RADIOLOGICAL IMPACT ASSESSMENT OF ADVANCED MATERIALS PLANT GEBENG INDUSTRIAL ESTATE KUANTAN, PAHANG

1. INTRODUCTION

1.1 PROJECT BACKGROUND

Lynas Malaysia Sdn. Bhd. (Lynas), a wholly owned subsidiary of Lynas Corporation Limited (Australia) intends 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 site 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 22,500 tpa (LnO or lanthanide oxide basis) of high purity lanthanide compounds. 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 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 plant site within the GIE.

The regional location of the plant site and a satellite image showing the site and its immediate surrounding areas are presented in **Figures 1.1** and **1.2.**

The lanthanide concentrate is known to contain a small amount of naturally occurring radioactive materials (NORM). As the process may disturb the physical and chemical structure of the concentrates and may eventually lead to slight enhancement of the original concentration of NORM, thus, the local law requires that operation of such facility should be assessed for any potential radiological impact to workers, the general public and the environment. The Company has requested the assistance of Malaysian Nuclear Agency to carry out a radiological impact assessment of the plant in order to fulfil such legal requirements imposed by the regulatory authority (Atomic Energy Licensing Board, AELB), which also ensure that operation of the plant will not cause unacceptable radiological risk to workers and members of the public.

This report highlights the basis and approach adopted for the assessment and presents results of the assessment made on the plant operation. The assessment has been made based on information of the plant and the site provided by the Company and its Consultant, Environ Consulting (M) Sdn Bhd, to Malaysian Nuclear Agency prior to carrying out the assessment.

1.2 OBJECTIVE

The main objectives of this study are to assess potential radiological impact caused by operation of the plant to the workers and the general public living in the surrounding areas of the plant and to confirm that such operation will not cause undue radiological risk beyond what is allowed by the regulatory authority, the AELB. The study takes into consideration both normal operation of the plant and possibility of abnormal occurrences that are plausible to occur during operation of the plant including during transportation of the materials to the plant.

1.3 SCOPE OF WORK

This study covers assessment of radiological safety aspects of the operation of the plant. It does not take into consideration non-radiological safety aspects of the operation of the plant, which may have similar impact to the health and safety of the people involved and which may have been covered under different studies sanctioned by the Company. Neither does the study take into consideration the radiological and non-radiological safety aspects of future decommissioning nor the disposal of the plant, after it has been decided to permanently cease operation. However, upon cessation of operation in the future, the Company will conduct the decommissioning in accordance with the regulations and procedures imposed by AELB. The guideline for decommissioning notification and approval may be obtained in the AELB guideline called LEM/TEK/38.

The study covers the radiological safety assessment of exposure scenarios, the critical pathways, the critical radionuclides and the critical groups identified in Section 6 covering both internal and external exposure situations. It covers all anticipated activities that may take place during operation of the plant. The assessment would be done based on preliminary information made available to Malaysian Nuclear Agency prior to carrying out the assessment.

2. REGULATORY SETTING

Any activity to be carried out in Malaysia, which has radiological implication, is governed by the Atomic Energy Licensing Act (AELA) of 1984 and its subsidiary legislation. The law is enforced by AELB, which, besides the existing regulations established under the Act, also introduces various guides, licensing requirements and conditions to ensure safe use, handling, storage, disposal and security of the radioactive materials in the country. The existing regulations cover basic radiation protection requirements, licensing and transport of radioactive materials. However, the existing law and regulations are very general in nature and they do not have any specific and detail deliberation made on construction, safe handling and operation of plants, which process materials containing NORM.

There is a guideline called LEM/TEK/30 Semakan 2, which is introduced by AELB to control radiological safety of NORM generated from oil and gas industry. There is a section in this document that details out on the need to prepare a radiological impact assessment for disposal of NORM contaminated oil sludge [1]. There is also a checklist for Class A Licence (Milling) issued recently by AELB to guide licensees on preparation of the information required for application of Class A Licence in respect of milling of materials containing or associated with radioactive materials [2]. At the moment, these are the only guides available for addressing technical issues related to safe handling of materials containing NORM or NORM contaminated wastes in Malaysia. However, for the purpose of this assessment, the company has been advised by AELB to follow the format of reporting given in Appendix A of LEM/TEK/30 Semakan 2 [1].

There is no specific definition of radioactive materials given in term of activity concentration neither in the AELA nor its subsidiary legislation. By the general definition of radioactive materials given in the AELA, it is understood that in practice all radioactive materials in use, transport, storage or in possession of any person in the country are placed under regulatory control except when they are exempted by the AELB under Clause 69 of the Act. At present, only very low activity radioactive materials in the form of check source, calibration source and reference source that will not cause significant radiological risk to a person (with anticipated dose of less than 10 μSv per year) can be considered for exemption [3]. This situation seems to imply that there is no exemption or exclusion from following the regulatory requirements given to the lanthanide concentrate to be brought into the country as feed material for the plant. Therefore, in carrying out the impact assessment, involvement of the lanthanide concentrate material right from the moment it arrives at the port and is unloaded from a vessel will be taken into account. When the lanthanide concentrate material is processed, their concentration will be disturbed and slightly enhanced and the radiological safety along the process lines until generation of the residue would, therefore, also be taken into account in the assessment.

In addition to LEM/TEK 30, there are two other documents, namely the Radiation Protection (Basic Safety Standard) Regulations 1988 [4] and the Radiation Protection (Transport) Regulations 1989 [5] that specifically address radiation protection aspects and safety of radiation sources and safe transport of radioactive materials, which are going to be used as the main reference for the purpose of this assessment.

3. PROJECT DESCRIPTION [6-15]

3.1 LOCATION

The site earmarked for the establishment of the Advanced Materials Plant is a parcel of industrial land located centrally within the Phase III area of the Gebeng Industrial Estate (GIE) in the Mukim of Sungai Karang, District of Kuantan, State of Pahang. The site lies at approximately latitude 04°00'N, and longitude 103°22'E. The total area of the site is 100 hectares.

The layout plan of the GIE, which includes the location of the plant, is shown in Figure 3.3.

The GIE is one of the main industrial areas in Pahang 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 stretch of the East Coast Expressway leads to the GIE.

The Pahang State Development Corporation (PASDEC) is responsible for the management of the GIE. Discussion with PASDEC and review of historical information indicates that construction of the estate commenced in 1982 with the initial development of the Phase I area. Prior to development, the area consisted of a mixture of low lying peat swamp forest, disturbed secondary forest and stretches of rubber plantation belonging to the State Government and the PASDEC.

A forested hill was reportedly located towards the west of the Phase III area. The Phase II area comprised mainly of the peat swamp, rubber plantation and stretches of secondary re-growth. Some parts of the Phase II area were reportedly used as a borrow area to provide fill for the Phase I development.

3.2 SITE CHARACTERISTICS

3.2.1 TOPOGRAPHY

Regionally, the GIE is located on the Kemajuan Tanah Tanah Merah area where Bukit Tanah Merah was flattened to construct the GIE. The GIE is located within the Sungai Balok catchment. The catchment is low-lying and is predominantly swampy. The estimated average land elevation is 7 m above mean sea level.

The hilly areas surrounding the site include Bukit Balok which is located about 6 km southwest of the GIE at a height of 230 m above mean sea level (MSL). Bukit Pangram which rises 197 m above MSL is located 7.5 km southeast of the industrial estate. Sungai Balok flows 3 km west of area flowing in the southerly direction. The nearest coastline is 3 km to the east.

A topographical survey of the site was carried out by Jurukur Teguh (Terengganu) in October 2007. The survey details are provided in Figure 3.4. The regional topographical setting is presented in Figure 3.5.

The topographical survey indicates that the site is relatively flat with an overall natural gradient of 0°. The ground levels at the site generally ranged between 7.4 m and 7.8 m above MSL. There is a shallow earth trench that cuts across the site in a south easterly direction. A second shallow earth trench bisects the site in a north-south direction.

The plant site has been largely cleared and filled to the existing platform level. Secondary vegetation was found sparsely distributed within the site. The vegetation type is typical of a disturbed area, and all species observed are very common pioneer and invasive species, typical of an open and disturbed vegetation type. No vegetation of ecological significance was observed at the site.

The proposed footprint of the Advanced Materials Plant and its ancillary facilities are on the low-lying and flat areas of the site. The main plant will be located within the western sector of the site.

3.2.2 DEMOGRAPHY

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 which is located about 3 km south of the site along the Kuantan-Pelabuhan Bypass road.

Based on statistical data obtained during the most recent population census in 2000 by the Department of Statistics Malaysia, the total population count for Taman Balok Perdana, Taman Balok Makmur and Kem TLDM Kampung Seberang Balok is 5,973. Of this population number, about 57% are 25 years and below. Eighty-seven percent of the population comprise Malays, 0.2% of the population are Chinese, while 2.2% of the population are Indians.

Other settlements neighbouring the site are Kampung Sungai Ular (2.5 km north of Kampung Gebeng), Kampung Hulu Balok (3km south-east of the site), Kampung Berahi (4.5 km south of the site), Kampung Seberang Balok (6 km south of the site).

South of Kampung Seberang Balok is Kampung Balok and Kampung Balok Baru. These settlements comprise residential and commercial structures. The majority of the areas are sparsely populated.

Other settlements include Kampung Gebeng (3 km north-east of the site) and Kampung Selamat (4 km south-east of the site).

3.2.3 HYDROLOGY

The GIE where the **proposed** plant site is to be located was formerly part of the the Paya Tanah Merah peat swamp forest. Subsequently, when the GIE was developed, the area was reclaimed using fill quarried from the nearby hilly areas. The two main rivers that drain the GIE are Sungai Balok and Sungai Tunggak. Sg. Balok originates as Sungai Batang Panjang from the hills to the northwest of GIE and generally serves the western catchment of the GIE. Sungai Tunggak originates from the Tanah Merah peat swamp forest and flows south along the eastern boundary of the GIE. which generally drains the areas within the eastern sector of the site. The site is within the Sungai Balok catchment (refer **Figure 3.6**) and thus all discharges from the site site will enter this river system.

The tide for the Kuantan area is predominantly diurnal, with a tidal range of 2 m – 3.5 m. Sungai Balok is likely to be tidal up to almost 10 km upstream of the river mouth.

Sungai Balok flows along the western boundary of GIE in a southerly direction before its confluence into the coastal waters of the South China Sea. The primary source of pollution into this river is the drainage discharge from the GIE at two locations along the river channel.

Sunggai Tunggak which is a tributary of Sungai Balok flows serves the eastern catchment of the GIE flows in a southerly direction before its confluence at Sungai Balok.

No historical river flow data are available for Sungai Balok and Sungai Tunggak from published records reviewed during the course of this study.

There are no impoundments for potable water supply within the catchments of Sungai Balok and Sungai Tunggak.

3.2.4 GEOLOGY

Information regarding the general geology, soil and hydrogeology of the site and the surrounding area was extracted from the following sources:

- District Memoir 6: The Geology and Mineral Resources of the Neighbourhood of Kuantan, Pahang (1952);

- Geological Map of the Kuantan Sheet, Pahang in 1 : 63,360 scale (1951);
- Geological Map of Peninsular Malaysia in 1 : 2,000,000 scale (8th Edition) (1985);
- Quaternary Geological Map of Peninsular Malaysia in 1 : 1,000,000 scale (1st Edition) (1989);
- Reconnaissance Soil Map of Peninsular Malaysia in 1 : 500,000 scale (1968); and
- Hydrogeological Map of Peninsular Malaysia in 1 : 500,000 scale (1975).

The *Reconnaissance Soil Map* indicated that surface soils at the site and the surrounding areas are alluvial in nature and comprise mainly of peat. A review of published geological memoirs and geological maps of the Kuantan area revealed that geologically, the site and much of Mukim Sungai Karang are underlain by alluvium up to a depth of approximately 115 feet (ft) or 38 meters (m). The general area was swampy and had been deposited with soil debris brought down by rivers. The *Quaternary Geological Map* further described that this alluvial layer to consist of peat, humic clay and silts of the Beruas and Simpang Formations.

Granite, reportedly formed in Cretaceous times, underlies the Quaternary Alluvium layer. This granite intruded into both the older Lower Carboniferous strata and older beds of the Arenaceous Series, and forms much of the bedrock underlying the Gebeng Industrial Estate, with the most prominent outcrop at Bukit Pengorak, about 3.0 km southeast of the site. The granite is reportedly variable in composition and texture, but is commonly porphyritic, medium grained biotite.

Arenaceous sedimentary rocks were reported in the Bukit Balok area and at Tanjung Gelang area, approximately 6.0 km southwest and 7.5 km southeast from the site respectively. The Arenaceous series predominantly consist of quartzite, grit and conglomerate.

In addition, basaltic rocks were also observed at shallow depths in a few small areas to the west and southwest near Sungai Balok. Reportedly, the basaltic magma rose, mostly through fissures in the granite.

The geological map of the site and surrounding areas are presented in **Figure 3.7.**

The *Hydrogeological Map of Peninsular Malaysia* indicates that the unconsolidated alluvial deposits in the general area have an estimated potential yield of between 4,000 and 6,000 gallons/hour/well.

Geotechnical site investigations carried out at the proposed project site revealed that subsurface conditions to be generally consistent with the information obtained from published geological reports and maps. The subsurface of site can generally be classified into the following:

- Fill material;
- Alluvium; and
- Weathered bedrock.

The upper fill material across the site consists of Clayey Sandy Gravel and Clayey Gravelly Sand, generally between 0.8 m and 1.8 m thick. Reportedly, the fill material was sourced from a local borrow and placed approximately four years ago.

Alluvial deposits, with a thickness of up to about 35 m, underlie the fill layer across the site. The alluvial deposits can be further subdivided into several sublayers. The upper alluvial layer comprises very soft medium plasticity Organic Clay and Peat. This layer has a thickness of about 0.6 m to 1.7 m, and contains partially decomposed plant material. The Organic Clay generally grades into a green-brown soft Clay and light grey loose Silty/Clayey Sand. Beneath this, alternating layers of Silty/Clayey Sand, Sandy/Clayey Silt and Sandy Clay of variable thickness were observed across the site.

Weathered bedrock and associated residual soils comprising hard Sandy Silt and Sandy Clay were encountered at depths of around 35 m below ground surface (bgs).

At the time of site investigations, stabilized groundwater level observed at boreholes, test pits and monitoring wells within the site were in the range of 0.95 to 3.5 m bgs. The water table appears to coincide with the Organic Clay of the upper alluvial deposits. Groundwater recharge at the site is anticipated to come almost entirely from rainfall. Increased recharge can be expected during the wet monsoon period in November and December. Field tests performed indicated that the hydraulic conductivity of Organic Clay and the underlying Silty Sand to be in the range of 10^{-7} – 10^{-8} m/s and 10^{-6} m/s respectively.

3.2.5 METEOROLOGY

The climate of Malaysia is equatorial characterized by fairly high but uniform temperatures, high humidity and copious rainfall throughout the year with little seasonal variation.

Rainfall distribution patterns over the country are affected by local topography and wind directions. Based on predominant wind flow regimes, four periods can be distinguished. The southwest monsoon is usually established in the later half of May or early June and ends in September. The prevailing wind flow is generally southwesterly and light. The northeast monsoon usually commences in early November and ends in March. During this period, steady easterly or northeasterly winds blowing from the South China Sea result in high precipitation, particularly to the east coast region of Peninsula Malaysia. The months of April and October are transitional or inter-monsoon periods and are characterized by variable wind conditions.

The nearest Malaysian Meteorological Service (MMS) station to the project site is located at the Sultan Ahmad Shah (SAS) Airport in Kuantan, Pahang approximately 30 km southwest of the GIE. The station is located at latitude 3° 47' N and longitude 103° 13'E at 15.3 m above MSL. As the airport is located 30 km southwest of GIE and further inland (12 km compared to 2 km), small differences in the microclimate are likely between the sites although the macroclimate is essentially the same. For purposes of this study, climate and meteorological data was obtained from the station for the period 1968 – 2005.

Wind Profiles

The annual wind rose and a wind speed/direction distribution matrix for the Sultan Ahmad Shah (SAS) Airport are presented in **Figure 3.8.**

On an annual basis prevailing winds are from the north (~ 25% of the time) and southwest (~11% of the time). However, wind speeds are generally low occurring below 3.3 m/s for 79% of the time and rarely exceeding 5.4 m/s (20 km/h). Higher wind speeds are typically associated with winds from the north, northeast, east and southwest.

Figure 3.9 which presents the seasonal wind roses for the period 1975–2005 clearly demonstrate the monsoonal wind regimes experienced between May and September (SW Monsoon) and November to March (NE Monsoon). Variable wind conditions are observed in the inter-monsoon periods in April and October.

Due to the close proximity of the proposed project site to the sea, the project site also experiences the effects of diurnal wind patterns (land and sea breezes) typically experienced at coastal locations.

Temperature

Temperature records for the period 1968–2005 showed fairly uniform temperatures throughout the year, with mean monthly temperatures ranging from 25°C in the months of January and December to 27.3°C in March. The slightly lower 24-hour mean temperatures observed in the period of November–February each year can be attributed to the high precipitation and high cloud cover during the wet northeast monsoon period. The mean annual temperature is averaged at 26.3 °C.

The mean monthly temperature variation for the period 1968 to 2005 is graphically illustrated in **Figure 3.10.**

Relative Humidity

The mean 24-hour relative humidity is also fairly high and constant throughout the year typically ranging from 83.7% in the period between July and August to 89% in the period between November and December. The average annual 24-hour relative humidity is 85.2%.

Mean monthly relative humidity variation for the period 1968 to 2005 is graphically illustrated in **Figure 3.10.**

Rainfall

The average annual rainfall recorded at the station over the period 1951–2005 is 2,957 mm with an average of 189 rainy days annually. The highest annual rainfall was recorded in 1967 at 4,266 mm.

Although rainfall is heavy throughout the year, variations are evident. The wettest months are October, November, December and January (NE Monsoon) with a monthly average of 275 mm, 365 mm, 620 mm and 310 mm respectively. The highest monthly rainfall was recorded in the month of December 2001 at 1,471 mm and the lowest monthly rainfall was recorded in February 1998 at 1.2 mm. The average monthly rainfall for the remaining months range between 147 mm and 215 mm.

Summaries of average annual rainfall and the number of rainy days recorded at the station are presented in **Figure 3.11.**

3.3 PRESENT AND FUTURE LAND USE

A breakdown of the various land uses within a 5 km radius of the Advanced Materials Plant is presented in Table 3.1. The land use pattern is illustrated in Figure 3.12 (**Exhibit 4.1**). The location of the site within the GIE is indicated in Figure 3.13.

The total land area allocated for GIE is 9,600 acres. PASDEC developed the industrial area in four phases (Phase I to IV). Details of various development stages are summarised below in **Table 4.2**.

Table 4.2 Development Stages of the Gebeng Industrial Estate (GIE)

Phase I	Established in 1982 and located to the south of the Phase II development. The development comprises an area of 700 acres and is fully occupied. The existing industries include MTBE, Polypropylene, AMC, Demi Bintang, Choice Woods, Hassan Milling, ATD, MEICO, Suasa Unik and Cargill Oil Palm.
Phase II	Established in 1993 and covers an area of 1,400 acres. At present only 80% of total area is occupied. The industries located here include BP Chemicals, Eastman, WR Grace, Cryovac, Kaneka, Flexsys and Kontena Nasional.
Phase III	Development commenced in 1997 and still expanding. Located northwest of the Phase II development, it covers a development area of 2,500 acres. The present occupants are BASF Petronas Chemicals, Petronas CUF, Petronas PDH and Polyplastic.
Phase IV	Presently undeveloped. It has total potential development area of 5,000 acres and PASDEC has allocated 60% from this area for petrochemical industries.

3.4 DESCRIPTION OF PROCESS

This section provides a description of the chemical processes that will be carried out at the Advanced Materials Plant. The lanthanide concentrate will be produced at Mt. Weld in Western Australia and transported to the plant via the Port of Kuantan. At the plant, the concentrate which is the primary raw material (main feed) will be processed within the Cracking & Separation Plant and the resultant cracked lanthanide will undergo leaching and neutralization and extraction. The extracted lanthanides will then be subject to the product finishing processes.

The overall process flow diagram is presented in **Figure 3.13.**

3.4.1 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 3.14.**

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 $10m^3$).

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 Liquified Petroleum Gas (LPG); 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.

Leaching and Neutralisation

The soluble lanthanide 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.

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 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:

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

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) LCPN Carbonate

LCPN chloride solution from SX2 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 SX5 or to the LCPN precipitation circuit, for precipitation with sodium carbonate solution. The LCPN 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.

b) 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 releached 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.

c) LaCe Carbonate

LC 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 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) Cerium Carbonate

C 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 C precipitation circuit, for precipitation with sodium carbonate solution. The C 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 Carbonate,

L 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 L 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.

f) Lanthanum Oxide

Lanthanum oxide will be produced by calcining Lanthanum carbonate at a temperature of 900°C in the LPG-fired tunnel furnace. The tail gas discharge from lanthanum calcinations process will contain CO_2 and H_2O, and no hazardous elements, and will be emitted to the atmosphere.

g) Dydimium (Dd) Oxide

Dydimium (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 LPG fired tunnel furnace. Tail gas discharge from Didymium calcinations process will contain CO_2 and H_2O with no hazard elements, and will be emitted to the atmosphere.

The operation of the proposed lanthanides plant will generate process wastewaters and waste gas emissions. All liquid waste streams will be treated in a wastewater treatment plant to meet the prescribed Standard B discharge limits of the Environmental Quality Act, 1979 and the radioactive discharge limit approved by AELB. The treated wastewater will be discharged into the storm water drain and finally to Sg. Balok. The waste gas emissions will be treated in a waste gas scrubber system prior to release to the atmosphere. The emissions released from the scrubber stack will comply with the Standard C limits of the Environmental Quality (Clean Air) Regulations, 1978 and the radioactive discharge limit approved by AELB. The environmental impacts arising from the non-radioactive pollution sources have been evaluated in the Preliminary Environmental Impact Assessment report prepared for the project.

Radiological monitoring of all discharges from the plant operations will be carried out to ensure that they meet the requirements of the discharge limit approved by AELB.

As a result of the processes at the Advanced Materials Plant operations, three types of residues will be generated, namely (1) Water Leach Purification Residue (WLP), (2) Flue Gas Desulphurisation Residue (FGD) and (3) Neutralization Underflow Residue (NUF). The residues are expected to be in the form of paste. Generation of these residues is estimated to be about 145,200 cubic meters per year with the total volume generated over the entire operational period of the plant (10 years) account to about 2,766,600 cubic meters. Details of the residue quantities generated are presented below.

Average Quantities of Residue Generated

Residue Stream	Annual Dry Mass Year 1 (tpa)	Assumed Dry Density (t/m^3)	Annual Volume Year 1 to Year 2 (m^3)	Annual Volume Year 3 to Year 10 (m^3)	10 Year Volume (m^3)
FGD	27,900	1.05	26,600	53,200	478,800
NUF	85,300	1.05	81,300	162,600	1,463,400
WLP	32,000	0.70	45,800	91,600	824,400
Biosolid	913	0.28	3,318	6,636	29,864
Total	**146,113**		**157,018**	**314,036**	**2,796,464**

In addition to the above, up to 2,000 tpa of biosludge will be generated from the Wastewater Treatment Plant (WWTP) and stored in the same cell as the WLP residue.

These residues will be transported by vehicle to a specially designed onsite facility (Residue Storage Facility or RSF) for storage. The company is developing plans for research and development of valuable uses for residues, and also permanent disposal options.

4. CURRENT STATE OF THE RADIOLOGICAL ENVIRONMENT

Processing of mineral concentrates containing NORM is not a new activity in Malaysia. There have been quite a number of companies involved with such activities with their specially designed plants still in operation in different parts of the country. The nature of operation involved is either physical or both physical and chemical processes of the minerals. Two of such companies i.e. Syarikat Asian Rare Earth Sdn Bhd, Ipoh, Perak which had ceased operation in 1994, and Huntsman Tioxide (M) Sdn Bhd, Kemaman, Terengganu are involved with physical and chemical processes of the minerals, which have similarities to the one proposed to be carried out by the Company.

The enhancements of NORM in the environment were also attributed to other economic activities. Mineral mining resulted in the concentration of the NORM after the mineral were removed from the soil. Under the National Mining Policy (NMP), a mining lease application must include an environmental protection plan that is approved by the Department of Environment of the Ministry of Natural Resources and Environment. The environmental aspects of mine development are covered under the Environmental Quality Act of 1974 (Act 127) and its subsidiary legislation. Tin is the most extensively mined mineral in Malaysia and currently it is being carried out by HWG Tin Mining Sdn Bhd. HWG Tin has been awarded on May 29, 2008, a 10 year mining lease to mine for tin and other minerals on an area of 500 acres of land located in Mukim Pengkalan Hulu, Daerah Hulu Perak, with a potential for a further 500 acres as the work on the initial area progress. Other mineral that are mined in Malaysia are copper at Mengapur copper mine and gold at Penjom gold mine. Both mine are in Pahang. Bauxite are obtain from one mine located in Sungai Rengit, Pengerang, Johore, and exported mainly to Thailand, Japan and Taiwan.

The melting of tin ores to produce tin metal is being carried out by Malaysia Smelting Corp. Bhd. (MSC), located in Butterworth, Penang. Currently it is the leading tin metal producer in the world. This activity produces tin slag as waste and tin slag is a TENORM.

The production of steel also contributed to the enhancement of NORM in the environment. One of the biggest steel producers in this country is Perwaja Steel Sdn. Bhd. Located in Kemaman, Terengganu. Gunawan Steel Sdn. Bhd., also located in Kemaman Terengganu is another steel producer in this country.

The site of the Lynas Advanced Materials plant is an industrial area alienated by the Pahang State Government for medium and heavy industries. Part of the area has already been occupied by a number of heavy industries, but none of them is known to have involved with activities associated with radioactive materials or have resulted in technologically enhanced NORM (TENORM).

It is a fact that NORM can be found almost everywhere including areas around the site where the proposed plant is going to be built. It varies depending on nature and type of soils and it significantly contributes to the presence of background radiation in a particular area. Earlier measurements of the background radiation revealed that the radiation level varies between 980 nGy/hr above the granitic soil and down to about 100 nGy/hr above the metasediments [16]. A more recent study carried out by Malaysian Nuclear Agency indicates that the concentration of thorium-232, uranium-238, radium-228 and radium-226 in the Malaysian soils varies around 22.4 ± 11.2 ppm (0.09 ± 0.05 Bq/g), 5.8 ± 4.1 ppm (0.07± 0.05 Bq/g), 0.13 Bq/g and 0.10 Bq/g and the level of thorium-232 and uranium-238 in Pahang is within 21 ± 12 ppm (0.08 ± 0.05 Bq/g) and 5.5 ± 3.1 ppm (0.07 ± 0.04 Bq/g) [17]. The presence of these radionuclides in terresterial water is also very low, in the order of 0.005 to 0.5 ppb for thorium and 0.01 to 0.8 ppb for uranium. Dement'yev and Syromyatnikov [18] noted that the thorium content of ground water varies and is generally higher in waters of low salinity, hardness, and pH, and high organic content. Most plants and animals contain less than 0.05

ppm thorium-232 in the dry matter. In the ash of plants growing in normal environment, thorium contents ranging from 10 to 30 ppm have been recorded [19].

It is, therefore, very important to note that even though operation of the proposed plant would result in generation of TENORM, but those present in the environment during its operational period does not immediately imply that they come from the plant. If there is any release from the plant to the environment that takes place during such operation, it would add in to what is already in the environment and it can be confirmed by environmental monitoring programme.

5. POTENTIAL SIGNIFICANT IMPACT

Operation of the plant would involve transportation and handling of lanthanide concentrate containing TENORM, some discharges of gaseous and liquid effluents to the environment at certain stages of the process and generation of TENORM residues (WLP, FGD and NUF) of varying concentrations at the end of the process. As described in Section 6.3, two of the TENORM residue are expected to contain enhanced concentration of TENORM and are potential to cause some impact to the people involved. The potential impact caused by operation of the plant can be in two forms, namely impact to workers working with the TENORM residue and members of the public living in the areas around the plant who may be exposed to TENORM contained in the effluents released from the plant and those migrated from the residues stored onsite of the plant. The potential impact caused can result from normal operation of the plant or occurrence of credible incidents or accidents that may happen during operational period of the plant. These potential impacts to both workers and members of the public have been taken into consideration in this assessment and as described in detail in Section 6, the foreseeable impact caused is small and does not seem to be significant with the anticipated doses received are well within the limits allowed by AELB.

6. RADIOLOGICAL IMPACT ASSESSMENT

Determining the right input data, the right method of assessment, exposure pathways and critical groups are very important in carrying out a radiological impact assessment of an activity. In this section, the data and methodology used and the exposure pathways involved in the assessment are described in detail and their dosimetric models are developed for those identified critical groups. Radiation doses received by the critical groups are then estimated based on the models developed.

Dosimetric models used tend to be conservative so that doses calculated could be regarded as upper limit estimates. For external dose calculations, because of the anticipated low doses involved and difficulties in rigorously defining exposure geometries, approximations rather than rigorous analytical solutions of the dosimetry models are generally used. These approximations are judged to be reasonable and will not result in underestimation of the anticipated doses.

6.1 ASSESSMENT DATA AND METHODOLOGY

The radiological impact assessment was made based on the information provided by the company to Malaysian Nuclear Agency. However, in some cases where additional data were required for the analysis, but were not immediately available, local data of similar situation would be used. In cases where none of the local data was available then the data established based on the same situation in other country or generic data available in the literature would be used. As far as possible generic data published or recommended by International Atomic Energy Agency (IAEA), United Nation Scientific Committee on Effects of Atomic radiation (UNSCEAR) and International Commission on Radiological Protection (ICRP) would be used.

The assessment was made based on the scenarios of all possible pathways which may lead to radiation dose received by critical groups as a result of working with the plant or living offsite the areas during operation of the plant. Detail information on the pathways and critical groups considered in this study are described in Section 6.4.

The study was carried out by first looking at the various Regulations, standards and guides issued by AELB to determine the radiation protection criteria, which were later used as a basis for assessing the dose received in the subsequent exposure pathways analysis. The next step was to determine the source term for the assessment. An evaluation was then made on all possible radionuclides present during operation of the plant in order to identify the most critical ones that are likely to cause significant exposure to the critical groups.

The subsequent step was to make an assessment of all possible modes of exposure of the identified critical radionuclides that may present or release during handling or normal operation of the plant and their subsequent migration and transport though the environment and determine the critical pathways through which these radionuclides may reach the critical groups and deliver radiation dose.

This was followed by identifying the critical groups among workers and members of the public whose exposure to the critical radionuclides through the identified critical pathways would be the maximum. The final step of the study was to come up with assessment models based on the identified scenarios and established guides to estimate the expected dose to be received by the critical groups from radionuclides identified in the source term. These estimated annual doses would then be assessed and compared with the dose constraints adopted by the radiation protection criteria described in Section 6.2.

6.2 RADIATION PROTECTION CRITERIA

In this study, the primary dose limit used in the assessment is 1 mSv/year, which is the annual permissible dose limit for non-radiation workers and members of the public specified by the Basic Safety Standard Regulations and 50 mSv/year for the workers [4]. These annual limits were used as a basis for determining individual exposure of identified members of the critical groups. However, it is recommended by IAEA and has been a practice in many countries to adopt a dose constraint for operational environmental release, which is set at a faction of the dose limit. The AELB in the past has adopted the dose constraint of 0.3 mSv/year and there is also a recommendation to adopt this figure as the maximum dose constraint for unrestricted release of contaminated sites, such, as ex-uranium mining, milling and tailings [20]. In view of uncertainties and unknown situation on future use of the lands near the site of the proposed plant, this study chose to adopt the same dose constraint for the impact assessment.

The new recommendations of ICRP and IAEA [21, 22], has reduced the dose limit for workers from 50 mSv/year to 20 mSv/year, which has also been adopted by many countries. In line with international practice, this limit was adopted as the dose constraint for the workers. The use of this dose constraints would ensure that, with all the uncertainties involved being taken into consideration, the estimated dose to be received by the critical groups will not exceed the permissible dose limit of 1 mSv/year for members of the public and 50 mSv/year for workers as stipulated by the Basic Safety Standard Regulations [4]. As required by the Basic Safety Standard Regulations [4], the individual dose used in the assessment refers to the total dose from both external radiation exposure and possible intake of radioactive materials into the body as a result of exposure to airborne contamination that may occur during handling of the radioactive lanthanide concentrate and the residues. .

In addition to meeting such requirement of individual exposure limit, as recommended by IAEA [22 -24], the study would also take into consideration the requirement to ensure that the collective dose to the population (the critical groups) would not exceed 1 man.Sv. These two conditions were used as criteria in this study to ensure that operation of the plant is acceptable.

In the context of this study workers means radiation workers who are directly involved with handling TENORM materials, TENORM residues or who work in areas where ore materials or TENORM residues are processed or kept. Members of the public are, on the other hand, representative individuals of the critical human population group who are expected to receive the highest level of radiation dose from operation of the proposed plant.

In making dose assessment to the critical groups, a number of mathematical modelling were selected and used on the exposure scenarios described in the following Section 6.4 and 6.5. Since none of these modelling were available in the local guides, therefore, models established and recommended by IAEA [24, 25] and U.S Department of Energy [26] were used in the study. As far as possible local and site specific data to which Malaysian Nuclear Agency managed to get access were used in the assessment. However, data on various conversion factors and transfer factors involved in the calculations of respective models were not available locally, and therefore, established data published by IAEA, ICRP and other scientific bodies were used.

6.3 SOURCE TERM

The Advanced Materials Plant will process lanthanide concentrate using physical and chemical treatment processes to produce high purity lanthanide compounds. The plant is scheduled to be fully operational in 2011 and will continue to be in operation for at least twenty years. The plant has been designed to process up to a maximum of 65,000 tpa of lanthanide concentrate (dry weight basis). Its initial processing rate is expected to be 32,408 tonnes per annum of lanthanide concentrate from Mount Weld in Western Australia.

The Mount Weld (Australia) lanthanide ore is high-grade averaging 17% lanthanide oxide (TLnO) and it typically contains 28 ppm of U_3O_8 and 750 ppm of ThO_2, which is equivalent to a total radioactivity of 31 Bq/g for the two decay chains.

After the physical beneficiation process in the Concentration Plant (at Mt Weld), the resultant lanthanide concentrate contains about 40% TLnO The lanthanide concentrate is slightly enriched in radioactivity and it typically contains 29 ppm of U_3O_8 and 1600 ppm of ThO_2, which is equivalent to a total radioactivity of 61 Bq/g for the two decay chains.

The Lanthanide concentrate will be subjected to the cracking and separation processes before the lanthanide elements can be separated into the high purity products. This process generates residues in various forms and amount. Based on initial production rate of 32,408 tpa of lanthanide concentrate the Company estimated that three residue streams will be generated:

- 27,900, tons per year of flue gas desulphurization (FGD) residue with radioactivity concentration of 0.47 Bq/g containing 12 ppm of thorium-232 (in ThO_2) and 0.3 ppm of uranium-238 (in U_3O_8);

- 85,300 tons per year of neutralization underflow residue (NUF) with radioactivity concentration of 0.25 Bq/g; and

- 32,000 tons per year of water leach purification residue (WLP) with radioactivity concentration of 61 Bq/g containing 1,655 ppm (6.62 Bq/g) thorium-232 (in ThO_2) and 22.5 ppm (0.28 Bq/g) of uranium-238 (in U_3O_8)

Of these three residues, only WLP residue has significant concentration of thorium and uranium, which is higher than the average concentration generally found in the soils in Pahang and Malaysia, whereas the content of the other two residues is at about the same level or lower than those found in the soils (see further description given in Section 4). Therefore, for the purpose of this study, only the WLP residue was taken into consideration.

As described above, the anticipated annual volume of WLP residue generated is expected to be around 45,800 cubic meters for the first year., For the 10 years continuous operation, the plant would generate residue in the order of 824,400 cubic meters.

The Company would establish a residue storage facility (RSF) onsite to separately store the three residue streams produced from the operation of the plant. The three residue streams are expected to be produced in the form of filter cake or paste and they are ready for storage in the RSF. The moisture content of the filter cake is expected to be between 30 % and 40 %. All three residue streams would be transported by a vehicle to the RSF cells where they will be deposited, spread and compacted.

In addition approximately 2,000 tpa of bio sludge from the wastewater treatment plant will be produced and stored with the WLP.

Thorium-232 has a half-life of 1.41 x 10^{10} years. It is the parent of a radioactive series, which decays via 10 radioactive daughter products to the stable isotope of lead-208. Six of the isotopes decay by alpha emission and five by beta emission. The half-life of these radioisotopes varies from less than one second to the longest one, which is 1.41 x 10^{10} years of the parent thorium-232 itself. Details of the thorium-232 decay series are shown in Figure 6.1. In a similar manner, uranium-238 with a half-life of 4.5 x 10^9 years also decays through a series of daughter products, which consist of eight alpha emitters and six beta emitters and eventually ends up with lead-206. The half-life of daughter products varies from a fraction of a second to the longest of 4.5 x 10^9 years, which is the parent uranium-238 itself. Detail of uranium-238 decay series is shown in Figure 6.2. Since thorium-232 and uranium-238 are not gamma emitters, therefore, they are not considered in the assessment of external exposures of all identified scenarios. As alpha emitters, however, they are very important for internal exposure assessments through inhalation and ingestion.

Bismuth, including the radioisotopes bismuth-210, 212, and 214 is relatively immobile in natural exogene settings readily forming an oxide and an oxycarbonate within the normal pH range (5 - 8) of most normal environment [19]. In soils much bismuth is retained in the clay and limonitic complexes and coupled with their short half-lives makes migration capacity of these radionuclides very insignificant for consideration in the long-term environmental pathway analysis. However, such short half-lived radionuclides with many high-energy gamma emissions can become a significant source of external exposure.

Thallium-208 in the thorium-232 series (Figure 6.1) has half-life of 3.1 minutes and hence its present is largely transitory and important only for short-term exposure assessment of the critical groups. It has a chemistry much like that of potassium, has a relatively high mobility, and exhibits a strong tendency to adsorption on clay minerals and various other natural colloids. Such chemical property possessed by this element makes it less significant in the environmental pathway assessment. However, its significant gamma emissions qualify it to be considered in the internal and external short-term exposure assessment.

All polonium radionuclides have a very short half-life and the most significant among them is polonium-210. In its natural form, polonium-210 is relatively mobile in both highly acid and highly alkaline environments. In the more normal pH environments (5 - 8), polonium-210 is relatively immobile due to the marked hydrolysis of its salts and its ready adsorption, absorption, or co-precipitation by iron and manganese gels, clay complexes and peat complexes. Even in uranium-enriched soils, polonium-210 is present at the level of 0.1 ppb and in other natural materials the contents are one hundredth to one thousandth of this value [19]. Such chemical properties possessed by these radionuclides allow them to be considered only in the short-term assessments of the scenarios.

With the exception of lead-210 in the uranium series, all of the other radioactive lead isotopes have short half-lives (minutes and hours) and hence their presence are transitory and considered only in the short term exposure pathway assessments. The isotope lead-210 has a half-life of 22.3 years and is, therefore, of interest as one of the critical radionuclide in the long-term environmental exposure pathway analysis.

There are four different radionuclides of radium being produced in the decay series of uranium and thorium, namely radium-226, radium-228, and radium-224 (see Figure 6.1 and 6.2) and radium-223 from decay series of uranium-235, which is usually ignored because of low natural abundance (0.72%) of its precursor. Of these four, radium-226 has always attracted particular attention, from the point of view of its health hazard to the public. This stems from the fact that radium-226 has a high degree of radiotoxicity, is 'bone seeking', has a long half-life (of 1600 years) and, as an alpha emitter, which is very potential for causing biological damage. In the case of operation of the proposed plant, since it is known that the percentage of thorium is very significant in the raw materials being processed, it is therefore also important to consider the health implication due to radium-228 (half-life 5.75 years). Ra-228 is more significant from the point of radiation protection than Ra-226. Whilst the inhalation of Ra-226 results in a dose that is about 1.2-1.5 times higher than from inhaling the same amount of Ra-228, the situation is opposite in case of ingestion of water (which is more reasonable pathway of exposure). When Ra-228 is ingested with water the dose is nearly three times higher than the dose resulting from the ingestion of the same amount of Ra-226.The third radionuclide of radium is considered significant only in the short-term assessment and it has always been excluded in most long-term environmental investigations owing to its short half-life.

All but one of the daughter products of thorium-232 is a solid. The one exception is radon-220, an isotope of radon, but commonly referred to as thoron. There is a possibility of thoron being able to emanate from the concentrate, the residue or thorium bearing contaminated materials so that the entire radioactive series may not be in secular equilibrium. When in secular equilibrium the thorium-232 radioactive series has an activity ten times the activity of thorium-232.

As illustrated in Figure 6.1 and 6.2 and further described in the preceding paragraphs, there is a group of radioisotopes produced by the decay of uranium and thorium but only a few of them are considered important or critical in radiological safety assessment. For external exposures, only gamma emitters are important to be considered in the assessment. Some of these radionuclides are also short half-lived and in view of the migration of radionuclides in the soil take place rather slowly, most of these radionuclides will be completely decayed before they could be transferred to the subsequent transport media that lead to human exposure. Thus, for internal exposure analysis of gas and liquid discharges and residues in storage, only radionuclides with half-life more than a year is considered critical. By taking this assumption into account, the internal pathway analysis of both uranium-238 and thorium-232 decay series in the soil from the release of gas and liquid discharges and storage of residue can then be narrowed down to lead-210, radium-226 and radium-228, thorium-228, thorium-232 and uranium-238.

In the pathway analysis of handling the concentrate and the residue streams, however, all parents and daughter products radionuclides with half-lives more than one hour are taken into consideration in the analysis.

Even though the actual exposure pathway assessment of the scenarios will not take into account contribution of the background radiation exposure produced by naturally occurring radioisotopes present in the areas of interest, but in view of the fact that the released radionuclides of interest will directly or indirectly enhance the presence of such background radiation, a comparison would be made with the level of radiation and radioactivity measured in these particular areas and it is described in Section 8.

6.4 EXPOSURE SCENARIOS AND CRITICAL GROUPS

Exposure scenarios and critical groups considered in this study are very simple and straightforward since it involves only operation of the advanced materials processing plant using imported lanthanides concentrate from Western Australia, which is going to be brought in through Kuantan Port. The scenarios look at the whole operation of the plant starting from receipt of consignments of the lanthanides concentrate in containers at the Kuantan Port to handling and storage of the residues generated from the process at identified locations within the plant site, and discharges of liquid effluents to the environment during normal operation of the plant. The first significant potential radiation exposure may come from a temporary storage of the lanthanide concentrate in container at the Kuantan Port after unloading from vessels, which may pose radiation exposure risk to the port workers.

The lanthanides concentrate will be transported in containers from Kuantan Port to the plant site using trucks. The next potential radiation exposure is to a worker unloading the lanthanide concentrate from container at the plant working near the stock piles. The lanthanide concentrate will be fed by loader to the cracking plant, which is expected to pose some radiation exposure to workers. The next stage, which is seen as potential to cause significant exposure to operation and maintenance workers, is during separation and neutralization process where the NORM is already segregated into residue in a similar concentration to the lanthanide concentrate. The residue streams will be transferred to a temporary storage on site using a truck and the radiation exposure of the truck driver and workers working at the residue storage cells will be assessed.

During normal operation, the plant is expected to discharge liquid and gaseous effluents into the environment after undergoing the necessary treatment processes which will ensure the residue streams meet the prevailing environmental regulatory discharge limits including those approved by AELB.

Exposure at the Port

When the Lanthanides Concentrate shipment reaches the Kuantan Port, it will be unloaded from the vessel and the containers stored temporarily. There are expected 20-50 consignments of containers per year. Since the material remains contained there will be no problem of exposure from airborne dusts, radon and thoron.

Exposure during Transportation

In this assessment, transportation of the lanthanide concentrate is assumed to start from the Kuantan port to a storage location with stockpiles within the premise of the plant. Transportation will be done by two semi-trailers, each hauling 20-ton containers. Lanthanide concentrate will be kept in wet or slightly moist form to minimize creation of dust during loading and unloading from the container. Unloading of the lanthanide concentrate from the containers to the storage location will be done by machine. The trailers will make six trips a day with each trip (to and from) taking about one hour.

The whole amount of lanthanide concentrate will be 65,000 tons per annum in 4000 containers, and is expected to be transported 6 days per week.

The drivers are expected to be exposed to external radiation from the lanthanide concentrate in the trucks or in the FEL. For the driver of the FEL, however, in addition to external radiation, he is also anticipated to receive additional radiation exposure from inhalation of airborne dust created as a result of loading operation. The trucks are expected to come back empty and with this situation, the exposure time of the drivers is actually half of the working time described above. More detail description of the exposure scenario is given in Table 6.1 and 6.2.

Radon and thoron daughters will not be considered in this scenario due to the fact that the operation is carried out in open space and dynamic air movement is considered enough to cause significant diffusion and dilution effect on whatever small concentration of these radionuclides present during the operation.

Exposure from stockpiles

At the plant site, the lanthanide concentrate is kept in a storage shed. The stockpile will comprise up to 5000 tonnes of the lanthanide concentrate which will be placed over an area of 20 meters by 50 meters within a building and the anticipated exposure to workers is, therefore, due solely to external radiation.

Operators will be working inside the building within the building, where concentrate bags are unloaded by forklift from sea container and emptied for stockpiling and blending.

There will also be involvement of a driver of a FEL to load the lanthanide concentrates material into a hopper, which will carry the material through a conveyance system to a roller mill.

Workers working at close distance (1 metre) to the lanthanide concentrate stockpile are expected to get external radiation exposure from the material heaps. Surveys carried out at similar situation in amang and other mineral processing plants indicate that radon and thoron daughters contribute to less than 11 percent of the annual dose limit received by the workers [17, 18].

Exposure from processing equipment

Once the lanthanide concentrate material is fed into the rotary kiln, there will be no further anticipation of internal exposure involved since the remaining operations will take place in closed environment. The exposure involved is only due to external radiation. There will be a number of workers who are assigned to monitor the operation of the plant, who will spend some time near equipment and piping containing TENORM. The detailed exposure scenario data for individuals working at respective location near processing equipment in the plant is shown in Table 6.1 and 6.2.

Exposure from the residue storage

The company plans to keep the radioactive residue generated from operation of the plant at an identified location on site. As described in Section 6.2, there will be three types of residues and they are kept separate in three adjacent locations on site. These residue storage cells will be designed to cater for residues generated for the first 10 years of plant operation. The residue tailings are planned to be transferred to the storage location by trucks and loaders. All the residues will be stored in cells that are progressively built and filled during the project. The FGD and NUF residues are expected to have negligible radioactivity.

The storage cells for the will have a dual liner system consisting of a clay layer and plastic layer to prevent migration and leakage of radionuclides into the environment. The residues are also going to be covered with special materials to minimize infiltration of rainwater into the residue materials and spread of the materials to the environment

The exposure scenarios considered in this assessment covered only the potential impact caused to the radiation workers working on the site at the tailings deposits. The only scenario identified is for depositing the WLP tailings to the designated site. The scenario was:

- WLP Scenario: In this scenario the potential exposures considered are to radiation workers working on-site the tailings deposit. The radiation workers were assumed to work on-site the residue deposit eight hours per day. The exposure pathway evaluated included external, inhalation and radon. The water supply was assumed from an unaffected off-site source and no possibility of ingestion pathways on-site.

For WLP scenario, the depositing of WLP residue will be conducted by dispersing the materials into the proposed residue storage facility (RSF) site with a thickness of 9 metres and area of 24000 m^2.

As for public scenario, the critical group will be the population living outside the plant boundary. The most likely pathways contribute to the estimated dose will be from drinking pathway and fish ingestion pathway. If any, the public will consume drinking water from well located off-site i.e. not from on-site. In addition to that the public will ingest fish from the river nearby.

In this public scenario, the model used for the public will be the worst-case scenario. The drinking water well modeled is assumed to be at the down gradient of the RSF but within the site, and the fish ingested will be from a pond (also assumed to be onsite) where dilution is not a possibility when compared to the river. Input parameters for these two pathways are shown in Table 6.3.

Exposure from Discharged gaseous and liquid effluents

Gaseous waste generated from the cracking process of the lanthanides lanthanide concentrate is passed through a scrubbing system for the removal of particulates, sulphur dioxide and sulphur trioxide, and discharged through a stack of 33.75 meter high. The amount of gaseous waste discharged is estimated to be 35,000 Nm^3/h.

Practically all of the particulates that are generated during the cracking process including those containing NORM are expected to be trapped in the scrubbing system. The cracking process used in the plant is also not anticipated to produce radioactive gases apart from radon and thoron gases which are initially trapped in the ore materials and are liberated during the cracking process. For the purpose of this study, the radon and thoron gases are assumed to be in equilibrium with their parents and their concentration are, therefore, taken to be the same as the concentration of the parents. The scrubbing system is also assumed to be ineffective for trapping the gases and practically all of them are assumed to be released through the stack.

In view of the fact that discharges of gaseous effluents is made at the point of 33.75 meters above the ground and is further supported by the existence of airflow at that height, it is expected that there will be dilution take place on the discharged gaseous effluents, which will make them significantly diluted upon reaching the ground. Due to this fact, it is not expected that gaseous effluents will cause significant exposure to members of the public.

Like gaseous effluents, all liquid waste streams arising from the plant operation will be treated in a wastewater treatment system to remove the contaminants including radionuclides before it is discharged into the environment at an average rate of 213 m^3/hr. The treated effluent will be monitored to ensure compliance to the Standard B discharge limits of the Environmental Quality (Industrial Effluents) Regulations 2009 and radiological discharge limit of 1 Bq/L for radium-226 and 1 Bq/L of radium-228 stipulated by AELB prior to discharge via a dedicated pipeline into Sg. Balok.

Process testwork conducted by the Company showed that the Ra226 and the Ra 228 concentrations in treated effluent were below the detection limit (< 0.5 Bq/l).

Since magnitude of the impact is very much dependent on the characteristic of the site, it is, therefore, very important to use as much as possible site-specific data in the assessment. The site for this study has been identified and its specific data have been gathered by a consultant engaged by the company. These data have been extended to Malaysian Nuclear Agency and were used in the assessment.

In this study, in view of that the capacity onsite for the storage of residue is only 10 years, the assessment will, therefore, be made for several span of time within the period. Assessments over a longer period beyond 10 years will not be looked at in this study because the residue streams are going to be in the RSF only as an interim measure as the Company has a plan to consider other alternatives for final disposal of the residues. This assessment is made based on available knowledge and data of the present environmental condition. Any global environmental changes taking place which may affect the condition of local or regional environment over the years for the next 10 years will not be taken into consideration.

Exposure from accidents or incidents

Design of the process and the plant itself has taken into consideration various technical and safety aspects to minimize chances for accidents or incidents to happen during normal operation of the plant. The company has engaged a risk assessment consultant to assess risk resulting from credible non-radiological accidents, which may arise from operation of the plant or from external sources that may affect safe operation of the plant.

The plant is also provided with various in-built safety features that will automatically be activated when any of the abnormal conditions is sensed to have occurred. The plant will either automatically or manually be shut down and all discharges of the effluents to the environment will be stopped. Therefore, it is deemed to be unlikely for TENORM materials to be immediately released to the environment when accident happened with the plant. It is due to these reasons that much more plausible radiological accident can be considered to happen during transportation of the TENORM materials i.e. transportation of the TENORM lanthanide concentrates from the Kuantan Port to the plant site and transportation of the NORM residue streams from the plant to temporary storage areas onsite. For the purpose of this study, the worst accident that can happen is, therefore, assumed to be a truck overturns when carrying TENORM concentrate or TENORM residues. As described in earlier parts of this Section, since transportation of the TENORM concentrate and TENORM residues is done with the materials are in wet form, therefore, the radiological risk involved is only due to external radiation. Estimation of the dose received resulting from such accidents is made using the same formula for exposure from stockpiles.

6.5 DOSIMETRY MODELLING AND IMPACT ANALYSIS

The model used in this study for assessing external radiation dose received by individual workers is taken from a similar model used by IAEA which, in turn, adopted from a standard guidelines initially developed by the United States Nuclear Regulatory Commission and recommendations made by Blizzard et al. It is developed based on the scenarios described in Section 6.3 for transportation of lanthanide concentrate and storage of residue. The exposure condition between the concentrate, which in this model, is regarded as a source of radiation, and the exposed subject is established according to the description given in the scenario. In calculating effective dose from external radiation during transport, the radiation source is represented by a half cylinder. Its arrangement and dimensions i.e. length (l) and radius (r) with respect to the dose receptor point which is taken in this study as 1 meter is shown in Figure 6.3. Detail dimension of the cylinder and the distance of the receptor point from the source for each exposure scenarios identified are given in Table 6.2. These figures are calculated by maintaining the same volume and length of the cylinder with the actual volume and length of the truck carrying the lanthanide concentrate. The effective dose from the half cylinder model is estimated by calculating the dose from a full cylinder divided by two. For a FEL during loading, the radiation source is represented by a full cylinder.

A truckload of lanthanide concentrate is modelled as a 20 ton homogeneous volume source having a half cylinder geometrical shape with length of 900 cm and radius of 60 cm. Throughout the operation, the drivers are assumed to be present at an average distance of 1 meter from the source. The trucks are expected to come back empty, and, therefore, the exposure time considered is only half of the effective working time of the drivers in a day. The effective dose received by all these personnel is calculated using the same Equation (4) described in this section.

For external exposure of the FEL driver, the source is modelled as a full cylinder or a cylindrical volume source with length of 280 cm and radius of 40 cm. The average distance of the loader from the side at half of the height of the cylinder source is 2 meters and Equation (5) is used to calculate the effective dose received in a year.

Loaders working in the warehouse and at the stockpile on site will be receiving dose from external radiation and inhalation of airborne particulates generated from loading of the lanthanide concentrates into the trucks at the Kuantan Port and into the hopper at the plant site.

Since the nature of the source and the actual distribution of radionuclides in the source are not known, as recommended in most of the modelling for external radiation exposure, the sources considered in this model are also represented by a self-absorbing, homogeneous, volume source. However, unlike modelling of certain exposure situations, external absorbers and shields are not considered in this model because with such arrangement, it will make the model more realistic to the actual situation and this approach, in general, tends to maximize the estimated dose equivalent obtained.

Based on this model and the exposure scenario described above, the general equation used for estimating the effective dose equivalent received by the workers from external radiation during transport of the lanthanide concentrates can be written as follows:

$$H_{EXT,j,s} = 1.24 \times 10^{-9}\ C_j\ B\ G_s\ W\ P\ t\ \sum_i \frac{f_i E_i}{\mu_{mi}} \quad (1)$$

With

$$DF_{EXT,j,s} = 1.24 \times 10^{-9}\ B\ G_s \sum_i \frac{f_i E_i}{\mu_{mi}} \quad (2)$$

and

$$G_s = [(1 - \cos\theta_1) + (1 - \cos\theta_2)]/8 \quad (3)$$

$$= 0.5 \text{ for an infinite volume source,}$$

Equation (1) then becomes

$$H_{EXT,j,s} = C_j\ DF_{EXT,j,s}\ W\ P\ t \quad (4)$$

In all of the equations above,

$H_{EXT,j,s}$ is the effective dose equivalent from one year's external exposure to radionuclide j in source scenario s (Sv/y);

t is the duration of exposure for the worker in the scenario assessment time of one year (hr/y);

C_j is the initial concentration of radionuclide j in the ore materials being transported (Bq/g)

$DF_{EXT,j,s}$ is the effective dose equivalent from external exposure to radionuclide j in source scenario s (Sv/hr per Bq/g) (calculated from Equation (2));

W materials handled by workers divided by the quantity of all materials handled by workers in a year taken to be 100% or 1.0 for this assessment);

P is the number of workers exposed (P= 1 for maximum Individual dose calculation);

B is the buildup factor for the material concerned (ores or steel);

G_s is the geometrical factor reflecting the solid angle at the receptor point for the source of scenario s, and calculated using Equation (3);

f_i is the fractional abundance of gamma photon of energy E_i MeV; and

μ_{mi} is the mass attenuation coefficient of the ore materials for gamma photon of energy E_i (cm^2/g).

The build-up factor B allows for multiple scattering of gamma rays occurring within the source material itself, which in effect increases the photon flux density over that computed from the simple geometry and photon energy. The value of B is a complex function of the source geometry and photon energy. For any geometry of the source within one mean free path, B can be shown to lie in the range of 1.3 to 3.5 for iron, concrete, soil and uranium ore with energies in the range of 0.1 to 3 MeV. An average B value of 1.0 - 2.0 are judged to be sufficiently conservative for ores with all photon energies from decay products of uranium and thorium considered in this study.

The equation used for estimating the effective dose from cylindrical volume sources excavator to the loader during loading is described by Equation (5).

At P_2, $$\Phi = \frac{B\, C_s\, R\, \rho}{2\pi} \sum_i f_i\, G(k, p, \mu_i R) \qquad (5)$$

where B and C_s are described above, $k = h/2R$, $p = b/R$ and the summation extends over all gamma transition of a given radioisotopes. Φ is the photon flux density (photons.cm^{-2} s^{-1}). The function G for various k, p and $\mu_i R$ values are plotted in Figure 6.4. The dimensional variables R, h, and b are described in Figure 6.3.

This position corresponds to that of the excavator's driver carrying a load of ores. The cylindrical excavator is radius 40 cm while the length 280 cm.

At P_3, $$\Phi = \frac{B\, C_s\, R\, \rho}{2\pi} \sum_i f_i\, G(k', p, \mu_i R) \qquad (6)$$

where k' = h/R, p = b/R. This equation is similar to that for P_2, above except that in the function G, k = h/2R. This position correspond s to that of the worker in process column at the plant working in the vicinity of cylindrical volume sources.

The equation (7) used for estimating the committed dose from inhalation received by the workers during loading and levelling as described in the scenarios for identified radionuclides is given as follows where contribution from both airborne contamination and resuspension of contaminant from surface contamination are considered:

$$H_{INH,j} = V\, t\, DF_{INH,j}\, W\, (\, C_d\, C_{w,j} + C_{s,j}\, RF\ \ TF_{INH}\,) \qquad (7)$$

Where:

$H_{INH,j}$ is the committed effective dose equivalent from one year's intake of radionuclide j by inhalation (Sv);

V is the breathing rate of the worker (m^3/hr) (= 1.2 m^3/hr from ICRP 23 ;

t is the duration of exposure for the worker (hr);

$DF_{INH,j}$ is the committed effective dose from inhalation of 1 Bq of radionuclide j (Sv/Bq)(taken from IAEA Report as given in Table 6.4 for this assessment);

W is the fraction of the ore materials handled by the workers which is being transported (taken to be 100% or 1.0 in this assessment);

C_d is the concentration of respirable dust in air (g/m^3); and

$C_{w,j}$ is the non-diluted concentration of radionuclide j in the ore materials being transported (Bq/g))(taken to be 1.0 Bq/g in this assessment).

$C_{s,j}$ is the concentration of radionuclide j present as surface contamination (Bq/cm^2) (taken to be 1 Bq/cm^2 or 10^{-4} Bq/m^2 in this assessment);

RF is the resuspension factor for surface activity (m^{-1}); and

TF_{INH} is the transfer factor for the inhalation of surface activity; the fraction of surface contamination available for resuspension (taken to be 1% or 0.01 in this assessment).

The concentration of respirable dust in air in populated areas used by UNSCEAR is about 10^{-4} g/m^3 and in ambient air within and outside work areas recommended by WHO is 5 - 9 x 10^{-4} g/m^3 and 1.5 x 10^{-4} g/m^3 respectively. These figures are found to be consistent with results of the measurements made at some partially operated mineral processing plants in Malaysia which indicate acceptable level of such suspended dust in the order of 4 x 10^{-4} g/m^3. However, the loading and unloading of loose mineral material from the trucks has the potential to create a slightly more dusty environment than the situations that can be found in most of the mineral processing plants, and, therefore, in this study, the respirable dust concentration in air is assumed to be slightly higher in the order of 5 x 10^{-4} g/m^3. This figure is similar to the figure used by IAEA in its guidelines on recycling and reuse of contaminated materials.

The probability of deposition of inhaled airborne dust in the various parts of the respiratory tract and the subsequent metabolism of radionuclides it contained are dependent upon particle size. Measurements carried out around dusty plant operation indicate that the airborne particulate generated varied in size from 2 μm to 10 μm with an average result around 5 μm. Therefore, in this study, the size of respirable dust involved is assumed to be 5 μm.

The relationship between surface contamination and the concentration of contaminant in air depends on the surface, the form of the contaminant, the way the surface is disturbed and the amount and pattern of the ventilation of the work areas. It is usually described by a resuspension factor having units of length^{-1}. For most of the areas, the resuspension factors have been determined by experiments and the results were found to vary around 10^{-6} m^{-1} with a few of them indicate higher values up to 10^{-3} m^{-1}. These results relate to the average surface contamination over substantial areas, several square meters at least, and there was some evidence that when the contamination was restricted to small areas, resuspension factors become very much lower. In general, the higher figures were associated with surfaces such as ores, from which dust is readily resuspended. In this assessment, resuspension factor is assumed as 10^{-6} m^{-1}.

For semi infinite space infinite source,

$$\Phi = \frac{B\, C_s}{2} \sum_i f_i / \mu_{mi} \qquad (8)$$

where B, Cs, f , $\mu_{mi,}$ and Φ are described in the preceding equations and the summation extends over all gamma transition of a given radioisotope. This formula is to estimate the dose received by workers from a heap of lanthanide concentrates in the Kuantan warehouse and stockpile site.

For exposure to a given radioisotope, the effective dose to the worker or receptor is proportional to the photon flux density at the receptor location. The following relationship:

$$H = 1.38 \times 10^{-8} \ \Phi E \ (Sv/h) \qquad (9)$$

The value of E for a given radioisotope is: $E = \Sigma f_i E_i$

where, Ei = gamma energy of transition i (MeV);
f_i = fractional abundance of transition i,

Annual occupational dose is given by the product of the effective dose rate H (Sv/h) and the total occupational exposure time per year in hours.

The assessment of ground level radon and thoron concentration from stack discharges received by the public is based on IAEA Safety Report [29]. The model for atmospheric dispersion can be represented by

$$C_A = P_p F Q_i / u_a$$

where

C_A is the ground level concentration at downwind distance *x* (Bq/m^3) (assuming *x* = 1 km)

P_p is the fraction of time during the year that the wind blows towards the receptor of interest (assuming $P_p = 1$)

F is the Gaussian diffusion factor appropriate for the height of release (50m) and the downwind distance being considered (m^{-2})

Q_i is the annual average discharge rate for radionuclide *i* (Bq/s)

u_a is the geometric mean of the wind speed at the height release representative of one year (m/s)

For the purpose of this study, the radon and thoron gases are assumed to be in equilibrium with their parents and their concentration are, therefore, taken to be the same as the concentration of the parents. The scrubbing system used is also assumed to be ineffective for trapping the gases and practically all of them are assumed to be released through the stack.

Analysis of exposure to be received by members of the public from uranium, thorium and their decay products contained in the liquid waste effluents and solid residue depends very much on ability of each individual radionuclides contained in the residues to release itself, leaches out and migrates from the place where the residues were originally disposed off and enters human domain. The solution and migration of these radionuclides in natural environment depends on numerous factors, the most important of which are the quality of the water that comes into direct contact with them namely the pH, Eh, presence of complexing and precipitating agents, availability of the elements in the soils traversed by the waters, nature of the ground water system and climatic factors. Because of such complexity of the environmental processes taking place to transfer and transport the radionuclides in the environment, it is, thus, very important, in making an assessment of radiological impact, to use site-specific data in order to get a very realistic estimate of the dose received.

Site specific data are, however, not readily available for most of the study areas in Malaysia. Thus, default parameters and data sets obtained from established literatures have to be used in some parts of the assessment. These default values are obtained from generic data sets recommended internationally and they have been designed to give conservative dose overestimate.

Dosimetric models were established based on the workers and exposure scenarios identified. The radiological impact caused on critical groups working on-site (radiation workers) and public living off-site as a result of depositing the residue at RSF site was analysed using RESRAD 6.5, computer code developed by Argonne National Laboratories (ANL), USA [30-31]. The exposure pathways considered in RESRAD is shown in Figure 6.5 and 6.6.

Inputs to the code were mostly based on information provided by the Company and site-specific data. Any unavailable local data was adopted from default figures recommended by the RESRAD, which, in most cases, were found to be very conservative. Details of these input data for workers are shown in Table 6.5. Analysis was conducted on the WLP residue with dimension of 24000 m^2 and height of 9 metres. As for public scenario, the critical group will be the population living off-site the proposed tailing storage facility. Input parameters are shown in Table 6.3.

Importantly it is a conservative assumption that the WLP residue is placed in an open area and in an uncontained stockpile on the ground at the operating site. The model assumes the residue is not covered and stormwater infiltrates into the residue and leaches through the soil stratums below.

6.6 RESULTS OF THE ANALYSIS

The models used in this study for assessing radiation dose received by identified individual workers are summarized in Table 6.2. Results of the analysis are given in Table 6.6 and they are given in summarized form in Table 6.7. Results of estimated individual annual doses for the driver, loader and all workers working in the process areas of the plant (neutralizing, filtering, purification, leaching) are found to vary between 3.04 x 10^{-2} mSv/y to 12.68 mSv/y. They are below the dose constraint of 20 mSv/y, which are well below the dose limits allowed for workers by the Radiation Protection (Basic Safety Standard) Regulations 1988 [4]. Most of the doses received are due to external radiation. The highest estimated dose of 12.68 mSv/y is expected to be received by worker working near the lanthanide concentrate stockpile and feed bin. The estimated collective doses for each type of work are also found to be below the criteria of 1 man.Sv used in the assessment.

Results of the analysis carried out for anticipated accident involving a truck carrying TENORM concentrate or TENORM residues indicate that the estimated dose rate involved is about 0.01 mSv/h at distance of about 1 meter from the materials. If cleaning work requires a single person to spend 5 hours, the estimated total dose received is still very small i.e. 0.05 mSv.

Based on the input given by the company and assumption made in section 6.5 for atmospheric dispersion modelling, the calculated dose to members of the public from stack discharge (radon and thoron) at I km distance were very low i.e. 0.02 µSv/y and 2 µSv/y year respectively.

Result of the RESRAD analysis for the WLP scenario is shown in Table 6.8. It is clear from this table that the maximum total doses expected to be received by the critical groups working on-site (radiation workers) as a result of depositing the WLP residue is 4.34 mSv/y. For WLP residue, the main pathway contribute to the dose are from external (97%). This estimated annual dose is found to be below the dose limit used in the assessment as suggested by the AELB i.e. 20 mSv/y.

Results of the RESRAD analysis for the public scenario namely WLP is shown in Table 6.9. Their graphic presentations are shown in Figure 6.7- 6.8. It is clear from these figures that along the life span of the project there will be no dose incur to the public living off site by drinking water and fish ingestion pathways. The total estimated dose would arise about after the year 1000 after all the WLP residue has been deposited to the RSF. The maximum doses are 6.23 mSv/y for WLP at the year 1558. The estimated dose limit of 1 mSv/y for public is at year 1225 and this dose is conservative because the model used the drinking water pathway from well located at the down gradient of the WLP site and the fish ingestion is from the pond (i.e. not river). The main pathway that contributes to the doses is the fish ingestion pathway. In order for the estimated dose not to exceed the dose limit, preventing the leaching of radionuclides through the soil is the best available method during the operational phase of the plant. The design of the storage cells includes a dual liner system comprising a plastic liner and clay layer to prevent leaching of radionuclides.

6.7 SENSITIVITY ANALYSIS

The estimated total dose received by the critical groups is a function of many variables. In the assessment, the input parameter values were selected based on the best available data obtained from the site.

Some default or estimated input values were used in this assessment since not all of the input values were site specific. These default values were assessed and chosen to be the most realistic to the condition of the site. However, as a normal practice in any impact assessment, the values chosen in such a way that use of these values in any situation would not result in under estimation of the dose being evaluated (slightly conservative).

The input parameters values that have contributed to significant change to the overall dose estimated in the analysis (e.g. WLP) are the indoor time fraction and fish consumption.

When the indoor time fraction (0.33) was subjected to an increase by a factor 1.5 i.e. within range values of the time fraction (0 to 0.5), the total doses obtained was increased by 54 %, whereas, a decrease by a factor of 1.5, resulting in a decrease in total doses by 35 %.

When the fish consumption (50 kg/y) was subjected to an increase by a factor 2, the total doses obtained was increase by 64 %, whereas, a decrease by a factor 2, resulting in a decrease in total dose by 27 %.

The preceding analysis indicates that any major changes made with the input parameters values used in this assessment would result in changes to the estimated dose calculated.

From the sensitivity analyses done to the critical parameters, the maximum dose received is still below the dose limit i.e. 20 mSv/y.

Transportation of Lanthanide Concentrate from Kuantan Port to the plant site will be done using trucks. All requirements of Radiation Protection (Transport) Regulations 1989 [5] will be complied with to ensure that the ore materials can be transported safely. The Regulations allow for the concentrate materials, which are classified as LSA Class-I, to be transported without any container under exclusive use and the radiation level on the surface of the truck is allowed to not more than 10 mSv/h.

A radiation protection programme will be established to ensure that activities carried out during normal operation of the plant will be done in a safe manner, with full compliance of the requirements of the Radiation Protection (Basic Safety Standard) Regulations 1988 [4] and with full subscription of the ALARA principle. This programme will include establishment of individual programme to cater for environmental monitoring, workplace monitoring, personnel monitoring, provision of safety and protection equipment, provision of appropriate and adequate measuring instruments, provision of necessary standard procedures and record keeping, training of personnel involved and necessary medical surveillance of personnel involved.

The concept of residue minimization has been taken into consideration and adopted for this project. The plant has been designed with the highest achievable efficiency and the most optimum performance that can be sustained throughout its operational life. It has been designed with minimum generation of residue resulting from routine maintenance. The processes involved have been designed such that some parts of the liquid effluents will be treated and recycled back into the process line.

In mitigation against the release of potentially contaminated liquid and gaseous effluents, the Company will employ the necessary technological means to render these emissions harmless to the receiving environment, in compliance to the prevailing regulatory requirements including those enforced by AELB. Details of the non-radiological pollution control systems proposed for the plant are deliberated in the Environmental Impact Assessment prepared for the project. Basically it consists of a scrubbing system that can practically trap and remove all particulates and non-radioactive gases and a 33.75 meter high stack through which the gaseous effluents will be released. The immediate environment around the plant will be monitored periodically to ensure that any release of the radioactive effluents will remained within the permissible limits.

For the solid residues generated, suitable alternatives are being considered by the Company as an alternative approach to long-term storage of the residue. Potential reuses of these solid residues (or by-products) are being explored and these options have been considered in a study prepared by the Company in conjunction with Worley Parsons Services Pty Ltd. Salient findings of this study are highlighted below:

- The FGD residue which consists predominantly of gypsum may be sold to the Malaysia plasterboard industry or the cement industry.
- The Company is assessing the possibility of using dolocrete which chemically bonds to the WLP residue to form a stable and inert matrix that can be used for the construction of *in-situ* concrete piles for future building within the site.
- The NUF material contains gypsum and magnesium and has potential application as a fertilizer or in the manufacture of cement or construction materials.

An emergency plan will be established with due recognition given on all possible accidents or incidents that can happen with the operation of the plant to ensure that immediate response action will be taken in timely manner to mitigate the consequences resulting from any of such accidents or incidents. The plan will be reviewed, maintained and tested regularly to ensure that it remains effective, relevant and implementable.

The company realises that the plant need to be decommissioned once it has decided that its operation is permanently ceased. The Company has taken into consideration the financial and radiological implication resulting from such decommissioning project. A decommissioning concept will be prepared to highlight the various options that can be taken to proceed with the decommissioning project. A decommissioning plan will be prepared based on the standard requirements stipulated in the Guidelines issued by AELB [2].

8. RESIDUAL IMPACTS

The radiological impact caused by operation of the plant has been described in Section 6. Results of the assessment indicate that the impact caused is acceptable, the estimated doses received by workers resulting from operation of the plant are less than 13 mSv/y, which are well below the annual exposure limits allowed by AELB. The estimated doses to members of the public is 0 mSv/y, which is below the annual exposure limit of 1 mSv/y. Considering that members of the public generally receive about 2 mSv/y from various background sources in the environment [24] and workers risk to occupational exposure is considered acceptable up to the exposure level of 20 mSv/y [22], it is concluded, that the doses received by workers and members of the public from operation of the plant, would not lead to any significant residual impacts.

It is expected that during the operational period (20 years) of the plant, the various anticipated exposures involved would be under adequate control with management, handling and process of TENORM concentrate and handling of TENORM residue are done in a manner that meets the standard requirements of the prevailing regulations and guidelines enforced by AELB. This situation is further ensured by establishment and implementation of mitigation measures described in Section 7. However, the situation is expected to change after the plant ceases operation. At this time, it is expected that there will be no further radiological impact caused by operation of the plant, but the presence of TENORM residue onsite, due to their radiological nature, may potentially impact people living in areas close to the plant. The assessment carried out in Section 6 indicates that if the residue remained in their present form assumed in this study for long-term storage, it is expected that there will be a period of about 1500 years from now when members of the public may get doses as high as 6.23 mSv/y from the residue. This does would be received by the ingestion of fish caught from the hypothetical pond located on the site.

The company has a plan to carry out a proper decontamination and decommissioning (D&D) plan at the end of operational life of the plant and also to arrange for a proper and safe disposal of the residue that can ensure that the residue materials will be isolated from human population over a very long period of time.

9. MONITORING PROGRAMME

An environmental monitoring programme has been established to capture and record environmental data of the site. It is planned to be carried out in two phases, that is, during pre-operational and operational period. The pre-operational environmental monitoring is done in partial fulfilment of the requirements of the checklist for Class A Licence (Milling) [2] and for the establishment of baseline data for future reference of the performance of the plant.

Monitoring stations have been identified during earlier site visits and they are located around the site with more attention is given in the downwind and downstream direction from the site. The program includes monitoring of external radiation, airborne particulates, soil, surface water, flora, ground water and river water and sediment. Samples are taken at the monitoring stations on monthly basis. The monitoring programme includes analyses of radium-226 and radium-228 concentrations using gamma spectrometers and uranium-238 and thorium-232 using neutron activation analysis or equivalent method. Radon and thoron progenies are also measured using continuous working level monitors. The instrument that may be used to measure radon and thoron progenies is alpha dosimeter manufactured by AlphaNuclear. Background radiation levels are measured using thermoluminescent dosimeter (TLD) chips, which are also done on monthly basis.

The pre-operational radiological monitoring of the environment around the proposed plant site was carried out from February 2008 – April 2009. The monitoring program includes sampling and analysis of radioactivity in soil, surface water, ground water, flora, sediment and airborne particulates. External background radiation and radon/thoron progenies in air were also measured.

The monitoring showed that the mean concentrations of Ra-226 and Ra-228 in soil samples at proposed plant site were 26 ± 8 Bq/kg and 64 ± 41 Bq/kg respectively whereas at offsite stations were 32 ± 14 Bq/kg and 69 ± 50 Bq/kg respectively. For sediment samples, the mean concentration of Ra-226 and Ra-228 were 41 ± 12 Bq/kg and 68 ± 29 Bq/kg respectively. The radium concentrations in water and airborne particulates samples were mostly below minimum detectable activities. The mean concentrations of Ra-226 and Ra-228 in flora (grass/lalang/fern) sample at onsite stations were 14 ± 14 Bq/kg and 43 ± 29 Bq/kg respectively whereas the mean concentrations at offsite stations were 25 ± 27 Bq/kg and 98 ± 160 Bq/kg respectively. Fern samples contained higher radium concentration compared to grass/lalang.

The mean concentrations of radon progenies in air at proposed plant site and offsite stations were 2.2 ± 1.9 Bq/m^3 and 1.9 ± 1.9 Bq/m^3 respectively while the mean concentrations of thoron progenies at onsite and offsite stations were 0.48 ± 0.42 Bq/m^3 and 0.32 ± 0.35 Bq/m^3 respectively. The mean background radiation levels at onsite and offsite stations were both 0.04 ± 0.01 mSv/month (equivalent to absorbed dose rate of 78 nGy/h).

The monitoring showed that the radium concentration in soil, external background radiation level, radon and thoron progenies concentrations in air were comparable with the value measured for Peninsular Malaysia.

The operational environmental monitoring programme will be submitted to AELB for approval prior to its implementation. The operational environmental monitoring programme will become part of the overall radiation protection programme to be developed by the Company to meet the requirements of the Radiation Protection (Basic Safety Standard) Regulations 1988 [4].

In addition to environmental monitoring, a similar programme will also be established for workplace monitoring and personnel monitoring, which will also become part of the overall radiation protection programme developed for the plant. The whole of radiation protection programme, which include workplace monitoring, personnel monitoring and the operational environmental monitoring programme will be established and presented to AELB for approval as soon as construction of the plant is completed and the facility is ready for full operation.

10. CONCLUSION

The results of the assessment have indicated that operation of the plant would not cause undue radiological risk to workers and members of the public.

The highest possible doses to be received by workers resulting from operation of the plant for the first 10 years are below 13 mSv per year. The possible dose to be received by members of the public resulting from operation of the plant is 0 mSv per year.

These estimated doses are well below the annual dose limits allowed for workers and members of the public by the Radiation Protection (Basic Safety Standard) Regulations of 1988.

There are residues generated from the process, and one of the streams appears to be slightly enhanced in term of concentration of TENORM, but the method adopted to keep them during the entire operational period of the plant has proved that the resulting doses to workers and members of the public are within the permissible annual dose limit.

Based on the results of the radiological impact assessment, it is concluded that operation of the plant would not caused any radiological risk to the workers and members of the public living in the surrounding areas of the site beyond what is allowed by the regulatory authority.

11. RECOMMENDATIONS

Based on the results and the conclusion of the radiological impact assessment, it is recommended that:

a. the proposal for the plant operation at the identified site in Gebeng, Kuantan, Pahang be given due consideration by the regulatory authority .

b. the assessment is to be revised again when more operational data are available to ensure that the estimated doses obtained in this assessment are further refined and the conclusion derived from this assessment is indeed realistic and acceptable.

c. the input data and information to be updated and finalised, in particular, the radioactivity content of the lanthanide concentrate materials and WLP residue and water discharges.

d. final and permanent disposal of the NORM contaminated residue streams generated to be looked at and analysed and a decision and proper planning is made to solve their problem.