**
External interference	28%
Corrosion	26%
Construction defects/material failure	16%
Ground movement	16%
Hot tap	6%
Others	8%

External interference remains the main cause of incidents with gas leakage.

As the diameter and wall thickness of the pipeline considered in this study are 300 mm, the accident involving pipelines in the category of 11 to 17 inches are considered. The frequency associated with the category 11 to 17 inches is 2.70 x 10^{-4} per km per year as derived from the EGIG data.

4.2.3 *Conclusions on Failure rate for Fuel Gas Pipeline*

The failure rates based on application of the EGIG data and US data to the Fuel Gas pipeline show that failure rates are *2.70 x 10^{-4}* and *1.69 x 10^{-4}* per km per year respectively. Both EGIG and US failure rates data are at the same order of magnitude of 1x10^{-4}.

As the gas pipelines concerned are new pipelines with no historical failure record. Therefore, a conservative approach is adopted with the application of the pipeline failure frequency from the EGIG data is considered in this assessment. The proposed failure frequency for Fuel Gas pipelines is as follows:

Fuel Gas Pipeline Failure Rate: 2.70 x 10^{-4} per km-year

4.3 *PIPELINE HOLE SIZE DISTRIBUTION*

4.3.1 *Pipeline Hole Size Distribution to be adopted in QRA Study*

For process equipment, interconnection piping, and pipelines, the following representative failure sizes were considered in this study following the leak frequency distribution for above ground transfer pipeline adopted in UK HSE [8]:

Rupture (> 110 mm)	2.4%
Large Hole (>75 - ≤ 110 mm)	12.4%
Small Hole (> 25 - ≤ 75 mm)	25.1%
Pin Hole (≤ 25 mm)	60.0%

Table 4.3 summarises the assumption for failure frequency of above ground pipeline hole size distribution adopted in this study.

Table 4.3 Hole Size Distribution for Fuel Gas Pipeline

Category	Hole Size (inch)	Proportion
Rupture	Full bore	2.4%
Large Leak	100 mm	12.4%
Small Leak	50 mm	25.1%
Pinhole Leak	25 mm	60.0%

4.4 EVENT TREE ANALYSIS (ETA)

An event tree analysis was performed to model the development of each event from the initial release to the final outcome. The event tree takes into consideration whether there is immediate ignition, delayed ignition or no ignition. Orientation of the release is also considered. A generic event tree for above ground gas releases is shown in *Figure 4.1*. The possible outcomes include jet fires, flash fires, and fireballs.

The various branches in the event trees are discussed in the following sections.

4.4.1 Orientation of Release

The consequences of a gas release are dependent on the release rate and the orientation of the release. Failures that occur on the top portion of the pipeline result in vertical jet releases (unobstructed) and are governed by momentum jet dispersion/ momentum jet fires. Failures that occur from the bottom portion of the pipeline lose momentum due to impingement/ obstruction with the surrounding earth (for buried sections of pipeline) and therefore are governed by buoyant plume rise followed by Gaussian dispersion. For releases from flanges and valves, the release may be horizontal or inclined in addition being vertical. The probability of orientation of releases to be considered in the assessment is listed in *Table 4.4*.

Table 4.4 Probability of Orientation of Release

Equipment/ Pipework	Vertical	Horizontal	Inclined (45°)
Pressurized Gas Pipeline (above ground)	0.5	0.25	0.25

4.4.2 IGNITION SOURCES

In order to calculate the risk from flammable materials, information is required on the ignition sources which are present in the area over which a flammable cloud may drift. The probability of a flammable cloud being ignited as it moves downwind over the sources can be calculated. The ignition source has three factors:

Presence factor is the probability that an ignition source is active at a particular location;

Ignition factor defines the "strength" of an ignition source. It is derived from the probability that a source will ignite a cloud if the cloud is present over the source for a particular length of time; and

The ignition sources are site specific. This allows the position of the source relative to the location of each release to be calculated. The results of the dispersion calculations for each flammable release are then used to determine the size and mass of the cloud when it reaches the source of ignition. The typical ignition sources are road vehicles and the population nearby.

Roads are line ignition sources in Phast Risk v6.7. The presence factor for a line source is determined based on traffic densities, average speed along the road and the length of the road element. The location of the line source is drawn onto the site map in Phast Risk v6.7. Probability of ignition for a vehicle is taken as 0.4 in 60 seconds [6].

Phast Risk v6.7 will automatically allow for people acting as ignition sources. These are based on the population data. The presence of such sources (e.g. cooking, smoking, heating appliances, etc.) is derived directly from the population densities in the area of concern.

4.4.3 *Ignition Probability*

The potential for ignition depends not only on the presence of ignition sources but it is also a function of release rate and duration of release. Larger releases are more likely to ignite than smaller releases. Similarly, releases that continue for a longer duration have a higher probability of ignition than short duration releases.

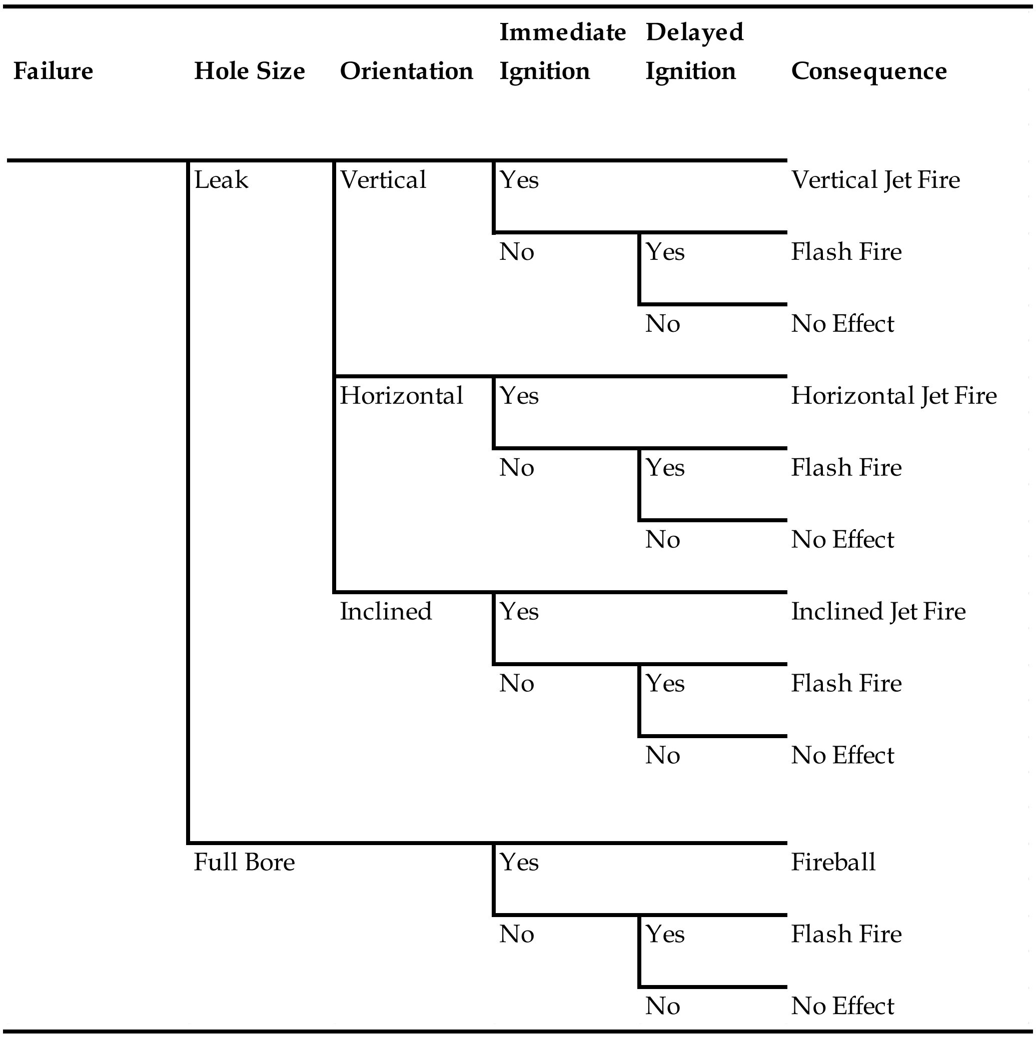
Based on a number of sources, Cox et al. [2] estimate an ignition probability based on spill size for gas and liquid releases as given in *Table 4.5*.

A factor of 0.4 was assumed for delayed ignition of all release.

Table 4.5 ***Ignition Probability for Plant Releases***

Leak Size	**Probability of Ignition**	
	Gas	**Liquid**
Minor (<1kg/s)	0.01	0.01
Major (1 to 50kg/s)	0.07	0.03
Massive (>50kg/s)	0.3	0.08

Figure 4.1 *Event Tree for Gas Release from Above Ground Pipeline*



4.5 *EVENT OUTCOME FREQUENCIES*

Combining the failure rates with leak size distribution and probabilities for release orientation and ignition allows the frequency of each event outcome to be calculated.

5 CONSEQUENCE ANALYSIS

Consequence analysis was involved the following steps:

- Source term modelling; and
- Physical effects modelling.

The source term modelling comprises the application of appropriate discharge rate models to define the release rate, duration and the quantity of release. The source term modelling output forms the inputs to physical effects modelling such as the dispersion and fire modelling.

5.1 SOURCE TERM

The gas dispersion modelling of *Phast Risk v6.7* should be adopted to estimate the release rates, which was used to determine the immediate ignition probability.

Physical Effects Modelling

The scenarios following a release may include:

- Fire ball;
- Jet fire; and
- Flash fire

5.1.1 Fireball Effects

Immediate ignition of releases caused by a rupture in the pipeline may give rise to a fireball upon ignition.

The consequence analysis for fireball scenario was conducted by *Phast Risk v6.7* [5] with Roberts (HSE) method as the calculation method, which adopts the following equation for estimation of fireball diameter.

$R = AxM^{1/3}$

where:
R is radius of fireball;
A is substance-specific factor;
M is mass of the fireball.

The Probit equation given by Purple Book [6] is used for estimation of fatalities due to thermal radiation effects. The Probit equation is given below:

$Pr = -36.38 + 2.56 \times \ln(Q^{4/3} \times t)$

where

Pr	Probit corresponding to the probability of death (-)
Q	heat radiation ($W\ m^{-2}$)
t	exposure time (s)

Assuming an exposure time of 30 seconds (corresponding to the time taken to escape to a safe area), the radiation level of fireball effect corresponding to 1% fatality is estimated as 12.5 kW/m^2 based on Eisenberg probit, which is adopted in this study.

Persons caught in the open within the fireball diameter are assumed to be 100% fatally injured.

5.1.2 *Jet Fire Effects*

Jet fires result from ignited releases of pressurized flammable gas or superheated/ pressurized liquid. The momentum of the release carries the materials forward in form of a long plume entraining air to give a flammable mixture. Combustion in a jet fire occurs in the form of a strong turbulent diffusion flame that is strongly influenced by the momentum of the release.

Assuming an exposure time of 30 seconds (corresponding to the time taken to escape to a safe area), the radiation level of jet fire effects corresponding to 1% fatality is estimated as 12.5 kW/m^2 based on Eisenberg probit, which is adopted in this study.

5.1.3 *Flash Fire Effects*

In the event that a release is not ignited immediately, the gas will disperse with the wind and may subsequently ignite if it reaches an ignition source. Portions of the cloud within flammability limits will then burn in a flash fire. The dispersion distance to the Lower Flammability Limit (LFL) was used as the hazard footprint. Dispersion modelling was performed using *Phast Risk v6.7* for the representative weather conditions at a particular site surrounding.

In summary, referring to *Figure 4.1,* the scenarios of Flash Fire, Jet Fire and Fireball were considered in this QRA study.

5.2 *RESULTS*

The results of the consequence analysis for each operating pressure conditions was modelled by *Phast Risk v6.7* for risk summation.

6 *RISK SUMMATION & EVALUATION*

The scenarios, frequency, meteorological data and suitable modelling parameters identified was input into *Phast Risk v6.7*. All risk summation should be modelled using *Phast Risk v6.7*. The inputs to the software comprise of:

- Release cases file detailing all identified hazardous events, and their frequencies and probabilities;
- Release location of hazardous events either at given points or along given routes;
- Weather frequencies file that details the local meteorological data according to a matrix of weather class (speed/stability combinations) and wind directions;
- Population data with the number of people and polygonal shape as well as indoor faction; and
- Ignition sources with ignition probabilities in a given time period.

6.1 *RISK MEASURES*

The two types of risk measures considered in this QRA study are societal and individual risks.

6.1.1 *Societal Risk*

Societal risk is defined as the risk to a group of people due to all hazards arising from a hazardous installation or activity. The simplest measure of societal risk is the Rate of Death or Potential Loss of Life (PLL), which is the predicted equivalent fatality per year. The PLL is calculated as follows:

$$PLL = f_1N_1 + f_2N_2 + f_3N_3 + ... + f_nN_n$$

where f_n is the frequency and N_n the number of fatalities associated with the n^{th} hazardous outcome event.

Societal risk can also be expressed in the form of an FN curve, which represents the cumulative frequency (*F*) of all event outcomes leading to N or more fatalities. This representation of societal risk highlights the potential for accidents involving large numbers of fatalities.

6.1.2 *Individual Risk*

Individual risk may be defined as the frequency of fatality per individual per year due to the realization of specified hazards. Individual Risk (IR) may be derived for a hypothetical individual present at a location 100% of time or a named individual considering the probability of his presence etc. (the latter case is known as Personal Individual Risk (PIR)). This study focuses on IR only.

6.2 *RISK EVALUATION*

The risks derived for the Fuel Gas Pipeline from the MOGE Gas Station to the CCGTP is evaluated by compar

ing against the risk criteria (guidelines) for BS PD 8010 Part 3 [10].

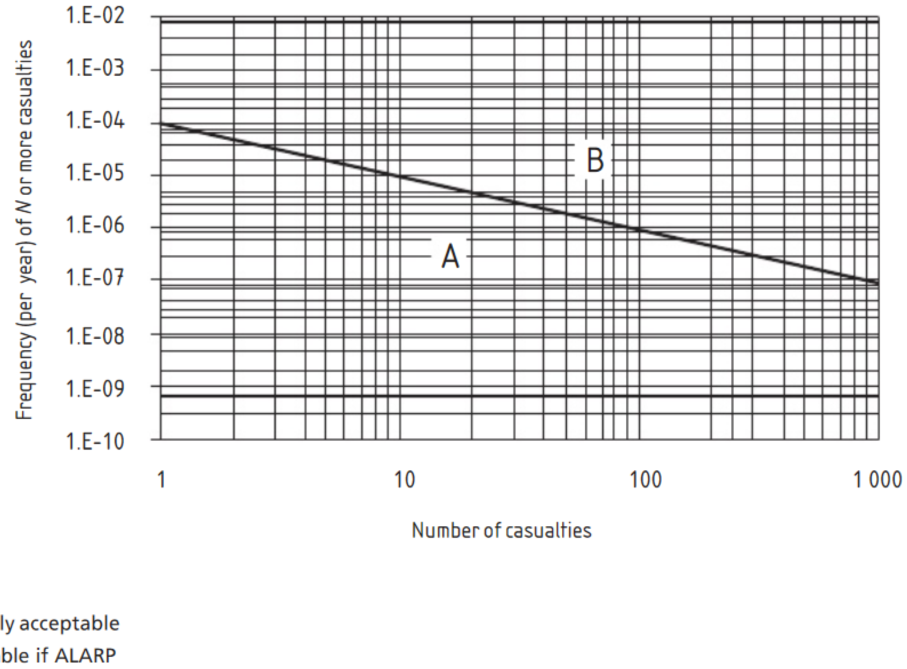
6.2.1 *UKHSE & BS PD 8010 Part 3 Guidelines*

The individual risk (IR) criteria specify that the risk of fatality to an individual is broadly acceptable if the risks are lower than 1 x 10^{-6} per year.

The societal risk guidelines in PD 8010 Part 3 are shown in *Figure 6.1*. There are two regions indicated on the figure:

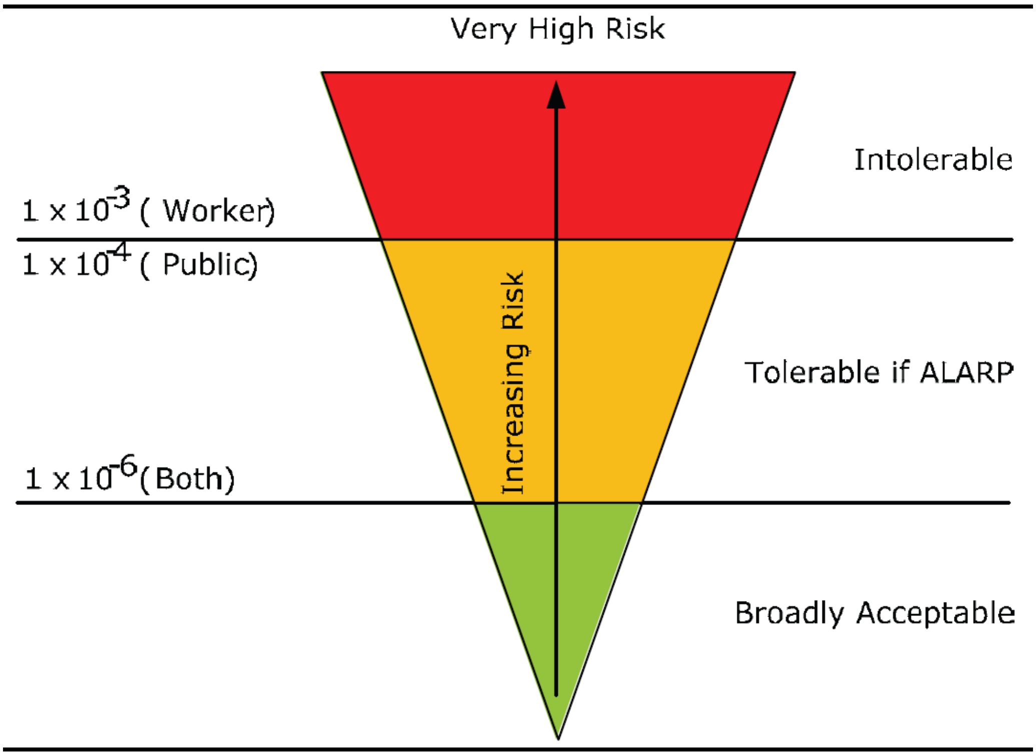
- Unacceptable region;
- ALARP region where risk is tolerable providing it has been reduced to a level As Low As Reasonably Practicable; and
- Acceptable region where risk is broadly acceptable.

Figure 6.1 ***Societal Risk Guidelines for Acceptable Risk Levels – BS PD 8010 Part 3 Guidelines***



From an analysis of the above risk results, the dominant contributors to risk were identified and measures to mitigate them may be specified. Such measures may either seek to reduce the likelihood of hazardous events occurring or to reduce the impact of the events should they occur, to As Low As Reasonably Practicable (ALARP).

Figure 6.2 HSE Framework for Tolerability of Risk [10]



6.3 INDIVIDUAL RISK RESULTS

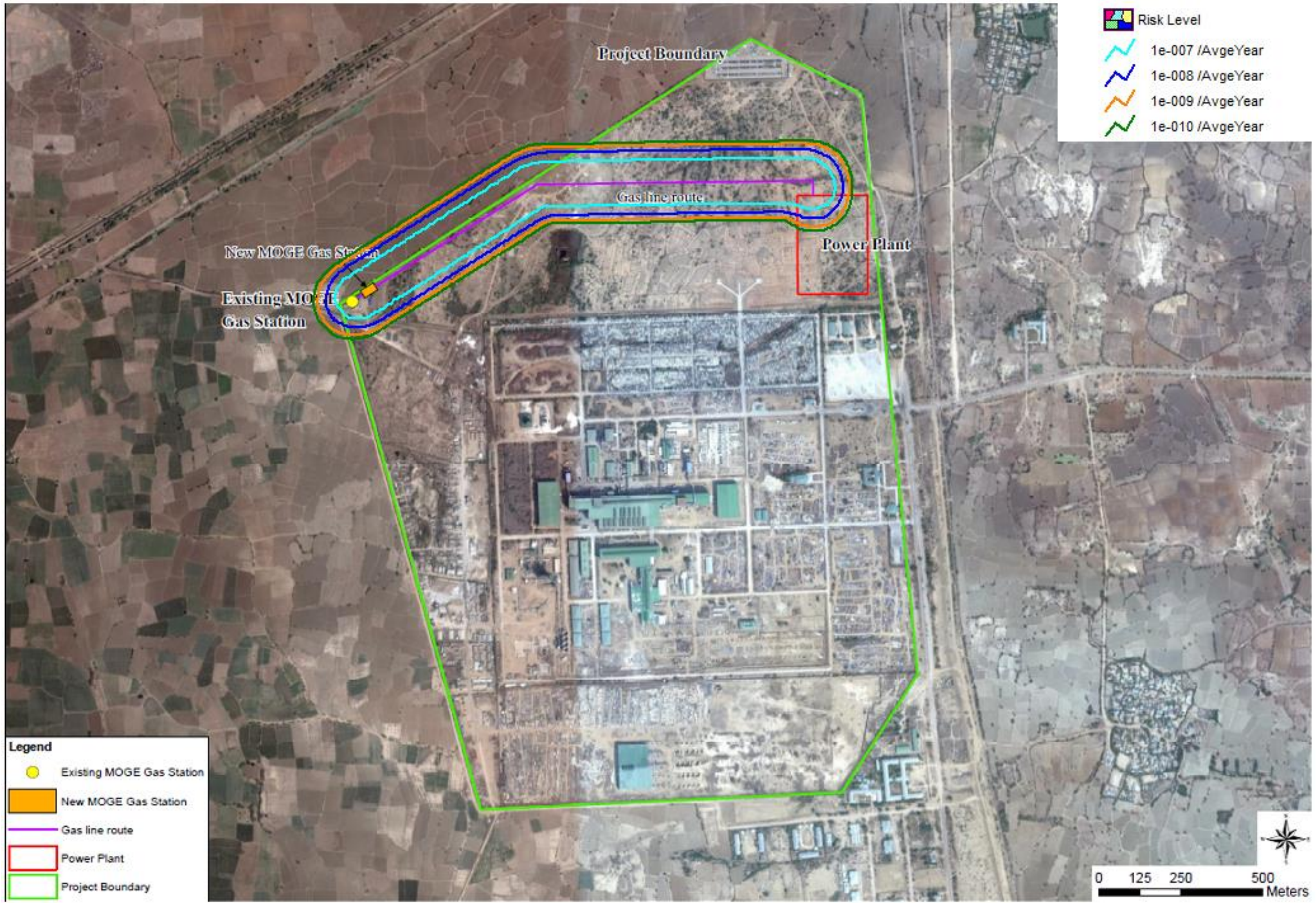
6.3.1 *Fuel Gas Pipeline at Base Case*

The Individual Risk Contours from 1 × 10^{-7} to 1 × 10^{-9} per year for Fuel Gas Pipeline at **Base Case** are depicted in *Figure 6.3*. The maximum individual risk contour generated is 1 × 10^{-7} per year.

The Individual Risk Contour of 1 × 10^{-9} per year is well confined within the study zone of the Fuel Gas Pipeline. It should be noted that all hazardous scenarios at credible frequency of 1 × 10^{-9} per year have been considered for the off-site population within the study zone.

It was conservatively assumed as 100% exposure factor to be applied for surrounding population of Fuel Gas Pipeline in this QRA Study. The maximum individual risk contour for the Fuel Gas pipeline is lower than 1 x 10^{-7}; therefore, the individual risk associated with the Fuel Gas pipeline is broadly acceptable to the off-site population and it could be concluded that the individual risk of the Fuel Gas pipeline is in compliance in UK HSE Guidelines [10] at **Base Case**.

Figure 6.3 Individual Risk for the Fuel Gas Pipeline (Base Case)



6.4 SOCIETAL RISK RESULTS

6.4.1 *Potential Loss of Life*

As there are no local population data available for the region, the average population density of Myanmar and the average population density of the major city Yangon were applied in the **Base Case** and **Comparison Case** respectively.

The societal risks for **Base Case** and the **Comparison Case** were expressed in terms of Potential Loss of Life (PLL) as summarized at *Table 6.1*.

The PLL has been increased significantly from **Base Case** to **Comparison Case** due to the increase in population, however it is noted that both are within or below the magnitude of 1 x 10^{-6} which is lower than the individual risk criteria for broadly acceptable from UK HSE.

Table 6.1 ***Societal Risk - PLL Results***

	PLL (per year)	
	Base Case	**Comparison Case**
Total	6.47E-07	4.87E-06

6.4.2 *FN Result*

The FN results for Fuel Gas Pipeline for **Base Case and Comparison Case** are presented in *Figure 6.4* and *Figure 6.5* respectively.

As shown in the figures, the societal risk for **Base Case and Comparison Case** are confined within "Acceptable" region based on BS PD 8010 Part 3.

Since the purpose of the comparison case is to understand if the societal risks associated with the Fuel Gas Pipeline are still in compliance with the societal risk guideline of BS PD 8010 Part 3 when the nearby population density has grown into the scale of the most populated city in Myanmar, it could be concluded that the societal risk associated with the Fuel Gas Pipeline is in compliance with BS PD 8010 Part 3 because both Base Case and Comparison Case are confined within the "Acceptable " region.

Figure 6.4 FN Curve for Fuel Gas Pipeline (Base Case)

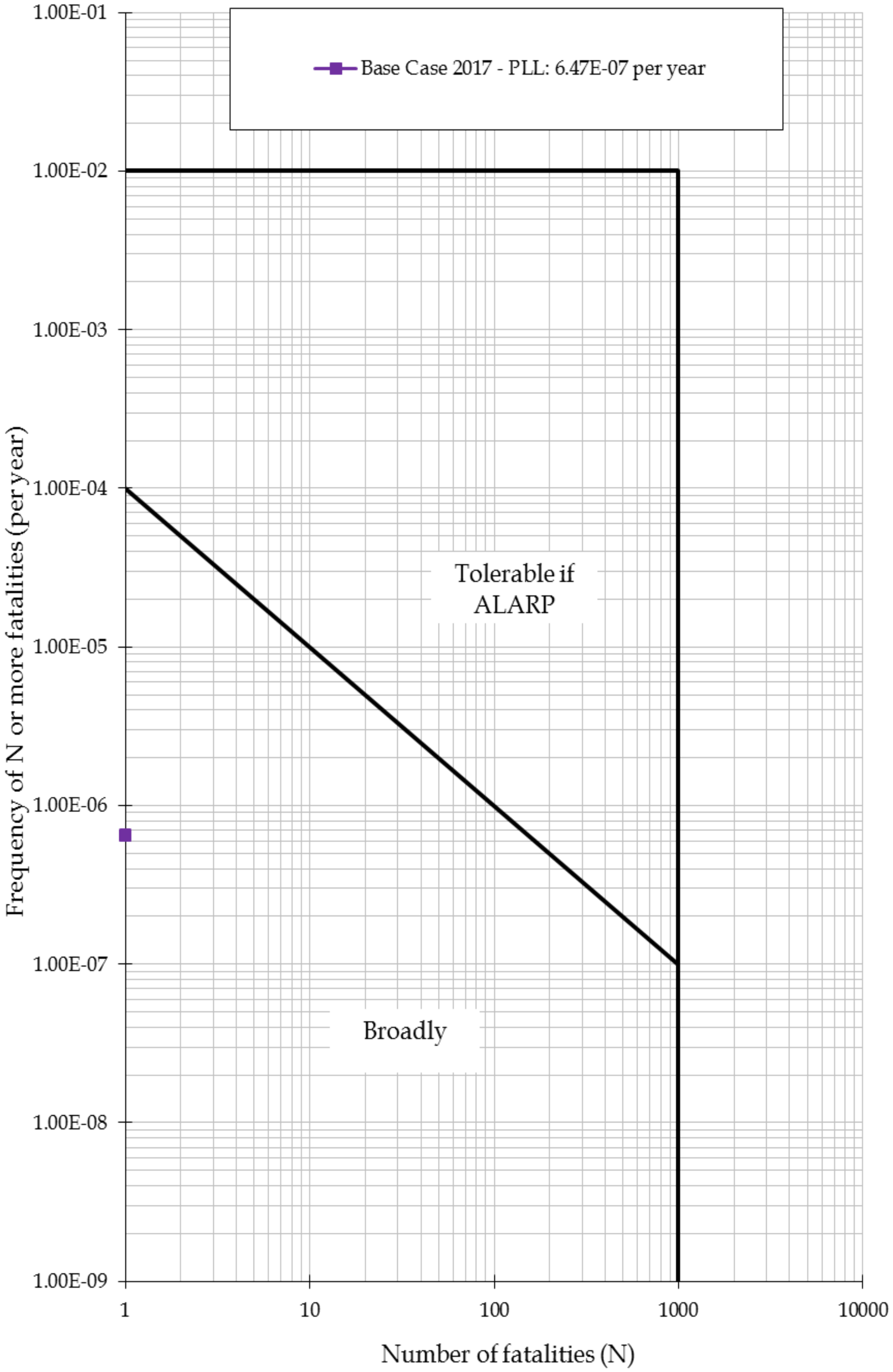
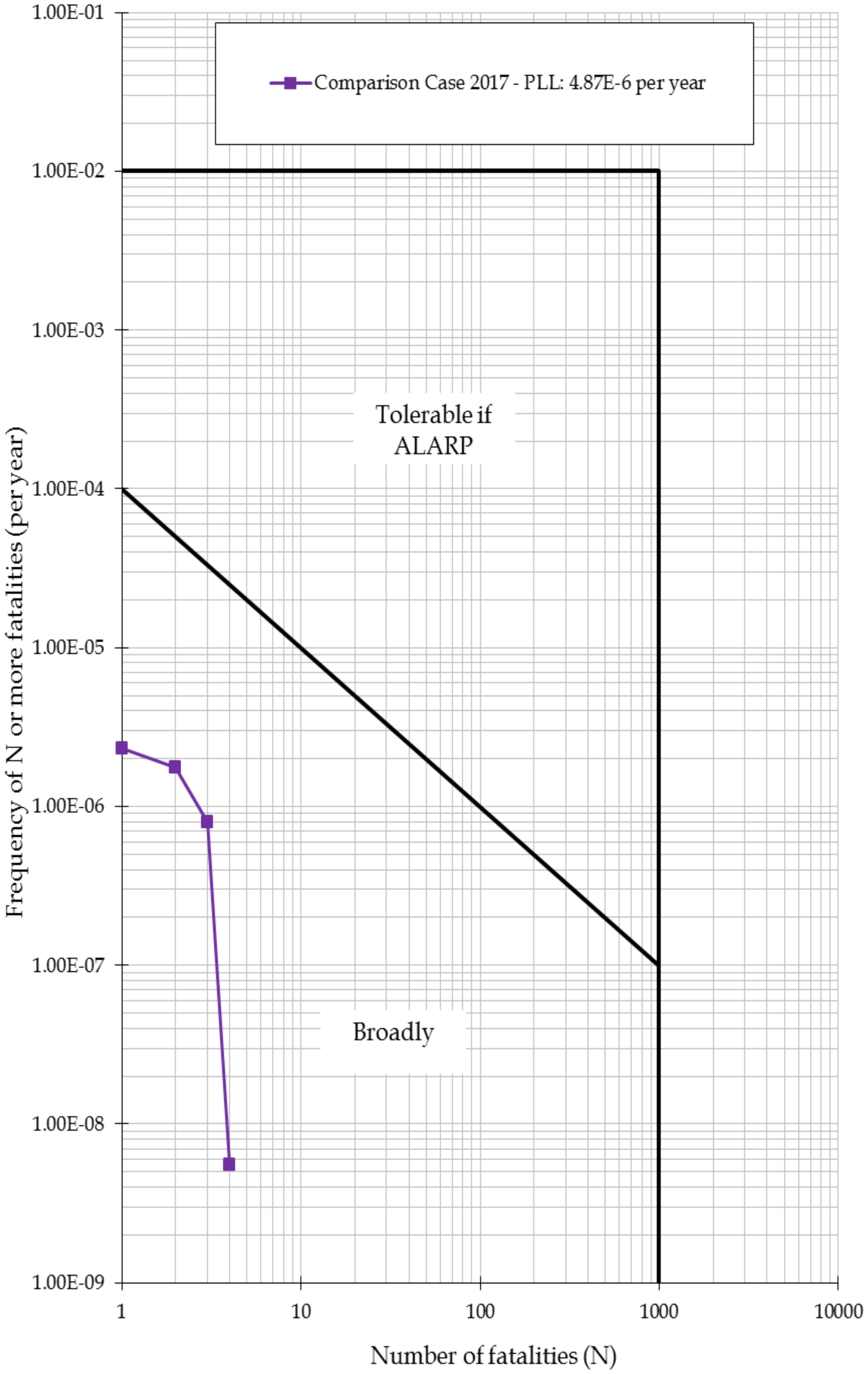


Figure 6.5 FN Curve for Fuel Gas Pipeline (Comparison Case)



7 *CONCLUSIONS & MITIGATION*

A Quantitative Risk Assessment (QRA) has been conducted for the Fuel Gas Pipeline to assess the risks posed by the Pipeline on surrounding population.

It is found that the maximum individual risk contour generated by Base Case and Comparison Case are 1×10^{-7} per year.

Base Case (Year 2017, Average Population Density of Myanmar):

The societal risk is confined within the "Acceptable" region based on BS PD 8010 Part 3.

Comparison Case (Year 2017, Average Population Density of Yangon)

The societal risk is confined within the "Acceptable" region based on BS PD 8010 Part 3.

Therefore, it could be concluded that the Individual Risk and the Societal Risk associated with the Fuel Gas Pipeline is compliant with UKHSE Guidelines and BS PD 8010 Part 3 respectively [10].

7.1 *GENERAL RECOMMENDATIONS*

1. Consider hot tapping as a high risk activity that is a likely cause of gas leakage. Ensure that all hot tapping activities are carried out only by trained and authorized personnel.
2. Consider implementing crash barriers and control of vehicle access, onsite speed limits and driver training programme to reduce risk of gas leakage incident arising from vehicle striking piping or equipment.
3. Consider implementing routine corrosion monitoring to reduce risk of gas leakage due to internal corrosion of pipeline.
4. Consider implementing routine inspection of coating integrity to reduce risk of gas leakage due to damaged coating.

8 REFERENCE

[1] Nick H. Proctor, James P. Hughes and Michael L. Fishman (1988), Chemical Hazards of the Workplace

[2] Cox, Lees and Aug, Classification of Hazardous Locations, IChemE, 1990

[3] PRC International, American Gas Association, Analysis of DOT Reportable Incidents for Gas Transmission and Gathering Pipelines, 1 January 1985 to 31 December 2013

[4] European Gas Pipeline Incident Data Group, 9th EGIG Report, 1970-2013

[5] DNV, *Phast Risk v6.7*.

[6] TNO, Guidelines for Quantitative Risk Assessment, the "Purple Book", Report CPR 18E, The Netherlands Organisation of Applied Scientific Research, Voorburg, 1999.

[7] Assessing the risks from high pressure natural gas pipeline, IGEM/TD/2 Edition 2.

[8] Health & Safety Executive, Failure Rate and Event Data for use within Risk Assessment (28/06/2012), 2012.

[9] World Bank Indicators - Myanmar – Density & Urbanization, http://www.tradingeconomics.com/myanmar/population-density-people-per-sq-km-wb-data.html, July 2016

[10] BSI, PD 8010-3:2009+A1:2013, Code of practice for pipelines Part 3, 2013

[11] Summary of the Provisional Results, The Population and Housing Census of Myanmar, 2014, Republic of the Union of Myanmar Department of Population, Ministry of Immigration and Population, August 2014

Annex A

Assumption Register

A. ASSUMPTIONS FOR QRA METHODOLOGY

A.1 SURROUNDING DATA ANALYSIS

A.1.1 Meteorological Data

Assumption Number: A.1.1

As per Appendix 4.B of "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)", at least six representative weather classes are recommended to be used in QRA study, covering the stability conditions of stable, neutral and unstable, low and high wind speed. At least the following six weather classes have to be covered in terms of Pasquill classes.

Stability class	**Wind speed (1)**
B	Medium
D	Low
D	Medium
D	High
E	Medium
F	Low

(1): Low wind speed corresponding to 1 – 2 m/s
Medium wind speed corresponding to 3 – 5 m/s
High wind speed corresponding to 8 – 9 m/s

Several rules were applied to classify the observations in the six weather classes:

1. Observations in the Pasquill stability classes A, A/B, B and B/C are grouped to class B while the wind speed of the weather class is equal to the average wind speed of the observations.

2. Observations in the Pasquill stability classes C, C/D, D are grouped to class D while the wind speed of the weather class is equal to the average wind speed of the observations. Wind speeds below 2.5 m/s, between 2.5 m/s and 6 m/s and above 6 m/s are classified as the wind speed categories low, medium and high respectively.

3. Observations in the Pasquill stability classes E and F are allocated on the basis of the wind speed. Wind speeds below 2.5 m/s and above 2.5 m/s are classified as weather classes F and E respectively. The wind speed in each weather class is equal to the average wind speed of the observations in the weather class.

Assumption Number: A.1.1

The allocation of six representative weather classes is shown in following figure.

<table>
<tr><th>Wind speed</th><th>A</th><th>B</th><th>B/C</th><th>C</th><th>C/D</th><th>D</th><th>E</th><th>F</th></tr>
<tr><td>< 2.5 m/s</td><td colspan="3" rowspan="3">B medium</td><td colspan="3">D low</td><td colspan="2">F low</td></tr>
<tr><td>2.5-6 m/s</td><td colspan="3">D medium</td><td colspan="2" rowspan="2">E medium</td></tr>
<tr><td>>6 m/s</td><td colspan="3">D high</td></tr>
</table>

The atmospheric pressure, ambient temperature and relative humidity are 1.013 bar, 28°C, and 70% respectively.

A.1.2 *Surface Roughness*

Assumption Number: A.1.2

The roughness parameter reflects the average roughness over which cloud is dispersing. For consequence modelling conducted using *Phast Risk 6.7*, a value of 50 cm should be selected representing a conditions of parkland, bushes, and numerous obstacles.

A.2 FREQUENCY ANALYSIS

A.2.1 Failure Frequency Database

Assumption Number: A.2.1

Regarding Fuel Gas Pipeline, the failure frequency is assumed as 2.7 x 10^{-4} per km per year to be used in this QRA Study.

A.2.2 *Release Hole Size Distribution*

Assumption Number: A.2.2

The following representative leak sizes of Natural Gas Pipeline are proposed to consider in this QRA methodology:

Rupture (> 110 mm)	2.4%
Large Hole (>75 - ≤ 110 mm)	12.4%
Small Hole (> 25 - ≤ 75 mm)	25.1%
Pin Hole (≤ 25 mm)	60.0%

A.2.3 *Release Orientation Probability*

Assumption Number: A.2.3

The consequences of a release from the pipeline depend on the orientation of release. Failures that occur on the top portion of the pipeline result in vertical jet release (unobstructed) and are governed by momentum jet dispersion/ momentum jet fires.

Failures that occur from the bottom portion of the pipeline lose momentum due to impingement/ obstruction with the surrounding earth (for buried sections of pipeline) and therefore are governed by buoyant plume rise followed by Gaussian dispersion, which is considered as inclined orientation release.

The probability of orientation of release from hole up to 100 mm size to be considered in this QRA methodology study is listed in following table.

Orientation of release may not be relevant for full bore failures, which are more likely to result in an upward release following the displacement of each cover. Therefore, full bore failures are considered to be completely unobstructed.

Equipment/ Pipeline	**Vertical**	**Horizontal**	**Inclined (45°)**
Pressurized Gas Pipeline (above ground)	0.5	0.25	0.25

A.2.4 Ignition Probability

Assumption Number: A.2.4

The potential for ignition depends not only on the presence of ignition sources but it is also function of release rate and duration of release. Larger releases are more likely to ignite than smaller release. Similarly, release that continue for a longer duration have a higher probability of ignition than short duration releases.

Based on Cox, Lees, Ang et al the ignition probability is estimated based on spill size for gas and liquid release as given in following table. The immediate ignition is estimated based on release rate from Cox et al.

A factor of 0.4 is assumed for delayed ignition of all release when the cloud is not ignited by ignition sources.

Leak Size	**Probability of Ignition**	
	Gas	**Liquid**
Minor (< 1 kg/s)	0.01	0.01
Major (1 to 50 kg/s)	0.07	0.03
Massive (> 50 kg/s)	0.30	0.08

A.2.5 *Probability of delayed ignition*

Assumption Number: A.2.5

As per Appendix 4.A of "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)", the probability of ignition a time interval of one minute for a number of sources is listed as following table:

Source	Probability of Ignition in one minute
1. Point Source	
motor vehicle	0.4
flare	1.0
outdoor furnace	0.9
indoor furnace	0.45
outdoor boiler	0.45
indoor boiler	0.23
ship	0.5
ship transporting flammable materials	0.3
fishing vessel	0.2
pleasure craft	0.1
diesel train	0.4
electric train	0.8
2. Line Source	
transmission line	0.2 per 100 m
road	Note 1
railway	Note 1
3. Area Source	
chemical plant	0.9 per site
oil refinery	0.9 per site
heavy industry	0.7 per site
light industrial warehousing	as for population
4. Population Source	
residential	0.01 per person
employment force	0.01 per person

Note 1:
The ignition probability for a road or railway near the establishment or transport route under consideration is determined by the average traffic density. The average traffic density, d, is calculated as:
$d = NE/v$
where:
N: number of vehicles per hour (h^{-1})
E: length of a road or railway selection (km)
v: average velocity of vehicle (km h^{-1})

A.3 *CONSEQUENCE ANALYSIS*

A.3.1 *Source Term Modelling*

Assumption Number: A.3.1

Most leak sources are at ground level or near ground level. However, taking into account that most release consists of light ends which are buoyant, 1.0 m is considered an accurate representative height for modelling purposes in this QRA methodology study.

The averaging time to be considered for dispersion modelling is 18.75 s.

A.3.2 *Fireball Effect*

Assumption Number: A.3.2

With regard to fireball, a 100% fatality is assumed for any person outdoors within the fireball radius.

A.3.3 Jet Fire Effect

Assumption Number: A.3.3

Fatality rates due to exposure to thermal radiation from Jet Fire to persons without protective clothing should be determined by "Guidelines For Quantitative Risk Assessment, CPR 18E (Purple Book)" Probit function, as follows:

$Pr = -36.38 + 2.56 \times \ln(Q^{4/3} \times t)$

where

Pr Probit corresponding to the probability of death (-)

Q heat radiation (W m^{-2})

t exposure time (s)

The exposure time, t, is limited to maximum of 20 s.

A.3.4 *Flash Fire Effect*

Assumption Number: A.3.4

With regard to flash fires, a 100% fatality is assumed for any person outdoors within the flash fire envelope. The extent of the flash fire is considered to be the distance to 100% of LFL (Lower Flammability Limit).