Lynas Kalgoorlie Pty Ltd

Lynas Rare Earths Ltd

Lynas Kalgoorlie Rare Earths Processing Facility

Radiation Impact Assessment

Revision 7

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TERMINOLOGY, DEFINITIONS AND ABBREVIATIONS

Term	Definition
AELB	Atomic Energy Licensing Board
ALARA	As Low As Reasonably Achievable
AMAD	Activity Median Aerodynamic Diameter
ANSTO	Australian Nuclear Science and Technology Organisation
ANZECC	Australian and New Zealand Environment and Conservation Council
ARPANSA	Australian Radiation Protection and Nuclear Safety Agency
ASLP	Australian Standard Leaching Procedure
Bq/g	Becquerels per gram
BOM	Bureau of Meteorology
BSF	By-Product Storage Facility
DWER	Department of Water and Environmental Regulation
DMIRS	Department of Mines, Industry Regulation and Safety
EPA	Environmental Protection Authority
EPBC	Environment Protection and Biodiversity Conservation
ERICA	Environmental Risk from Ionising Contaminants: Assessment
ERMP	Environmental Radiation Monitoring Program
HDPE	High-density Polyethylene
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LAMP	Lynas Advanced Materials Plant
Lynas	Lynas Kalgoorlie Pty Ltd
MDL	Minimum Detectable Limit
MSIA	Mines Safety and Inspection Act 1994
NORM	Naturally Occurring Radioactive Material
OEMP	Occupational Exposure Monitoring Program
OSL	Optically Stimulated Luminescence
ppm	Parts per million
RBA	Radionuclide Balance Analysis
RE	Rare Earth
REPF	Rare Earths Processing Facility
RHC	Radiation Health Committee
RIA	Radiation Impact Assessment
RMP	Radiation Management Plan
RO	Reverse Osmosis
RSA	Radiation Safety Act 1975

Term	Definition
RSO	Radiation Safety Officer
RWMP	Radioactive Waste Management Plan
SVO	Surface Ventilation Officer
TLD	Thermo-luminescence Dosimeters
TSP	Total Suspended Particulate
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
WESP	Wet Electrostatic Precipitator

1 INTRODUCTION

1.1 Report Purpose

Lynas Kalgoorlie Pty Ltd (Lynas), a wholly owned subsidiary of Lynas Rare Earths Ltd, proposes to construct and operate a Rare Earths Processing Facility (REPF) at 70 Johns Road, Yilkari, near the town of Kalgoorlie (formerly Lot 500, Great Eastern Highway, Yilkari, and referred to within this document as Lot 500), and an associated permanent off-site By-product Storage Facility (BSF) on Common Reserve 8767, Yarri Road, Parkeston (Yarri Road) in the City of Kalgoorlie-Boulder (Figure 1). The REPF will further separate and concentrate the Mt Weld RE concentrate to produce an RE carbonate, which will be exported to the Lynas downstream production facilities, including the Lynas Advanced Materials Plant (LAMP) located in Kuantan, Malaysia, and a proposed facility in Texas, USA, via Fremantle port in Western Australia.

The RE concentrate and iron phosphate by-product contain naturally occurring radioactive material (NORM) at concentrations exceeding the recognised level for radioactive classification.

The purpose of this Radiation Impact Assessment (RIA) is to assess the radiological impact from the Kalgoorlie REPF and BSF to workers, members of the public and the environment.

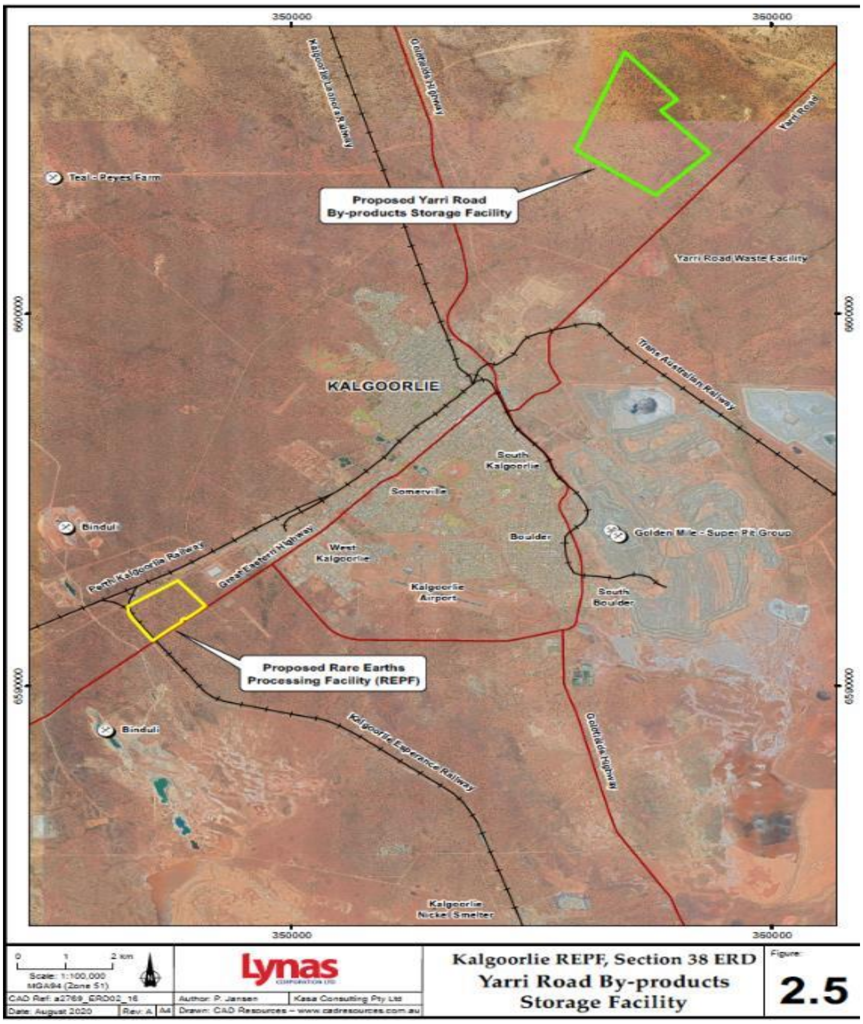

Figure 1. Regional Site Location

2 RADIATION PROTECTION OVERVIEW

This document assumes the reader possesses a basic understanding of the principles of radiation protection. A brief overview of key aspects of radiation and radiation protection are outlined below to provide context for the radiation impact assessment.

2.1 Radiation Overview

All matter is comprised from atoms consisting of protons, neutrons and electrons. Some atoms are unstable as they contain excess energy that they will seek to release. These atoms (called isotopes) will pursue a lower energy state by emitting radiation (called radioactive transformation or decay) in the form of alpha or beta particles or gamma rays. The radioactivity associated with each radioactive isotope is usually classified in accordance with the rate at which decay occurs and the type of radiation emitted.

When an isotope undergoes radioactive decay, it changes into either a new element or a different isotope of the same element, which is known as a decay product. The process of radioactive decay will continue until a stable and non-radioactive isotope is formed. The individual decay products are known as radionuclides and the sequence of radioactive decay constitutes the decay chain.

The primary natural decay chains of relevance to mining and mineral processing are ^{238}U and ^{232}Th. Appendix A shows the respective decay chains including the stages of decay, types of radiation emitted and the half-lives of each radioisotope.

2.2 Radiation Exposure Types

Three main types of radiation associated with mining and mineral processing are alpha (α), beta (β) and gamma (γ) radiation.

Alpha-radiation is considered a hazard if its source is located inside the body, highlighting an internal radiation risk. In mining and mineral processing, the main way in which the source can get into the body is when it is breathed in as dust (inhalation). Small amounts may be taken in through the mouth (ingestion), but this material is typically disposed from the body by excretion.

Dust that is inhaled could stay in the lungs for long periods. If the dust contains alpha-emitters, the lungs will be subject to a certain dose of alpha-radiation. Other sources of internal alpha-radiation within the body are decay products of radon (^{222}Rn) and thoron (^{220}Rn), radioactive gases in the decay chains of uranium and thorium.

Beta-radiation mainly affects skin and the tissue that lies immediately underneath the skin.

Sources of gamma-radiation could cause radiation damage without residing within the body. A person located near any radioactive material, which emits gamma-radiation, will be subject to a certain radiation dose. Gamma radiation affects skin, deep tissue and organs depending on the dose received. Beta and gamma radiation both present an external radiation risk.

2.3 Background Radiation

Naturally occurring background radiation is the ionising radiation within the environment that people are continuously exposed to. Soils, water, air and cosmic radiation all contribute to natural ionising background radiation that is highly variable dependent on geographic location.

Background radiation varies globally from 1-13 mSv per year dependent on exposure to naturally occurring radiation (i.e., higher altitude, distance from equator, geological formations, etc.). *Australian Radiation Protection and Nuclear Safety Agency* (ARPANSA) estimates the average natural background radiation in Australia is approximately 1.5 mSv/year.

2.4 Radiation Protection Framework

Radiation protection is generally legislated at a state level through adoption of publications from national and international organisations who specialise in radiation protection.

Radiation protection is administered through adherence to the as low as reasonably achievable (ALARA) principle which requires radiation doses be maintained “as low as reasonably achievable” with consideration of social and economic factors.

The framework of radiation protection is presented in Figure 2 below.

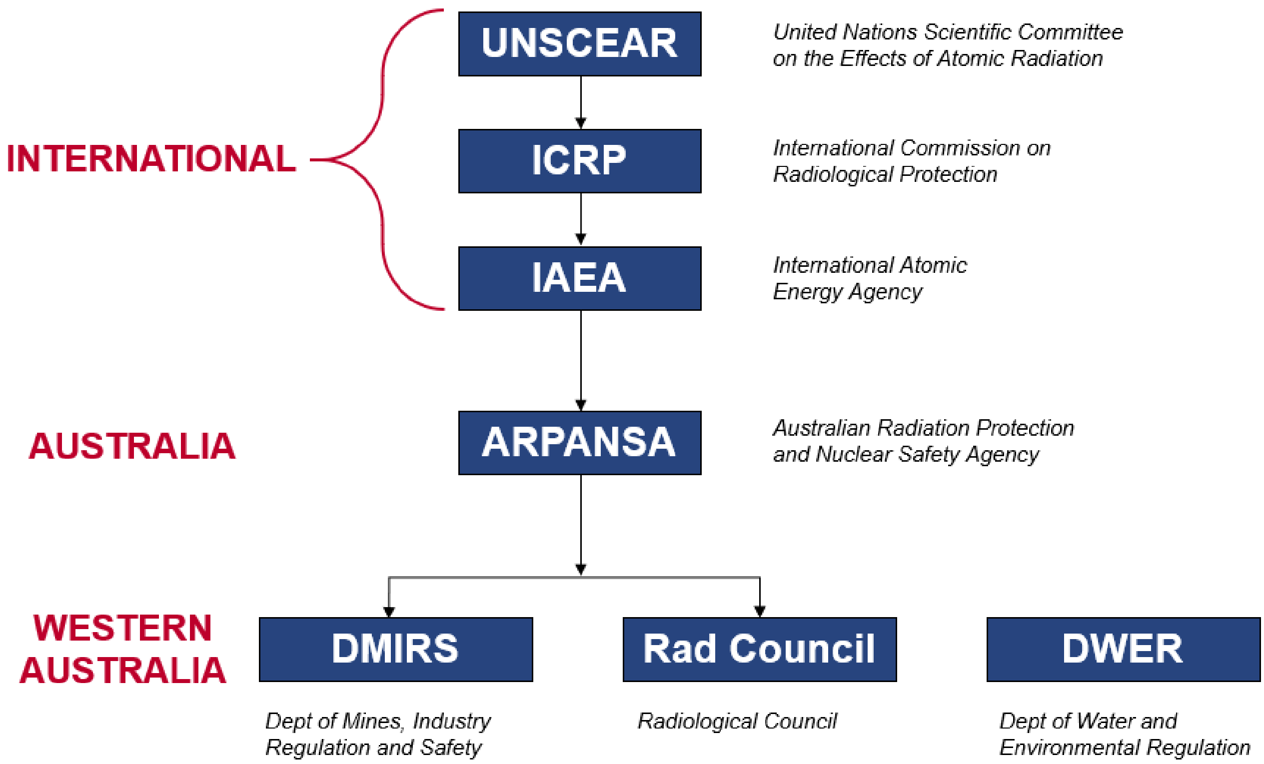

Figure 2. Radiation Protection Regulatory Framework

2.4.1 International Approach

Ionising radiation (containing sufficient energy to break chemical bonds between atoms in molecules) has been studied for 120 years and is utilised extensively in industry and medicine. The preeminent international organisations that oversee radiation protection and provide safety guidance material are:

- The *United Nations Scientific Committee on the Effects of Atomic Radiation* (UNSCEAR) collects, evaluates and provides summaries of research into the effects of radiation on human beings and the environment. UNSCEAR publications are regarded as the most comprehensive source of scientific information for radiation protection.
- The *International Commission on Radiological Protection* (ICRP) provides guidance on matters of radiological protection concerning ionising radiation by developing and publishing radiological protection recommendations and guidelines.
- The *International Atomic Energy Agency* (IAEA) publishes targeted safety standards and codes of practice for the safe use of ionising radiation within industries such as mining and mineral processing.

2.4.2 Australian National Approach

Radiation protection in Australia is regulated at a state and territory level. ARPANSA is the national authority on radiation protection which only possess direct jurisdiction over Commonwealth entities. The *Radiation Health Committee* (RHC) is a branch within ARPANSA which prepares national policies, codes of practice and standards for adoption by states and territories based on IAEA and ICRP publications.

The primary publications relating to radiation protection for the mining or mineral processing of radioactive materials are:

- RPS C-1 (Rev. 1) Code for Radiation Protection in Planned Exposure Situations (2020)
- RPS C-2 (Rev. 1) Code for the Safe Transport of Radioactive Material (2019)
- RPS 9 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)

2.4.3 Western Australian Approach

In Western Australia, regulation of radiation protection is through the following legislative articles:

- *Radiation Safety Act 1975* (RSA)
  - *Radiation Safety (General) Regulations 1983*
  - *Radiation Safety (Qualifications) Regulations 1980*
  - *Radiation Safety (Transport of Radioactive Substances) Regulations 2002*
- *Mines Safety and Inspection Act 1994* (MSIA)
  - *Mines Safety and Inspection Regulations 1995* (MSI Regulations)

While the ALARA principle guides the approach to maintaining radiation protection, radiation dose limits established in IAEA (2014) and adopted in Western Australia provide structural protection from radiation exposures. The dose limits apply to the sum of all radiation exposure pathways and do not take background radiation into consideration. The IAEA dose limits have been adopted under the RSA which are:

Radiation workers:

- Maximum effective dose of 20 mSv per year averaged over 5-year period.
- Maximum effective dose of 50 mSv in one-year pro rata over any period less than 12 months.

Non-radiation workers/members of the public:

- Maximum effective dose of 1 mSv per year averaged over 5 years.
- Maximum effective dose of 5 mSv per year in one year.

The DMIRS published NORM Guidelines 2010 are a series of explanatory documents outlining best practice and regulatory compliance for WA mining operations that involve NORM. The DMIRS is publishing an updated NORM-V Guideline in 2021 that will supersede NORM-5. Guidance from the NORM Guidelines has been used in the preparation of the radiation impact assessment.

2.4.4 Classification for Radioactive Material

The primary guidance for classification of radioactive material is given in ARPANSA RPS 9 (ARPANSA, 2005), which adopts recommendations set out in IAEA Safety Standards Series No. RS G-1.7 (Application of the Concepts of Exclusion, Exemption and Clearance). The assessment provided in RPS 9 states levels for NORM below 1 Bq/g head-of-chain activity for the uranium and thorium decay chains in secular equilibrium are considered inherently safe and are therefore exempt from regulation. ARPANSA (2020) has also reconfirmed the validity of the 1 Bq/g criterion.

The classification also applies for the combined activity if both decay chains are present. For the purpose of the radiation impact assessment, a material is considered radioactive if the sum of uranium (^{238}U) and thorium (^{232}Th) head-of-chain exceeds 1 Bq/g.

3 PROJECT OVERVIEW

Lynas is intending to process lanthanide RE concentrate from its Mt Weld concentrator at the proposed REPF in Kalgoorlie. A solid RE carbonate material will be produced that will be packaged, transported to Fremantle and exported to Lynas Advanced Materials Plant (LAMP) located in Kuantan, Malaysia. There will be three solid by-products generated: iron phosphate, gypsum and salts.

The Mt Weld RE concentrate feed and iron phosphate by-product contain low amounts of naturally occurring radioactive uranium and thorium at combined concentrations exceeding 1 Bq/g and are therefore classified as radioactive.

3.1 Site Description

The Project will be developed on two Greenfield sites:

- Rare Earths Processing Facility (REPF) at 70 Johns Road, Yilkari 6430, (formerly referred to as Lot 500, Great Eastern Highway, Yilkari), located approximately 8 km west of Kalgoorlie on Great Eastern Highway;
- By-product Storage Facility (BSF) on Common Reserve 8767, Yarri Road, Parkeston (Yarri Road) in the City of Kalgoorlie-Boulder.

3.1.1 REPF

The proposed REPF will be developed on a Greenfield site located approximately 8 km west of Kalgoorlie (Figure 1), on Lot 500, Great Eastern Highway, Yilkari (Lot 500).

The REPF has an area of 135 hectares (ha). The development footprint will be 120 ha of the entire area of Lot 500. The footprint is required for the process plants, by-product storage facilities, evaporation ponds and ancillary infrastructure as shown in in Table 1.

Table 1. Footprint Components

Components	Area (Ha)
Plant Site	9.4 ha
IP Storage Facility	10.2 ha
Gypsum Storage Facility	42.6 ha
Evaporation Pond	38.0 ha
Dams – Water and Process Liquors	4.0 ha
Buildings, Civils, Utilities and Internal and External Buffers	10.3 ha
Roads and Access Corridor	5.2 ha
Total Disturbance Envelope	**120 ha**
External Green Buffers	15 ha
TOTAL LOT AREA	**135 ha**

3.1.2 Yarri Road By-Products Storage Facility (BSF)

Whilst there will be an initial period of up to five years of onsite storage of by-products (gypsum and iron phosphate) at the REPF, Yarri Road is the preferred site for a long-term by-product storage facility for the Kalgoorlie REPF. This was one of three sites suggested by the Western Australian Government for the purpose of permanent storage of by-products. The locational attributes of the Yarri Road site are that it is at least 3km from any residential development, on land free from any mining tenure, relatively near to the REPF, can be readily accessed via a Heavy Vehicle bypass route and would have sufficient capacity for an extended operational life of the Kalgoorlie RE Processing facility.

Lynas recognises that there is potential for the re-use of the by-products from the Kalgoorlie REPF. The proposed operation of the Yarri Road BSF will consider the potential to re-use the by-products from the REPF by initially storing them separately.

The proposed location and layout of by-product storage at the BSF is displayed in Appendix D.

3.2 Process Description

The feed material to the REPF is lanthanide RE concentrate produced at the Mt Weld concentrator near Laverton, WA. The REPF will process Mt Weld RE concentrate to produce a RE carbonate that will undergo further processing at the LAMP. The key stages of the REPF are depicted in Figure 3 and detailed below.

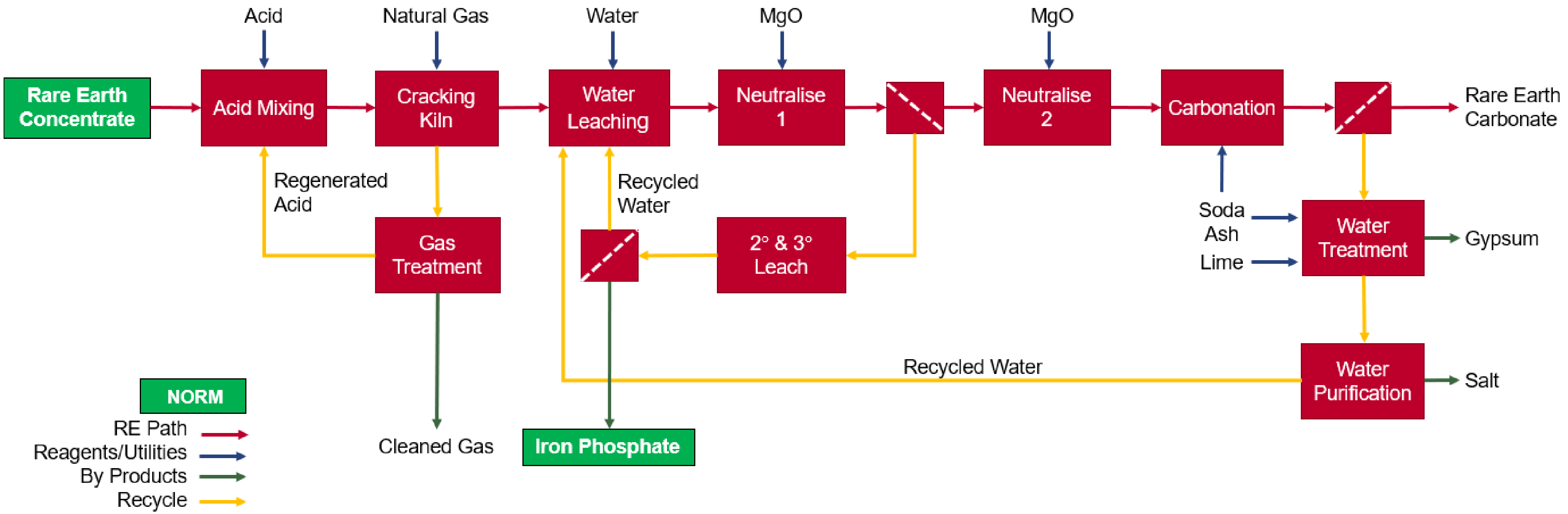

Figure 3. Process Flowchart

3.2.1 RE Transport

Concentrate will be transported from the Mt Weld concentration plant to the REPF in closed containers, with handling at the REPF undertaken by a fixed tipper which is hooded and drafted through a bag filter to eliminate dust.

Container transport between Mt Weld and Kalgoorlie will comprise of a mix of road and rail with the logistical arrangement to be confirmed following detailed feasibility assessments. Concentrate will remain in containers and stored on an engineered hardstand in a container yard adjacent to the feed hopper and feed conveyor at the REPF site to minimise handling and dust generation.

Lynas has transported RE concentrate from Mt Weld to the Fremantle Port for export to Lynas Malaysia without incident since 2012. Sea containers containing concentrate in lined bags were transported on road between 2012-2015 along a route of Mt Weld, Laverton, Leonora, Kalgoorlie through to the Fremantle Port. Since 2015 concentrate has been transported on road from Mt Weld to Leonora, with subsequent rail transport from Leonora, Kalgoorlie terminating at Fremantle Port. Annual transport emergency exercises have been conducted since 2011 in conjunction with external providers.

RE concentrate is not considered radioactive for transport purposes as defined by the WA Radiation Safety (Transport of Radioactive Substances) Regulations 2002.

The RE carbonate product will be packaged in containers and transported by rail to the Fremantle port for export to Lynas Malaysia. RE carbonate is not classified as radioactive for both transport or processing purposes.

Process chemicals will be transported and stored in accordance with Dangerous Goods Codes and will not impact RE or by-product transport/storage.

3.2.2 Acid Mixing

During acid mixing, concentrate containing RE minerals from Mt Weld will be mixed with concentrated sulphuric acid.

Concentrate is transferred directly from specially designed containers that can be emptied using a Rotainer tippler unit into an enclosed hopper. The concentrate is then conveyed into the acid mixing tank located above the kiln, where concentrated sulphuric acid will be mixed with the RE concentrate.

3.2.3 Cracking Kiln

The mixture of concentrated sulphuric acid and RE concentrate will be gravity fed into a rotary kiln. The mixture will be heated to 600 degrees C, forming a soluble RE sulphate. This process will also convert thorium into an insoluble thorium pyrophosphate. Further information regarding radionuclide deportment and characterisation of radionuclide secular equilibrium is provided in Section 3.6.

3.2.4 Gas Treatment

Gases from the kiln will be cleaned using a flue gas treatment system, which includes a combination of two venturi scrubbers, spray tower and Wet Electrostatic Precipitator (WESP) to ensure that emissions meet environmental standards prescribed by the DWER through the site environmental licence and to ensure that ambient air quality standards are complied with.

An emergency gas scrubbing system will be installed as a backup in the event of any failure of the primary gas treatment system.

On-line SO_2 monitoring and periodic SO_3, HF and particulate monitoring will be implemented in the gas treatment plant. Gas treatment at the Kalgoorlie REPF is an enhanced design based on the already successful gas treatment system utilised at the LAMP, which is supported by the low radionuclide measurements from previous LAMP stack monitoring.

3.2.5 Water Leach

Cracked material will be discharged from the kiln into the primary leach circuit where the RE sulphate will be dissolved in water, leaving insoluble material, including thorium pyrophosphate, in suspension.

3.2.6 Neutralisation and Filtration

The slurry from Primary Water Leach will be neutralised with magnesium oxide to a pH of approximately 3.5 which precipitates iron, phosphate and some of the aluminium, leaving the REs in solution.

The slurry will be filtered producing a filter cake which will be re-leached in secondary and tertiary leaching to recover unleached REs. The slurry from secondary and tertiary leaching will be filtered, producing an IP filter cake which will be stored and dried in an engineered and lined IP Drying and Storage Facility at the REPF. After drying it will either be transported to a dedicated facility at the BSF or stored in-situ at the REPF. The filtrate will be recycled to the primary water leach circuit to recover REs.

3.2.7 RE Carbonate Production

The RE carbonate precipitate will be produced from the neutralised RE sulphate solution. The precipitate will be filtered and bagged for shipping to Malaysia for separation and product finishing.

3.2.8 Water Treatment

The design of the REPF and process will maximise the recovery and re-use of water in the process as far as practicable. Wastewater from gas treatment and RE carbonate production will be neutralised with calcium oxide (quicklime) to form gypsum. This resulting slurry will be pumped into the Gypsum Storage Facility where gypsum settles out and the water can be recovered for treatment. The water will then be softened with sodium carbonate (soda ash) and sent to a Reverse Osmosis (RO) plant which will recover water to recycle back into the process. The raffinate (brine) discharge from the water recovery process will contain sodium and magnesium sulphate salts and will be directed to the lined evaporation pond onsite.

3.3 Non-process Infrastructure and Ancillary Plant

Non-process infrastructure on the REPF site will include raw and finished materials storage, offices, laboratory, warehouse, workshop, control rooms and substations, as well as an access road and carparking. Additionally, the ancillary plant area will include compressed air, communications and control system.

A buffer of between 30 to 50 m along the plant boundary, which will not be cleared, will be left around the perimeter of the site to act as a visual screen.

3.4 Utilities

Natural gas will be supplied through a spur to the Goldfields gas pipeline, operated by APA. Access agreements are currently being discussed between Lynas and APA.

Approximately 1 GL per annum of water supply will be required for the industrial processes associated with the REPF. CKB (who hold the head lease for Lot 500) has agreed to supply reclaimed water to the REPF site to meet this requirement. CKB is responsible for the construction of pipeline infrastructure from its reclaimed water service to the REPF site boundary and is responsible for obtaining all relevant easements and approvals for the delivery of reclaimed water to the REPF site.

Potable water will be supplied from the Goldfields Water Supply Scheme. Lynas is currently in commercial discussions with Water Corporation for supply of potable water.

Given the above, no groundwater will be abstracted from beneath or in proximity to the proposed site, and therefore no applications for groundwater licensing under the WA *Rights in Water and Irrigation Act, 1914* are required.

Power will be supplied from the grid and/or a local source. Lynas is currently in commercial discussions with Western Power and third-party providers. Potential opportunities to establish a solar farm for power generation purposes (either during operations and/or post closure) are being assessed by Lynas.

3.5 LAMP Radiation Monitoring

The LAMP has been processing Mt Weld RE concentrate since late 2012. Cracking and Leaching is the first stage of processing at the LAMP. The Kalgoorlie Cracking and Leaching plant is based on the C&L plant at the LAMP.

Radiation safety in Malaysia is regulated by the Atomic Energy Licensing Board (AELB). The AELB impose stringent radiation monitoring requirements at the LAMP through the issuing of operating licenses covering radionuclide importation, transport, treatment and storage. AELB personnel were stationed on-site at the LAMP between 2012 – 2016 to conduct independent and confirmatory radiation monitoring.

A condition of the LAMP operating licence issued by the AELB is radiation monitoring to be conducted monthly under an Occupational Exposure Monitoring Program (OEMP) and two-monthly under the Environmental Radiation Monitoring Program (ERMP). The monitoring programs cover gamma radiation, radon and thoron gas, soil, dust particulate, stack emission, sediment and discharge water monitoring. Over the past seven years an extensive dataset of radiation monitoring results has been accumulated that will be directly comparable to radiation exposures at the Kalgoorlie REPF.

The IAEA conducted an independent expert review of radiation and health aspects at the LAMP in 2011 with the report finding "*compliance with international radiation standards*". A follow-up independent review was conducted by the IAEA in 2014 with the report confirming "*the radiological risks to members of the public and to the environment associated with the operation of Lynas Advanced Material Plant are intrinsically low.*"

The radiological risk profile of the Kalgoorlie REPF is expected to be equivalent to the intrinsically low risk at the LAMP due to the replication of processing methods and inherently low input radioactivity.

3.6 NORM Characterisation

The feed material to the REPF is lanthanide RE concentrate produced from the Mt Weld concentrator near Laverton, WA. The RE concentrate contains a low amount of naturally occurring radioactive elements from the natural uranium and thorium decay chains. RE concentrate contains approximately 40 ppm U_3O_8 (0.4 Bq/g) and 1700 ppm ThO_2 (6.1 Bq/g).

Expected radionuclide concentrations within major processing streams at the REPF are displayed in Table 2 below. An RBA conducted at LAMP and analysed at ANSTO characterises the radionuclide concentrations for RE Concentrate and Iron Phosphate. Internal testwork was conducted to produce a representative RE Carbonate product, which was also analysed at ANSTO.

Table 2. Expected Radionuclide Concentrations in Major Plant Streams

Radionuclide	**RE Concentrate** *Bq/g*	**Iron Phosphate** *Bq/g*	**RE Carbonate** *Bq/g*
^{238}U Decay Chain			
^{238}U	0.4	0.3	0.26 ± 0.02
^{226}Ra	0.5	0.7	< 0.007
^{210}Pb	0.3	0.4	< 0.12
^{232}Th Decay Chain			
^{232}Th	6.1	6.2	0.010 ± 0.001
^{228}Ra	5.4	6.2	< 0.011
^{228}Th	5.6	7.0	0.011 ± 0.001

Radionuclides will enter the Process within RE concentrate and report to iron phosphate in near totality. The formation of insoluble thorium species during the cracking stage will ensure equilibrium of the thorium decay chain is maintained (trace amounts of thorium may report to leach liquor). A small amount of ^{238}U will leach and report to the carbonation stage, representing a potential disruption to equilibrium of the uranium chain.

The concentration of radionuclides reporting to the RE Carbonate product will be below the threshold for radioactive classification according to the radionuclide mixtures calculation.

Following plant commissioning, an assessment of the radionuclide balance at the REPF will be undertaken to evaluate the state of equilibrium in both thorium and uranium decay chains and to confirm if actual radionuclide concentrations align with anticipated levels.

4 RADIOLOGICAL ASSESSMENT

An assessment of potential radiological impacts from the proposed REPF and BSF will be carried out through identification of radiation exposure pathways and evaluation of expected radiation exposure to workers, members of the public and non-human biota.

Where possible the assessment will draw on radiation monitoring data from LAMP rather than using predicted values for the basis of the radiological impact on workers, members of the public and non-human biota.

4.1 Assessment Factors

The following factors are used in the dose assessment:

<u>Exposure Conditions:</u>

- Worker exposure hours – 1,950 hours per year
  - Based on 4/4 roster with 12 hour shifts and 20 days annual leave per year.
- Member of public exposure hours – 8,760 hours per year
- Worker breathing rate – 1.2 m^3/hr (DMIRS 2010)
- Member of the public breathing rate – 0.96 m^3/hr (DMIRS 2010)

<u>Radionuclide in Airborne Dust Calculation Factors:</u>

- Relationship between uranium, thorium and radionuclide activities:
  - 1 ppm U = 12.384 mBq/g
  - 1 ppm Th = 4.055 mBq/g
- Worker activity median aerodynamic diameter (AMAD) – 5 µm
- Member of the public AMAD – 1 µm
- Slow (s) radionuclide solubility class used (most restrictive)
- Iron phosphate thorium:uranium ratio – 20:1
- Iron phosphate dose conversion factors (mSv/Bq) (ICRP, 2017):
  - Occupational worker – 0.0156 mSv/Bq
  - Member of public – 0.0271 mSv/Bq

<u>Radon and Thoron Inhalation Factors:</u>

- Radon progeny equilibrium factor (F_{RnP}) – 0.2 (outdoors)
- Radon dose conversion factor – 3.14 mSv/(mJh/m^3) (DMIRS 2021)
- Thoron progeny equilibrium factor (F_{TnP}) – 0.004 (outdoors)
- Thoron dose conversion factor 1.36 mSv/(mJh/m^3) (DMIRS 2021)

4.2 Occupational Dose Assessment

The potential radiological impact to workers at the REPF will be described in the section below through evaluation of following radiation exposure pathways:

- Gamma radiation exposure;
- Inhalation of radon, thoron and their respective progeny;
- Inhalation of radionuclides in airborne dust;
- Exposure to radionuclides from stack emission;
- Exposure during IP transport.

The areas of the REPF that workers will interact with radioactive material are concentrate handling and iron phosphate storage areas at both the REPF and BSF. Where applicable, radiation exposures will utilise LAMP monitoring data.

4.2.1 Gamma Radiation Exposure

Personal external gamma monitoring has been undertaken at LAMP under the OEMP with occupational workers in concentrate handling and iron phosphate storage areas required to wear optically stimulated luminescence (OSL) monitors. A summary of the annual dose to LAMP radiation workers from external gamma exposure between 2014 – 2019 is shown in Table 3 below.

Table 3. LAMP 2014-19 Average Radiation Worker OSL Gamma Dose

	Concentrate Handling Area ***(Arithmetic Mean ± SD)***	**Iron Phosphate Storage Area** ***(Arithmetic Mean ± SD)***
Average Gamma Dose *(mSv/year)*	0.5±0.1	0.6±0.3

The external gamma dose to workers at the REPF is expected to be similar to LAMP exposure. The average LAMP gamma dose will be used in the occupational dose assessment for workers in concentrate handling and iron phosphate storage areas at the REPF and for iron phosphate storage areas at the BSF.

4.2.2 Inhalation of Radon and Thoron

A process improvement to be implemented at the REPF will be the elimination of a concentrate storage shed, with concentrate to be transferred directly from specially designed containers that can be emptied using a Rotainer tippler unit into an enclosed feed hopper. Removal of the intermediate concentrate stockpile at the REPF will reduce occupational radiation exposure as there will be insignificant potential for emanation and accumulation of radon or thoron gases in occupied work areas, unlike the storage area at the LAMP.

The exposure from inhalation of radon, thoron and their progeny in the concentrate handling area is subsequently expected to be negligible and only the Iron Phosphate Storage Facility is anticipated to present the levels of radon and thoron that may require an occupational exposure assessment.

Monitoring of radon (^{222}Rn) and thoron (^{220}Rn) concentrations in air is conducted at LAMP under the ERMP using an electronic Durridge RAD7 detector. Average concentrations of radon and thoron at the Concentrate and Iron Phosphate Storage Areas are shown in Table 4 below.

Table 4. LAMP Average Occupational Radon and Thoron Concentrations in Air

	Concentrate Storage Area ***(Arithmetic Mean ± SD*)***	**Iron Phosphate Storage Area** ***(Arithmetic Mean ± SD*)***
Radon Concentration *(Bq/m^3)*	22±11	14±13
Thoron Concentration *(Bq/m^3)*	450±337	105±115

**Large standard deviation values due to highly variable concentrations in air*

The internal dose to workers at both the REPF and BSF from exposure to radon and thoron in the Iron Phosphate Storage Facility is calculated below in accordance to the NORM-V Guideline (DMIRS 2021) utilising LAMP measurements. As previously stated, removal of the concentrate storage shed at the REPF will reduce occupational radon and thoron exposure. The radon and thoron concentrations within the LAMP concentrate storage area displayed in Table 4 highlight the internal dose (approximately 0.5 mSv/year) that will be avoided at the REPF. Radon and thoron monitoring will still be conducted in concentrate transfer areas at the REPF to confirm the decreased exposure.

Potential alpha energy exposures to radon and thoron progeny are determined from the concentrations of radon and thoron gas in air using the following formulae:

$$P_{RnP}\ [mJh/m^3] = 5.56 * 10^{-6} * t * F_{RnP} * C_{RnP}$$

$$P_{TnP}\ [mJh/m^3] = 7.57 * 10^{-5} * t * F_{TnP} * C_{TnP}$$

Where:

- P_{RnP}, P_{TnP} are the potential alpha energy exposures to radon and thoron progeny (mJh/m^3).
- *t* is the exposure time (hours).
- F_{RnP}, F_{TnP} are the radon & thoron progeny equilibrium factors.
- C_{Rn}, C_{Tn} are the radon & thoron gas concentrations (Bq/m^3).

The subsequent dose from radon and thoron exposure is then calculated using the following formulae:

$$Dose_{Rn}\left[\frac{mSv}{year}\right] = P_{RnP} * DCF_{Rn}$$
$$Dose_{Tn}\left[\frac{mSv}{year}\right] = P_{TnP} * DCF_{Tn}$$

Where:

- DCF_{Rn}, DCF_{Tn} are the respective dose conversion factors for radon and thoron [$mSv/(mJh/m^3)$] as set out in NORM V (DMIRS 2021).

Radon: $P_{RnP} = 5.56 * 10^{-6} * 1950 * 0.2 * 14 = 0.03\ mJh/m^3$
$\mathbf{Dose_{Rn} = 0.03 * 3.14 = 0.10\ mSv/year}$

Thoron: $P_{TnP} = 7.57 * 10^{-5} * 1950 * 0.004 * 105 = 0.06\ mJh/m^3$
$\mathbf{Dose_{Tn} = 0.06 * 1.36 = 0.08\ mSv/year}$

It should be noted that natural background concentrations of radon and thoron were not taken into account in the above calculations.

4.2.3 Inhalation of Radionuclides in Airborne Dust

Dust generation during the concentrate unloading process will be minimal due to the direct transfer between closed container and feed hopper eliminating the need for stockpiling. The reach stacker operator will be inside an enclosed cabin with air filtration and a baghouse dust filtration unit will also be utilised to further reduce dust exposure risk from the enclosed hooded and drafted feed hopper. The generation of dust and subsequent exposure to radionuclides within the concentrate handling area is expected to be negligible.

Only the iron phosphate storage areas at the REPF and BSF will be considered for occupational exposure due to inhalation of radionuclides in airborne dust. Through the long-standing experience with IP at the LAMP in Malaysia, Lynas have robust scientific data indicating that during storage, the IP filter-cake is at 45% moisture at deposition. Iron Phosphate is typically of a clay like consistency and does not become dusty until it gets to around 20% moisture. If the stockpile does become dusty, a proven management method that can be adopted at the proposed REPF is to utilise a chemical dust suppressant (e.g. Gluon® or waterglass (sodium silicate)) which is sprayed onto completed stockpiles for dust control.

Monitoring of radionuclides in airborne dust has been conducted at LAMP under the ERMP using a GilAir-5 air sampler in accordance with Malaysian regulations and guidelines. The average gross alpha activity in the iron phosphate storage area is shown in Table 5 below. Note the average gross alpha activity is below the minimum detectable limit (MDL) of 0.021 Bq/m^3. The MDL will therefore be carried through to the dose assessment calculations.

Table 5. Average LAMP Dust Gross Alpha Activity

	Iron Phosphate Storage Area
Gross Alpha Activity *(Bq/m^3)*	<0.021

Monitoring of radionuclides in airborne dust at the REPF will be conducted in accordance with DMIRS Guideline NORM-3.4 and the relevant Australian Standard.

The internal dose assessment for a worker from the exposure to radionuclides in airborne dust is calculated in accordance with the NORM-V Guideline (DMIRS 2021), as follows:

$$\mathrm{Dose_{dust}}\left[\frac{\mathrm{mSv}}{\mathrm{year}}\right] = \mathrm{AM} * \mathrm{HW} * \mathrm{BR} * \mathrm{DCF}$$

Where:

- *AM* is arithmetic mean of gross alpha-activity concentration (Bq/m^3).
- *HW* is the exposure time (hours).
- *BR* is the worker breathing rate (m^3/hr).
- *DCF* is the dose conversion factor (mSv/Bq).

$$\mathbf{Dose_{dust} = 0.021 * 1950 * 1.2 * 0.0156 = 0.77\ mSv/year}$$

The dose from exposure to radionuclides in dust is conservative due to the high MDL of the gross activity alpha analysis.

4.2.4 Exposure to Radionuclides from Stack Emission

The C&L process will have an emission stack equivalent to the LAMP process that offers potential release of radionuclides into atmosphere. The stack in the gas treatment area at the REPF presents a radiation exposure risk through dispersion of suspended particles into the vicinity of workers.

Table 6 shows particulate results of stack emission monitoring carried out at LAMP under the ERMP conducted at the elevated stack exhaust.

Table 6. LAMP Stack Emission Radionuclide Analysis

	Gas Treatment Stack *(Arithmetic Mean ± SD)*
^{238}U Particulate *(Bq/m^3)*	(9.22±7.71)x10^{-4}
^{232}Th Particulate *(Bq/m^3)*	(3.52±2.27)x10^{-4}

The Gaussian plume model detailed in IAEA (2001) is widely accepted for use in radiological assessments. The model is used to assess point-source dispersion of long-term continuous atmospheric releases at a distance up to 20 km. The ground level concentrations of ^{238}U and ^{232}Th calculated from the model are attributed to the exposure of radionuclides from stack emissions for workers at the REPF. The dispersion of continuous atmospheric releases is illustrated in Figure 4.

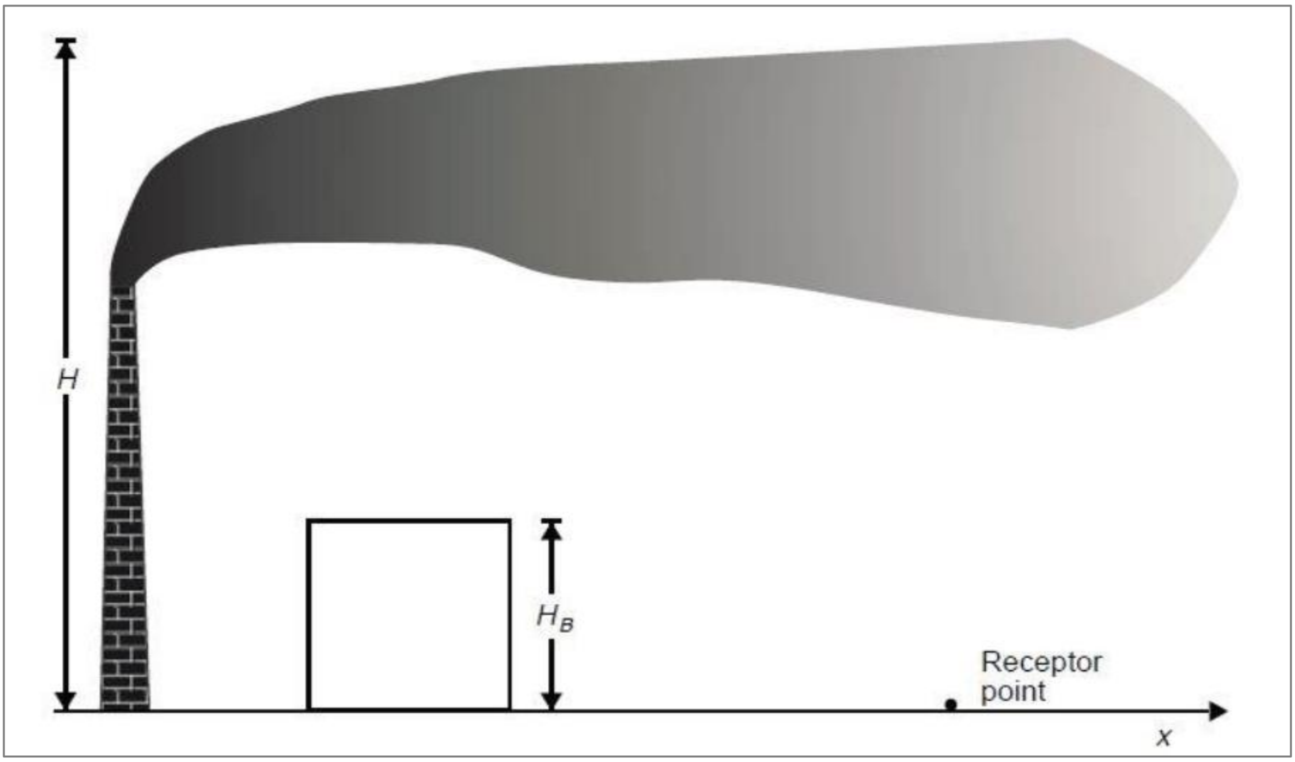

Figure 4. Illustration of Stack Atmospheric Release

The model is characterised by the existence of a building with height H_b in the plume dispersion zone with the height of the stack H greater than 2.5x H_b. In this scenario the building wake effects do not need to be considered in the modelling (i.e., the building will not impact the plume dispersion).

The following assumptions are also included in the modelling:

- A single wind direction and speed for each air concentration calculated. According to (BOM, 2019) in Kalgoorlie the wind predominantly blows from the east with a long-term average 15.5 km/h (4.3 m/s) wind speed.
- A neutral atmospheric stability class (Pasquill-Gifford Stability Class D).

Based on these assumptions, the screening model for atmospheric dispersion can be represented by:

$$C_A = \frac{P_P * F * Q_i}{u_a}$$

Where:

- C_A is the ground level air concentration at downwind distance '*x*' (Bq/m^3).
    - For this assessment, x <1000 m to estimate exposure to workers.
- P_P is the fraction of the year that the wind blows in the direction of the receptor.
    - For this assessment P_P = 0.45 is adopted as an approximate summation of wind blowing from the east as taken from the wind rose displayed in Appendix B.
- u_a is the geometric mean of the wind speed at the height of release representative of one year (m/s).
    - The average wind speed of 4.3 m/s was used for the assessment.
- *F* is the Gaussian dispersion factor appropriate for the height of release *H* and the downwind distance *x* being considered (m^{-2}).
    - The stack release height is approximately 60 m, therefore F value for <1000 m is 2x10^{-5} m^{-2} (IAEA, 2001).
- Q_i is the expected average discharge rate for radionuclide *i* (Bq/s).
    - Maximum stack flow rate is conservatively estimated at 106,500 m^3/hr. Radionuclide discharge rates are calculated as the sum of stack concentrations from Table 6.

$$Q_U = \frac{106{,}500 * 9.22\text{x}10^{-4}}{60 * 60} = 0.03\ \text{Bq/s}$$

$$Q_{Th} = \frac{106{,}500 * 3.52\text{x}10^{-4}}{60 * 60} = 0.01\ \text{Bq/s}$$

^{238}U: $$C_A = \frac{0.45 * 2\text{x}10^{-5} * 0.03}{4.3} = \mathbf{5.71x10^{-8}\ Bq/m^3}$$

^{232}Th: $$C_A = \frac{0.45 * 2\text{x}10^{-5} * 0.01}{4.3} = \mathbf{2.18x10^{-8}\ Bq/m^3}$$

The internal dose assessment for a REPF worker from the exposure to radionuclides from stack emissions is calculated using the same method as airborne dust in Section 4.3.3.

$$\mathbf{Dose} = (\mathbf{5.71x10^{-8}} + \mathbf{2.18x10^{-8}}) * \mathbf{1950} * \mathbf{1.2} * \mathbf{0.0156} = \mathbf{2.88x10^{-6}}\ \mathbf{mSv/year}$$

The calculated internal dose to REPF workers from exposure to radionuclides from stack emissions is extremely low and is indistinguishable from natural background radiation. The radiation exposure from stack emissions is subsequently assumed to be zero for the occupational assessment.

There is no stack at the BSF and subsequently there is no occupational exposure to radionuclides from stack emissions.

4.2.5 Exposure During Iron Phosphate Transport

Whilst the specific activity of IP is below applicable transport limits, the gamma-radiation emitted is above natural background levels, typically in the order of 0.8 – 1.3 μSv/hr. It is therefore necessary to determine the potential radiation exposure to employees involved with transport of IP between the REPF and BSF.

An assessment of gamma-radiation exposure to RE concentrate truck drivers previously conducted at Mt Weld determined that the gamma exposure inside the truck cabin is equivalent to natural background – the average result being 0.10 μSv/hr. External gamma radiation checks will be conducted in IP transport driver cabins to ensure exposure is equivalent to natural background.

Radionuclide concentrations of RE concentrate and IP are very similar meaning the outcome of the assessment of gamma exposure to RE concentrate truck drivers is also applicable to employees transporting IP. It is therefore deemed that truck drivers transporting IP to the BSF will not be exposed to gamma radiation above natural background levels.

4.2.6 Summary of Occupational Dose Assessment

A summary of the estimated doses for occupational workers at the Kalgoorlie REPF is displayed below in Table 7. It is estimated the dose for occupational workers at the REPF will be approximately 1.6 mSv/year which is less than 10% of the radiation worker limit (20 mSv/year) as set by the Regulations under the RSA.

Table 7. Summary of Occupational Doses

Exposure Pathway	Radiation Dose *(mSv/year)*		
	Concentrate Handling Area	*REPF IP Storage Area*	*BSF IP Storage Area*
Gamma	0.5	0.6	0.6
Radon Inhalation	0.0	0.1	0.1
Thoron Inhalation	0.0	0.1	0.1
Dust Inhalation	0.0	0.8	0.8
Stack Emission	0.0	0.0	-
IP Transport	0.0	0.0	0.0
Total	**0.5**	**1.6**	**1.6**

A validity check of the estimated occupational dose at the Kalgoorlie REPF should see the dose be similar and no lower than the measured annual doses to workers at Mt Weld and LAMP sites. Table 8 shows the estimated occupational dose at the Kalgoorlie REPF is in line with doses measured at both Mt Weld and LAMP operations, providing confidence that appropriate figures have been used in the assessment.

Table 8. Annual Occupational Dose Comparison

	Annual Occupational Dose *(mSv/year)*	**Radiation Worker Limit *(mSv/year)***	**Percentage of Limit**
Mt Weld Average *(2011-2020)*	0.6	20.0	3%
Mt Weld 2019/20 Occupational Dose*	1.3	20.0	7%
LAMP Maximum Dose *(2014-2019)*	1.7	20.0	9%
Proposed Kalgoorlie REPF* *(Estimated)*	1.6	20.0	8%

**Dose assessments incorporated updated dose coefficients from ICRP 137: OIR Part 3* (ICRP, 2017)

4.3 Public Dose Assessment

The potential radiological impact to the public from REPF operations at both the REPF and BSF will be described in the following section. Radiological impact to the public is considered to occur when radiation exposures impact on people beyond either Project sites.

Two critical public groups in the vicinity of the REPF and one in the vicinity of the BSF have been identified as being external to the Project and will be subject to dose assessment:

Critical Group 1. Residential and commercial occupants approximately 60 m from the REPF northern boundary (Figure 8).

Critical Group 2. West Kalgoorlie industrial area occupants approximately 1.8 km from the REPF eastern boundary (Figure 9).

Critical Group 3. Ningamia Community approximately 4km from the BSF (Figure 10).

Note: Critical Group locations are depicted in Appendix C.

The public dose assessment will be conducted by evaluation of following radiation exposure pathways:

- Gamma radiation exposure;
- Inhalation of radon, thoron and their respective progeny;
- Inhalation of radionuclides in airborne dust;
- Exposure to radionuclides from stack emission;
- Exposure during IP transport.

4.3.1 Gamma Radiation Exposure

Gamma radiation exposure to the public is generally considered to be insignificant as gamma radiation emitting sources will be located in areas inaccessible and/or at distance to the public. Gamma radiation dose rate decreases significantly at increasing distance from a source according to the inverse square law (double the distance from gamma source will yield a quarter of the dose rate).

The only gamma radiation emitting source that is in the vicinity of site boundaries at either REPF or BSF is the iron phosphate stockpiles.

The IP stockpile at the REPF was purposely positioned at the western boundary to maximise distance to the nearest public group (Critical Group 1). A 30 m green buffer zone will separate IP stockpiles from site boundaries at both REPF and BSF (site layouts displayed in Appendix D).

The gamma dose rate from iron phosphate at the site boundaries of the REPF & BSF can be calculated according to the inverse square law:

$$\mathrm{DR_1} * (\mathrm{r_1})^2 = \mathrm{DR_2} * (\mathrm{r_2})^2 \rightarrow \mathrm{DR_2} = \frac{\mathrm{DR_1} * (\mathrm{r_1})^2}{(\mathrm{r_2})^2}$$

Where:

- DR_1 is the iron phosphate dose rate which is typically 1.3 µSv/hr.
- r_1 is the distance the DR_1 dose rate was measured – 1 m.
- DR_2 is the dose rate at the site boundary.
- r_2 is the distance from the iron phosphate stockpile – 30 m.

$$\text{Boundary Dose rate} = \frac{1.3 * (1)^2}{(30)^2} = \frac{1.3}{900} = \mathbf{0.0014\ \mu Sv/hr}$$

The calculated gamma dose rate from exposure to iron phosphate at the site boundaries of REPF and BSF is indistinguishable from natural background and is assumed to be zero for the public assessment.

4.3.2 Inhalation of Radon and Thoron

As stated in the occupational dose assessment, monitoring of radon and thoron in air has been conducted at LAMP under the ERMP. In addition to monitoring occupational areas with expected concentrations (iron phosphate storage), radon and thoron monitoring has also covered areas with low expected concentrations to ensure there is minimal exposure to non-radiation workers and members of the public.

Monitoring in “processing facilities” is performed in areas within the plant that are outside controlled radiation areas. Results of radon and thoron monitoring in processing facilities will be attributed to Critical Group 1 for the assessment as it represents the most comparable exposure for the residence near the REPF.

Radial monitoring is also performed at 1 km from the LAMP site to ensure there is no radiological impact to members of the public in the vicinity of the plant. Results of the 1 km radial monitoring will be attributed to Critical Group 2 and Critical Group 3.

Average radon and thoron concentrations in the processing facilities and 1 km radial zone areas are shown in Table 9 below. It is noted that concentrations of radon and thoron in air are highly variable and dependant on wind and atmospheric conditions. It is likely that exposures measured offsite in Malaysia originate from sources external to Lynas operations.

Table 9. LAMP Average Radon and Thoron Concentrations in Air

	Processing Facilities ***(Arithmetic Mean ± SD)***	**1 km Radial Zone** ***(Arithmetic Mean ± SD)***
Radon Concentration *(Bq/m^3)*	7±5	4±2
Thoron Concentration *(Bq/m^3)*	26±18	7±3

A national survey of naturally occurring radon gas concentrations detailed in ARPANSA (1990) describes the background radon concentration in Kalgoorlie to be between 11 – 13 Bq/m^3. The public exposure to radon gas from the REPF is expected to be indistinguishable from naturally occurring background radon gas concentrations.

The internal dose to the critical groups from exposure to radon and thoron is calculated using the same method detailed in Section 4.2.2 using factors for members of the public rather than occupational workers.

The internal dose to Critical Group 1 is **0.21 mSv/year** from radon exposure and **0.05 mSv/year** from thoron exposure.

The internal dose to Critical Group 2 and Critical Group 3 is **0.12 mSv/year** from radon exposure and **0.02 mSv/year** from thoron exposure.

As previously noted, radon and thoron concentrations are highly dependent on regional climate. Measurements of radon and thoron at the REPF will be collected prior to operation to confirm the natural background concentrations detailed in ARPANSA (1990).

4.3.3 Inhalation of Radionuclides in Airborne Dust

The only likely public exposure from inhalation of radionuclides in airborne dust is from the iron phosphate stockpile. The moisture retained by iron phosphate following filtration will largely prevent fugitive dust generation, however the potential risk for dust emissions outside the Project site exists.

Atmospheric dispersion and dust deposition modelling conducted by Environmental Technologies & Analytics (ETA 2021) determined potential air quality impacts associated with REPF and BSF operations. The ground-level concentrations for key pollutants including particulates, SO_2, NO_X and CO were modelled at sensitive receptors in the area surrounding both sites with results shown in Appendix E.

For the purposes of the public assessment, the modelled total suspended particulate (TSP) concentrations at sensitive receptor locations correlating to the Critical Groups will be utilised to calculate dose from exposure to radionuclides in airborne dust. It is assumed the modelled particulate concentrations originated from the iron phosphate stockpile (in practice, a proportion of dust would be barren of radionuclides). This assumption will provide the most conservative assessment of radiation exposure from radionuclides in airborne dust.

The radionuclide activity concentration in dust is calculated as follows:

$$\text{Dust Activity Concentration (DAC)} \left[\frac{\text{Bq}}{\text{m}^3}\right] = \text{Dust TSP Concentration} \left[\frac{\mu\text{g}}{\text{m}^3}\right] * \text{Radionuclide Activity} \left[\frac{\text{Bq}}{\text{g}}\right]$$

Where:

- *Radionuclide activity* for iron phosphate is:
  - ^{238}U = 0.3 Bq/g
  - ^{232}Th = 6.1 Bq/g

The dose from exposure to radionuclides in airborne dust is then calculated as follows:

$$\text{Dose}_{\text{dust}} \left[\frac{\text{mSv}}{\text{year}}\right] = \text{DAC} * \text{HW} * \text{BR} * \text{DCF}$$

Where:

- *DAC* is the radionuclide activity concentration in dust (Bq/m^3).
- *HW* is the exposure time (hours), 8760 hours (full year) for members of the public.
- *BR* is the breathing rate for a member of the public (0.96 m^3/hr).
- *DCF* is the dose conversion factor (mSv/Bq), for dust particle size of 1 micron (members of the public) the factor for the Th:U ratio of 20:1 (0.0271 mSv/Bq).

The estimated dose from inhalation of radionuclides in dust at the critical groups is shown in Table 10.

Table 10. Airborne Dust Concentrations

	Receptor Identification	**TSP Dust Concentration** *(µg/m^3)*	**Total Dust Activity Concentration** *(Bq/m^3)*	**Dose** *(mSv/year)*
Critical Group 1	I1	5.5	4.43×10^{-5}	**0.008**
Critical Group 2	I7	2.8	1.41×10^{-5}	**0.004**
Critical Group 3	R_4	7.6	4.88×10^{-5}	**0.011**

It is noted that the modelled TSP dust concentrations utilised in the assessment are below the minimum detection limit of equipment that will be used during operational dust monitoring. A maximum permissible TSP concentration of 50 µg/m^3 was also evaluated and showed the dose to be below 0.10 mSv/year, further indicating that the potential impact to the public from inhalation of radionuclides is very low.

4.3.4 Exposure to Radionuclides from Stack Emission

The exposure to radionuclides from stack emission calculated for workers in Section 4.2.4 will also be used for exposure to members of the public to ensure the most conservative estimate is used.

The internal dose assessment for a member of the public from exposure to radionuclides from stack emissions is calculated using the same method and factors as public airborne dust in Section 4.3.3.

$$\mathbf{Dose} = (\mathbf{5.71x10^{-8}} + \mathbf{2.18x10^{-8}}) * \mathbf{8760} * \mathbf{0.96} * \mathbf{0.0271} = \mathbf{1.80x10^{-5}\ mSv/year}$$

The internal dose to members of the public from exposure to radionuclides from stack emissions is extremely low and considered negligible for the purpose of public dose assessment.

There is no stack at the BSF and subsequently there is no public exposure to radionuclides from stack emissions.

4.3.5 Exposure During Iron Phosphate Transport

There are two potential exposure scenarios in which members of the public may be exposed to radiation during transport of IP from the REPF to BSF; both of which are due to irradiation by gamma-radiation from the contained IP.

Scenario A: Members of the public driving behind truck:

A member of the public may follow a truck containing IP along the transport route from the REPF to BSF. The annual exposure time is estimated at 116 hours per annum (assumed to follow one truck per day at a distance greater than 20 metres).

Scenario B: Public in suburban areas:

The transport route passes through an area occupied by residential and industrial premises in South Boulder in which members of the public may be exposed to gamma-radiation. The approximate distance of dwellings from the road is 20 metres. There will be approximately seven trucks with three containers each passing through this area each day. At a truck speed of 50 km/hr, this equates to approximately one hour per annum of exposure time to a resident at the property.

The following equation was used to estimate the gamma-radiation dose rate from two containers at various distances:

$$\text{Dose Rate} = \text{EDR}_{\text{surface}} * \left[1 - \text{d}/(\text{d}^2 + \text{A} * \frac{\text{B}}{3.14})^{0.5}\right]$$

Where:

- $EDR_{surface}$ is the emitted dose rate at the container surface (2 µSv/hr).
- d is the distance from the source.
- A is the container height.
- B is the container width.

The results of the assessments are summarised in the table below:

Table 11. Summary of Possible Public Exposures

Scenario	A	B
Distance (m)	20	20
Height (m)	2.4	2.4
Width (m)	2.4	18
Exposure (hr/year)	116	1
Dose Rate (µSv/hr)	0.005	0.034
Dose (mSv/year)	**0.0005**	**0.00003**
Percentage of Public Limit	0.053%	0.003%

The above assessments show that the external dose to members of the public from transport of IP from the REPF to BSF is extremely low and would be indistinguishable to natural background radiation. The radiation exposure from IP transport is considered negligible for the purposes of public dose assessment.

4.3.6 Summary of Public Dose Assessment

An assessment of the estimated radiological impacts from the Kalgoorlie REPF to the three identified critical public groups has been performed with estimated doses displayed in Table 12.

Table 12. Summary of Public Doses

Exposure Pathway	Radiation Dose *(mSv/year)*		
	Critical Group 1	*Critical Group 2*	*Critical Group 3*
Gamma	0.00	0.00	0.00
Radon Inhalation	0.21	0.12	0.12
Thoron Inhalation	0.05	0.02	0.02
Dust Inhalation	0.01	0.00	0.01
Stack Emission	0.00	0.00	0.00
IP Transport	0.00	0.00	0.00
Total	**0.27**	**0.14**	**0.15**

It should be noted that natural background concentrations of radon and thoron were not taken into account in the above estimations.

Critical Group 1, representing the residential and commercial occupants approximately 60 m from the REPF northern boundary is the closest public group to the REPF. The assessment shows an estimated dose of approximately 0.3 mSv/year, which is 30% of the limit to members of the public as set by the Regulations under the RSA.

4.4 Environmental Assessment

The potential radiological impact to the environment from Kalgoorlie REPF operations will be described in the following section. The two aspects of environmental impact under consideration are migration of radionuclides in dust from the REPF and BSF to the surrounding environment and potential leaching of radionuclides from iron phosphate stockpiles.

4.4.1 Exposure to Non-Human Biota

The radiological impact on non-human biota was assessed using the Environmental Risk from Ionising Contaminants: Assessment (ERICA) software tool as detailed in ARPANSA (2010). The software package provides a practical framework for assessing absorbed dose rates to non-human species through change in media radionuclide concentration over time.

As described in Section 4.3.3, atmospheric dispersion and dust deposition modelling was conducted at sensitive receptors to determine potential air emission impacts associated with REPF and BSF operations. Dust deposition modelling results displayed in Appendix E were used to determine the potential radionuclide concentration increase in soil outside the Project site for subsequent use in the ERICA assessment. The determination of soil radionuclide concentrations is shown in Table 16 within Appendix F.

Tier two ERICA assessments were conducted for both REPF and BSF operations using the highest dust deposition values modelled in proximity to both sites. The assessments were conducted assuming the maximum modelled dust deposition value is resultant entirely of emissions from the iron phosphate stockpile, ensuring the most conservative assessment of radionuclide exposure to non-human biota. A custom 1.0 µGy/hr screening dose rate was applied instead of the conventional 10.0 µGy/hr to again ensure the most conservative assessment was performed.

Outputs from the two ERICA assessments are displayed in Table 17 within Appendix F and show the assessed total dose rate per organism is well below the applied screening rate, with total radionuclide risk quotients of 0.3 and 0.2 for the REPF and BSF, respectively. The results of the ERICA assessments indicate there is low radiological risk to non-human biota from the REPF and BSF operations with no further assessment warranted.

4.4.2 Iron Phosphate Radionuclide Mobility

The Iron Phosphate Storage Facility at the REPF will be lined with high-density polyethylene (HDPE) to prevent radionuclide migration into the subsurface. It is still pertinent to characterise the potential for radionuclide transport and mobility from iron phosphate to understand the potential risk associated with the facility.

4.4.2.1 Radionuclide Transport

Radionuclide transport in soil is evaluated based on solution flow driven by the downward movement of water. Some physical and chemical factors, such as adsorption and a change of oxidation state, work to retard radionuclide movement and are expressed as a “retardation factor”.

Partition coefficient (K_d) testwork captures the net effects of a radionuclide's tendency to go into solution and retarding forces which cause the radionuclide to remain in or on a solid phase. Partition coefficient (K_d) is expressed as a ratio of radionuclide in solid phase to radionuclide in solution and is the most common measure used to quantify reduction in the rate of transport of a contaminant relative to groundwater.

A K_d of low numerical value means the radionuclide exhibits a tendency to go into solution. Conversely, high values of K_d represent radionuclides that resist going into solution.

Partition coefficient testwork was conducted on iron phosphate by SGS Radiation Services in 2020. The measured partition coefficient results displayed in Table 13 indicates mobility of radioactive radium, lead and thorium would be extremely limited and presents low potential for groundwater impacts. The lower K_d value for uranium indicates some radionuclide mobility, however the potential for groundwater impact remains low due to the low concentration of uranium (^{238}U) within iron phosphate.

Table 13. Iron Phosphate Partition Coefficient Results

	R_d (K_d) Value for Radioactive Element *(mL/g)*
Radium	51,000 ± 20,000
Lead	>9,000
Uranium	342 ± 44
Thorium	47,200 ± 6,100

4.4.2.2 Radionuclide Leaching Potential

To characterise leaching potential of iron phosphate, the Australian Standard Leaching Procedure (ASLP) test was conducted at pH 2.9 and deionised water at pH 7. Iron phosphate has a typical pH between 3 – 4 which allows interpolation of the pH range used in ASLP tests to assess potential leachates. Results of ASLP tests are displayed in Table 14 with the available trigger level from ANZECC Livestock Drinking Water Guidelines (2000).

Table 14. Results of ASLP Tests on Iron Phosphate

	ASLP pH 2.9 *(mg/L)*	**ASLP DIW** *(mg/L)*	**ANZECC Trigger Level** *(mg/L)*
Thorium	0.019	0.008	-
Uranium	0.053	0.032	0.2

An ANZECC guideline is only available for uranium, of which the maximum leachate concentration is less than 30% of the trigger level.

The thorium concentration in leachate is very low and considerably lower than uranium despite the relative content of thorium greatly exceeding uranium within iron phosphate. The low thorium leachate concentration is attributed to the conversion of thorium species into insoluble thorium pyrophosphate (ThP_2O_7) during the cracking stage that inhibits thorium leaching from iron phosphate.

4.4.3 Summary of Environmental Assessment

4.4.3.1 Surface and Groundwater

An Environmental Site Assessment including a Baseline Hydrogeological Assessment (Ramboll, 2020) commissioned by Lynas confirmed that there are no recorded surface water bodies found on or within the vicinity of the REPF. The closest surface water body is an intermittent stream, located approximately 120 m to the south. Furthermore, there are a collection of lakes located to the south-east, approximately 2.5 km away. No proclaimed surface water bodies are within proximity to the REPF. No Ramsar wetlands were found to occur within 100 km of the REPF on the DWER Clearing Permit System Map (DWER 2019).

Depth to groundwater at the site is significant, measured in groundwater investigation bores at 38 mbgl (Ramboll, 2020) as is typical for the area away from modern drainage features (Kern, 1995). Regionally the water table elevation will generally mimic the topography, with groundwater flowing away from elevated areas and basement highs. The local groundwater flow direction is to the south, south west towards the Hannan palaeodrainage and associated playa lakes 6.5 km south south-west.

The baseline hydrogeological investigation also confirmed that field conductivity is generally high across onsite monitoring bores, ranging between 50,000 – 84,000 µs/cm, and not conducive to public drinking water, and limited in terms of stock watering potential.

4.4.4 Flora, Vegetation and Fauna

A direct impact to flora and vegetation on the REPF site will occur from ground disturbance over the 135 ha site, and removal of approximately 47 ha of vegetation.

This area also represents potential fauna habitat. Surveys have shown that all flora and fauna species, vegetation types and habitat are well represented outside of the development envelope. Proposed activities on the REPF site will not result in a significant impact on biological diversity and ecological integrity of the site and surrounds.

4.5 Summary of Radiological Impacts

The radiological impact to the environment from operation of the Iron Phosphate Storage Facilities at both the REPF and BSF have been assessed by considering migration of radionuclides in dust to the surrounding environment and potential leaching of radionuclides from iron phosphate.

The ERICA assessment determined the maximum radionuclide concentration increase in soil outside the Project area due to dust emissions to be well below the highly conservative screening dose rate. Results of the ERICA assessment indicates low radiological risk to non-human biota from the Project.

Radiometric testwork has shown iron phosphate to have very low radionuclide mobility potential, primarily due to the formation of the insoluble thorium pyrophosphate species during cracking. The leaching of radionuclides from iron phosphate therefore presents a low environmental risk that is further alleviated by HDPE lining of iron phosphate storage facilities to prevent any radionuclide migration into the subsurface.

The preceding assessment has shown radiological impacts of the REPF and BSF will be low.

The IAEA has previously confirmed the radiological risks to members of the public and the environment from LAMP operations are intrinsically low. The radiological risk profile of the REPF will be equivalent to LAMP due to the inherently low input radioactivity of the process.

Doses to occupational workers are estimated to be less than 2 mSv/year, which is well below the 20 mSv/year limit for radiation workers. Public doses are also expected to be low, with the closest residence estimated at approximately 0.3 mSv/year, well below the 1 mSv/year limit. There is very low risk of radiological impact to the environment through either interaction with non-human biota or radionuclide leaching from iron phosphate.

The potential risk associated with seepage from dry stacked iron phosphate will be mitigated through the installation of a synthetic liner at the base of the storage facility prior to commissioning. In addition, the network of nested groundwater monitoring bores will continue to be monitored for key radiological and other parameters during the life of the project.

Development of a Closure Plan will be implemented in consultation with all applicable regulatory agencies and authorities including Radiological Council, DMIRS, EPA and key stakeholders to ensure that any residual iron phosphate remaining onsite post closure will be safe, stable and non-polluting. Lynas is continuing to investigate offsite disposal options (including return of iron phosphate to Mt Weld) as well as re-use opportunities of iron phosphate as a soil conditioner.

5 SUMMARY

The radiation impact assessment summarised in Table 15 shows estimated doses are well below the limits to both workers and the public with no impact to the environment expected. Through application of the ALARA principle of radiation protection, it is expected there will be no radiological impact to workers, the public or environment.

Table 15. Summary of Radiological Impact from REPF Operation

Impacted Group	*Estimated Dose (mSv/year)*	*Dose Limit (mSv/year)*
Workers	1.6	20.0
Public	0.3	1.0
Environment	No measurable impact	-

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APPENDICES

Appendix A: 238U and 232Th decay series
Appendix B: Kalgoorlie-Boulder wind rose
Appendix C: Public Critical Groups
Appendix D: Site Layout
Appendix E: Air Dispersion and Dust Deposition Modelling Outputs
Appendix F: ERICA Assessments

Appendix A: ^{238}U and ^{232}Th Decay Series

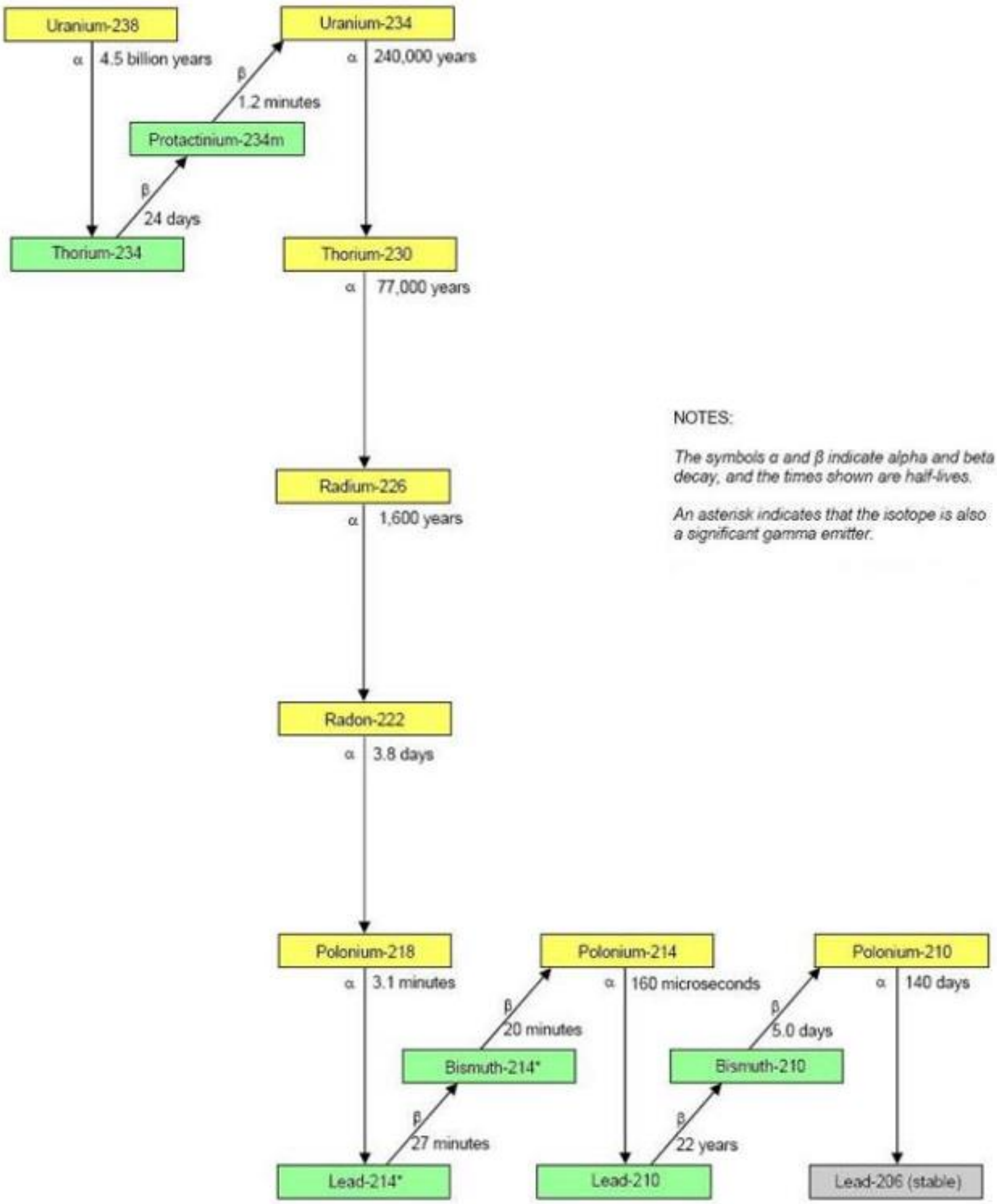

Figure 5. ^{238}U Decay Chain

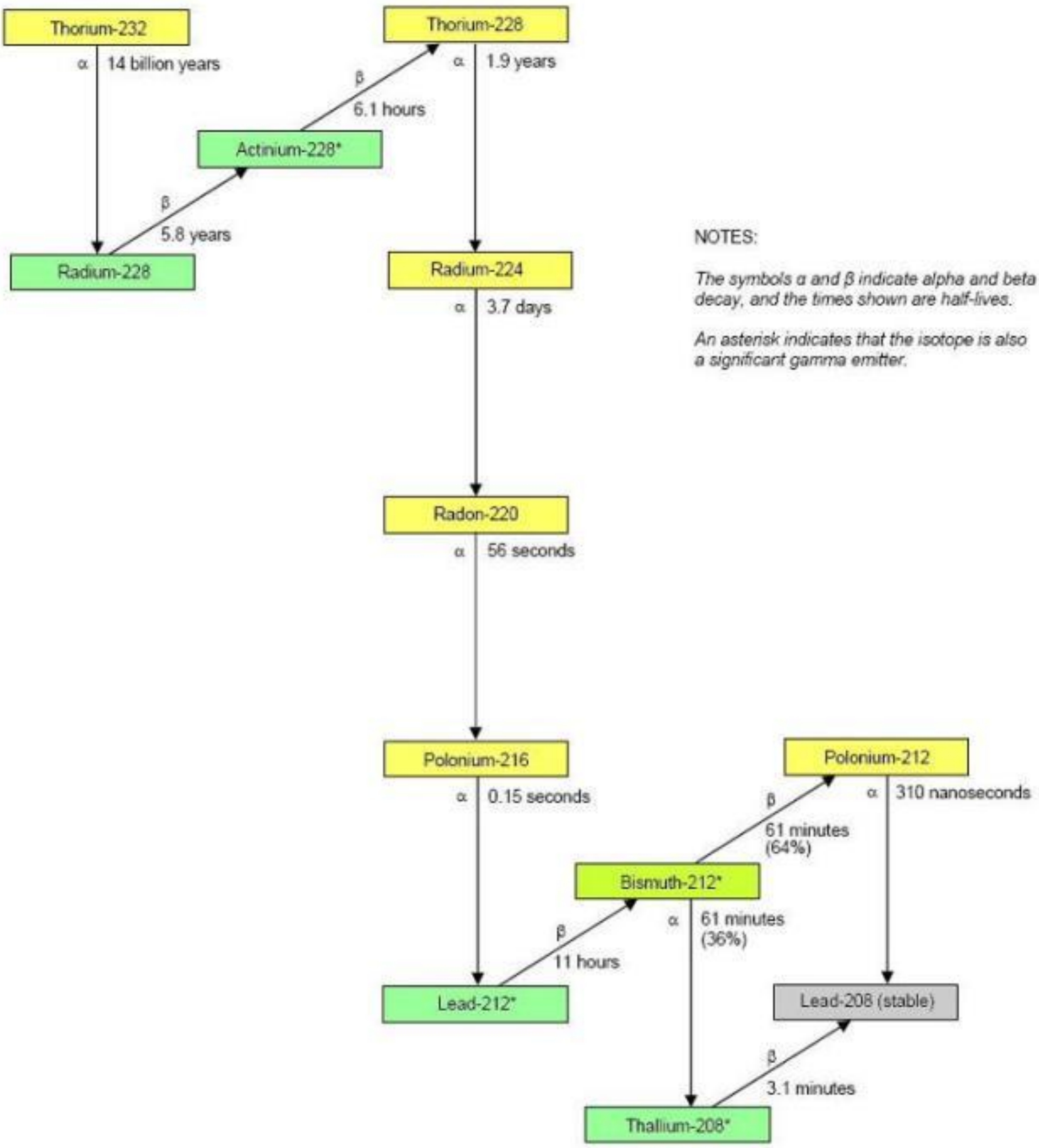

Figure 6. ^{232}Th Decay Chain

Appendix B: Kalgoorlie-Boulder Wind Rose

Rose of Wind direction versus Wind speed in km/h (22 Mar 1939 to 31 Jul 2019)
Custom times selected, refer to attached note for details
KALGOORLIE-BOULDER AIRPORT
Site No: 012038 • Opened Feb 1939 • Still Open • Latitude: -30.7847° • Longitude: 121.4533° • Elevation 365.m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

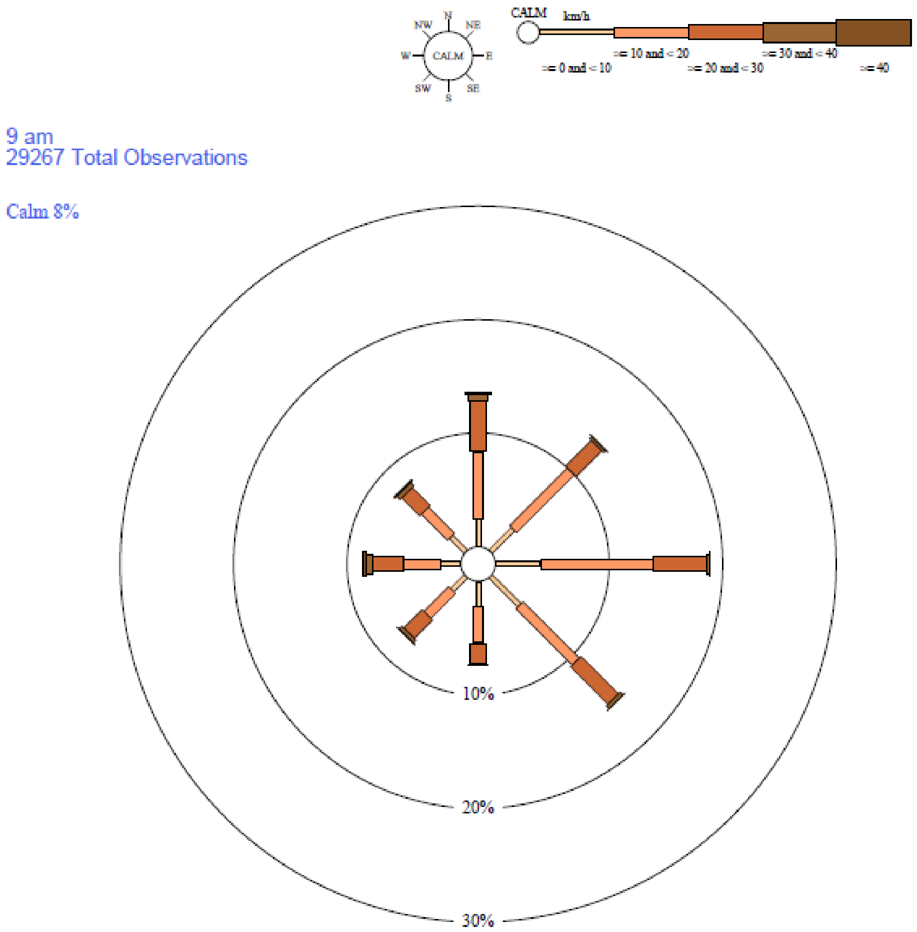

Figure 7. Kalgoorlie-Boulder Wind Rose (BOM, 2019)

Appendix C: Public Critical Groups

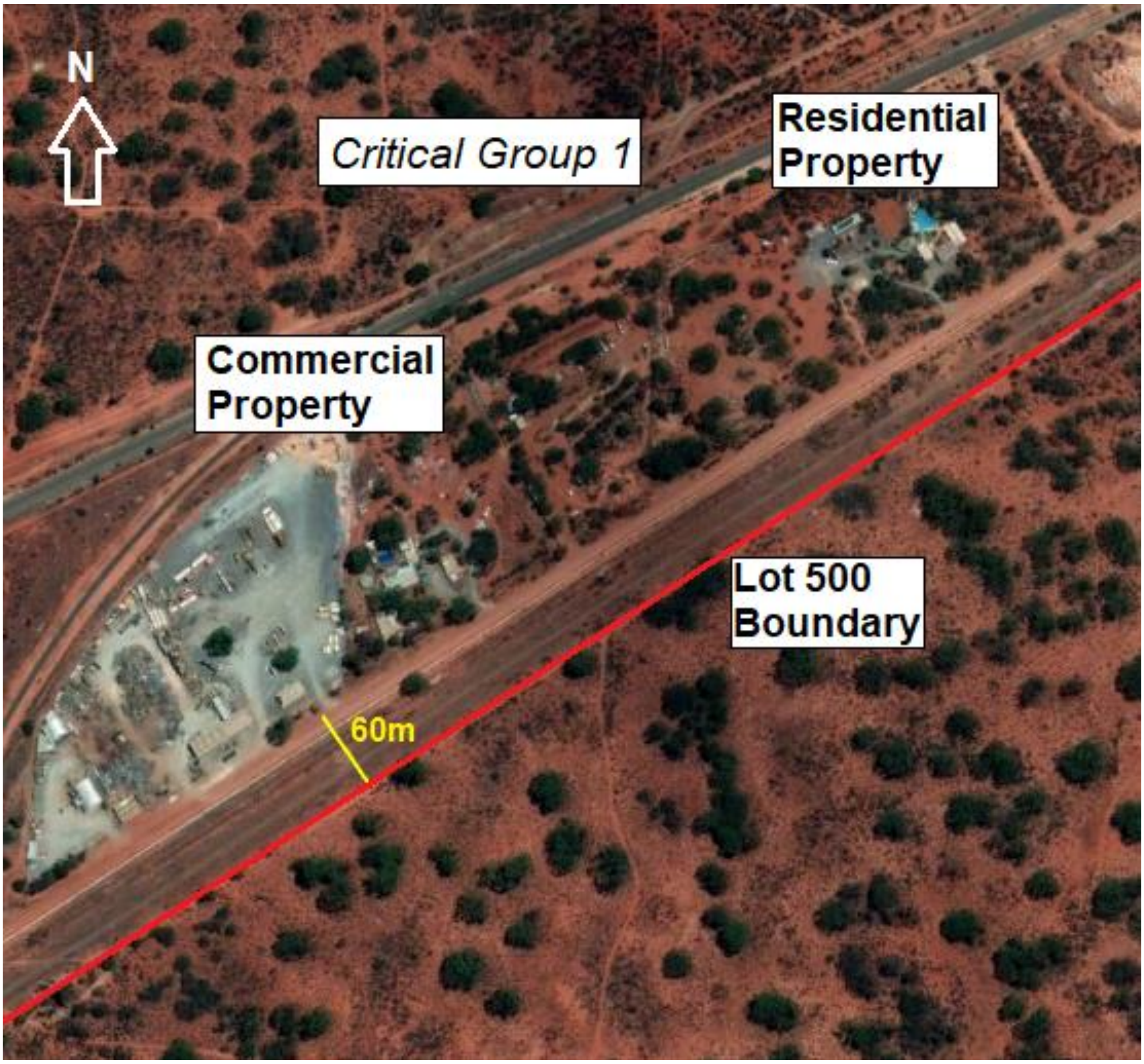

Figure 8. Critical Group 1

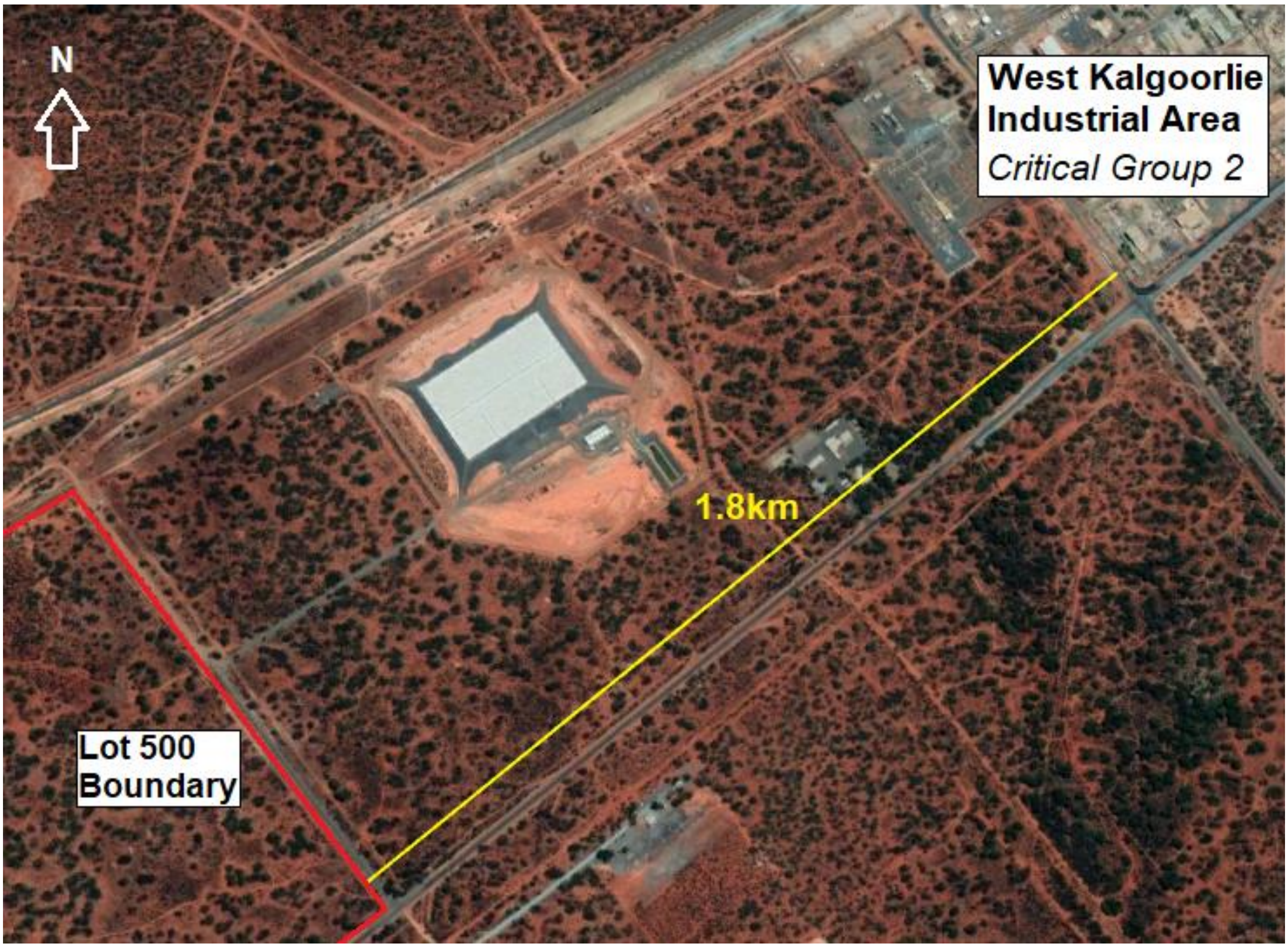

Figure 9. Critical Group 2

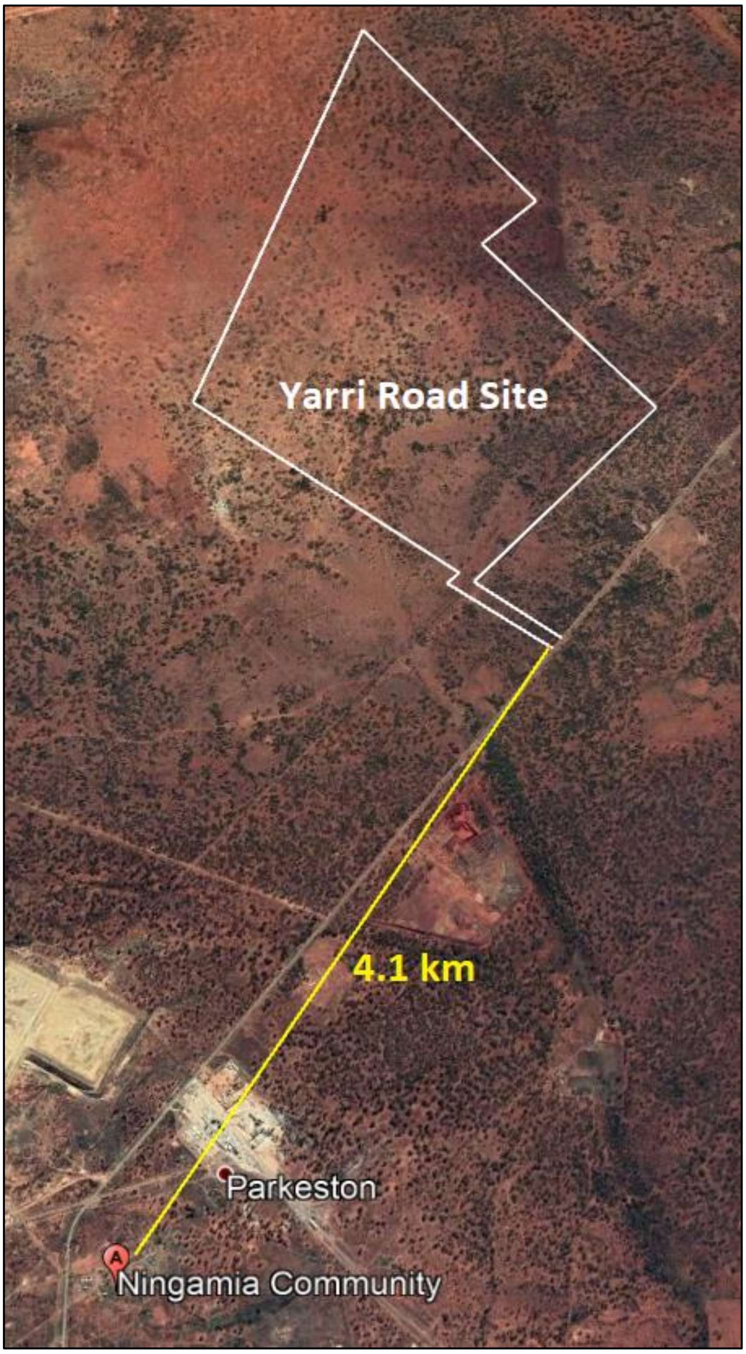

Figure 10. Critical Group 3 (Ningamia Community)

Appendix D: REPF Site Layout

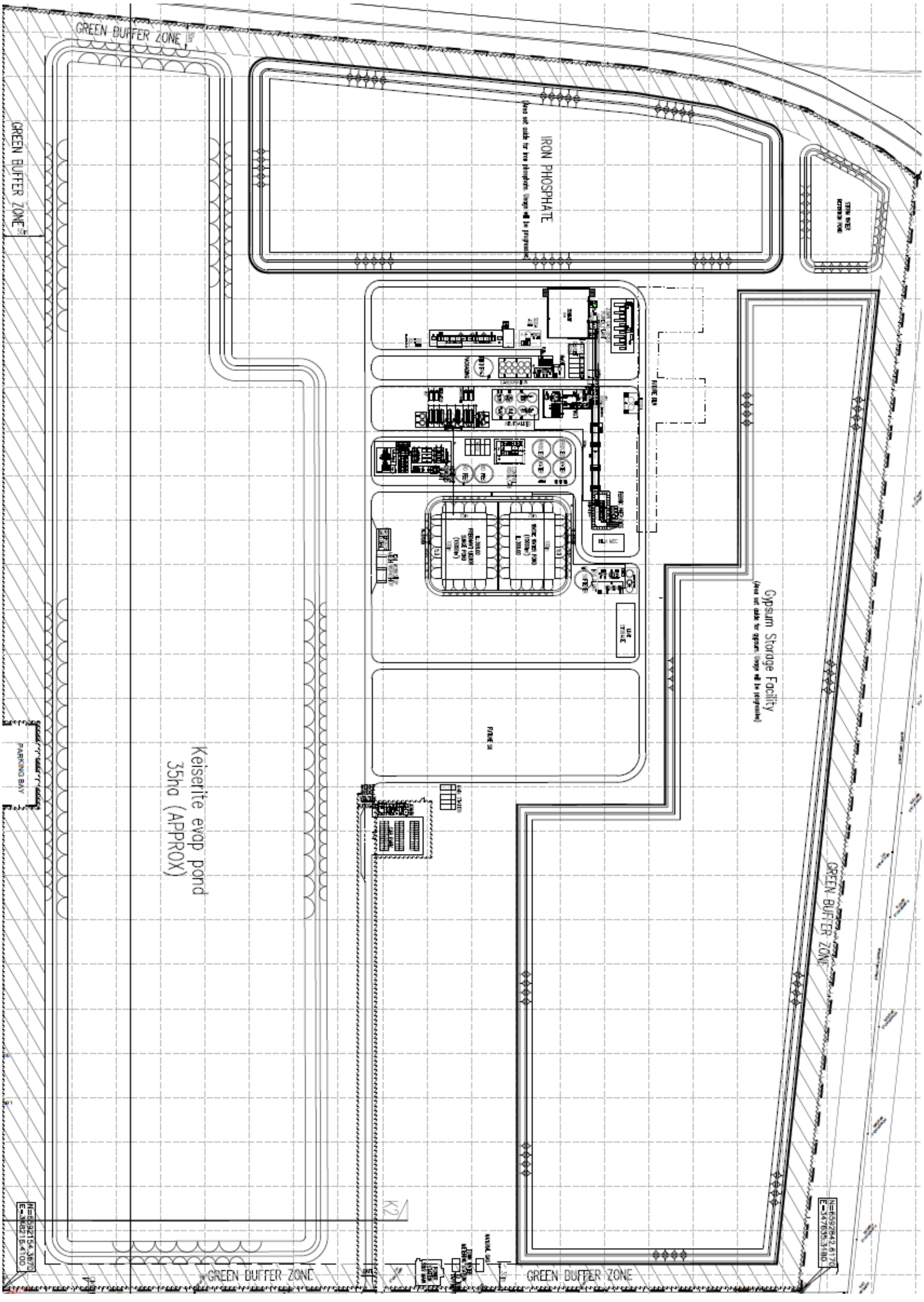

Figure 11. REPF Site Layout

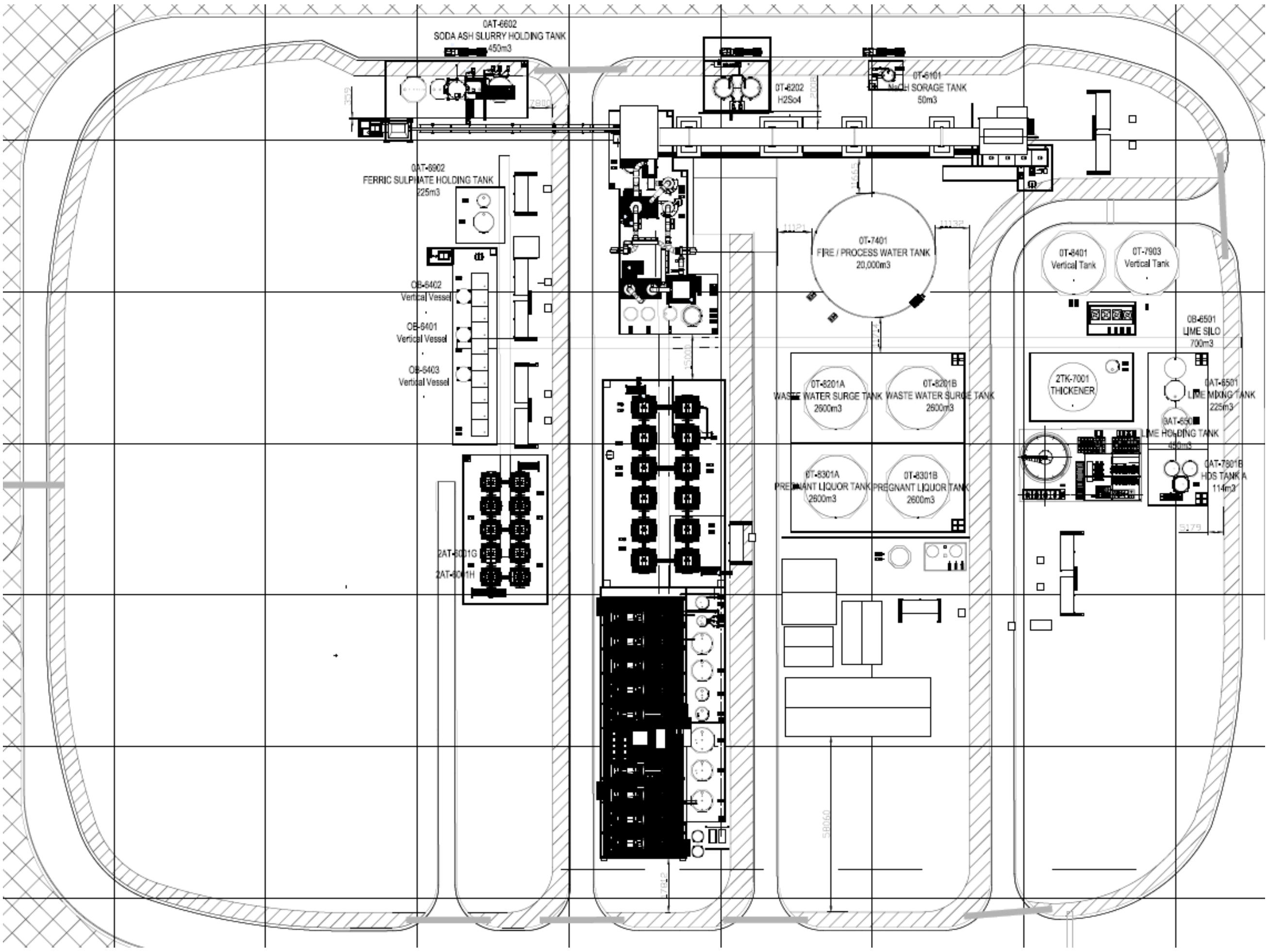

Figure 12. REPF Plant Layout

Figure 13. BSF Proposed Site Layout

Appendix E: Air Dispersion and Dust Deposition Modelling Outputs

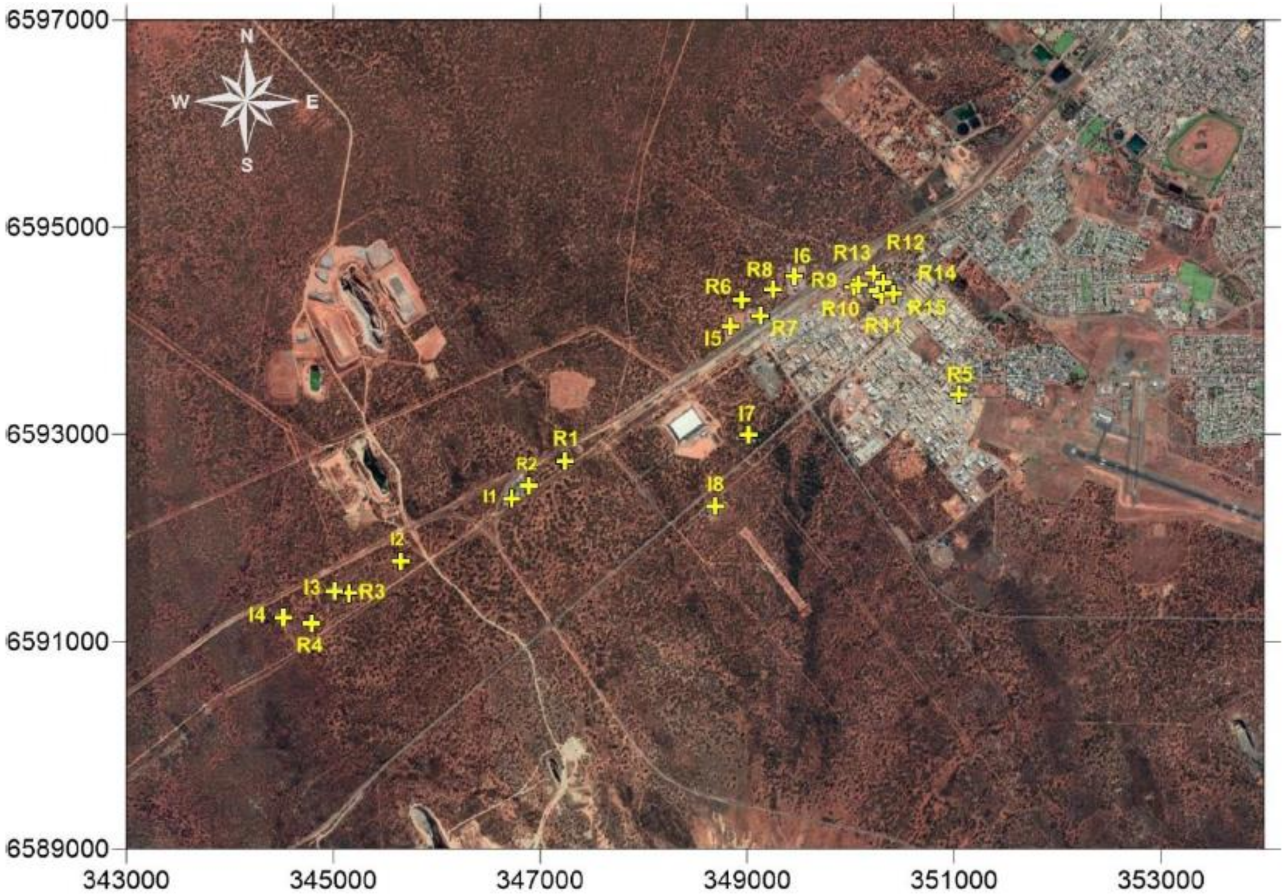

Figure 14. Air Dispersion Modelling Sensitive Receptors (REPF Site Only)

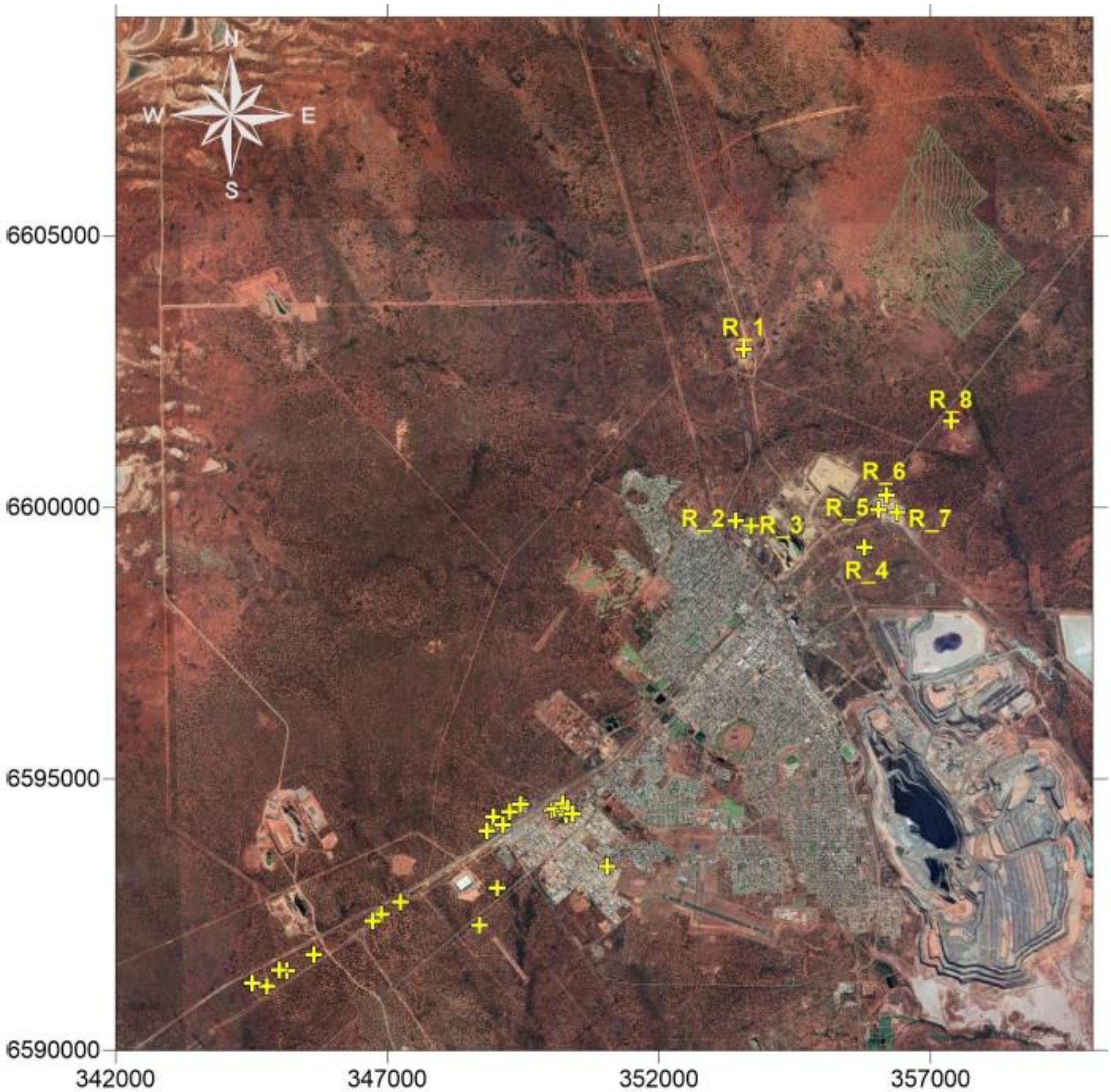

Figure 15. Air Dispersion Modelling Sensitive Receptors (Total Project)

ID	Coordinates (m)		Address	Maximum GLC at Sensitive Receptor Locations (ug/m³)									
				TSP 24hr		PM_{10} 24hr		$PM_{2.5}$ 24hr		SO_2 1hr		SO_2 24hr	
	x	y		ug/m³	% of 90	ug/m³	% of 50	ug/m³	% of 25	ug/m³	% of 571	ug/m³	% of 229
R1	347245	659737	Lot 317 Hall Road	3.9	4.3%	2.9	5.7%	1.0	4.1%	22.7	4.0%	7.4	3.2%
R2	346886	6592502	Lot 187 Hall Road	4.3	4.8%	3.0	6.0%	1.2	4.6%	25.5	4.5%	4.4	1.9%
R3	345151	6591473	Lot 183 Hall Road	3.7	4.1%	2.8	5.5%	0.8	3.1%	14.8	2.6%	5.8	2.5%
R4	344787	6591178	Lot 272 Hall Road	3.0	3.4%	2.0	4.1%	0.7	2.6%	13.6	2.4%	4.4	1.9%
R5	351047	6593385	Cnr Epis Street & Kybo Street	2.7	3.0%	1.6	3.2%	0.6	2.5%	8.6	1.5%	3.3	1.5%
R6	348949	6594301	5 Treloar Road	2.7	3.0%	1.4	2.7%	0.7	2.7%	11.1	1.9%	2.0	0.9%
R7	349129	6594146	Lot 184 Western Road	2.9	3.2%	1.4	2.9%	0.7	2.8%	10.4	1.8%	2.1	0.9%
R8	349253	6594398	Lot 270 Western Road	2.9	3.2%	1.4	2.9%	0.7	2.8%	9.2	1.6%	2.1	0.9%
R9	350033	6594421	85 Wortley Street	3.0	3.4%	1.5	3.0%	0.8	3.0%	9.4	1.6%	1.7	0.7%
R13	350079	6594445	83 Wortley Street	3.0	3.4%	1.5	3.0%	0.8	3.0%	9.2	1.6%	1.7	0.7%
R10	350260	6594389	4 Hunter Street	3.2	3.6%	1.6	3.2%	0.7	2.9%	8.8	1.5%	1.9	0.8%
R11	350297	6594337	6 Hunter Street	3.2	3.6%	1.6	3.2%	0.7	2.8%	8.9	1.6%	1.9	0.8%
R12	350226	6594550	Cnr Hunter & Wortley Street	3.1	3.5%	1.5	3.1%	0.8	3.0%	8.7	1.5%	1.7	0.7%
R14	350316	6594465	Hunter Street	3.2	3.6%	1.6	3.2%	0.7	2.9%	8.6	1.5%	1.8	0.8%
R15	350413	6594357	Hunter Street	3.3	3.7%	1.6	3.3%	0.7	2.9%	8.5	1.5%	1.8	0.8%
I1	346723	6892380	Lot 198 Hall Road	5.5	6.1%	3.8	7.6%	1.3	5.4%	25.5	4.5%	7.0	3.0%
I2	345652	6591770	Vacant crown land	3.8	4.2%	2.7	5.4%	0.9	3.4%	20.8	3.6%	5.6	2.5%
I3	345013	6591484	Lot 273 Hall Road	3.5	3.9%	2.6	5.3%	0.8	3.1%	14.5	2.5%	5.6	2.4%
I4	344516	6591233	Lot 300 Hall Road	2.9	3.3%	2.0	4.1%	0.6	2.5%	12.4	2.2%	4.6	2.0%
I5	348838	6594047	Lot 193 Western Road	2.7	3.0%	1.4	2.7%	0.7	2.7%	10.1	1.8%	2.2	1.0%
I6	349457	6594526	Lot 181 Western Road	2.9	3.3%	1.5	2.9%	0.7	2.9%	9.3	1.6%	1.9	0.8%
I7	349015.6	6592994	Western Power	2.8	3.1%	1.6	3.2%	0.6	2.6%	12.0	2.1%	3.2	1.4%
I8	348693.6	6592303	Rifle Club	2.8	3.1%	1.9	3.7%	0.6	2.5%	16.8	2.9%	4.1	1.8%
R_1	353557	6602912	Speedway	13.8	15.3%	6.8	13.6%	2.9	11.5%	2.9	0.5%	0.8	0.3%
R_2	353409	6599757	Hannans North	6.2	6.9%	3.0	5.9%	1.4	5.7%	2.9	0.5%	0.5	0.2%
R_3	353690	6599661	Goldfield Institute	6.2	6.9%	3.1	6.2%	1.5	6.2%	3.0	0.5%	0.6	0.2%
R_4	355787	6599261	Ningamia	7.6	8.5%	3.8	7.6%	1.8	7.4%	2.6	0.4%	0.5	0.2%
R_5	356035	6599951	Cockburn Cement	10.0	11.1%	4.7	9.4%	2.1	8.5%	2.9	0.5%	0.5	0.2%
R_6	356186	6600222	Duratec Australia	9.6	10.7%	4.7	9.4%	2.3	9.1%	2.9	0.5%	0.5	0.2%
R_7	356373	6599918	Parkeston Industrial	10.4	11.5%	5.1	10.3%	2.4	9.5%	2.8	0.5%	0.5	0.2%
R_8	357379	6601584	Yarri Rd Waste Facility*	20.3	22.6%	9.9	19.8%	3.3	13.2%	2.3	0.4%	0.4	0.2%

Note: Highest, second highest and third highest results for each parameter is highlighted.
* Location is entrance/exit point on Yarri Road to the long-term storage facility

Figure 16. Air Dispersion Modelling Results

ID		Coordinates (m)		PM_{10} Maximum GLC at Sensitive Receptor Locations			
		x	y	ug/m²/s (30 day average)	mg/m²/month	ug/m²/s (Annual Average)	mg/m²/year
R1	Lot 317 Hall Road	347.245	6592.737	4.15E-05	0.11	2.53E-05	0.80
R2	Lot 187 Hall Road	346.886	6592.502	9.65E-05	0.25	2.84E-05	0.90
R3	Lot 183 Hall Road	345.151	6591.473	6.56E-05	0.17	3.36E-05	1.06
R4	Lot 272 Hall Road	344.787	6591.178	4.26E-05	0.11	2.69E-05	0.85
R5	Cnr Epis Street & Kybo Street	351.047	6593.385	7.66E-05	0.20	2.27E-05	0.72
R6	5 Treloar Road	348.949	6594.301	6.79E-05	0.18	1.94E-05	0.61
R7	Lot 184 Western Road	349.129	6594.146	3.24E-05	0.08	1.59E-05	0.50
R8	Lot 270 Western Road	349.253	6594.398	2.35E-05	0.06	1.39E-05	0.44
R9	85 Wortley Street	350.033	6594.421	2.04E-05	0.05	1.29E-05	0.41
R13	83 Wortley Street	350.079	6594.445	2.04E-05	0.05	1.29E-05	0.41
R10	4 Hunter Street	350.26	6594.389	2.01E-05	0.05	1.31E-05	0.41
R11	6 Hunter Street	350.297	6594.337	2.01E-05	0.05	1.33E-05	0.42
R12	Cnr Hunter & Wortley Street	350.226	6594.55	2.05E-05	0.05	1.29E-05	0.41
R14	Hunter Street	350.316	6594.465	2.02E-05	0.05	1.32E-05	0.41
R15	Hunter Street	350.413	6594.357	2.01E-05	0.05	1.36E-05	0.43
I1	Lot 198 Hall Road	346.723	6592.38	3.89E-04	1.01	7.32E-05	2.31
I2	Vacant crown land	345.652	6591.77	8.43E-05	0.22	4.04E-05	1.27
I3	Lot 273 Hall Road	345.013	6591.484	6.41E-05	0.17	3.19E-05	1.00
I4	Lot 300 Hall Road	344.516	6591.233	4.65E-05	0.12	2.59E-05	0.82
I5	Lot 193 Western Road	348.838	6594.047	7.26E-05	0.19	2.14E-05	0.68
I6	Lot 181 Western Road	349.457	6594.526	2.16E-05	0.06	1.30E-05	0.41
I7	Western Power	349.016	6592.994	2.31E-04	0.60	5.14E-05	1.62
I8	Rifle Club	348.694	6592.303	2.73E-04	0.71	5.13E-05	1.62
Additional sensitive receptor locations associated with Yarri Road facility in operation							
R_1	Speedway	353.557	6602.912	5.73E-05	0.15	2.99E-05	0.94
R_2	Hannans North	353.409	6599.757	3.93E-05	0.10	1.90E-05	0.60
R_3	Goldfield Institute	353.69	6599.661	3.92E-05	0.10	1.96E-05	0.62
R_4	Ningamia	355.787	6599.261	2.81E-05	0.07	1.63E-05	0.51
R_5	Cockburn Cement	356.035	6599.951	3.42E-05	0.09	1.99E-05	0.63
R_6	Duratec Australia	356.186	6600.222	3.85E-05	0.10	2.17E-05	0.68
R_7	Parkeston Industrial	356.373	6599.918	3.34E-05	0.09	2.05E-05	0.65
R_8	Yarri Rd Waste Facility	357.379	6601.584	8.98E-05	0.23	3.87E-05	1.22

Figure 17. Dust Deposition Modelling Results

Appendix F: ERICA Assessments

Assumptions:

- 20-year project duration
- Soil area of 1 m^2
- Total soil mixing to 10 mm depth
- Soil density of 1 m^3 = 1 tonne
- Soil mass available for mixing is 10 kg
- ^{238}U activity: 0.3 Bq/g
- ^{232}Th activity: 6.1 Bq/g

Table 16. ERICA Assessment Input Determination

	REPF ***I1 Receptor***	**BSF** ***R_8 Receptor***
Dust Deposition (*g/m²*.*month*)	2.31	1.22
Dust Deposited *(20 yrs)*	0.28	0.15
^{238}U Deposited (*Bq/20yrs*)	1.7	0.9
^{232}Th Deposited (*Bq/20yrs*)	33.9	17.9
$\Delta^{238}U$ Soil Concentration (*Bq/kg*)	**0.2**	**0.1**
$\Delta^{232}Th$ Soil Concentration (*Bq/kg*)	**3.4**	**1.8**

Radionuclide concentration inputs for ERICA assessment:

- REPF:
  - 0.2 Bq/kg ^{238}U and decay chain
  - 3.4 Bq/kg ^{232}Th and decay chain
- BSF:
  - 0.1 Bq/kg ^{238}U and decay chain
  - 1.8 Bq/kg ^{232}Th and decay chain

Table 17. ERICA Assessment Summary

Total (Internal + External) Dose Rate ***(µGy/hr)***	**REPF** ***I1 Receptor***	**BSF** ***R_8 Receptor***
Th-232	2.98E-02	1.58E-02
Ra-228	1.20E-03	6.36E-04
Th-228	2.41E-01	1.27E-01
U-238	4.40E-03	2.20E-03
U-234	5.00E-03	2.50E-03
Th-230	2.05E-03	1.02E-03
Ra-226	1.97E-02	9.87E-03
Pb-210	9.89E-05	4.94E-05
Po-210	1.59E-02	7.94E-03
Σ Lychen & Bryophytes Risk Quotient	**0.3**	**0.2**
Dose Rate Screening Value (*µGy/hr*)	**1.0**	**1.0**
Percent of Screening Value	**30%**	**20%**