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# TECHNICAL REPORT

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## QUANTITATIVE RISK ASSESSMENT STUDY OF PROPOSED ADVANCED MATERIAL PLANT WITHIN THE GEBENG INDUSTRIAL ESTATE, KUANTAN, PAHANG

REPORT No EP029020

REVISION No 2  
FINAL REPORT

DET NORSKE VERITAS



## TECHNICAL REPORT

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# TECHNICAL REPORT

## Table of Contents

Page

<b>EXECUTIVE SUMMARY .....</b>	<b>1</b>
<b>1 INTRODUCTION .....</b>	<b>2</b>
1.1 Project Title .....	2
1.2 Project Background and Location.....	2
1.3 Scope and Objectives of Project.....	3
1.4 Project Initiator .....	4
1.5 Risk Assessment Consultant.....	5
1.6 Report Structure .....	6
<b>2 SITE DESCRIPTION .....</b>	<b>7</b>
2.1 Description of Project Site.....	7
2.2 Surrounding Land-use.....	8
2.3 Meteorological Conditions.....	8
<b>3 PROCESS DESCRIPTIONS .....</b>	<b>9</b>
3.1 Concentration Plant (Mt Weld, Western Australia).....	9
3.2 Cracking and Separation Plant.....	10
3.3 List of Equipment.....	16
3.4 List of Reagent and Annual Consumption.....	16
<b>4 INTRODUCTION TO QRA METHODOLOGY .....</b>	<b>20</b>
4.1 Definitions .....	20
4.2 Key Components in a QRA .....	21
<b>5 DETAILED QRA METHODOLOGY .....</b>	<b>24</b>
5.1 Introduction .....	24
5.2 Weather Data.....	28
5.3 Ignition Probabilities Modelled.....	32
5.4 Explosion Impact Criteria .....	33
<b>6 HAZARD IDENTIFICATION &amp; FAILURE CASE DEFINITION .....</b>	<b>34</b>
6.1 Leak Sizes to be Modelled .....	34
6.2 Release Duration to be Modelled .....	34
6.3 Release Surface to be modelled.....	35
6.4 Failure Case Selection .....	35
6.5 Failure Case Definition Methodology.....	37
6.6 Failure Case Naming Convention .....	40
6.7 Defined Failure Cases .....	40
<b>7 LEAK FREQUENCY ESTIMATION .....</b>	<b>41</b>
7.1 Historical Equipment Failure Data .....	41

Page i



---

## TECHNICAL REPORT

---

7.2	Failure Case Leak Frequency Estimation.....	44
8	CONSEQUENCE ASSESSMENT.....	45
9	RISK CRITERIA & RISK RESULTS.....	48
9.1	Risk Criteria .....	48
9.2	Overall Risk Results.....	49
10	CONCLUSIONS.....	50
11	GLOSSARY .....	51
12	REFERENCES .....	52

### APPENDIX I

### Failure Cases Modelled



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## TECHNICAL REPORT

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### EXECUTIVE SUMMARY

**Project Title:** “Quantitative risk assessment study of Proposed Advanced Materials Plant within the Gebeng Industrial Estate, Kuantan, Pahang.”.

**Project Location:** Lynas Malaysia Sdn. Bhd. (Lynas) proposes to construct and operate an Advanced Materials Plant on a 100 hectare plot of industrial land located within the Gebeng Industrial Estate in Kuantan, Pahang.

The Gebeng Industrial Estate is located approximately 35 km north of the Kuantan town centre. The nearest airport is the Sultan Ahmad Shah Airport, located 30 km south of GIE. Kuantan Port is located 4 km east of GIE. Both the airport and the port are accessible via the main trunk road which is the Federal Route 3 (connects Kuantan to Kuala Terengganu). The phase 1 of the East Coast Expressway leads to Gebeng. The overall site lay out is shown in Figure 1.

**Site Description and Land-use within 3 km:** A full Site Description is provided in the Environmental Impact Assessment Report and hence is not repeated here.

**Meteorological Conditions:** Section 5.2 describes the meteorological conditions and weather class and wind speed data that were used for the study.

**Description of Process Hazards, hazardous substance properties and inventories:** Section 3 provides a description of all hazardous substances and inventories.

**List of Identified Hazardous Incidents:** All failure Cases are listed in Appendix I. The approach was taken to model all process equipment within each process area, i.e. not screen out any potential incidents.

**Probability of occurrence of Identified Hazardous Incidents:** The Generic Failure Data used and Methodology for assessing the equipment failure frequencies is described in Section 7 of this report.

**Individual Risk Results:** The LSIR contours for fatality risk are shown in Figure 9.1.

### Conclusions of the Risk Assessment

Based on a comparison of the LSIR contour results with the Malaysian Department of Environment Risk Criteria (DOE), the following conclusions may be drawn:

Figure 9.1 LSIR contour results for the Advanced Materials Plant demonstrate that both the  $1 \times 10^{-5}$  per year and the  $1 \times 10^{-6}$  per year fatality risk contour remain onsite and hence the LSIR risk results may be deemed to meet the DOE risk criteria.



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## TECHNICAL REPORT

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### 1 INTRODUCTION

#### 1.1 Project Title

“Quantitative Risk Assessment Study of Rare Earths Ore Refining Plant”.

#### 1.2 Project Background and Location

Lynas Malaysia Sdn. Bhd. (Lynas), a wholly owned subsidiary of Lynas Corporation Limited (Australia) intends to construct and operate an Advanced Materials Plant on two plots of industrial land (PT 8249 and PT 13637) located within the Gebeng Industrial Estate (GIE), Kuantan, Pahang. The proposed site is currently vacant and has an area of 100 ha.

The plant will process up to 80,000 tonnes per annum (tpa) wet weight basis of lanthanide concentrate (equivalent to 65,000 tpa dry weight basis) and produce 22,934 tpa (LnO or lanthanide oxide basis) of high purity lanthanide compounds in the form of a suite of six (6) different products. These products will be exported directly to the company's global customers based in the US, Japan, Europe and China.

Lynas Corporation Limited operates an open pit mine on a rich lanthanide deposit at Mt. Weld, Western Australia. At the mine site, the lanthanide ore will be extracted, crushed and concentrated to produce the lanthanide concentrate which is the primary raw material for the proposed plant. The concentrate will be transported from Mt. Weld by road and rail to Port for shipment via sea containers to Port of Kuantan in Pahang. The containers will be transported from the Kuantan Port by road to the project site within the GIE.

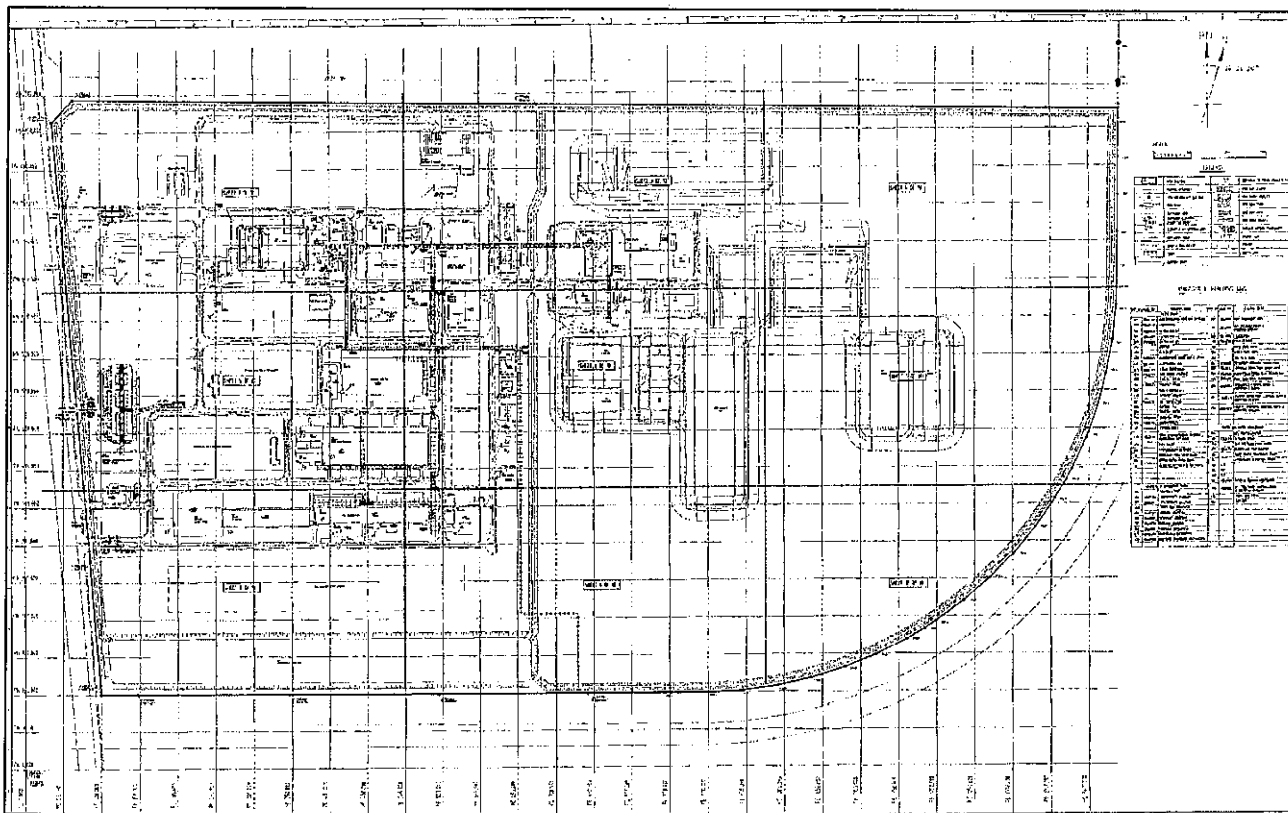
The Gebeng Industrial Estate is located approximately 35 km north of the Kuantan town centre. The nearest airport is the Sultan Ahmad Shah Airport, located 30 km south of GIE. Kuantan Port is located 4 km east of GIE. Both the airport and the port are accessible via the main trunk road which is the Federal Route 3 (connects Kuantan to Kuala Terengganu). The phase 1 of the East Coast Expressway leads to Gebeng. The overall site lay out is shown in Figure 1.

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## TECHNICAL REPORT

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**Figure 1 –Advanced Materials Plant Overall Layout**



### 1.3 Scope and Objectives of Project

The scope of the study was to model and appraise the risks associated with all flammable and toxic hazards resulting from potential loss of containment accident scenarios, due to the operation of all planned REO refining facilities and associated utilities.

The objectives of this study were to:

1. Build a Quantitative Risk Assessment model for the whole site.
2. Include in the Risk Model all possible flammable and toxic vapour accident scenarios, so that full off-site risk results may be produced.
3. Evaluate the level of Major Accident Risk produced by the operation of all planned onsite facilities and to assess these risks in relation to the Risk Tolerability Criteria issued by the Department of Environment (DOE).



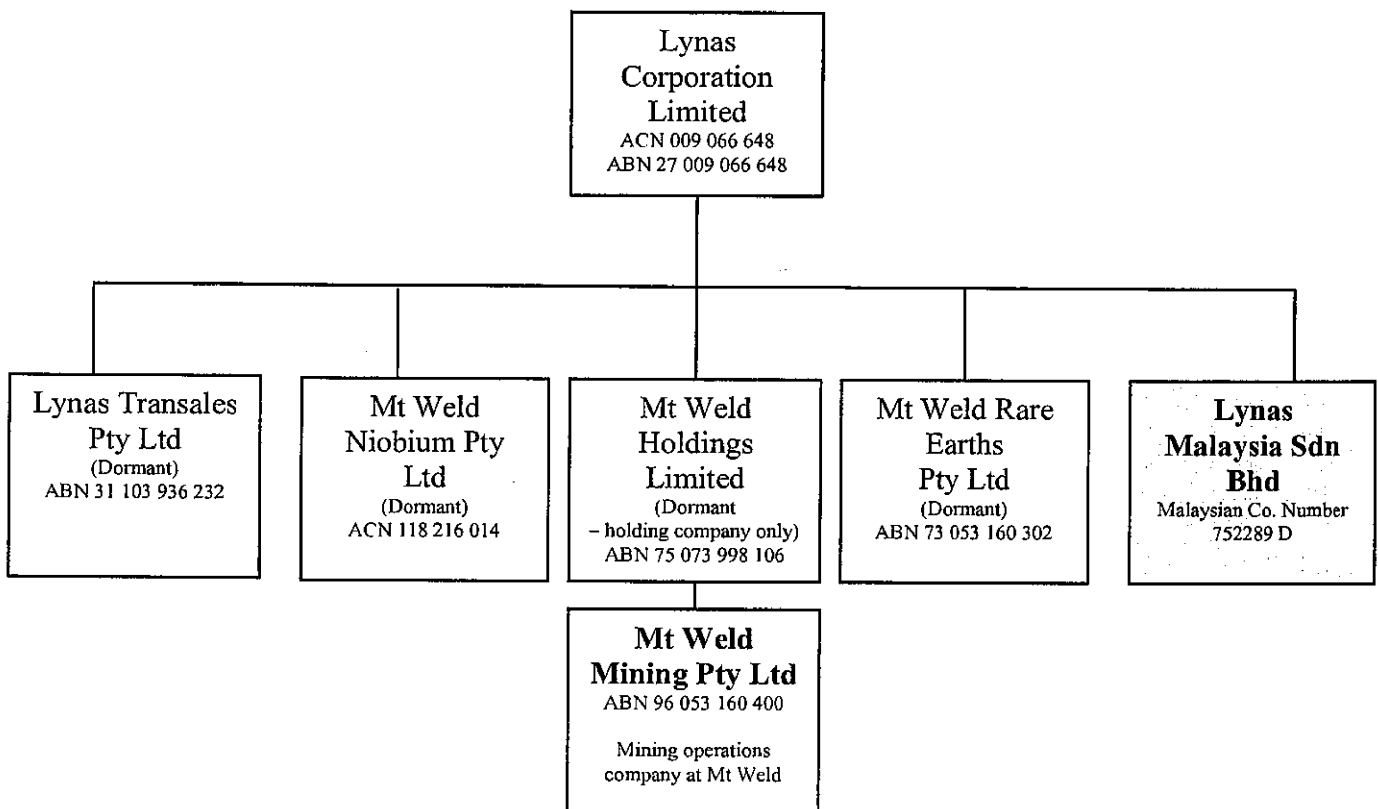
## TECHNICAL REPORT

### 1.4 Project Initiator

The Project Proponent is Lynas Malaysia, a wholly owned subsidiary of Lynas Corporation Limited which is an Australian company headquartered in Sydney, New South Wales. The company is listed on the Australian Stock Exchange and the Singapore Stock Exchange, and has over 20 years of experience in the mining industry and 6 years of experience in the lanthanides industry. The major shareholders of the company are Morgan Stanley, JP Morgan and The Capital Group.

The company currently owns one of the few commercially viable lanthanides deposit outside of China, at Mount Weld in Western Australia which is the richest lanthanide oxide deposit globally.

The current corporate structure of the Lynas Group is illustrated below:







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## TECHNICAL REPORT

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All enquires pertaining to the company, the proposed Advanced Materials Plant in Malaysia and the mining and concentration operations at Mt. Weld, Western Australia are to be directed to:

### *Malaysia*

Lynas Malaysia Sdn. Bhd.  
Lot PT 8249 & Lot PT 13637, Kawasan Perindustrian,  
Gebeng, Mukim Sungai Karang, Kuantan, Pahang.  
Telephone: +60 95834445  
Facsimile: +60 95834449

**Contact Person:**  
**Dato' Mashal Ahmad**  
**Managing Director**

### *Australia*

Lynas Corporation Ltd  
Level 7, 56 Pitt Street  
Sydney NSW 2000  
Australia

Telephone: +61 2 8259 7100  
Facsimile: +61 2 8259 7199

**Contact Persons:**  
**Mr. Carlos Guedes**  
**Vice President (Industrial), Lynas Corporation Ltd**

**Mr Eric Novrez**  
**Chief Operations Officer, Lynas Corporation Ltd**

**Mr. Nicholas Curtis**  
**Executive Chairman, Lynas Corporation Ltd**

## 1.5 Risk Assessment Consultant

On behalf of Lynas Corporation Ltd, the EIA consultant, Environ consulting Services (M) Sdn. Bhd. has commissioned Det Norske Veritas (DNV) to carry out the Quantitative Risk Assessment Study for the Advanced Material Plant.

The risk assessment consultant's registered address and correspondence is:



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## TECHNICAL REPORT

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**Det Norske Veritas As Sdn. Bhd (86517-V)**  
Level 24, Menara Weld,  
76, Raja Chulan  
50200 Kuala Lumpur, Malaysia  
Tel: 03-2050 2888  
Fax : 03-2050 0886  
Contact Person : Rizal Wong  
*Manager Risk Department*

### 1.6 Report Structure

The QRA Report is structured as follows:

- Introduction (Section 1);
- Site Description (Section 2)
- Process Description (Section 3);
- Introduction to quantitative risk assessment methodology (Section 4);
- Detailed QRA Methodology (Section 5);
- Hazard Identification & Failure Case Definition (Section 6);
- Leak Frequency Estimation (Section 7);
- Consequence modelling (Section 8);
- Risk criteria and risk results (Section 9);
- Conclusions and Recommendations (Section 10);
- Glossary (Section 11) and.
- References (Section 12).

Appendix I              Failure Cases Modelled



## TECHNICAL REPORT

### 2 SITE DESCRIPTION

#### 2.1 Description of Project Site

Lynas intends to construct and operate the Advanced Materials Plant within the Gebeng Industrial Estate (GIE) in Kuantan, Pahang, Malaysia. The lanthanide concentrate which is the primary raw material for the plant will be obtained from the Mt. Weld mine operations located near Laverton in Western Australia. The lanthanide deposit at Mt Weld was discovered more than 20 years ago and over the years some AUD 25 million has been spent for the improvement of its resource quality. The deposit is based on a concentration of lanthanide elements within a residual weathered horizon which overlies the 3 km-diameter carbonatite intrusive.

The proposed Advanced Materials Plant in Malaysia will process the lanthanide concentrate (raw material) to produce a suite of products comprising individual lanthanide elements or mixtures of elements which can be used directly in selected industries or subjected to further downstream processing.

At Mt. Weld, the lanthanide ore will be extracted via open pit mines, stockpiled and crushed onsite to a particle size of 40mm. These aggregates will then be conveyed to a concentrator plant located within the mine site. The resultant product of the concentration process is the lanthanide concentrate which will be shipped to Port of Kuantan, Pahang, Malaysia.

From the Port of Kuantan, the concentrate will be transported to the proposed plant site within the GIE which lies about 3 km northwest of the port.

At the Advanced Materials Plant within the GIE, the imported lanthanide concentrate will undergo two main stages of processing, i.e. (1) cracking and separation and (2) product finishing. In the first stage, the concentrate will be roasted with sulphuric acid in rotary kilns at high temperatures and atmospheric pressure and, water leached to produce a lanthanide sulphate solution. This solution will then be subjected to a series of solvent extraction systems for the extraction of the lanthanide elements in solution. The solution will then be further separated and purified into the final products (individual lanthanide elements or mixed lanthanide elements) in the product finishing stage.

The Advanced Materials Plant will be designed for a lanthanide production capacity totalling some 22,934 tpa (REO or Rare Earths Oxide), distributed over a range of high purity products.

The mix of products can be varied within a range according to market demand, and design capacities for individual lanthanide products are as follows (volumes are REO equivalent):

SEG/HRE Carbonate	1,127 tpa
Lanthanum Chloride, Carbonate or Oxide	2,817 tpa
Lanthanum-Cerium Carbonate	8,251 tpa
Cerium Chloride, Carbonate or Oxide	5,303 tpa
Dydimium Oxide	2,780 tpa
Neodymium Oxide	2,052 tpa
Praseodymium Oxide	601 tpa



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## TECHNICAL REPORT

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The radioactivity levels of these products will be very low as the majority of radioactive components present in the ore (uranium and thorium) will be retained in the solid waste streams generated from the processes within the plant.

The finished products from the RE Plant will be packaged and transported to the Port of Kuantan for shipment via containers to the company's global customers.

### 2.2 Surrounding Land-use

The site is located in the middle of the Gebeng Industrial Estate in the District of Kuantan, which is an area zoned for industrial use.

Residential settlements in the vicinity of the GIE are primarily located along the existing road network.

The nearest human settlements to the project site are Taman Balok Perdana and Taman Balok Makmur about 3km south of the site. They are located along the Kuantan-Pelabuhan By-pass road, across the GIE. Based on statistical data obtained during the most recent population census in 2000 by the Department of Statistics Malaysia, the total population count is 539. Of this population number, about 60% are 25 years and below. Ninety-two percent of the population comprise Malays and the remaining 8% are made up of foreigners (non-citizens).

Other settlements along the coast to the south and south-east of the RE Plant site. They include Kampung Hulu Balok about 3km south-east of the site, Kampung Berahi about 4.5km south of the site, Kampung Seberang Balok about 6km south of the site. Another 1km south of Kampung Seberang Balok is Kampung Balok, while Kampung Balok Baru is 1km south of Kampung Balok. These settlements are generally residential and commercial structures. Majority of the areas are sparsely spread, with one or two sectors of each settlement being more dense representing the settlement's business centre.

Kampung Selamat is located about 4km south-east of the site. Kampung Gebeng is located about 3km north-east of the site, while Kampung Sungai Ular is about 2.5km north of Kampung Gebeng.

### 2.3 Meteorological Conditions

Refer the discussion in Section 5.2 of this report.



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## TECHNICAL REPORT

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### 3 PROCESS DESCRIPTIONS

#### 3.1 Concentration Plant (Mt Weld, Western Australia)

The concentration process will be undertaken at the Concentration Plant located within the mine site at Mt. Weld in Western Australia. The main processes include:

- Crushing
- Milling
- Rougher flotation and three stages of scavenger flotation
- Five stages of cleaner flotation
- Concentrate thickening and filtration
- Tailings, concentrate storage and packaging, and discharge to storage facility

The flotation circuit will consist of one stage of rougher flotation and three stages of scavenger flotation, with the combined rougher-scavenger concentrate fed to a cleaning circuit consisting of five stages of cleaner flotation. The final product will be a concentrate assaying approximately 40% rare earth oxide basis (REO), at a design recovery of 63%. Each flotation stage will include conditioning tanks as required for addition of the following:

- Steam for heating.
- Sodium hydroxide solution for pH modification.
- Sodium silicate solution for dispersion.
- Sodium fluorosilicate and sodium sulphide solutions for gangue depression.
- Fatty acid collector, DQ.

The final lanthanide concentrate will be de-aerated and mixed with flocculant and lime before being fed to the concentrate thickener. Thickened concentrate will be pumped to a plate and frame filter for dewatering. The filter will produce a filter cake with <20% moisture, and a filtrate solution, which will be returned to the concentrate thickener for recovery of ultra-fine solids.

It is envisaged that the lanthanide concentrate filter cake will be directly bagged (2.2 tonne bags or 1 x 20 tonne bag) and placed into sea containers on weigh cells to hold exactly 20 tonnes of material. The sea containers will then be loaded onto road trains for haulage to Leanora where they will be placed on to the rail for haulage down to Fremantle for shipment to the Advanced Materials Plant in Malaysia.

Approximately 66,000 tonnes of lanthanide concentrate at < 20% moisture content will be shipped annually from the Port of Fremantle in Western Australia to the Eastern Wharf of the Port of Kuantan in Pahang. This quantity will be shipped weekly via 60 to 80 sea containers movements per week. The sea containers will then be unloaded at the port after the standard port and customs clearance procedures.



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## TECHNICAL REPORT

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The sea containers will be loaded onto trucks and delivered to the advanced plant site within the Gebeng Industrial Estate which is located about 3 km west of the port. On an average, the transportation frequency is expected to be 6 days per week 13 deliveries per day.

The specific radiation activity (total activity) of the ore is 61.0 Bq/g. The thorium and uranium content of the ore are 1600 ppm (as  $\text{ThO}_2$ ) and 29 ppm (as  $\text{U}_3\text{O}_8$ ) by weight respectively. The Malaysian Nuclear Agency, the radiological consultants appointed by Lynas are presently in the midst of determining radiation safety issues pertaining to lanthanide concentrate storage, handling and transport.

### 3.2 Cracking and Separation Plant

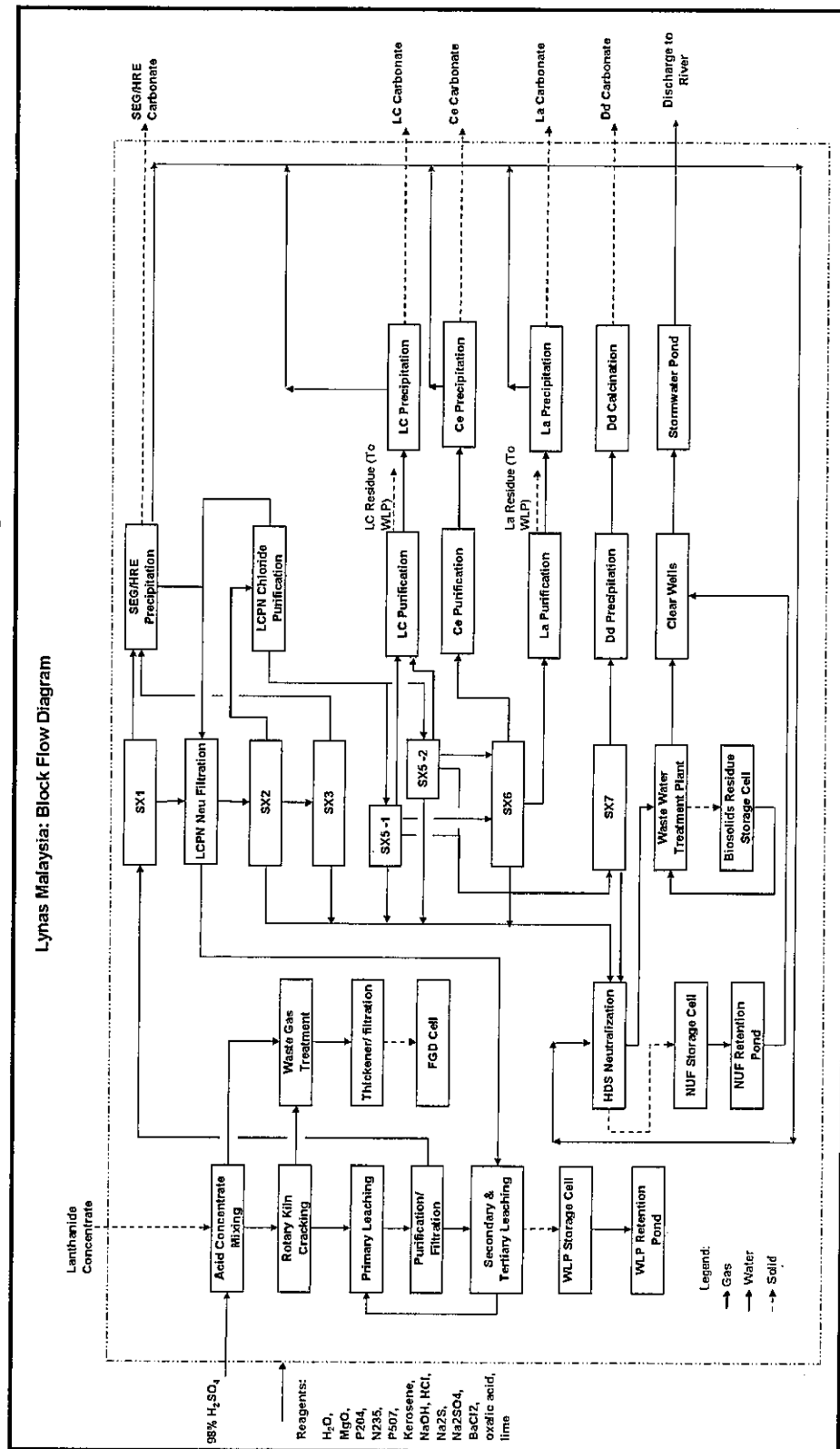
The main processes involved in the Cracking & Separation Plant include:

- Lanthanide Concentrate Handling
- Lanthanide Concentrate Cracking
- Leaching
- Upstream Extraction
- Downstream Extraction
- Product Finishing

A block flow diagram representing the processes within the Cracking and Separation Plants is presented in Figure 3.1.

# TECHNICAL REPORT

Figure 3.1 : Overall Process Block Diagram





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## TECHNICAL REPORT

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### 3.2.1 Lanthanide Concentrate Cracking

A diesel powered loader will be used to transfer the lanthanide concentrate from the site stockpile into the concentrate feed hopper (capacity of 10m<sup>3</sup>).

From the hopper, the concentrate will be fed onto a belt conveyor and transported to the cracking plant which will consist of two parallel processing trains. The lanthanide concentrate will be fed via two belt weigh-feeders into the concentrate-acid mixers, where sulphuric acid (98%) will be added. The mixed slurry will be pumped into the rotary kilns where it will be heated to approximately 650°C over a period of 2.5 hours. The products from the kilns will comprise cracked concentrate and tail gas.

The kilns are fuelled by hot gas generated by the combustion of Natural Gas; gas flow will be automatically controlled by the temperature at the hot end of the kiln. To allow for future expansion of the plant's processing capacity, an area has been provided in the layout for two (2) additional rotary kilns. These new kilns will be located in parallel to the original two (2) kilns.

Cracked concentrate discharges from the kiln into the leach tanks. Oversize from the kiln discharge will be collected in a skip, and will be crushed prior to feeding into the water leach circuit.

### 3.2.2 Leaching and Neutralisation

The soluble rare earth sulphates will be recovered from the cracked concentrate in a three stage leaching process. After the primary leach, the slurry will be filtered in two (2) filter presses to enable solid-liquid separation. The primary filter cake will be subjected to a second stage of leaching and filtration. Filtrate from this stage will be recycled to the primary leach circuit and the filter cake will be mixed with water for the third stage of leaching. After filtration, the final solids residue, which is referred to as the Water Leached Purification (WLP) solids, will be stored onsite in the secure WLP storage cell. Filtrate from the tertiary leach is recycled to primary and secondary leaching.

To remove some of the soluble impurities, the primary leach filtrate will be neutralized with magnesium oxide powder to achieve a pH of 3.5-4.0. The neutralized slurry will be filtered in two (2) filter presses. The filtrate from this operation will be filtered through a polishing filter press before being transferred to the first solvent extraction plant.

The filter cake from the neutralization process will be leached with weak sulphuric acid to recover precipitated rare earth oxide. The residue from this process will be filtered through a filter press and the filtrate will be recycled to the primary leach. The filter cake will be water washed and filtered with the tertiary leach product to become part of the WLP solids.

### 3.2.3 Extraction

Solvent extraction will be used to purify, separate and concentrate the lanthanides before their precipitation into products.

In solvent extraction, the lanthanide elements will be selectively extracted from the aqueous phase into an organic phase using a battery of mixer-settlers. A mixer settler refers to a combination of an





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## TECHNICAL REPORT

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agitated tank, where the aqueous and organic phases are mixed and the metal extraction occurs, and a rectangular settling vessel where the phases separate into two distinct layers. The organic and aqueous phases will flow through the battery of mixer-settlers counter-current to one another to achieve the optimum levels of organic loading, separation and recovery. As the aim of each stage of extraction is different, the conditions within the mixer-settlers will be controlled to remove part of, or all lanthanide elements to the organic phase from aqueous phase.

To further improve separation efficiencies, the loaded organic phase will be scrubbed with either dilute sulphuric or dilute hydrochloric acid. Scrubbing equipment will be similar to the extraction equipment, involving a group of mixers and settlers.

The scrubbed organic phase, which is loaded with lanthanides, will then be stripped by contact with either 4.5M or 6M hydrochloric acid. Stripping is the transfer of lanthanides from the organic back into the aqueous phase. The lanthanides in the aqueous strip solutions will either be transferred to the next extraction system for separation into individual lanthanide elements or used to produce a mixed lanthanide product directly.

After stripping, the organic phase will be washed with water in additional mixer-settlers. The wash solutions will contain hydrochloric acid, and will be routed to the hydrochloric acid preparation circuit for re-use. The washed organic will be stored in a tank, from where it will be continually recycled to extraction.

A total of five (5) organic liquids will be used for extraction in the cracking and separation plant. These are:

- Extractant: P204, Di(2-ethylhexyl) phosphoric acid ( $C_{16}H_{35}O_4P$ )
- Extractant: P507, 2-ethylhexyl phosphonic acid mono-2-ethylhexyl ester ( $C_{16}H_{35}O_3P$ )
- Extractant: N235, Iso Octylamine
- Modifier: Isooctyl alcohol,  $C_3(C_2H_5)C_5H_{10}OH$
- Diluent: Kerosene

Hydrochloric acid (0.5M, 4.5 and 6M) will be used in solvent extraction. Concentrated hydrochloric acid (> 30%) will be transported by trucks to the Cracking and Separation Plant area and stored in 3 storage tanks. The acid will be pumped into agitated dilution tanks located within the extraction plant by two concentrated acid feeding pumps. Diluted hydrochloric acid will be fed to the extraction plant from these tanks.

Sodium hydroxide (6M) will also be used in the solvent extraction plant. The sodium hydroxide solution (30wt %) will be transported by trucks and stored in a storage tank. The solution will be pumped via two pumps to the agitated dilution tanks located within extraction plant. Diluted sodium hydroxide will be fed to the extraction plant directly from these tanks.

The extraction process is divided into two systems:

- Upstream Extraction; which has a sulphate based aqueous phase and uses P204 solvent for extraction, and



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## TECHNICAL REPORT

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- Downstream Extraction; which has a chloride based aqueous phase and uses P507 solvent for extraction.

Upstream extraction consists of three (3) extraction circuits for the purification of the lanthanides as a group:

- SX1 – SEG elements extracted from the LCPN elements
- SX2 – bulk extraction of the LCPN and the remaining SEG elements from SX1 raffinate.
- SX3 – In this battery, N235 is used to remove iron from SX1 and SX2 strip solutions.

Downstream Extraction employs three (3) extraction circuits for the separation of the lanthanides.

- SX5 – LC-PN separation, where PN are extracted away from the LC elements.
- SX6 – L-C separation, where C is extracted from the SX5 raffinate
- SX6 – this battery also includes a N235 extraction to remove Fe from the C strip solution
- SX7 – Didymium Purification, where the SEG elements are extracted from the SX5 strip solution which contains the PN elements.

Area for expansion of the extraction process has been provided for.

### 3.2.4 Product Finishing

In the post-treatment stage, the lanthanide chloride strip solutions will be purified, to remove impurities, and precipitated into carbonate or oxalate forms.

The following lanthanide products will be produced;

#### *a) SEG-HRE Carbonate*

SEG and HRE chloride solution from the SX1/SX3 extraction lines will be neutralised with magnesia to a pH of 2.5. The neutralised solutions will be filtered in a filter press to remove any precipitated solids which will be re-leached with acid to recover co-precipitated REO. The final residue from the re-leach will be discharged and the filtrate will be recycled within the SEG/HRE area.

Carbonate salts will be precipitated from the purified SEG/HRE solutions using sodium carbonate. The carbonate products will be transferred to a centrifuge for solid liquid separation and washing. The wastewater generated from the process will be a sodium chloride solution and will be transferred to the HDS system for treatment.

#### *b) LaCe Carbonate*

LaCe chloride solution (raffinate from SX5) will be purified by the addition of sodium sulphide, barium chloride and sodium sulphate solutions. The neutralized slurry will be filtered in a filter press to remove the solid impurities which will be discharged from the circuit. The filtrate will be routed to the precipitation circuit, for precipitation with sodium carbonate solution. The LC carbonate product



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## TECHNICAL REPORT

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will be transferred to a centrifuge for solid liquid separation and washing. The wastewater generated from the washing process will be transferred to the High Density Sludge (HDS) plant for treatment.

*c) Cerium Carbonate*

Ce chloride solution from SX6 will be purified by the addition of sodium carbonate solution to achieve pH 4. The neutralized slurry will be filtered in a filter press to remove the solid impurities which will be recycled to the leach circuit. The filtrate will be routed to the Ce precipitation circuit, for precipitation with sodium carbonate solution. The Ce carbonate product will be transferred to a centrifuge for solid liquid separation and washing. The wastewater generated from the washing process will be transferred to the High Density Sludge (HDS) plant for treatment.

*d) Lanthanum Carbonate,*

La chloride solution (raffinate from SX6) will be purified by the addition of sodium sulphide, barium chloride and sodium sulphate solutions. The neutralized slurry will be filtered in a filter press to remove the solid impurities which will be discharged from the circuit. The filtrate will be routed to the precipitation circuit, for precipitation with sodium carbonate solution. The La carbonate product will be transferred to a centrifuge for solid liquid separation and washing. The wastewater generated from the washing process will be transferred to the High Density Sludge (HDS) plant for treatment.

*e) Lanthanum Oxide, Cerium Oxide*

The La oxide and Ce oxide will be produced by calcining the La carbonate and Ce Carbonate respectively at a temperature of 900°C in the electric tunnel furnace.

*f) Didymium (Dd) Oxide, Praseodymium Oxide and Neodymium Oxide*

Didymium (Dd) is a mixture of Pr and Nd. The chloride solution containing Dd is the SX7 raffinate and will be precipitated with oxalic acid, washed and centrifuged to produce Dd oxalate. The wastewater generated from the Didymium precipitation process is a dilute hydrochloric acid solution, and will be transferred to HDS for neutralisation.

Didymium oxide will be produced from the calcination of didymium oxalate at a temperature of 900°C in the electric tunnel furnace.

Praseodymium Oxide and Neodymium oxide is produced in the same method from the Pr chloride and Nd chloride from SX8.



## TECHNICAL REPORT

### 3.3 List of Equipment

The list of main equipment to be installed at the plant is presented in Table 3.1 below.

**Table 3.1 : List of Major Equipment within the Advanced Materials Plant**

Description	No of Units
Pressure Filters	20
Rotary Kilns	2
Waste Gas Treatment Unit	1
Solvent extraction cells	200
Centrifuges	27
Tunnel furnaces	2
Boilers	2
Water treatment Bio-reactors	3

### 3.4 List of Reagent and Annual Consumption

Reagents consumed at the plant and their anticipated annual usage quantities are presented in Table 3.2.

**Table 3.2 : Annual Reagent Consumption for the Cracking & Separation Plant**

Reagent	Annual Consumption (tonnes)
H <sub>2</sub> SO <sub>4</sub> (98%)	110,238
HCl (31%)	146,774
MgO	23,348
BaCl <sub>2</sub> ·2H <sub>2</sub> O	602
Na <sub>2</sub> CO <sub>3</sub>	19,632
P204	496
P507	184
NaOH (30%)	81,120
Na <sub>2</sub> SO <sub>4</sub>	93
Na <sub>2</sub> S	164
H <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	8,924
Kerosene	1,720
N235 Mixed	24
Hydrated Lime	111,386
Iso-octyl alcohol	24

Separation of the incompatible reagents and the alkalis has been considered when developing layouts. The dry reagents are separated in the storage shed by a barrier, while the wet chemicals are separately banded with dedicated sump pumps.



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## TECHNICAL REPORT

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### 3.4.1 Reagent Storage & Handling

#### a. *Caustic Soda*

Caustic soda or sodium hydroxide will be supplied to the plant in 24 tonne bulk tankers as a 30% solution w/w. The tanker will discharge into a 330 m<sup>3</sup> storage tank located within the tank farm proposed to the northwest of the plant. The solution will be pumped at full strength via individual pumps to the plant dose points.

#### b. *Sodium Sulphide*

Sodium sulphide will be supplied in 1 tonne bulk bags. The main plant storage will therefore be held as dry powder. The powder will be mixed to a 10% solution in a single-stage agitated tank.

A hoist will raise the bags to a bag breaker located above an agitated tank. During reagent mixing, the mix tank will be isolated and the dosing pumps will draw from a small buffer tank. The mixing / storage tank will be filled with water (10 m<sup>3</sup>) to allow the target concentration to be met by the addition of 1 tonne of powder. A fume extraction fan will be provided to remove any harmful gaseous by-product. This tank volume is adequate for 50 hours operation. Distribution to the plant will be by a diaphragm dosing pump.

#### c. *Flocculant*

The flocculant mixing system will be located separately in the HDS thickener area. A reagent shed for storage of dry chemicals and reagent drums will be located adjacent to the Product Finishing Area.

Flocculant will be supplied in 25 kg bags on 900 kg pallets. The bags will be loaded by hand into a dry powder hopper. The dry powder will be metered into a dry transfer system and will be pneumatically transported to a wetting head. In the wetting head, the powder will be contacted with raw water from a number of spray heads. This concentrate solution will discharge into an agitated tank where water will be added to achieve a 0.5% solution.

This solution will be transferred into a storage tank for distribution to the plant. The facility will be a stand-alone package that will be controlled by a vendor-supplied PLC.

#### d. *Hydrated Lime*

Hydrated lime will be used scrubbing of kiln off-gas and for the neutralisation of waste water. Lime will be supplied in bulk and transferred into a silo before mixing to a 20%-slurry. The milk of lime slurry will be pumped to user locations in waste gas treatment and HDS neutralisation areas.

The mixing-storage tank will consist of two tanks (30 m<sup>3</sup> each) that will be large enough to allow incremental addition of water and lime powder. When the tank levels have declined the tank will be topped up with raw water to a predetermined level and the dry lime powder added. This tank volume is adequate for 4 hours operation so addition of lime will be on an as-required basis.

The reagent mixing area will be bunded separately and will be provided with two sump pumps for clean up.



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## TECHNICAL REPORT

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*e. Sulphuric Acid*

Sulphuric acid (98% concentration) will be piped in to the site through the southern fence from the neighbour supplier. The sulphuric acid can also be trucked into the site and stored in two (2) storage tanks (250 m<sup>3</sup>) within the bunded tank farm. The acid will be pumped into elevated tanks from where the acid will be meter-fed into the concentrate-acid mixers.

Sulphuric acid will be diluted and used to scrub lanthanide impurities from the organic phase in the Extraction Units. The diluted acid will be stored in two (2) tanks within the solvent extraction area.

*f. Hydrochloric Acid*

Hydrochloric acid (31% concentration) will be trucked into the site and stored in five (5) storage tanks (330m<sup>3</sup> each) within a bunded tank farm. The acid will be pumped for dilution in the extraction sections where it is prepared to several concentrations for use in the solvent extraction processes.

*g. Magnesium Oxide (MgO)*

Magnesium Oxide or magnesia will be imported in 1t bags and transported to site in open truck or sea container. This material is a free flowing white powder that easily absorbs carbon dioxide and moisture. The bags will be unloaded and stored in the purification section of the water leaching building - close to the point of use. The bags are hoisted above and emptied into hoppers with screw feeders that deliver the material to the process.

*h. Sodium Carbonate (Na<sub>2</sub>CO<sub>3</sub>)*

Sodium Carbonate or soda ash will be imported in 1t bags or bulk and transported to site in sea container or pneumatic road tanker. This material is a free flowing white powder that easily absorbs moisture. The bags will be unloaded and stored in the post treatment building - close to the point of use. The bags are hoisted above and emptied into hoppers with screw feeders that deliver the material to the process.

8% soda ash solution is piped in through the neighbour supplier through the south fence line.

*i. Oxalic Acid (H<sub>2</sub>C<sub>2</sub>O<sub>4</sub>)*

Oxalic acid will be imported in 1t or 50kg bags and transported to site in open truck or sea container. This material is a free flowing white powder that easily absorbs moisture. The bags will be unloaded and stored in the post treatment building - close to the point of use. The bags are hoisted above and emptied into an agitated tank.

The magnesia, soda ash and the hydrated lime will be stored separately within the plant due to the volumes consumed, and to ensure these materials are stored separate from acidic chemicals.

*j. Industrial Kerosene*

A low volatility and high flash point kerosene (65<sup>0</sup>C) will be used as the base solvent for the extraction liquid. The kerosene will be received in truck tanker or in 200 litre drums, and unloaded into a storage tank from where the solvent will be pumped to blending tanks for mixing with other organic solvents.



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## TECHNICAL REPORT

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*k. D2EHPA (P204)*

An acidic phosphorus extraction reagent known as D2EHPA or P204 will be used as the extraction agent. The flash point of this material is 206 °C. This reagent will be received in 1000 litre drums which are emptied by pumping directly into the extraction circuits.

*l. P507*

An acidic phosphorus extraction reagent known as P507 or PC-88A or Ionquest 801 will be used as the extraction agent. This reagent will be received in 1000 litre drums which will be emptied by pumping directly into the extraction circuits.

*m. N235*

A tertiary amine N235 will be used as an extraction agent for the removal of impurities (metals) in the extraction process. This reagent will be received in 200 litre drums which will be emptied by pumping directly into the extraction circuits.

*n. Iso-Octyl Alcohol*

An iso-octyl alcohol (Iso-octanol) is used as a phase modifier. This reagent is received in 200 litre drums and emptied by pumping directly into the extraction circuits.

Iso-octyl alcohol will be transported in 200 litre HDPE drums and stored within the chemical store until required in the process. The drums will be transported to the extraction buildings by forklift and mixing of these chemicals will be carried out at the point of use within the plant.

*o. Other Chemicals*

Other chemicals received in solid powder form include  $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ ,  $\text{Na}_2\text{SO}_4$ , and  $\text{Na}_2\text{S}$  which will be transported to the site in 1t bulker bags or 50kg bags and stored within the chemical store or dedicated storage areas close to the point of use.

Barium chloride is a white solid that absorbs moisture. The 1t bags used to store the compound will be hoisted above and emptied into a mixing tank to prepare the barium chloride solution. This solution will be added to lanthanide chloride solution to remove sulphates.

Sodium sulphate is a white solid that absorbs moisture, and will be imported in 50kg bags. These bags will be emptied into a mixing tank and then added to the lanthanides chloride solution to remove radium.



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## TECHNICAL REPORT

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### 4 INTRODUCTION TO QRA METHODOLOGY

#### 4.1 Definitions

The definitions are presented here to assist the reader who is not familiar with the terms used in this quantitative risk assessment report.

A process plant is intended to benefit its owners, operators and the country, by helping to produce products, providing employment and generating wealth. However, such installation also has the potential to cause harm, such as:

- Sickness, injury or death of workers;
- Damage to property and investments;
- Degradation of the physical and biological environment; and
- Interruption to production and disruption of business.

Physical situations that have the potential to cause such harm are known as **hazards**. Thus a fuel storage tank is a hazard because it has the potential to cause a fire; processes such as high-pressure natural gas treatment is a hazardous activity because it has the potential to cause jet fires and vapour cloud explosions. The word 'hazard' does not express a view on the magnitude of the consequences or how likely it is that the harm will actually occur.

A 'major hazard installation' is a facility for storing or processing large quantities of flammable and/or toxic chemicals, which present the potential to cause fatalities and plant damage.

**Accidents** are the actual realisation of a potential hazard. They are sudden unintended departures from normal conditions, in which some degree of harm is caused. They range from minor incidents such as a small gas leak, to major accidents such as Flixborough, Mexico City, Bhopal and Pasadena. Sometimes, the more neutral term 'event' is used in place of the more colloquial term 'accident'. For flammable accidents, ignition has to take place for a hazard to be realised. For toxic releases, the release itself may pose a hazard, if sufficient vapours are generated.

**Risk** is the combination of the likelihood and the consequences of such accidents. More scientifically, it is defined as the probability of a specific adverse event occurring in a specific period or in specified circumstances. The **likelihood** may be expressed either as a frequency (i.e. the rate of events per unit time) or a probability (i.e. the chance of the event occurring in specified circumstances). The **consequence** is the degree of harm caused by the event.

**Risk** is sometimes defined as the product of likelihood and consequence. In fact this is just one of several possible measures of risk and such a definition may be over-simplistic.





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## TECHNICAL REPORT

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The distinction between '**hazard**' and '**risk**' is an important one, although in colloquial use, and also in popular dictionaries, risk and hazard are treated virtually as synonyms. Rimmington (1992) has suggested that 'hazard' was first used in its modern sense in relation to a physical obstacle in the game of golf, whereas 'risk' has been used in the insurance market for nearly 300 years to signify the chance of a specific hazard being realised, such as the loss of a ship at sea.

'Risk' is sometimes used as a very general term roughly equivalent to 'danger' (e.g. a platform with high risks, a low-risk operation etc), and sometimes as a precise scientific term with many qualifications (e.g. the risk of impairment of escape routes due to hydrocarbon fires, or the individual risk of death per annum for a helicopter pilot).

**Safety** is the inverse of risk. The higher the risk for an occupation or installation, the lower is its safety. The popular understanding of safety sometimes appears to be 'zero risk', but this is impossible in an intrinsically hazardous activity such as oil and gas production.

### 4.2 Key Components in a QRA

The first stage is **system definition**, where the potential hazards associated with an installation or the activities are to be analysed. The scope of work for a QRA should be to define the boundaries for the study, identifying which activities are to be included and which are excluded, and which phases of the installation's life are to be assessed.

The **hazard identification** consists of a qualitative review of possible accidents that may occur, based on previous accident experience or judgement where necessary. There are several formal techniques for this, which are useful in their own right to give a qualitative appreciation of the range and magnitude of hazards and indicate appropriate mitigation measures. This qualitative evaluation is described in this guide as 'hazard assessment'. In a QRA, hazard identification uses similar techniques, but has a more precise purpose – defining the boundaries of a study in terms of materials to be modelled, release conditions to be modelled, impact criteria to be used, and identifying and selecting a list of failure cases that will fully capture the hazard potential of the facilities to be studied. Failure cases are usually derived by breaking the process system down into a larger number of sub-systems, where failure of any component in the sub-system would cause similar consequences.

Once the potential hazards have been identified, **frequency analysis** estimates how likely it is for the accidents to occur, based on the type and number of equipment components included in the defined failure cases. The component failure frequencies to be used are usually derived from an analysis of historical accident experience, or by some form of theoretical modelling.

In parallel with the frequency analysis, **consequence modelling** evaluates the resulting effects if the accidents occur, and their impact on people, equipment and structures, the environment or business, depending on the defined scope of the QRA study. Estimation of the consequences of each possible event often requires some form of computer modelling, but may be based on accident experience or judgements if appropriate.



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## TECHNICAL REPORT

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When the frequencies and consequences of each modelled event have been estimated, they can be combined to produce **risk results**. Various forms of risk presentation may be used, such as:

- Individual risk - the risk experienced by an individual person (or equipment item) in a given location.
- Group (or societal) risk - the risk experienced by the whole group of people (or process equipment) exposed to the hazard.

Up to this point, the process has been purely technical, and is known as **risk analysis**. The next stage is to introduce **criteria**, which are yardsticks to indicate whether the risks are acceptable, or to make some other judgement about their significance. **Risk assessment** is the process of comparing the level of risk against a set of criteria as well as the identification of major risk contributors.

The purpose of risk assessment is to develop mitigation measures for unacceptable generators of risk, as well as to reduce the overall level of risk to as low as reasonably practical (ALARP).

In order to make the risks acceptable, **risk reduction measures** may be necessary. The benefits from these measures can be evaluated by repeating the QRA with them in place, thus introducing an iterative loop into the process. The economic costs of the measures can be compared with their risk benefits using **cost-benefit analysis**.

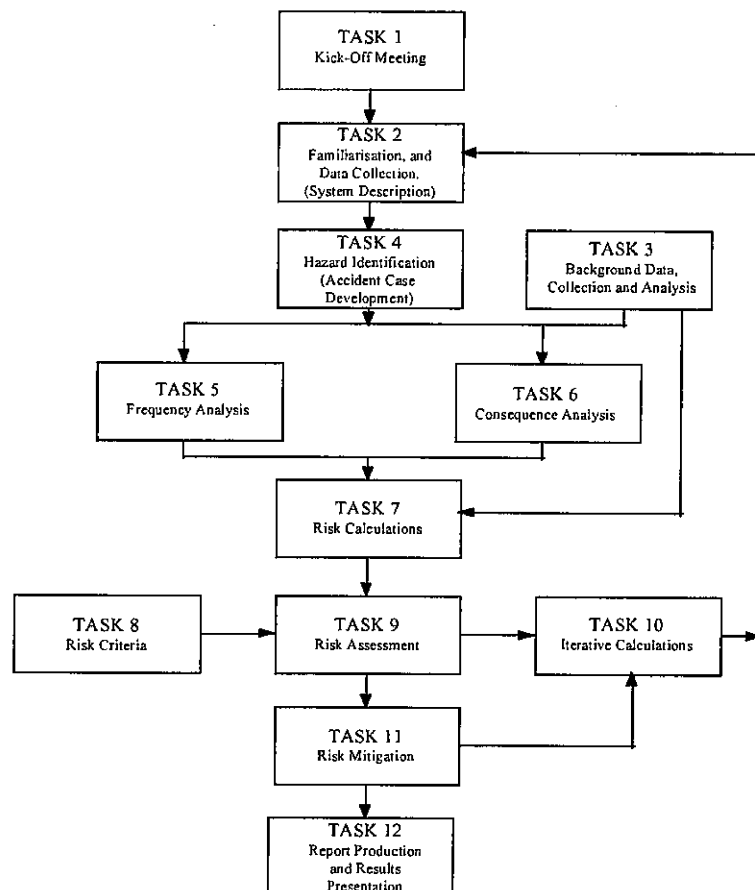
QRA results may be used to provide some form of **input to the design** or **on-going safety management** of the installation, depending on the objectives of the study.

The traditional QRA methodology is visualised in Figure 4-1. Details of the QRA methodology used in this Hazard Escalation study are explained in the following Sections.

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**TECHNICAL REPORT**

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**Figure 4-1: Typical QRA Methodology**



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## TECHNICAL REPORT

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### 5 DETAILED QRA METHODOLOGY

#### 5.1 Introduction

Up until now the discussion on the QRA methodology has been very generic. The following discussion is intended to provide more insight into the actual QRA methodology.

The basis for the current QRA study is DNV's proprietary risk modelling software, SAFETI Version 6.54. The SAFETI software is used throughout DNV, as well as by a number of government agencies around the world as well as by major international chemical and petrochemical companies.

One of the programs within the SAFETI Version 6.54 risk modelling software is PHAST 6.54, DNV's proprietary consequence modelling software package. The SAFETI / PHAST software package has been in existence since the 1970s, and has been under continual development and improvement ever since, which is managed by DNV's London-based software development division.

An electronic database of approximately 1400 materials is available to the PHAST / SAFETI software, with the material properties regularly reviewed and if required re-adjusted, based on the latest available data. The PHAST consequence modelling results (for each material) are regularly reviewed and where required re-calibrated, based on the latest available accident and test data.

The SAFETI software combines the PHAST calculated dispersion and consequence modelling results for all specified weather classes and wind speeds with the failure case specified release frequency data, specified weather class, wind speed, wind directional probability data, specified immediate ignition probability data, SAFETI calculated delayed ignition probability data, built-in event tree alternate consequence outcome branch probability data, fatal impact probability data for each alternate consequence outcome (e.g. jet fire, flash fire, explosion), based on the specified consequence impact criteria levels, and specified population data by location, to produce individual and societal risk results, as required.

The SAFETI risk modelling software requires the following inputs to be able to produce risk results:

- An electronic map of the study area, on which individual fatality risk contour results may be produced.
- The electronic map may be programmed in SAFETI to:
  - Superimpose all on-site and off-site populations within the study area by location, and specifying the day / night number of people for each location.
  - Superimpose all potential ignition sources within the study area, which may cause delayed ignition of a flammable release.
  - Delayed ignition sources may be specified as point sources (e.g. flares, fired heaters, diesel-generators, and transformers), area sources (e.g. welding work shops) or line sources (e.g. roads, railway lines, and overhead power lines). Each ignition source



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## TECHNICAL REPORT

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carries additional specification in terms of presence factor and ignition source strength (probability of ignition per unit time, when in contact with a flammable vapour cloud between LFL and UFL). The actual delayed ignition probability of any release is calculated by SAFETI, based on the dispersion modelling results and event duration.

- The immediate ignition probability associated with each flammable failure case is a risk analyst programmed value, based on historical ignition data, which varies with leak size and release phase (Gas / Liquid / 2-Phase) (the larger the leak vapour flow rate, the higher the ignition probability, typically varying from 1% to 30%, unless above auto ignition, then 100%).
- Prepare and import weather class, wind speed and wind direction probability data for the study area. Normally separate day / night, weather class, wind speed, wind directional probability files are entered into SAFETI, most often broken down into 16 wind directions.
- Enter all identified failure cases, which are defined in terms of: Location, Material released, Quantity released (or release duration), Temperature, Pressure, Leak size, Leak direction (e.g. horizontal, vertical), Leak elevation, Leak frequency and Immediate ignition probability.
- Each failure case calculation in SAFETI starts with discharge modelling. Based on release duration and release phase (gas, liquid, 2-phase), SAFETI directs the dispersion and consequence calculations to one of 4 alternate, built-in consequence outcome event trees (continuous vapour release, continuous release with rain-out, instantaneous vapour release, instantaneous release with rain-out), where each event tree branch probability carries default values, which may be re-programmed by the risk analyst.
- SAFETI will then calculate all alternate consequence outcomes (e.g. jet fire, explosion) of the event tree selected, in terms of hazard range and event duration (where applicable), for each weather class / wind speed combination.
- So far the calculations performed in SAFETI only relate to the alternate consequence outcomes and the consequence hazard ranges, for each specified failure case. To produce risk results, SAFETI will perform impact frequency calculations, using the failure case specified leak frequency as starting point. Frequency aspects of the risk calculations relate to the:
  - Risk analyst defined failure case leak frequency
  - Weather class, wind speed and wind directional probability, for each of the 16 wind directions
  - Specified immediate ignition probability and SAFETI calculated delayed ignition probability. The delayed ignition probability calculation is based on the strength and location of all specified ignition sources and the failure case dispersion hazard range, combined with vapour cloud persistence (duration).
  - SAFETI selected event tree and branch probabilities, for each alternate consequence outcome.



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## TECHNICAL REPORT

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- Fatal Impact probability for each alternate consequence outcome. This is based on the SAFETI calculated magnitude of each consequence and the SAFETI default impact probability criteria or risk analyst specified impact criteria for that type of consequence.
- Location and number of people (or equipment) within hazard area for societal risk results, with separate calculations for day and night, indoors and outdoors.
- SAFETI performs its individual and societal risk calculations based on a 200 x 200 grid (40,000 points), with the grid point spacing automatically varied, based on the consequence hazard range results.
- For each release case, SAFETI takes the failure case release frequency as initial input, multiplies this by the first weather class / wind speed probability, for the first of 16 wind directions.
- SAFETI takes this result and multiplies it by the immediate ignition probability, while also separately multiplying this result by the SAFETI calculated delayed ignition probability.
- These 2 results are multiplied by the first of the event tree consequence branch probabilities, relating to immediate or delayed ignition branch path.
- SAFETI takes the PHAST calculated consequence hazard range and verifies which grid points are within the consequence hazard area. For each grid point within range SAFETI then calculates the magnitude of the consequence at each grid point (e.g. explosion overpressure at a particular grid point may be 3psi).
- The calculated consequence magnitude at each grid point is then compared to the SAFETI programmed impact criteria level, and the likelihood of fatality or damage calculated, based on the impact probability criteria specified in SAFETI, for the type of consequence and the magnitude of the consequence.
- This calculation is repeated for each event tree alternate consequence outcome at each grid point, for that weather class / wind speed and wind direction, and the result added to the previous risk level, at each grid point.
- The above calculations are then repeated for each of the 16 wind directions, cumulatively adding to the risk level at each grid point.
- The above calculations are repeated for all day / night weather classes, wind speeds and wind directions, cumulatively adding these risk results at each grid point.
- Once all risk calculations at these grid points have been completed for the first failure case, the next failure case will be calculated, again adding all results cumulatively at each grid point. This is repeated until all failure cases have been calculated, while SAFETI also tracks the risk contribution made by each failure case at each grid point.
- Once completed, SAFETI produces individual risk contour results by linking points of equal risk, based on the pre-specified levels of individual fatality risk (or equipment damage) to be plotted, and using linear interpolation between relevant grid points. The risk contour results are super imposed on the electronic site map, entered in the SAFETI software.



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## TECHNICAL REPORT

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- SAFETI can also produce societal risk results by comparing the calculated level of individual risk at all 40,000 grid points, and combining this with the number of people indoors and outdoors, entered by the risk analyst by location.

The above discussion demonstrates that the meteorological data, ignition data and population data entered into the SAFETI software are critical to the risk results. Section 6 discusses the defined failure cases.

Note that with default settings the risk modelling within SAFETI aims to produce **conservative (over estimated) offsite fatality risk** results. This is achieved by the build-in but programmable parameter settings, which include:

- **Indoor & outdoor people fatality impact criteria levels, for each alternate consequence outcome.** For flammable releases the alternate consequences would be spill fires, fire balls, jet fires, flash fires and vapour cloud explosions (VCEs), each with pre-defined values for the impact levels that will affect people. For jet fires, pool fires and fire balls the varying percentage fatalities (with distance) is calculated based on the Eisenberg Probit equation. For flash fires the LFL envelope is used and for VCE overpressure two impact criteria levels are used, 1.5 psi (0.1 barg) and 5 psi (0.34 barg).
- **4 built-in event trees** (Continuous No Rain Out; Continuous With Rain Out; Instantaneous No Rain Out; Instantaneous With Rain Out) that are automatically selected based on the type of material and the release conditions. Each event-tree assigns a 'split' between alternate consequence outcomes (spill fires, fire balls, jet fires, flash fires, VCEs and no hazard), based on the immediate ignition, delayed ignition and no ignition probabilities.
- **People vulnerability criteria**, which pre-determines the fraction of fatalities resulting indoor & outdoor from being exposed to specific consequence outcomes for a specified duration, or to one or more specified criteria levels. The normal default people fatal fraction impact criteria used in SAFETI are shown in Figure 5.1.1.

## TECHNICAL REPORT

Figure 5.1.1 : SAFETI Default Vulnerability Parameters

General Risk Parameters			
General Risk   Flammable Risk   Toxic Risk   Vulnerability   Grid			
Lethality modification factors for societal and individual risk			
	Units	Outdoors	Indoors
Heavy Explosion Damage	fraction	1	1
Light Explosion Damage	fraction	0	0.025
Flash Fire	fraction	1	1
Fireball Societal Radiation Criteria Zone	fraction	1	1
Fireball Individual Radiation Criteria Zone	fraction	1	1
Fireball Societal Flammable Probit Zone	fraction	0.14	0
Fireball Individual Flammable Probit Zone	fraction	1	0
Jet Fire Societal Radiation Criteria Zone	fraction	1	1
Jet Fire Individual Radiation Criteria Zone	fraction	1	1
Jet Fire Societal Flammable Probit Zone	fraction	0.14	0
Jet Fire Individual Flammable Probit Zone	fraction	1	0
Pool Fire Societal Radiation Criteria Zone	fraction	1	1
Pool Fire Individual Radiation Criteria Zone	fraction	1	1
Pool Fire Societal Flammable Probit Zone	fraction	0.14	0
Pool Fire Individual Flammable Probit Zone	fraction	1	0
Toxics	fraction	1	1

The following sections discuss the specific measures taken and methodologies used to ensure that SAFETI 6.5.4 produces comprehensive fatality risk results, consistent with the study scope and objectives.

## 5.2 Weather Data

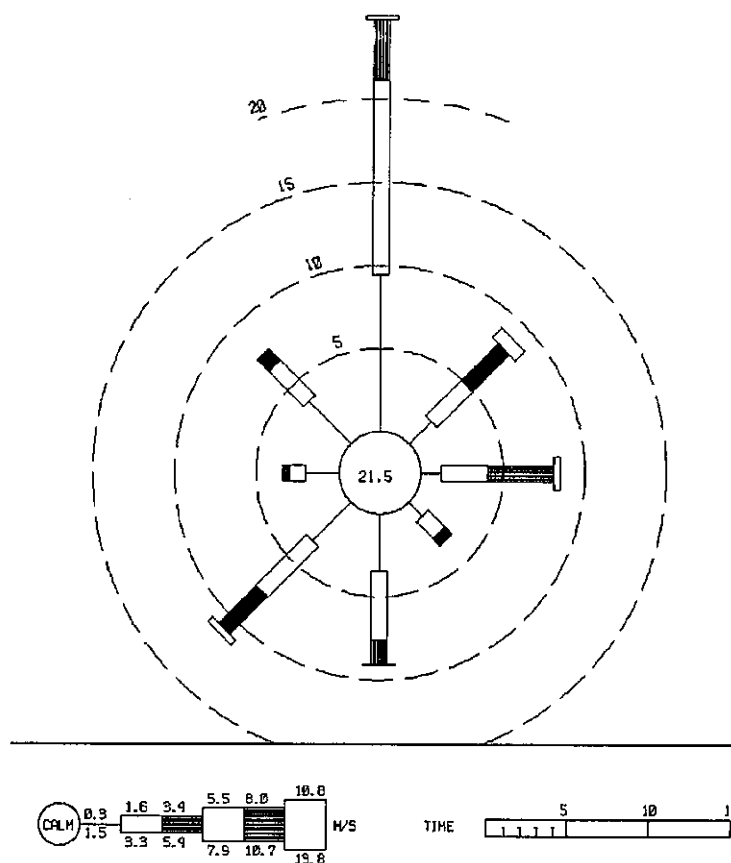
The Advanced Materials Plant will be situated on the East coast of the Malaysian Peninsula. The nearest Malaysian Meteorological Service (MMS) station to the project site is located at the Sultan Ahmad Shah (SAS) Airport in Kuantan, Pahang. The station is located at latitude 3° 47' N and longitude 103° 13'E at 15.3 m above MSL.

Figure 5.2.1 and Table 5.2.1 show the raw meteorological weather station data as a Wind Rose and in Tabular format respectively.



## TECHNICAL REPORT

Figure 5.2.1 : Kuantan Annual Wind Rose, 1975 – 2005 Data





## TECHNICAL REPORT

**Table 5.2.1 : Annual Weather Data**

WIND SPEED (m/s)	WIND DIRECTION PERCENT PROBABILITY (Coming From)							
	N	NE	E	SE	S	SW	W	NW
< 0.3	-	-	-	-	-	-	-	-
0.3 - 1.5	9.4	1.9	1.2	1.2	3.4	3.3	2.0	3.6
1.6 - 3.3	11.7	3.0	2.8	1.4	4.2	4.3	1.0	3.0
3.4 - 5.4	3.6	3.2	4.1	0.6	1.4	3.2	0.4	1.0
5.5 - 7.9	0.2	0.8	0.4	0.0	0.1	0.4	0.0	0.0
8.0 - 10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
> 10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
<b>TOTAL</b>	24.9	8.9	8.5	3.2	9.1	11.2	3.4	7.6
<b>Calm</b>	21.5%							

The reported Period of Calm was 21.5 percent. These data were re-analysed by DNV and assigned to the different day / night weather stability classes, while also distinguishing day and night time hours.

Table 5.2.2 and Table 5.2.3 show the day and night processed weather class / wind speed, wind directional probability data for the site, broken down in to 16 wind directions. In the tables, the wind speed is shown in metres per second following the atmospheric stability class (e.g. A, B, C, D, E and F). The representative wind speed for each weather class was calculated as the weighted average of the category members.

For other key meteorological parameters, annual averages are used. The data used are:

- Ambient temperature: 25.6°C
- Ground temperature: 25.6°C
- Ambient pressure: 1 atm
- Relative humidity: 85.2%



## TECHNICAL REPORT

**Table 5.2.2 : Day Time Meteorological Data**

Wind Direction (coming from)	Weather Class / Wind Speed Probability (%)				
	A1.5	B2.5	C4.4	D6.7	Totals
N	5.8978	7.7586	2.3873	0.1326	16.1763
NNE	3.5449	4.8740	2.2546	0.3316	11.0052
NE	1.1921	1.9894	2.1220	0.5305	5.8340
ENE	0.9725	1.9231	2.4204	0.3979	5.7139
E	0.7529	1.8568	2.7188	0.2653	5.5938
ESE	0.7529	1.3926	1.5584	0.1326	3.8365
SE	0.7529	0.9284	0.3979	0.0000	2.0792
SSE	1.4431	1.8568	0.6631	0.0332	3.9961
S	2.1332	2.7851	0.9284	0.0663	5.9131
SSW	2.1019	2.8183	1.5252	0.1658	6.6112
SW	2.0705	2.8515	2.1220	0.2653	7.3092
WSW	1.6627	1.7573	1.1936	0.1326	4.7462
W	1.2548	0.6631	0.2653	0.0000	2.1832
WNW	1.7568	1.3263	0.4642	0.0000	3.5472
NW	2.2587	1.9894	0.6631	0.0000	4.9112
NNW	4.0782	4.8740	1.5252	0.0663	10.5438
<b>Total</b>	32.6260	41.6446	23.2095	2.5199	100.0000

**Table 5.2.3 : Night Time Meteorological Data**

Wind Direction (coming from)	Weather Class / Wind Speed Probability (%)				
	F1.5	C2.5	C/D4.4	D6.7	TOTALS
N	5.8978	7.7586	2.3873	0.1326	16.1763
NNE	3.5449	4.8740	2.2546	0.3316	11.0052
NE	1.1921	1.9894	2.1220	0.5305	5.8340
ENE	0.9725	1.9231	2.4204	0.3979	5.7139
E	0.7529	1.8568	2.7188	0.2653	5.5938
ESE	0.7529	1.3926	1.5584	0.1326	3.8365
SE	0.7529	0.9284	0.3979	0.0000	2.0792
SSE	1.4431	1.8568	0.6631	0.0332	3.9961
S	2.1332	2.7851	0.9284	0.0663	5.9131
SSW	2.1019	2.8183	1.5252	0.1658	6.6112
SW	2.0705	2.8515	2.1220	0.2653	7.3092
WSW	1.6627	1.7573	1.1936	0.1326	4.7462
W	1.2548	0.6631	0.2653	0.0000	2.1832
WNW	1.7568	1.3263	0.4642	0.0000	3.5472
NW	2.2587	1.9894	0.6631	0.0000	4.9112
NNW	4.0782	4.8740	1.5252	0.0663	10.5438
<b>Total</b>	32.6260	41.6446	23.2095	2.5199	100.0000



## TECHNICAL REPORT

### 5.3 Ignition Probabilities Modelled

The delayed ignition probability for any failure case is a calculated value within SAFETI, which is based on the defined ignition sources on site. For each release case the calculated value will vary with weather class, wind speed and direction and the number, strength and contact duration of ignition sources with the dispersing flammable vapour cloud. The defined on site ignition sources are shown in Table 5.3.1.

**Table 5.3.1 – Defined Ignition Sources (causing delayed ignition)**

Ignition Source	Ignition Probability	In Time Period (seconds)	Operating Probability
Boiler	0.9	60	1
Rotary Kilns	0.9	60	1
Calibration Area Source, per km <sup>2</sup>	0.9	60	0.5

For onshore process facilities Cox, Lees & Ang (1990) derived the overall (immediate + delayed) ignition probabilities for varying release rates, while also distinguishing between hydrocarbon liquid releases and gaseous releases, as given in Table 5.3.2.

**Table 5.3.2 Generic Ignition Probabilities**

Release Rate Category	Release Rate (kg/s)	Gas Leak Ignition Probability	Liquid HC Leak Ignition Probability
SMALL	< 1	0.01	0.01
MEDIUM	1 – 50	0.07	0.03
LARGE	>> 50	0.30	0.08

Historical ignition data show a split of 2/3 immediate ignition and 1/3 delayed ignition.

The immediate ignition probability may be directly specified for each failure case, but assigns a common default value if not. The SAFETI default immediate ignition probability is 0.3, which would only apply to very large flammable gas releases in a large industrial complex, which is consistent with the conservative approaches adopted for offsite fatality risk assessment.

The approach taken in this study is to perform preliminary discharge modelling of all failure cases when entered in the SAFETI Risk Model, to ascertain the flow rate and rain-out fraction.

For each failure case the immediate ignition probability is then directly specified as part of the failure case input data, using the Table 5.3.2 data and based on the calculated discharge flow rate and the calculated vapour and liquid fraction after release.



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## TECHNICAL REPORT

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### 5.4 Explosion Impact Criteria

By default SAFETI uses (programmable) blast overpressure levels of 1.5 psi and 5 psi for assessing indoor and outdoor offsite fatality impact. These overpressure levels correspond to light damage and total destruction of ordinary brick (residential) housing.

The default SAFETI hydrocarbon vapour cloud explosion efficiency is set to 10 percent, consistent with the objective to produce conservative offsite fatality risk estimates. This is an overestimation compared to historical data.

Early ignition vapour cloud explosions are modelled in SAFETI at the centre of release.

For delayed ignition the SAFETI explosion modelling takes into account the defined ignition sources. SAFETI will first perform discharge calculations and dispersion modelling. Where a dispersing vapour cloud contacts one or more of the defined ignition sources, SAFETI will then calculate the time varying ignition probability at that time. The explosion mass is calculated based on the mass of vapour between UFL and LFL at that time.

SAFETI will then place the explosion centre of this calculated mass at one of 3 optionally programmable locations (set in the SAFETI parameters):

- At 0.5 LFL (the default location; most conservative and not credible)
- At LFL (not credible)
- At cloud centroid (credible, but still conservative)

For delayed ignition the SAFETI explosion modelling results are based on the last option, i.e. locating the centre of the explosion at the centre of the vapour cloud mass.



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## TECHNICAL REPORT

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### 6 HAZARD IDENTIFICATION & FAILURE CASE DEFINITION

The following discusses various aspects of the hazard identification performed, to allow definition of the failure cases, which should be consistent with the scope and objectives of the risk assessment.

#### 6.1 Leak Sizes to be Modelled

A question to address is what leak sizes to model (and specify in the failure case definition), as leak sizes may vary from pinhole leaks to equipment rupture. The following leak sizes ranges may be (typically) considered for modelling in a risk study:

- Small leaks 1 to 10 mm
- Medium leaks 10 to 50 mm
- Large Leaks 50 to 150 mm
- Line Ruptures Pipe diameter
- Instantaneous Vessel inventory

As small flammable leaks have a very low historical ignition probability (1 percent) and hazard range, they will contribute little to direct risks or to hazard escalation risks, and therefore there will be no loss of accuracy in terms of risk results not to model Small leaks. Note that for toxic releases, the need to also model small leaks needs to be reviewed on a case by case basis.

Hence Medium, Large, Full Bore leaks and Ruptures were used in the failure case definition, and hence carried forward in the risk assessment model.

#### 6.2 Release Duration to be Modelled

The following assumptions were made with respect to the time required to detect a leak and isolate facilities within individual process areas, tank farms, and other operational areas.

- Process Areas: The time to detect a leak, investigate and then initiate an emergency shutdown is estimated as 20 minutes.
- Compressors fitted with auto shutdown facilities: The time to initiate an emergency shutdown is estimated as 1 minute.
- Attended ship and road tanker loading or unloading operations: The time to initiate an emergency shutdown is estimated as 1 minute.



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## TECHNICAL REPORT

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- Tank Farms: The time to detect a leak, investigate and then initiate an emergency shutdown is estimated as 60 minutes.
- Non-isolatable Inventories: Leaks will continue until inventory is exhausted, but subject to a modelling cut-off limit of 60 minutes.

### 6.3 Release Surface to be modelled

The following assumptions were made with respect to the release surface, which affects the extent of spill spreading, and hence pool fire, pool evaporation and flash fire results. Within SAFETI, the type of surface may be specified as:

- Deep water, modelled within in SAFETI with a maximum spill depth of 5mm.
- Concrete (flat), modelled within in SAFETI with a maximum spill depth of 10mm.
- Wet soil, modelled within in SAFETI with a maximum spill depth of 30mm.
- Dry soil, modelled within in SAFETI with a maximum spill depth of 50mm.

For failure case definition it is important that the SAFETI specified release surface takes into account the actual physical conditions that would be encountered on-site in terms of potential spill spreading. In all failure cases the following SAFETI Release Surfaces were specified:

- Process Areas: Process area concrete paving is always sloped to drain, typically with a slope of 1:100. In recognition of the grading to drain, which limits spill spreading, process area failure case surface is specified in SAFETI as "Dry Soil", rather than "Concrete".
- Tank Farms: All tank farms are modelled with "Dry Soil" as the specified surface. Tanks spills are limited by the bunded area size, while spills at transfer pumps are only limited by spill rate and Surface Type.

### 6.4 Failure Case Selection

All process equipment within each process area, capable of flammable hazards or toxic vapour materials, was included in the failure case definition and hence the SAFETI risk model, whether capable of producing an offsite risk or not.

Based on the List of Reagents in Table 3.1 and 3.2 and planned Utilities detailed in Section 3.4, Table 6.4.1 lists the materials for inclusion in the Risk Study.



## TECHNICAL REPORT

**Table 6.4.1 – Materials to be Included in the QRA**

Hazardous Material	Location / Uses	Process Conditions
Natural Gas	Incoming NG pipeline, before pressure letdown at the metering station.	18 barg, 25.6 °C
	Distribution piping to Boilers, Rotary Kilns & Cracking Furnaces, after pressure letdown to 4.2 barg	4.2 barg, 25.6 °C
Kerosene Sulfonate	Direct import of Kerosene Sulfonate by road tanker. This is used in 3 locations within the Extraction plant as solvent.	Ambient, indoor in dedicated building
	Low pressure pumps and 50mm distribution piping from storage to the extraction plant.	0.6 barg, 25.6 °C

One additional potential concern would be due failures, associated waste gas scrubbing systems due to toxic vapour content (SO<sub>2</sub>). The worst-case concerns the waste gas generated from the concentrated ore cracking furnaces, with a waste gas composition as shown in Table 6.4.2. However preliminary consequence modelling (using a ground level horizontal release) confirmed that there would be no fatality impact as the SO<sub>2</sub> concentration is too low. Hence the modelling of toxic waste gases due to failure of scrubbing systems was excluded from the risk modelling.



## TECHNICAL REPORT

**Table 6.4.2 – Cracking Furnace Flue Gas Composition to Scrubber**

23	Flow Rate of Gaseous Components				
24	Component	Mass flow rate kg/h	Molar flow rate kmol/h	Volume flow rate m³/h	Volume flow rate Nm³/h
25	Water vapour	2137,8442	118,688385	6117,5540	2859,8130
26	Nitrogen	17033,3882	608,044230	28327,6495	13628,6000
27	Oxygen	3702,2752	115,700440	5006,6379	2563,2400
28	Argon				
29	Carbon dioxide	1107,7736	25,171066	1086,7628	564,1800
30	Carbon monoxide				
31	Sulfur dioxide	633,4479	9,868538	426,8985	221,6400
32	Nitrogen monoxide				
33	Nitrogen dioxide				
34	Dinitrogen tetroxide				
35	Hydrogen chloride				
36	Chlorine				
37	Hydrogen fluoride				
38	Hydrogen bromide				
39	Sulfur trioxide	51,6950	0,645718	27,8513	14,4730
40	Ammonia				
41	Sulfuric acid	1049,3381	10,699509	436,1250	239,8170
42	Silicon tetrafluoride	6,5474	0,062908	2,7238	1,4100
43	Phosphoric acid	10,0400	0,102454	4,4362	2,2964
44					
45					
46					
47					
48					
49					
50	total, gases	25732,3	888,983	38479,9	19925,5
51	total, gases, dry	23594,5	770,315	33362,3	17285,7

## 6.5 Failure Case Definition Methodology

The basis for failure case definition are all process equipment and process lines within each process unit that are in use during normal operations. Start-up lines and other normally isolated systems (e.g. manual vent and drain lines) are excluded from the failure case definition. Where there are duplicate facilities such as on-line and standby pumps, compressors, filters, etc, only the duty equipment is included in the failure case leak frequency count.

Failure cases and their boundaries are defined based on a study of the Process Flow Diagrams, the Piping & Instrument Diagrams and Plot Plans, and based on the following data and concepts:

- **Process Flow Rate Information** – For failure case definition the PFD indicated materials, process temperature, pressure and flow information form the basis for assessment. Note however that the leak flow may be larger than the PFD flow, if leaks are upstream of flow controlling valves, as verified by leak discharge modelling.
- **Vessel Inventories** – Vessel inventories were calculated based on normal operating liquid level. Tanks were modelled as full.



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## TECHNICAL REPORT

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- **Mixtures of Materials** – Most refining processes are mixtures of materials with a varying boiling point range. Though SAFETI allows specification of such mixtures based on mole composition, it in fact creates a single new material with the mole percentage weighted properties in terms of flammable limits, flash point and boiling point, etc. The approach taken in this study is to consistently specify a single component material for each failure case, such that it is most representative of the percentage flash that would result from a process leak.
- **Release Phase** – Liquid and vapour releases are modelled as separate failure cases.
- **Non-Isolatable Leaks** – These concern vessel liquid or vapour leaks, upstream of any ESD valves. For bottom liquid outlet lines the whole inventory is modelled as lost, aggravated by continued inflow, where appropriate. For vapour lines this is the time until operations manages to stop the feed.
- **Isolatable Leaks** – Isolatable (liquid or vapour) leaks are downstream of ESD valves, where the ESD valves are modelled to limit the maximum leak duration, based on the estimated time to detect & isolate a leak. The flow is only limited by upstream source vessel temperature and pressure conditions, line size, line length and leak size at the point of the leak.
- **Limited Flow Leaks** – Limited flow (liquid or vapour) leaks are leaks downstream of control valves, where the control valves limit the leak flow rate to a maximum of the operational set-point, while (upstream) ESD valves (if any) limit the maximum leak duration, based on the estimated time to detect and isolate a leak. Positive displacement pumps and compressors may also act as flow limiting devices for downstream leaks, which are limited by their rated capacity.
- **Pressure, Temperature or Phase Change** – Failure cases are further split, where there is a large step change in terms of temperature, pressure or phase (liquid to vapour), e.g. at fired heaters, heat exchangers, pumps or compressors.
- **Failure Case Location** - Each of the above failure cases may be further split, if the geographical location of failure case equipment components is widely separated within the process unit. This was done to improve the accuracy in terms of the produced risk results.

For each failure case the following data may be entered as part of its definition:

- Failure Case unique identifier, based on equipment number and leak size & phase
- Material & Mass Released, Temperature, Pressure & Phase (Gas / Liquid / 2-Phase)
- Release Coordinates and Elevation of Release
- Leak Size (25mm, 100mm, Rupture)
- Leak Orientation (Horizontal, Vertical, Inclined, Impinged)
- Pipe Length, Diameter and Surface Roughness (where applicable)
- Vessel / Tank Liquid Head (where applicable)
- Averaging Time to be used for consequence calculations (toxic or flammable)



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## TECHNICAL REPORT

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- Immediate Ignition Probability (a varying number, based on preliminary consequence modelling and Cox, Lees & Ang Ignition Probability Data; refer Section 5.3)
- Frequency of Release (based on failure case equipment count & historical accident data for all equipment components; refer Section 7)
- Type of Release Surface (concrete, dry soil, wet soil, shallow water, deep water) & Bunded Area Size (if any)

If specifying failure cases as leaks or ruptures (as detailed above), SAFETI performs discharge calculations, and based on these results, directs the calculation to one of 4 event trees, where all alternate consequence outcomes are calculated.

Where a single known consequence outcome results from a failure, SAFETI also allows the failure case to be directly specified in terms of this consequence outcome. The available models include directly specified Pool Fires, BLEVE / Fire Balls, VCEs, Jet Fires and BLEVE Blast Overpressure models. Stand alone models were used by exception for specific accident scenarios where the above process leak failure case definition would not correctly model the worst case consequence results. Some examples of such failure cases are further discussed on the next page.

As part of the failure case definition stage, all failure cases were pre-modelled in SAFETI to verify the resulting leak discharge rate, and to verify the percentage flash upon release.

The pre-calculated percentage flash is compared to PFD stream liquid / vapour data, and if necessary the (single component) material selected for failure case modelling revised to ensure that the final material selection is consistent with the PFD data. Where necessary, adjustments were further made to the PFD specified temperature or pressure to achieve the desired percentage flash result.

The adjusted failure case was then remodelled using the final selected material and (in some cases) revised temperature & pressure data. Based on these discharge and percentage flash calculations, the failure case immediate ignition probability was assigned, which must be in line with Cox, Lees and Ang historical ignition data, refer Section 5.3.

Failure case discharge calculations were also used as a tool in decision making, to re-define the correct pressure and temperature conditions to be modelled for leaks down stream of pumps, which may be in variation to the PFD information. In such cases the resulting line rupture flow may either be due to the pump rated capacity (assumed as 150% of design flow), or due to the suction vessel temperature and pressure conditions, whichever gives the higher flow. Where the suction vessel caused flow is higher than the pump maximum flow, the failure case pressure and temperature conditions were re-specified as the suction vessel temperature and pressure conditions, not the pump discharge conditions.



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## TECHNICAL REPORT

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### 6.6 Failure Case Naming Convention

To illustrate the naming convention used, some examples of unique Failure Case names are given below:

- NG-BL-25V
- NG-METER-200V
- NG-PIPEL-25V
- NG-PIPEL-100V
- KS-STOR-PF
- KS-IMP-25L
- KS-FEED-25L

All failure cases start with the Material released, which may be NG = Natural Gas, KS = Kerosene Sulfonate

The second term defines the equipment location, BL = Battery Limit, METER = NG Metering Station (and Pressure Reducing Station), PIPEL = NG distribution piping after metering, STOR = KS Storage, IMP = KS Import pipeline, FEED = Piping from Kerosene Sulfonate Storage to user points.

The Last Term defines LEAK SIZE (in mm) followed by L for liquid cases or V for vapour cases. RL = Rupture liquid line or vessel, 25V = 25mm vapour leak, PF = Pool fire (for KS flammable liquid storage).

### 6.7 Defined Failure Cases

Appendix I provides a full list of all defined failure cases.



## TECHNICAL REPORT

### 7 LEAK FREQUENCY ESTIMATION

#### 7.1 Historical Equipment Failure Data

In line with the DNV world-wide recommended approach, the selected historical failure frequencies used in this study are based on the UK HSE Offshore Hydrocarbon Release database. The HCRD records cover leaks from October 1992 to March 2003 (inclusive).

Within DNV further research and work has been done by John Spouge, who analysed the UK HSE database data. The leak database file was downloaded from the HSE website on 19 January 2004. The matching equipment populations were provided in a spreadsheet by HSE on 21 January 2004. The data covers leaks of hydrocarbon from all UK offshore installations.

Based on this work it became clear that leaks (and leak frequencies) may be sub-categorised as:

- Full flow Leaks – flow at the normal operating pressure through the hole, until depressurised or isolated by the ESD/blow down systems.
- Limited Flow Leaks – flow at 8% of the rate that a full leak of the same size would have, with 6% of the duration.
- Zero Pressure Leaks – an instantaneous release of 1.3% of the inventory of the process system.

The results of the DNV analysis of HSE Data are presented below for some typical equipment diameters and hole size categories. Leak frequencies for other equipment diameters and hole sizes (in the range 1mm to D) can be obtained from the leak frequency functions, defined as follows:

$$F(d) = C(1 + aD^n) d^m + F_{rup}$$

where:

F	=	frequency of leaks (per equipment item year) exceeding size d
C, m	=	constants representing hole size distribution
a, n	=	constants representing equipment size dependency
F <sub>rup</sub>	=	additional rupture frequency (per equipment item year)
D	=	equipment diameter (mm) or diameter of inlet pipe
d	=	hole diameter (mm)

The leak functions were developed for total, full and zero pressure leaks, using separate parameters C, a, n, m and F<sub>rup</sub>, as tabulated below. The frequency for limited leaks is then calculated as:

$$F_{\text{limited}} = F_{\text{total}} - F_{\text{full}} - F_{\text{zero}}$$



## TECHNICAL REPORT

The frequencies depend on equipment diameter only for pipes, flanges and manual valves. For other equipment, parameters 'a' and 'n' are zero, and so the frequencies do not depend on equipment diameter.

For this study the frequencies associated with **Full Flow Leaks** were used, consistent with current DNV recommendations for onshore & offshore frequency estimation. Table 7.1.1 provides an overview of the Historical Equipment Failure Frequencies used for estimation of failure case leak frequencies. For piping the quoted leak frequencies are per metre per year.

**Table 7.1.1 – Historical Equipment Failure Frequencies Full Flow Leaks**

TYPE OF EQUIPMENT	FAILURE FREQUENCY PER YEAR			Comment
	25mm Leak	100mm Leak	>150mm Leak	
PIPE25	4.94E-06	0.00E+00	0.00E+00	1" NB, per metre process pipe
PIPE40	2.82E-06	0.00E+00	0.00E+00	1.5"NB, per metre process pipe
PIPE50	2.19E-06	0.00E+00	0.00E+00	2" NB, per metre process pipe
PIPE80	1.19E-06	1.35E-07	0.00E+00	3"NB, per metre process pipe
PIPE100	9.59E-07	1.09E-07	0.00E+00	4" NB, per metre process pipe
PIPE150	6.78E-07	7.68E-08	0.00E+00	6" NB, per metre process pipe
PIPE200	5.52E-07	4.94E-08	1.31E-08	8" NB, per metre process pipe
FLANGE25	1.83E-06	0.00E+00	0.00E+00	Per flange pair
FLANGE40	1.85E-06	0.00E+00	0.00E+00	Per flange pair
FLANGE50	1.88E-06	0.00E+00	0.00E+00	Per flange pair
FLANGE80	1.71E-06	2.80E-07	0.00E+00	Per flange pair
FLANGE100	1.80E-06	2.94E-07	0.00E+00	Per flange pair
FLANGE150	2.11E-06	3.45E-07	0.00E+00	Per flange pair
FLANGE200	2.55E-06	3.07E-07	1.09E-07	Per flange pair
VALVE25	5.98E-07	0.00E+00	0.00E+00	Manual valves only
VALVE40	7.96E-07	0.00E+00	0.00E+00	Manual valves only
VALVE50	9.51E-07	0.00E+00	0.00E+00	Manual valves only
VALVE80	1.28E-06	2.30E-07	0.00E+00	Manual valves only
VALVE100	1.65E-06	2.96E-07	0.00E+00	Manual valves only
VALVE150	2.74E-06	4.93E-07	0.00E+00	Manual valves only
VALVE200	4.04E-06	5.24E-07	2.00E-07	Manual valves only
ESDV25	1.43E-05	0.00E+00	0.00E+00	All actuated valves
ESDV40	1.43E-05	0.00E+00	0.00E+00	All actuated valves
ESDV50	1.43E-05	0.00E+00	0.00E+00	All actuated valves
ESDV80	1.24E-05	1.88E-06	0.00E+00	All actuated valves
ESDV100	1.24E-05	1.88E-06	0.00E+00	All actuated valves
ESDV150	1.24E-05	1.88E-06	0.00E+00	All actuated valves
ESDV200	1.24E-05	1.41E-06	4.71E-07	All actuated valves
INSTRUM	3.03E-05	0.00E+00	0.00E+00	PI, LI, TT, etc complete
VESSEL50	2.08E-04	0.00E+00	0.00E+00	Based on size of largest outlet
VESSEL80	9.54E-05	1.13E-04	0.00E+00	Based on size of largest outlet
VESSEL100	9.54E-05	1.13E-04	0.00E+00	Based on size of largest outlet
VESSEL150	9.54E-05	1.13E-04	0.00E+00	Based on size of largest outlet
VESSEL200	9.54E-05	3.86E-05	7.45E-05	Based on size of largest outlet



## TECHNICAL REPORT

TYPE OF EQUIPMENT	FAILURE FREQUENCY PER YEAR			Comment
	25mm Leak	100mm Leak	>150mm Leak	
C-PUMP50	1.43E-04	0.00E+00	0.00E+00	Centrifugal, size discharge
C-PUMP80	1.19E-04	2.43E-05	0.00E+00	Centrifugal, size discharge
C-PUMP100	1.19E-04	2.43E-05	0.00E+00	Centrifugal, size discharge
C-PUMP150	1.19E-04	2.43E-05	0.00E+00	Centrifugal, size discharge
C-PUMP200	1.19E-04	1.71E-05	7.27E-06	Centrifugal, size discharge
R-PUMP50	1.17E-03	0.00E+00	0.00E+00	Reciprocating, size discharge
R-PUMP80	6.47E-04	5.23E-04	0.00E+00	Reciprocating, size discharge
R-PUMP100	6.47E-04	5.23E-04	0.00E+00	Reciprocating, size discharge
R-PUMP150	6.47E-04	5.23E-04	0.00E+00	Reciprocating, size discharge
R-PUMP200	6.47E-04	2.21E-04	3.02E-04	Reciprocating, size discharge
C-COMP50	3.48E-05	0.00E+00	0.00E+00	Centrifugal, size discharge
C-COMP80	3.27E-05	2.05E-06	0.00E+00	Centrifugal, size discharge
C-COMP100	3.27E-05	2.05E-06	0.00E+00	Centrifugal, size discharge
C-COMP150	3.27E-05	2.05E-06	0.00E+00	Centrifugal, size discharge
C-COMP200	3.27E-05	1.75E-06	2.96E-07	Centrifugal, size discharge
R-COMP50	2.70E-04	0.00E+00	0.00E+00	Reciprocating, size discharge
R-COMP80	2.59E-04	1.08E-05	0.00E+00	Reciprocating, size discharge
R-COMP100	2.59E-04	1.08E-05	0.00E+00	Reciprocating, size discharge
R-COMP150	2.59E-04	1.08E-05	0.00E+00	Reciprocating, size discharge
R-COMP200	2.59E-04	9.60E-06	1.20E-06	Reciprocating, size discharge
HX-S50	3.52E-04	0.00E+00	0.00E+00	Shell side Heat Exchanger
HX-S80	2.18E-04	1.34E-04	0.00E+00	Shell side Heat Exchanger
HX-S100	2.18E-04	1.34E-04	0.00E+00	Shell side Heat Exchanger
HX-S150	2.18E-04	1.34E-04	0.00E+00	Shell side Heat Exchanger
HX-S200	2.18E-04	6.46E-05	6.93E-05	Shell side Heat Exchanger
HX-T50	1.70E-04	0.00E+00	0.00E+00	Tube side Heat Exchanger
HX-T80	1.21E-04	4.92E-05	0.00E+00	Tube side Heat Exchanger
HX-T100	1.21E-04	4.92E-05	0.00E+00	Tube side Heat Exchanger
HX-T150	1.21E-04	4.92E-05	0.00E+00	Tube side Heat Exchanger
HX-T200	1.21E-04	2.81E-05	2.11E-05	Tube side Heat Exchanger
HX-P50	1.14E-03	0.00E+00	0.00E+00	Tube side Heat Exchanger
HX-P80	7.84E-04	3.59E-04	0.00E+00	Plate Exchanger
HX-P100	7.84E-04	3.59E-04	0.00E+00	Plate Exchanger
HX-P150	7.84E-04	3.59E-04	0.00E+00	Plate Exchanger
HX-P200	7.84E-04	1.96E-04	1.63E-04	Plate Exchanger
FINFAN50	2.23E-04	0.00E+00	0.00E+00	Air cooler
FINFAN80	1.54E-04	6.90E-05	0.00E+00	Air cooler
FINFAN100	1.54E-04	6.90E-05	0.00E+00	Air cooler
FINFAN150	1.54E-04	6.90E-05	0.00E+00	Air cooler
FINFAN200	1.54E-04	3.81E-05	3.09E-05	Air cooler
FILTER50	4.89E-05	0.00E+00	0.00E+00	Cartridge Filter
FILTER80	4.25E-05	6.44E-06	0.00E+00	Cartridge Filter
FILTER100	4.25E-05	6.44E-06	0.00E+00	Cartridge Filter
FILTER150	4.25E-05	6.44E-06	0.00E+00	Cartridge Filter
FILTER200	4.25E-05	4.82E-06	1.61E-06	Cartridge Filter



## TECHNICAL REPORT

TYPE OF EQUIPMENT	FAILURE FREQUENCY PER YEAR			Comment
	25mm Leak	100mm Leak	>150mm Leak	
PIG RECEIVER50	4.45E-05	0.00E+00	0.00E+00	Pig Launcher / Receiver
PIG RECEIVER80	4.13E-05	3.23E-06	0.00E+00	Pig Launcher / Receiver
PIG RECEIVER100	4.13E-05	3.23E-06	0.00E+00	Pig Launcher / Receiver
PIG RECEIVER150	4.13E-05	3.23E-06	0.00E+00	Pig Launcher / Receiver
PIG RECEIVER200	4.13E-05	2.69E-06	5.39E-07	Pig Launcher / Receiver
HEATER Explos			1.00E-04	
X COUNTRY PIPE100	9.25E-08	3.65E-08	6.65E-08	Pipelines, per metre
X COUNTRY PIPE150	7.50E-08	2.90E-08	5.30E-08	Pipelines, per metre
X COUNTRY PIPE200	7.08E-08	2.75E-08	3.02E-08	Pipelines, per metre
LPG HOSE	2.50E-03		5.00E-04	LPG (un)loading hose
LIQ HC HOSE	2.50E-02		5.00E-03	Hydrocarbon (un)loading hose
LPG TANKS	7.10E-06	4.30E-06	4.70E-07	Pressurised Storage Tanks

## 7.2 Failure Case Leak Frequency Estimation

For each defined failure case all equipment items are counted (based on P&ID information and for piping lengths a study of the unit plot plans), which contribute towards the potential leak frequency. Where equipment items are normally isolated from the process, they are excluded from the equipment count. Table 7.2.1 provides an example of the leak frequency calculations for the incoming NG supply (at the Metering / Pressure Reducing Station).

**Table 7.2.1 - Example of Leak Frequency Calculations  
(Incoming NG Pipeline 8", Metering Station, 25mm, 100mm & 200mm leaks)**

Failure Case Identifier	Type of Equipment Items within Failure Case	Generic Equipment 25mm Leak Freq / year	Generic Equipment 100mm Leak Freq / year	Generic Equipment Full Bore Leak Freq / year	No. off Eqpt Items	Total 25mm Leak Freq / year	Total 100mm Leak Freq / year	Total Full Bore Leak Freq / year
NG-METER-25V	PIPE200	5.52E-07	4.94E-08	1.31E-08	20	1.10E-05	9.87E-07	2.63E-07
NG-METER-100V	VALVE200	4.04E-06	5.24E-07	2.00E-07	10	4.04E-05	5.24E-06	2.00E-06
NG-METER-200V	FILTER200	4.25E-05	4.82E-06	1.61E-06	2	8.49E-05	9.65E-06	3.23E-06
	FLANGE200	2.55E-06	3.07E-07	1.09E-07	6	1.53E-05	1.84E-06	6.54E-07
LOC: 73 / 767						1.52E-04	1.77E-05	6.15E-06

### Legend:

PIPE200 = Process piping, 200mm diameter; Frequency is per metre of pipe per year

VALVE200 = Manual valve, 200mm nominal size (8")

FILTER200 = Filter, inlet & outlet are 200mm nominal size (8")

FLANGE200 = Flange pair, 200mm nominal size (8")

LOC = Release Case Location, using plant coordinate system

Appendix I provides full detail of all failure cases defined, and the associated leak frequency estimates.





## TECHNICAL REPORT

### 8 CONSEQUENCE ASSESSMENT

Each defined failure case was entered into SAFETI risk model, where the corresponding consequence calculations and fatality impact calculations were performed, based on the 4 built-in programmable event trees and for all alternate consequence outcomes, based on the Table 8.1 consequence criteria and the Table 8.2 vulnerability parameters.

**Table 8.1 SAFETI Consequence Impact Criteria for Fatality**

Consequence	Risk Criteria Level	Remarks
VCE	> 5 psi	Area of heavy explosion damage & fatality
	1.5 – 5 psi	Area of moderate explosion damage & fatality
Flash Fire	LFL envelope	Area of fatality; none outside LFL
Fire Ball / BLEVE	Eisenberg Probit	Variable impact based on duration, and using 5 impact levels
Jet fire	35 KW/m <sup>2</sup> Envelope & Eisenberg Probit below 35 KW/m <sup>2</sup>	35 KW/m <sup>2</sup> is considered as flame, 100% Fatality. Outside the flame, the impact is based on Probit calculations, using 5 impact levels and iteration
Pool fire	35 KW/m <sup>2</sup> Envelope & Eisenberg Probit below 35 KW/m <sup>2</sup>	As above
Toxic vapour	Toxic Probit Equations	Impact varies with concentration and exposure duration, unique for each material

## TECHNICAL REPORT

**Table 8.2 : SAFETI Default Vulnerability Parameters**

General Risk Parameters			
General Risk	Flammable Risk	Toxic Risk	Vulnerability
Lethality modification factors for societal and individual risk			
	Units	Outdoors	Indoors
Heavy Explosion Damage	fraction	1	1
Light Explosion Damage	fraction	0	0.025
Flash Fire	fraction	1	1
Fireball Societal Radiation Criteria Zone	fraction	1	1
Fireball Individual Radiation Criteria Zone	fraction	1	1
Fireball Societal Flammable Probit Zone	fraction	0.14	0
Fireball Individual Flammable Probit Zone	fraction	1	0
Jet Fire Societal Radiation Criteria Zone	fraction	1	1
Jet Fire Individual Radiation Criteria Zone	fraction	1	1
Jet Fire Societal Flammable Probit Zone	fraction	0.14	0
Jet Fire Individual Flammable Probit Zone	fraction	1	0
Pool Fire Societal Radiation Criteria Zone	fraction	1	1
Pool Fire Individual Radiation Criteria Zone	fraction	1	1
Pool Fire Societal Flammable Probit Zone	fraction	0.14	0
Pool Fire Individual Flammable Probit Zone	fraction	1	0
Toxics	fraction	1	1

*Note that the Table 8.2 fatality impact levels relate to the impact criteria in Table 8.1.*

For each defined failure case, discharge, dispersion and consequence modelling calculations are performed to determine the potential consequence hazard ranges, for all defined weather classes. SAFETI always calculates the hazard range of all alternate possible consequences, which can include pool fires, jet fires, flash fires, fire balls, vapour cloud explosions and toxic vapour impact. For each process unit all process equipment was included in the risk model, whether capable of producing an offsite risk result or not, consistent with the objective to build a fully detailed risk model that can produce accurate onsite and offsite risk results.

Table 8.3 provides an overview of the worst case consequence fatality hazard ranges that are posed by Advanced Materials Plant operations, which are due to the 200mm Natural Gas Supply into the site. (Kerosene Sulfonate release incidents present only a very local impact due to pool fires).



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**TECHNICAL REPORT**

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**Table 8.3 : Worst Case Hazard Ranges**

Failure Case	Description	Consequence Type	Impact Level	Worst-Case Hazard Distance (m)
NG-200V	Full bore leak on NG supply within the site boundaries (200mm)	Jet Fire	12.5 kW/m <sup>2</sup>	114m
		Flash Fire	LFL Envelope	117m
		VCE	1.5 psi	No VCE



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## TECHNICAL REPORT

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### 9 RISK CRITERIA & RISK RESULTS

#### 9.1 Risk Criteria

The Malaysian Risk Acceptance Criteria are contained in document "Environmental Impact Assessment Guidelines for Risk Assessment", December 2004, published by the Department of Environment of the Ministry of Natural Resources and Environment. The recommended risk tolerability criteria for Malaysia are:

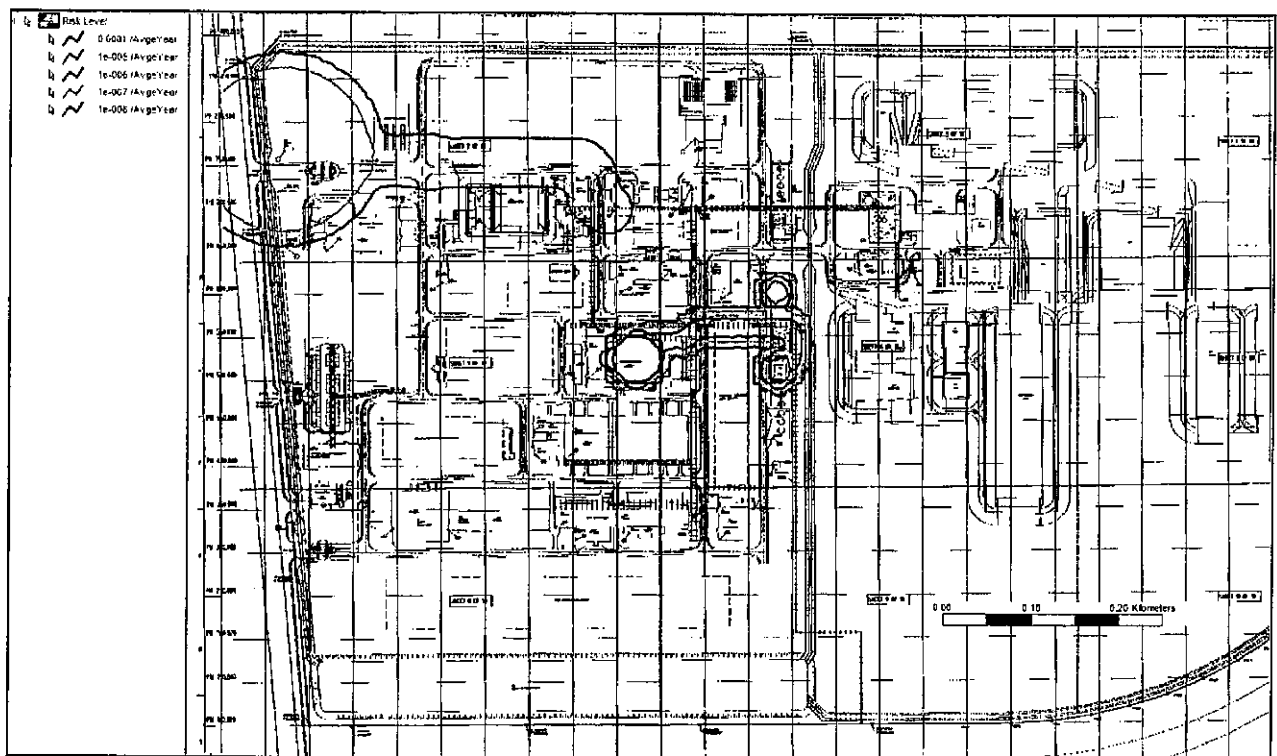
- (i) The  $1 \times 10^{-6}$  fatalities/person per year individual risk contour should not encompass involuntary recipients of industrial risks such as residential areas, schools, hospitals, and places of continuous occupancy, etc.
- (ii) The  $1 \times 10^{-5}$  fatalities/person per year individual risk contour should not extend beyond industrial developments.

## TECHNICAL REPORT

### 9.2 Overall Risk Results

Figure 9.1 shows the LSIR contour results for all Advanced Materials Plant facilities.

Figure 9.1 : Overall LSIR Contour Results



No societal risk FN-results could be produced as there are no defined population areas outside the site boundaries within the potential hazard area.



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## TECHNICAL REPORT

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### 10 CONCLUSIONS

Based on a comparison of the LSIR contour results with the Malaysian Department of Environment Risk Criteria (DOE), the following conclusions may be drawn:

Figure 9.1 LSIR contour results for the Advanced Materials Plant demonstrate that both the  $1 \times 10^{-5}$  per year and the  $1 \times 10^{-6}$  per year fatality risk contour remain onsite and hence the LSIR risk results may be deemed to meet the DOE risk criteria.




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## TECHNICAL REPORT

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### 11 GLOSSERY

ALARP	As Low As Reasonably Practicable
Barg	Bar Gauge
Deg C	Degrees Centigrade
DNV	Det Norske Veritas
ESD	Emergency Shut-Down
ESDV	Emergency Shut-Down Valve
F & G	Fire and Gas Detection
HC	Hydrocarbon
HCRD	Hydro Carbon Release Database (UK HSE)
IR	Individual Risk
IRPA	Individual Risk Per Annum
JF	Jet Fire
Kg/s	Kilogrammes per second
KJ	Kilo Joules, a measure of thermal dose
KW/m <sup>2</sup>	Kilo Watt per Square Metre, a measure of heat flux or radiant heat
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Fatality Risk per year
MAH	Major Accident Hazard
mm	Milimetre
MMSCFD	Million Standard Cubic Feet Per Day
NG	Natural Gas
P&ID	Piping and Instrumentation Diagram
PLL	Potential Loss of Life
Psi	Pounds per square inch, a measure of (over) pressure
QRA	Quantitative Risk Analysis
UK HSE	UK Health and Safety Executive
UFL	Upper Flammable Limit
VCE	Vapour Cloud Explosion



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## TECHNICAL REPORT

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### 12 REFERENCES

- /1/ NFPA, "NFPA 30: Flammable and Combustible Liquids Code", 2003 Edition
- /2/ HSE (2000), "Offshore Hydrocarbon Releases Statistics 1999", Offshore Technology Report OTO 1999 079, Health & Safety Executive

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