9 QUANTITATIVE RISK ASSESSMENT (QRA)

9.1 QRA Objectives and Scope

9.1.1 Objective

QRA study provides a demonstration that the measures for prevention and mitigation employed by the facility will result in a level of risk that is 'as low as reasonably practicable' (ALARP).

This Chapter provides a summary of the QRA report. The full QRA document can be found in *Appendix G*.

9.1.2 Scope of Work

The scope of work of the QRA comprised the following:

- **Hazard identification** – a qualitative review of possible accidents that may occur (based on industrial accident records or, as necessary, professional judgement) involving the hazardous substances stored and/or utilised by the project;
- **Scenario identification** – definition of the specific scenarios to be studied in this QRA, with each scenario assigned a unique identification code or isolatable section number;
- **Event tree and frequency analysis** – determination of the frequency or likelihood of occurrence of all identified scenarios;
- **Consequence modelling** – determination of the consequence distances (hazard zones) that would result from realisation of each scenario identified by outcome, e.g. pool fire, jet fire, flash fire, vapour cloud explosion (VCE) and toxic release;
- **Risk Summation**– the summation of consequences and frequencies of all isolatable sections to determine the Individual Risk (IR) and Societal Risk (SR); and
- **Evaluation against Risk Acceptance Criteria** – to determine acceptability of the projects risks to the site surroundings with regards to DoE Individual Risk Acceptance Criteria and, as necessary, to recommend mitigation measures to ensure compliance and that risks are *as low as reasonably practical (ALARP)*.

The QRA was carried out in accordance with *DoE's EIA Guidelines for Risk Assessment.*

9.2 Hazard Identification and Selection of Scenarios

9.2.1 Introduction

A hazard in this context is defined as a loss of containment (LoC) that has the potential to cause offsite damage to people, property or the surrounding environment. The following section identifies and selects the specific hazardous scenarios to be address in this QRA. The following sections summarise the main findings of the QRA.

9.2.2 Chemical Inventory and Properties of Hazardous Substances

The substances that will be stored and are subject to a QRA are Condensate, Naphtha, Sour Naphtha, Sweet Naphtha, Pentane, Dodecene, LPG, Butane, Kerosene, Propane, Ethane, Hydrogen, Diesel, Heptane, Sulfolane, Hydrogen Sulfide, Toluene, Xylene, Para-xylene, Hexane, Aromatics, Benzene, Tetramethylbenzene (TTMBZ), Diethylbenzene (DEBZ), and Trimethylbenzene (TMBZ).

The materials are chosen based on high mass percentage in each unit (equipment and pipeline).

Information on the location, hazards, physical properties, physical condition and storage/processing vessels for each hazardous substance is summarised in the tables below. It should be noted that maximum quantities/ inventories and worst case operating/ processing conditions are used in the QRA to ensure conservatism. In particular the QRA was based on preliminary design data whereby inventories in key process vessels were estimated based on the empty volume of the vessels.

9.2.3 Hazard Identification

Based on potential LoC from the storage vessels and ancillary equipment and the process vessels and ancillary equipment, the major flammable hazards identified are releases of dodecane/diesel, hexane, butane, ethane, propane and hydrogen. The potential outcomes are a jet fire, pool fire, flash fire, vapour cloud explosion, fire ball. Toxic hazards identified are releases from hydrogen sulphide.

Leaks can range in size from a pinhole leak to a catastrophic failure. In general, smaller leaks have higher accident likelihood but lower consequence distances. On the other hand, larger releases have lower accident likelihood but longer consequence distance. The representative scenarios considered in this study are as follows:

- Pipelines;
  - Small leak (10 mm);
  - Large leak (25 mm); and
  - Catastrophic failure (which is represented by inner diameter of the pipe).
- Pressurised Vessels;
  - Small leak (10 mm);
  - Large leak (50 mm);
  - Catastrophic failure; and
- Atmospheric Tanks;
  - Small leak (150 mm);
  - Large leak (500 mm); and
  - Catastrophic failure.

The possible events from the respective release scenarios are described in detail in *Appendix G*.

9.3 Frequency Analysis

9.3.1 Base Failure Frequencies

Generic failure rate data for these equipment items have been taken from publications and technical papers and from searches of database sources such as the *UK HSE Failure Rate and Event Database*. The table below summarises the generic equipment failure data used in this study. Please refer to *Appendix G* for the event tree calculations.

Table 9.1: Historical Onshore Equipment Failure Rates

Equipment Item	Failure Size	Base Failure Frequency
Tank	Small	2.5×10^{-3} per vessel year
	Large	1×10^{-4} per vessel year
	Catastrophic	5×10^{-6} per vessel year
LPG Butane Tank	Catastrophic	2×10^{-6} per vessel year
Pipe of diameter between 0 – 49mm	10 mm diameter	1×10^{-5} per m per year
	25mm diameter	5×10^{-6} per m per year
	Guillotine	5×10^{-6} per m per year
Pipe of diameter between 50 – 149mm	10mm diameter	1.68×10^{-6} per m per year
	25mm diameter	1×10^{-6} per m per year
	Guillotine	5×10^{-7} per m per year

Equipment Item	Failure Size	Base Failure Frequency
Pipe of diameter between 150 – 299mm	10mm diameter	9.14x 10^{-7} per m per year
	1/3 pipework diameter	4 x 10^{-7} per m per year
	Guillotine	2 x 10^{-7} per m per year
Pipe of diameter between 300 – 499mm	10mm diameter	7.14 x 10^{-7} per m per year
	1/3 pipework diameter	2 x 10^{-7} per m per year
	Guillotine	7 x 10^{-8} per m per year
Pipe of diameter between 500 - 1000 mm	10mm diameter	6.14 x 10^{-7} per m per year
	1/3 pipework diameter	1 x 10^{-7} per m per year
	Guillotine	4 x 10^{-8} per m per year
Pressurized vessel	Small	1.00 x 10^{-5} per vessel per year
	Large	5.00 x 10^{-6} per vessel per year
	Catastrophic	6.00 x 10^{-6} per vessel per year
Pump	Small	3.50 x 10^{-4} per pump per year
	Large	1.50 x 10^{-4} per pump per year
Heat Exchanger/compressor	Small	2.61 x 10^{-3} per HE per year
	Large	8.07 x 10^{-5} per HE per year
Valve	Small	1.40 x 10^{-4} per valve per year
	Large	6.00 x 10^{-5} per valve per year

9.3.2 Ignition Probabilities

Apart the base failure frequency data, the ignition probability data is a key element for the event frequency calculation. The ignition probabilities were determined from the look-up correlation, *IP Research Report*[1] for onshore scenarios as provided in *Table 9.2*, selected based on the size of PEC plant.

Table 9.2: Look-up Correlation Selection Guide (Onshore Scenarios)

No.[1]	Look-up Release Type	Application
9	**Large Plant Liquid** (Liquid release from large onshore plant)	Releases of flammable liquid that does not have any significant flash fraction (10% or less) if it is released from large onshore outdoor plants (plant area above 1,200 m^2, site area above 35,000 m^2).
Note 1:	Reference number based on look-up correlation selection guide.	

The ignition probability for each identified scenario was determined based on the release rate and representative release rate as presented in *Table 9.3*.

Table 9.3: Ignition Probability based on Release Area

Release Rate (kg/s)	Ignition Probability at Large Plant Liquid	Immediate Ignition Probability	Delayed Ignition Probability
0.1	0.001	0.001	0
0.2	0.0013	0.001	0.0003
0.5	0.0019	0.001	0.0009
1	0.0025	0.001	0.0015
2	0.0045	0.001	0.0035
5	0.0097	0.001	0.0087
10	0.013	0.001	0.012
20	0.031	0.001	0.03

[1] IP Research Report, Ignition Probability Review, Model Development and Look-up Correlations, January 2006

Release Rate (kg/s)	Ignition Probability at Large Plant Liquid	Immediate Ignition Probability	Delayed Ignition Probability
50	0.067	0.001	0.066
100	0.12	0.001	0.119
200	0.13	0.001	0.129
500	0.13	0.001	0.129
1000	0.13	0.001	0.129

9.4 Consequence Analysis

9.4.1 Hazard Zones

To estimate the hazard zone distances, consequences analysis/modelling for each outcome event has been conducted as follows:

- *Jet Fires* - based on heat flux causing 90%, 50% and 3% fatalities (to those exposed), corresponding to 34.9, 24.7 and 13 kW/m^2 thermal radiation harm footprints;
- *Pool fires* - based on heat flux causing 90%, 50% and 3% fatalities (to those exposed), corresponding to 34.9, 24.7 and 13 kW/m^2 thermal radiation harm footprints;
- *Flash Fires* - based on 100% fatality assumed within the extent of a flammable cloud to its Lower Flammable Limit (LFL);
- *Vapour Cloud Explosion*s - based on overpressures of 0.35, 0.5 bar (exposure to which is assumed to result in 15% and 100% fatality respectively); and
- *Toxic dispersion* - based on 90%, 50% and 3% fatality for those exposed to toxic concentrations.

9.4.2 Methodology and Consequence Models Used

The software package *TNO Riskcurves version 10.1.9* has been used for calculation of consequence effects. Consequence analysis is carried out for identified outcome events, including release rates, and estimates of heat flux and toxic distances are made. Individual Risk calculations are performed with *TNO Riskcurves Version 10.1.9*.

9.5 Risk Summation & Evalution

9.5.1 Individual Risk Results

9.5.1.1 PEC Individual Risk Results

Figure 9.1 presents the Individual Risk contours overlain on the satellite image of the Pengerang site, for loss of containment events as assessed in detail in this QRA. The 1 x 10^{-5} and 1 x 10^{-6}/year contours shown include the contributions from jet fires, pool fires, flash fires, explosions, fireballs and toxic dispersion.

As shown in the figure, the Individual Risk (IR) contour for 1x 10^{-5} and 1 x 10^{-6} per year contour are attained, and extends offsite, however is contained within the Industrial Area. The maximum offsite distance is ~75m and ~670m towards the North respectively. The QRA found the major offsite risk contributors from the PEC plant resulted from failures of the Butane Storage Tank (842TK1) and Area A2 (Xylene Splitter Area). The PEC Facilities is in compliance with *DoE's Risk Acceptance Criteria*.

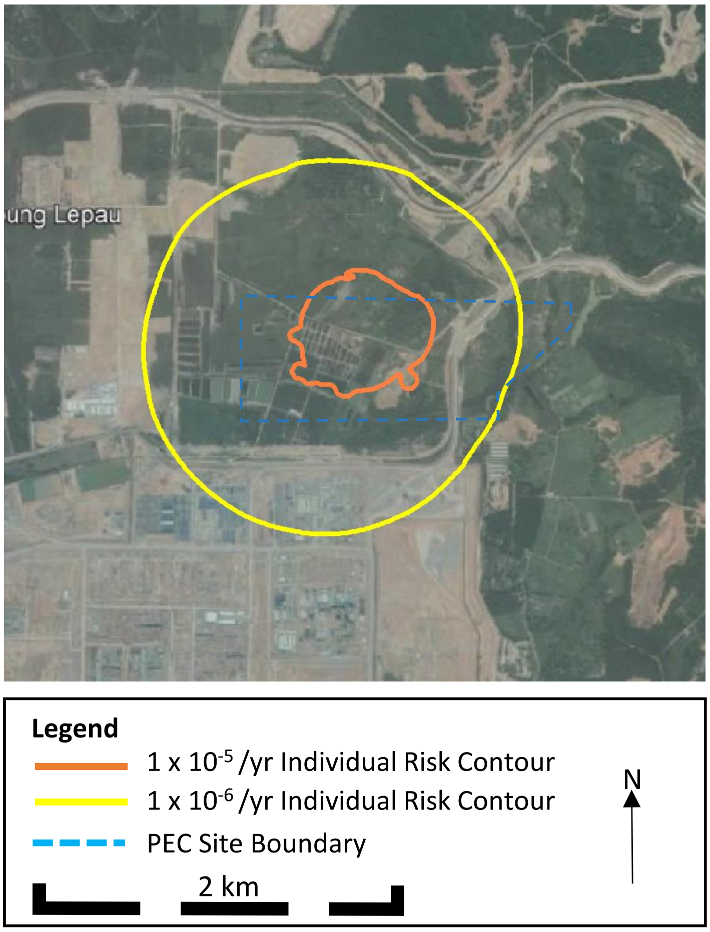

Figure 9.1: PEC Individual Risk Contours

9.5.2 Societal Risk Results

Figure 9.2 presents the societal risks for the PEC Plant. The maximum number of offsite fatalities associated with major accidents events (MAEs) arising from within the PEC site was assessed at 22 with a frequency of 7.85 x 10^{-8}/year, which is found to be within the "Tolerable" region. Hence no additional mitigation measures are required to be implemented in accordance with the ALARP principle.

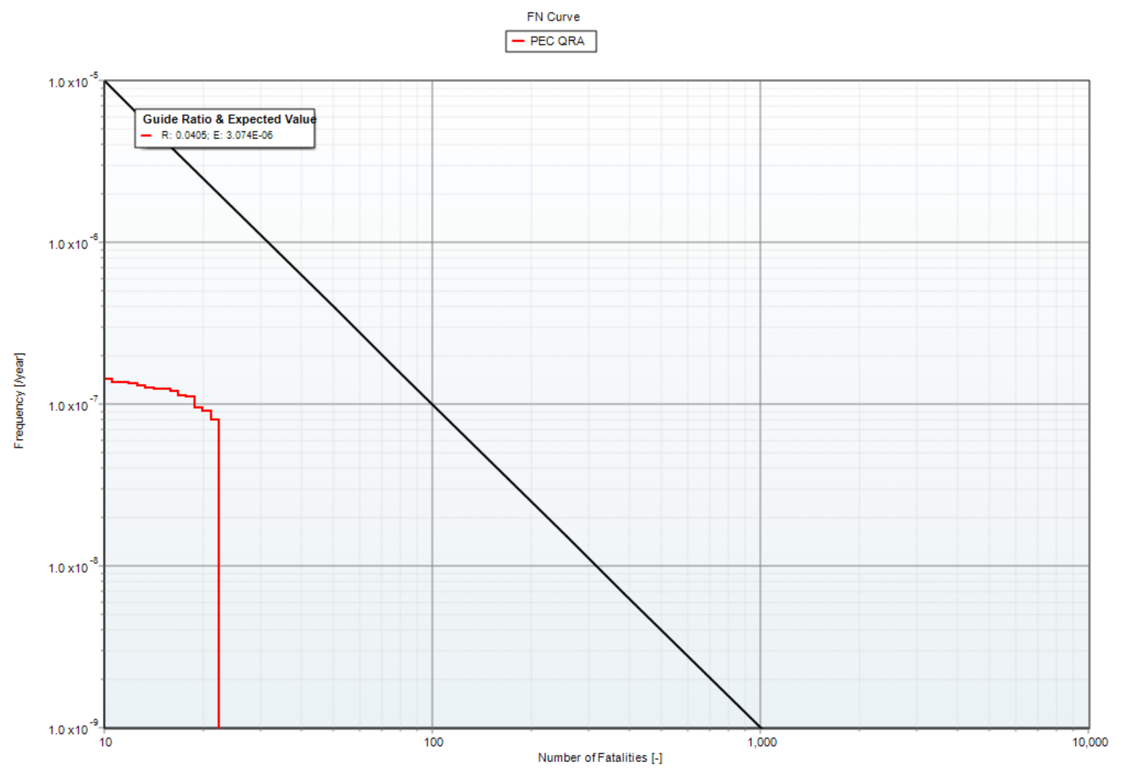

Figure 9.2 – FN Curve

9.6 QRA Conclusions

9.6.1 Frequency Analysis and Consequence Results

The QRA conservatively addresses the failure frequencies of all the facilities at the PEC site and determines the consequences of the hazards identified before performing risk summation and evaluation.

Conservatisms ensure risks are not underestimated and, in this case, include usage of maximum inventories of hazardous substances in vessels and modelling releases based on the worst-case situation, i.e. the isolatable sections are modelled without quantitatively considering the benefits of all safety systems (excepting the tank bunds), procedural or firefighting safety measures onsite.

The identified worst-case scenarios by event are summarised in *Table 9.4.*

9.6.2 Risk Summation and Evaluation against Risk Acceptance Criteria

9.6.2.1 Individual Risks

The QRA quantifies its Individual Risk (IR) and found that while the 1 x 10^{-6} per year IR contour extends offsite, it remains confined within the Industrial Area (ie. PIPC). Hence the risks comply with *DoE Risk Acceptance Criteria*. The QRA found the major offsite risk contributors from the PEC plant resulted from failures of the Butane Storage Tank (842TK1) and Area A2 (Xylene Splitter Area).

Table 9.4: Worst Case Scenarios Result Summary

Isolatable Section	Hazard Type	Fatality Levels- Harm Footprint	Maximum Hazard Zone [m]
003_100V018_C (catastrophic rupture	Pool Fire	90% fatality	170
		50% fatality	205
		3% fatality	258

Isolatable Section	Hazard Type	Fatality Levels- Harm Footprint	Maximum Hazard Zone [m]
under weather condition C3)			
130_Xylene_pipe_B (large leak under weather condition F1)	Jet Fire	90% fatality	181
		50% fatality	190
		3% fatality	206
200_842T001_C (catastrophic rupture under weather condition F1)	Fireball (BLEVE)	90% fatality	825
		50% fatality	1,083
		3% fatality	1,502
199_840T001_C (catastrophic rupture under weather condition F1)	Flash Fire	LFL	1,686
201_841T001_C (catastrophic rupture under weather condition F1)	Explosion	90% fatality	Not Attained
		50% fatality	560
		3% fatality	561
189_60V003_C (catastrophic rupture under weather condition F1)	Toxic Dispersion:	90% fatality	1
		50% fatality	2
		3% fatality	100

Notes:
1. N/A – not attainable
2. LFL – Lower Flammable Limit

9.6.2.2 Societal Risks

The Societal Risk (SR) is within the 'Tolerable' region of the adopted Societal Risk Tolerability Criteria, adopted as provided in *RIVM Reference Manual Bevi Risk Assessments*. The maximum number of offsite fatalities associated with major accidents events (MAEs) arising from within the PEC site was assessed at 22 with a frequency of 7.85 x 10^{-8}/year, which is found to be within the "Tolerable" region. Hence no additional mitigation measures are required to be implemented in accordance with the ALARP principle.

9.6.3 Conclusions of the QRA

Based on the QRA results summarised above, it is concluded that the PEC Plant satisfies the *DoE Risk Acceptance Criteria* for Individual Risk as:

- The 1 x 10^{-5} fatalities per year contour remains within the industrial area; and
- The 1 x 10^{-6} fatalities per year contour does not encroach to any public areas, such as residential areas, schools, hospitals.

Therefore, no additional mitigation measures are deemed to be mandatory to further reduce the risks associated with the PEC.

The Societal Risk associated with the PEC Plant is found to be within the tolerable region. Therefore, it can be concluded risks are acceptable and no additional mitigation measures are required to reduce risks to a level *as low as reasonably practical (ALARP)*.