

Appendix S

Radiation Risk Assessment





ILUKA RESOURCES LIMITED

TECHNICAL REPORT

ILUKA-TR- 1725034

BALRANALD MINERAL SANDS PROJECT

RADIATION RISK ASSESMENT

BY

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EXECUTIVE SUMMARY

Iluka Resources Limited (Iluka) proposes to develop a mineral sands mine in south-western New South Wales (NSW), known as the Balranald Mineral Sands Project. The Balranald Project includes construction, mining and rehabilitation of two linear mineral sand deposits, known as West Balranald and Nepean. Iluka is seeking development consent under Part 4, Division 4.1 of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) for the Project. Division 4.1 specifically relates to the assessment of development deemed to be State significant development (SSD). The Balranald Project is a mineral sands mining development which meets the requirements for SSD.

An application for SSD must be accompanied by an environmental impact statement (EIS), prepared in accordance with the NSW Environmental Planning and Assessment Regulation 2000 (EP&A Regulation). As part of the EIS, an assessment of the radiation risk associated with the Project was conducted. The objectives of the radiation assessment were to:

- Describe and characterise sources of radiation and identify current levels of radiation within the Balranald Project area.
- Determine if any materials are classified as radioactive waste according to NSW and Commonwealth criteria.
- Assess the risk and describe measures to minimise, mitigate and control radiation exposure to the public and workforce during mining, processing and transport activities.
- Describe radiation management and monitoring plans to be implemented to comply with RPS 9, the 'Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)' (ARPANSA 2005).

The results of a review of the baseline conditions on the radionuclide content of soil in the project area (the head of chain specific activities and the total contained activities) of the five lithologies (mine materials) are summarised in Table A.

Table A: Specific head-of-chain and total contained activities of mine materials

Radionuclide Results(Bq/g)	Balranald Mine Materials				
	Surface Soils (SS)	Non-Saline overburden (NSOB)	Saline overburden (SOB)	Organic overburden (OOB)	Mineral Sands Ore
Head of Chain Specific Activity: U & Th (Bq/g)	0.087	0.121	0.037	0.16	1.818
Total contained activity	1.5	1.9	0.57	1.0	20.9

Based on the information presented in Table A, it was concluded that none of the (five different lithologies: surface soils (SS); non-saline overburden (NSOB); saline overburden

(SOB); organic overburden (OOB) or mineral sands ore are classified as “radioactive ore”, or as “radioactive substances” under the *Radiation Control Act 1990*.

Key findings from the baseline conditions for groundwater included the following:

- With respect to human health screening (i.e. ingestion of water), only one water (sampled from WB20) exceeded the Australian Drinking Water Guidelines dose threshold of 1 mSv per year, largely driven by uranium-238, and radium-228 from the thorium series. Notwithstanding the activity, it is not expected that such water would be suitable for potable use due to salinity.
- Radium 228 appears to be generally elevated in all waters sampled, relevant to WHO radium 228 screening criterion for drinking waters (0.1 Bq/L), independent of zones / domains.

Key conclusions from the classification test-work of Mining By Products (MBPs) samples have identified that:

- Based on Part 3 of the *NSW Waste Classification Guidelines* (NSW DoECC 2008) relating to wastes containing radioactive material, one stream (the combined monazite reject) is likely to be classified as Hazardous Solid Waste.
- Based on Part 3 of the *NSW Waste Classification Guidelines* (NSW DoECC 2008) relating to wastes containing radioactive material, the remaining MBP ie the Primary Dry Circuit (PDC) ilmenite, Hyti (leucogene), combined zircon wet tails, rutile wet concentrate circuit, PDC conductors oversize and float plant tails streams are likely to be classified as Restricted Solid Waste.

In addition to the review of baseline conditions and waste characterisation activities, and assessment of the radiological risks to human health and the environment associated with the Balranald Project was also completed. The results of the assessment are provided in Table B.

Table B: Summary of the radiological risks to human health and the environment associated with the Balranald Project

Project element	Risk to human health and the environment
Balranald and Nepean mine operations	With the implementation of identified management measures the risk of harm to employees, members of the public and the environment from the handling and stockpiling of the Heavy Mineral Concentrate (HMC), mineral concentrates, Mineral Separation Plant (MSP) process waste and blended process waste is considered to be negligible.
Transport of mineral concentrates and MSP process wastes	With the implementation of identified management measures the risk of harm to employees, members of the public and the environment from the transport to mineral concentrates and MSP process waste is considered to be negligible.

Based on the existing environment baseline information collected for the Project, waste characterisation work and results from the completed radiological risk assessment it is considered that with the implementation of the identified mitigation measures, the Project will present a negligible radiological risk to human health and the environment.

ABBREVIATIONS

The following abbreviations shall apply:

- **ADWG** – Australian Drinking Water Guideline
- **ALARA** – As Low As Reasonable Achievable
- **ANSTO** – Australian Nuclear Science and Technology Organisation
- **ARPANSA** – Australian Radiation Protection and Nuclear Safety Agency
- **DNA** – Delayed neutron Activation
- **EIS** – Environmental Impact Statement
- **EP&A Act** – Environmental Planning and Assessment Act 1979
- **EPBC Act** – Environment Protection and Biodiversity Conservation Act 1999
- **GME** – Groundwater Monitoring Event
- **GMP** – Groundwater Monitoring Plan
- **HMC** – Heavy Mineral Concentrate
- **ICP-MS** – Inductively Coupled Plasma Mass Spectrometry
- **ICRP** – International Commission on Radiological Protection
- **ISP** – Ilmenite Separation Plant
- **MBP's** – Mining by-products
- **MSP** – Mineral Separation Plant
- **MUP** – Mining Unit Plant
- **NAA** – Neutron activation Analysis
- **NORM** – Naturally Occurring Radioactive Material
- **NSOB** – Non Saline Overburden
- **NSW** – New South Wales
- **OOB** – Organic Overburden
- **ORE** – Mineral Sand Ore
- **PCP** – Pre Concentrator Plant
- **PoEO Act** – Protection of the Environment Operations Act, 1997
- **PoEO Regulation** – Protection of the Environment Operations (Waste) Regulation, 2014
- **RC Act** – Radiation Control Act, 1990
- **RC Regulation** – Radiation Control Regulation, 2003
- **RMP** – Radiation Management Plan
- **RWMP** – Radiation Waste Management Plan
- **SA** – Specific Activity
- **SEAR** – Secretary Environmental Assessment Requirements
- **SOB** – Saline Overburden
- **SSD** – State Significant Development
- **SS** – Surface Soils
- **TSF** – Tailing Storage Facility
- **UNSCEAR** – United Nations Scientific Committee on the Effects of Atomic Radiation
- **WCP** – Wet Concentrator Plant
- **WHIMS** – Wet Magnetic High Intensity Magnetic Separation
- **WHO** – World Health Organisation
- **ROM** – Run of Mine
- **XRF** – X-Ray Fluorescence Spectrometry

1. INTRODUCTION

1.1 Overview

Iluka Resources Limited (Iluka) proposes to develop a mineral sands mine in south-western New South Wales (NSW), known as the Balranald Mineral Sands Project (the Balranald Project). The Balranald Project includes construction, mining and rehabilitation of two linear mineral sand deposits, known as West Balranald and Nepean. These mineral sands deposits are located approximately 12 kilometres (km) and 66 km north-west of the town of Balranald. Figure 1 shows the location of the Balranald Project and its major features.

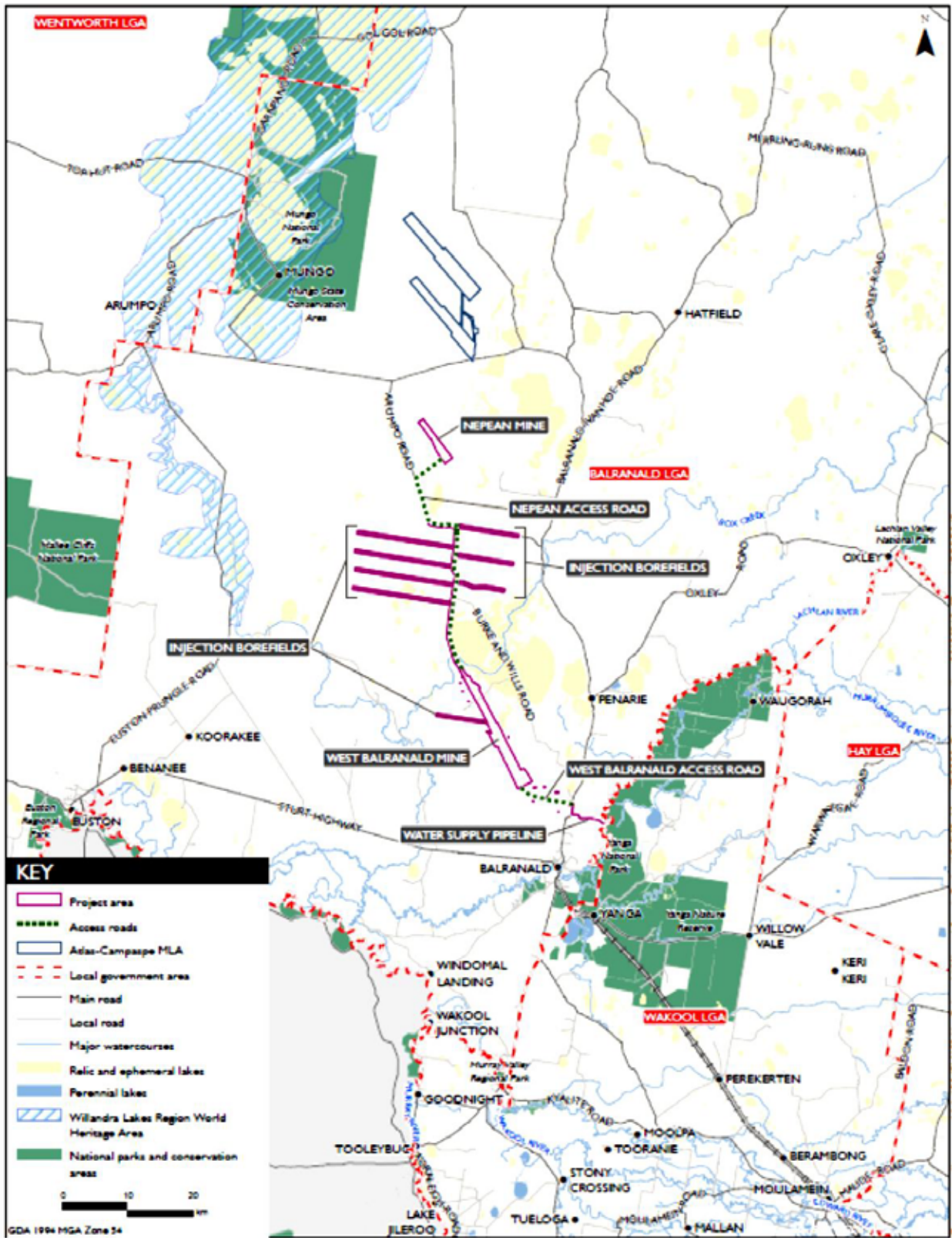
Iluka is seeking development consent under Part 4, Division 4.1 of the NSW Environmental Planning and Assessment Act 1979 (EP&A Act) for the Balranald Project, broadly comprising:

- open cut mining of the West Balranald and Nepean deposits, referred to as the West Balranald and Nepean mines, including progressive rehabilitation;
- processing of extracted ore to produce heavy mineral concentrate (HMC) and ilmenite;
- road transport of HMC and ilmenite to Victoria;
- backfilling of the mine voids with overburden and tailings, including transport of by-products from the processing of HMC in Victoria for backfilling in the mine voids;
- return of groundwater extracted prior to mining to its original aquifer by a network of injection borefields;
- an accommodation facility for the construction and operational workforce;
- gravel extraction from local sources for construction requirements; and
- a water supply pipeline from the Murrumbidgee River to provide fresh water during construction and operation.

Separate approvals are being sought for:

- the construction of a transmission line to supply power to the Balranald Project; and
- project components located within Victoria.

Figure 1: Project location



Source: EMM 2015

1.2 Approval process

In NSW, the Balranald Project requires development consent under Part 4, Division 4.1 of the EP&A Act. Part 4 of the EP&A Act relates to development assessment. Division 4.1 specifically relates to the assessment of development deemed to be State significant development (SSD). The Balranald Project is a mineral sands mining development which meets the requirements for SSD.

An application for SSD must be accompanied by an environmental impact statement (EIS), prepared in accordance with the NSW *Environmental Planning and Assessment Regulation 2000* (EP&A Regulation).

An approval under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is required for the Balranald Project (with the exception of the transmission line which will be subject to a separate EPBC Act referral process). A separate EIS will be prepared to support an application in accordance with the requirements of Part 8 of the EPBC Act.

1.3 Secretary's environmental assessment requirements

The EIS has been prepared to address specific requirements provided in the Secretary's environmental assessment requirements (SEARs) for the SSD application, issued on 2 December 2014.

This radiation assessment has been prepared to address specific requirements for radiation in the SEARs. The SEARs relating to radiation are listed in Table 1 and include the section of the report where they are addressed.

Table 1: Relevant SEARs for this assessment

Requirement	Section addressed
A detailed description of the management of concentrate and back-loaded waste material during transport, storage and handling	5, 6 and 7

1.4 Purpose of this report

Iluka has prepared this assessment for the SSD application for the Balranald Project. A number of consultants have been commissioned to undertake related investigations including:

- Earth Systems: *Balranald Mineral Sands Project Preliminary Mine Materials Radiation Assessment* (February 2015) (Appendix A);
- Earth Systems: *NSW Waste Classification of Hamilton Mining By-Products* (March 2015) (Appendix B); and
- Land and Water Consulting: *Pre-mining Radionuclide Groundwater Monitoring, Balranald Mineral Sands Project, Murray Basin, New South Wales*; (February 2015) (Appendix C).

1.5 Scope of Assessment

Iluka has prepared this radiation assessment based on the above listed investigations. The key objectives of the assessment include:

- Describe and characterise sources of radiation and identify current levels of radiation at the Balranald Project;
- Determine if any materials are classified as radioactive waste according to NSW and Commonwealth criteria;
- Assess the risk and describe measures to minimise, mitigate and control radiation exposure to the public and workforce during mining, processing and transport activities; and
- Describe radiation management and monitoring plans to be implemented to comply with RPS 9 the 'Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)' the (the Code) (ARPANSA 2005).

1.6 Report structure

The structure of this report is as follows:

- Chapter 1 provides an introduction to the radiation assessment, including an overview of the Balranald Project, and the purpose and scope of the radiation assessment;
- Chapter 2 provides an overview of the theory of radiation and exposure pathways in the mineral sands industry;
- Chapter 3 provides an overview of the relevant legislation, policies, guidelines and codes to the Balranald Project;
- Chapter 4 provides an overview of the project considering project description, area, tailings and by-product management as well as transport;
- Chapter 5 defines the baseline conditions for the radionuclide content of soils in the project area as well as the background radionuclide concentrations in groundwater;
- Chapter 6 outlines materials characterisation and classification under the NSW *Radiation Control Act 1990* and NSW *Protection of the Environment Operations Act 1997* for both mine materials and by-products;
- Chapter 7 discusses the outcomes of the radiological impact assessment for the Balranald Project's and includes impacts on both human and environmental receptors, inclusive of future mitigation and management measures;
- Chapter 8 provides the conclusion of the radiation assessment; and
- Chapter 9 lists the reference material that serves as baseline for the radiation assessment.

2. BACKGROUND TO MINERAL SANDS RADIATION

2.1 Radiation theory

2.1.1 *Atoms, isotopes and radioactive decay*

All matter is made of atoms. Atoms have a central core (nucleus) of positively charged protons and neutral neutrons. The nucleus is surrounded by a cloud of negatively charged electrons. Normally, the number of electrons equals the number of protons so that the charges balance out, leaving the atom overall electrically neutral. The number of protons (and thus the number of electrons) determines the chemical properties of the atom. Thus every atom with 1 proton is an atom of hydrogen, and every atom with 92 protons is an atom of uranium. The number of neutrons in a particular element is variable. Hydrogen usually has none, but can have one or two. Uranium most commonly has 146 neutrons but can have from about 125 to 150. Atoms of an element with different numbers of neutrons are called "isotopes" of that element: thus hydrogen has three isotopes and uranium 25. An isotope is generally written with its normal chemical symbol and its "mass number" – the total number of protons and neutrons in its nucleus. Thus the commonest isotope of uranium has 92 protons and 146 neutrons and is written ^{238}U (pronounced and sometimes written U-238).

Not all combinations of protons and neutrons in a nucleus are stable: some are unstable, and break down, in the process emitting energy in the form of sub-atomic particles or electromagnetic radiation, and forming a lighter nucleus. This process of breakdown is called radioactivity or radioactive decay. Isotopes that undergo it are called radioactive (radioisotopes or radionuclides) and the energy emitted is called radiation. Not all radioactive atoms decay at the same rate. Some are extremely unstable and decay in minute fractions of a second; others may take billions of years to decay. The time taken for one half of the atoms of a radioisotope to decay is called the half-life, and is always constant for that particular isotope.

2.1.2 *Types of radiation*

Knocking of electrons out of an atom is called ionisation. The remaining atom is called an ion and is electrically charged. If the particles or energy emitted by radioactive decay have enough energy to knock electrons out of other atoms, then that radiation is called "ionising radiation".

There are three types of ionising radiation that are important in mineral sands mining:

- **Alpha radiation** consists of relatively heavy particles (two protons and two neutrons bound together) travelling relatively slowly. They ionise heavily when they pass through matter, and in doing so, lose their energy rapidly. This causes them to have a short range and low penetrating abilities (less than a sheet of paper, or a few centimetres in air).
- **Beta radiation** consists of a stream of high energy electrons. They ionise moderately, and have a range of up to a few meters in air, and can pass through a centimetre or so of matter. Beta radiation can be shielded by low density materials such as plastic.
- **Gamma radiation** does not consist of particles, but bundles of intense electromagnetic energy. They are very similar to x-rays, but generally have more energy and greater

power to penetrate matter. They can travel right through the human body, but are stopped by thick metal or concrete layers.

Radiation that cannot ionise matter is called non-ionising radiation. Examples include light, lasers, ultra-violet and infra-red, radio waves, microwaves etc. Non-ionising radiation is quite different to ionising radiation and will not be considered here: "radiation" will mean "ionising radiation"

2.1.3 Uranium and Thorium and its decay products

As noted above the most common isotope of uranium is ^{238}U , which comprises about 99.3% of naturally occurring uranium. ^{238}U has a long half-life of 4.2 billion years, and decays by emitting an alpha particle, turning into an isotope of the element thorium, ^{234}Th . But ^{234}Th in itself is radioactive, and it decays by emitting a beta particle, and turning into an isotope of Protactinium ^{234}Pa , which is also radioactive. In total, there are 14 decay steps, before the original atom of uranium becomes an atom of lead, ^{206}Pb , which is stable, and does not decay.

Similar to the uranium decay chain, ^{232}Th has an even longer half-life of 14 billion years, and decays by emitting an alpha particle, turning into an isotope of the element radium, ^{228}Ra . But ^{228}Ra in itself is radioactive, and it decays by emitting a beta particle, and turning into an isotope of Actinium ^{228}Ac , which is also radioactive. In total, there are 12 decay steps, before the original atom of thorium becomes an atom of lead, ^{208}Pb , which is stable, and does not decay.

Mineral sand ore will contain all of these radioactive isotopes, from both the uranium and thorium decay chains and they need to be considered in determining the radiological effects of mineral sands, and the protection measures needed.

2.1.4 Radiation exposure pathways

A radioactive material is of no human health concern unless there is some pathway by which the radiation it emits can reach a person. There are two general ways that radiation exposure can occur:

- External exposure is exposure from radiation that is outside (external to) the body. Examples are exposure from a medical x-ray, or gamma dose from standing near a pile of ore; and
- Internal exposure is exposure from radioactive material that is inside the body. Usually this is material that has been taken in by inhalation or in food or water that has been consumed.

There are three main exposure pathways associated with mineral sands mining:

- External gamma radiation. Mineral sands ore contains several isotopes that emit gamma radiation, and persons in the vicinity of ore, concentrates or waste materials can receive a dose as a result;
- Inhalation of radioactive dusts. Dusts from ore, waste or concentrates contain radionuclides which if inhaled can lodge in the lung. They may remain in the lung, or be absorbed into the bloodstream and taken to other organs; and

- Inhalation of radon decay products. One of the radioactive isotopes in the uranium and thorium decay chain is a gas, called radon. It can diffuse out of ore into the air, and be inhaled. Radon itself is not retained in the lung, but it decays fairly quickly into “radon decay products” (or radon progeny). These are metals, and if inhaled may lodge in the lung, where they may decay and release alpha radiation.

2.1.5 Radiation quantities and units

There are two main types of measurement in radiation protection. The first concerns the amount of a *radioactive substance*, and the second concerns the amount of *radiation* absorbed by an object. They are quite different and there is generally no simple relationship between the two.

Activity is the name given to the amount of radioactive material. It is measured by the number of radioactive decays occurring per second. The unit is the becquerel (Bq) and is equivalent to an activity of 1 decay per second. A becquerel is quite a small unit: 1 kg of typical soil contains a total of approximately 1000 Bq. For large activities, units of kBq (kiloBecquerel) and MBq (MegaBecquerel) are commonly used. Very large radioactive sources (for example those used in cancer treatment) can have activities of many billions of becquerels (GBq). Concentrations of radioactive material are typically expressed as becquerels per kilogram (Bq/kg) in solids, becquerels per litre (Bq/L) in liquids and becquerels per cubic metre (Bq/m³) in air.

Dose is the name given to the amount of radiation absorbed by an object. As ionising radiation is defined by its ability to ionise, “dose” is based on the amount of ionisation produced per unit mass. There are a number of different types of dose but the most commonly used is called “effective dose”. It is based on the amount of ionisation per unit mass, but includes corrections for the different biological effects of different types of radiation (alpha, beta, gamma etc), and for the different sensitivities of the various organs and tissues of the body to radiation. The unit of effective dose is the sievert (Sv), but as this is a very large dose, practical doses are in millisieverts or microsieverts (mSv or μ Sv). The “dose rate” is the amount of radiation absorbed in a unit time, commonly in microsieverts per hour (μ Sv/h). When the term “dose” is used, it usually means “effective dose”.

2.1.6 Health effects of radiation

The health effects and the degree of risk caused by exposure to ionising radiation depend on the type of radiation, the total dose received, the rate at which the dose is received, the part of the body exposed, and the person’s age and state of health at the time of exposure.

The health effects of exposure to radiation are well known. At high doses (several thousand millisieverts) significant numbers of cells may be killed, leading to the breakdown of sensitive tissues, organ failure or death. Uranium mine workers generally receive doses hundreds of times lower than the levels which would cause these kinds of effects.

At lower doses, health effects can arise from cells that are damaged by radiation but continue to live. Such cells may develop the ability to proliferate without being under the body’s normal controls, and this may be the initiating event in development of a cancer. However, the body has mechanisms to repair damage, and the damaged cells may not

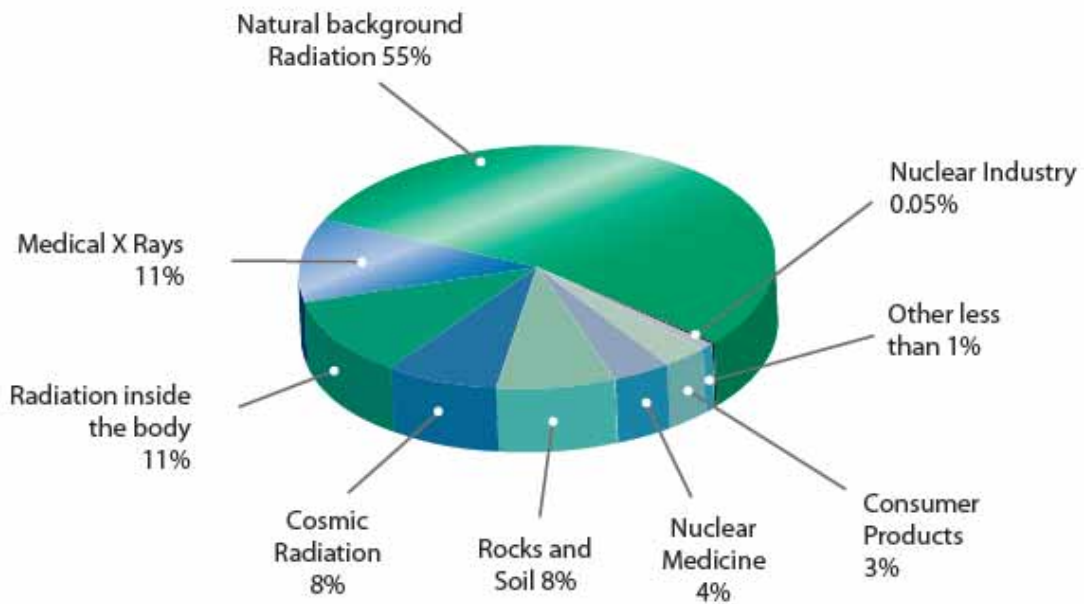
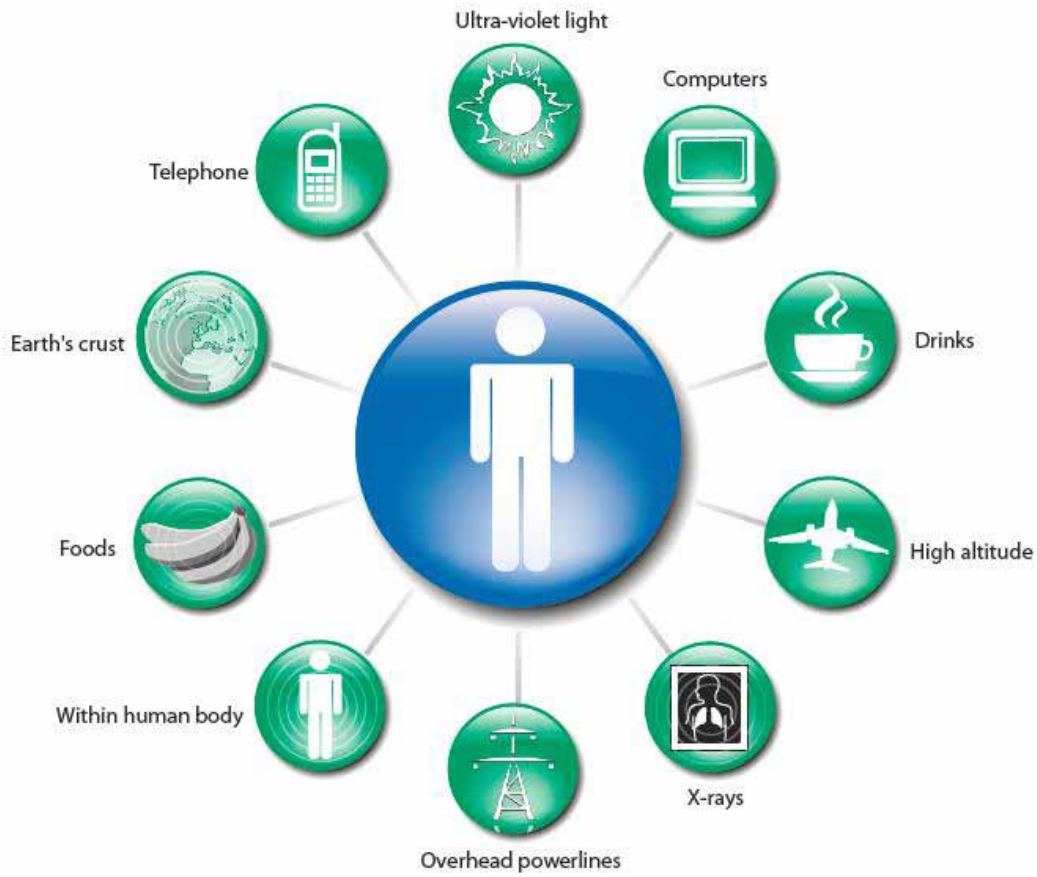
survive. Studies have shown that the increased cancer risk rises approximately proportionally with the radiation dose received; however at low doses (below about 50 mSv), any increase in risk, if present, is too small to be detected. No studies have been able to find genetic effects on humans, although such effects have been seen in animal studies, and are presumed to also apply to humans.

These risks and potential risks have been used in the setting of radiation standards. The International Commission on Radiological Protection has stated that in setting standards, “it must be presumed that even small radiation doses may produce some deleterious effects”. This is often paraphrased as there being “no safe level of radiation”. In relation to safety, this equates to “no risk at all”, which is not the normal definition of “safe”. People generally consider that activities involving some level of risk may be considered safe if the level of risk is considered “acceptable”. An example is commercial air travel, where people recognise that there is some element of risk, but still consider it “safe”.

2.1.7 *Natural background radiation*

Radiation is very common in nature and everyone is exposed to natural radiation throughout their life (see Figure 2). This radiation comes from the rocks and soil of the earth, the air we breathe, water and food we consume, and from space. Exposure to this radiation is from both external and internal.

Figure 2: Natural and man-made sources of radiation



Source: National Council of Radiation Protection and Measurements, NRC 1993.

2.1.7.1 External radiation background

The main two sources of external background radiation are cosmic and gamma radiation from soil. Cosmic radiation is a form of ionising radiation that comes from outer space. The atmosphere provides shielding against cosmic rays, and consequently cosmic radiation exposure is higher at higher altitudes. Aircrew who regularly fly at high altitudes can receive significant doses from cosmic radiation. Almost all normal soils naturally contain uranium, thorium and potassium. The average uranium and thorium soil concentrations are approximately 3 parts per million (ppm) and 10 ppm respectively. Both of these have gamma-emitting radionuclides in their decay series, and co-contribute to external radiation levels. In addition, one of the isotopes of potassium, K-40, is radioactive, emitting both gamma and beta radiation, and this also contributes to the external dose rate. In several parts of the world, soils naturally contain much higher concentrations of radionuclides. This is particularly so of thorium, and some parts of Brazil and southern India have quite high natural external dose rates for this reason (UNSCEAR 2000) ^[19].

2.1.7.2 Internal radiation background

Naturally occurring radionuclides can enter the human body through inhalation and ingestion. The largest internal natural background dose generally comes from the decay of radium in soil. Being a gas, radon can diffuse from the soil and enter the atmosphere, but normal atmospheric mixing keeps concentrations quite low. The dose from inhaling radon itself is quite small, but radon decays into radioactive material called radon decay products (formerly known as radon daughters) and if these are inhaled they may lodge in the lung, resulting in quite significant doses.

The world average background dose from all sources is about 2.4 mSv per year (UNSCEAR 2000)^[18]. Doses in Australia are less than 2 mSv/y, largely because the dose from radon decay products is much lower because the climate and open-air lifestyle lead to better ventilation of houses, reducing the build-up of radon concentrations (Langroo et al. 1991).

The other main pathway is ingestion, or swallowing of radioactive material that is present in food and drink. Plants will take up a small amount of the radionuclides in the soil in which they grow. The radionuclides may then enter our food chain either directly, by eating the plants, or indirectly, by eating animals that have grazed on them. Similarly, almost all surface and ground waters contain natural radionuclides. Consuming such food or water will result in an internal radiation dose. The largest contribution to internal dose from ingestion is usually from potassium-40 (40K). Potassium is an essential part of the body, and the body will extract its requirement from food. As the body cannot distinguish between the radioactive potassium (40K) and non-radioactive potassium isotopes, the body will always contain some 40K. Other natural radionuclides, including uranium and thorium decay series isotopes will also be consumed with food and water and hence are present in the body.

2.2 Radiation in mineral sands

Deposits of mineral sands containing heavy or dense minerals originate from erosion and weathering of rocks and occur in certain locations as a result of the concentrating effects of wind, ocean currents and wave action. These deposits are therefore found in the vicinity of

present or ancient coastlines. In the latter case, the deposits may be found many kilometres inland.

The main heavy mineral constituents of these sands are the titanium-bearing minerals, predominately ilmenite, but also rutile and leucocoxene, zircon, and the rare earth bearing minerals, monazite and xenotime. The relative proportion of these minerals varies from deposit to deposit, but ilmenite contributes by far the largest proportion of the heavy mineral constituents, commonly 50-70%.

Uranium and thorium are also present in these minerals. The concentrations of uranium and thorium are generally in trace amounts except for monazite, which typically contains 5% to 7% thorium and 0.1% to 0.3% uranium (KOP 1993, UPT 1996). Consequently, the mining and processing of heavy mineral ores has the potential to cause elevated radiation exposures of both workers and the public during operations and from the management of waste arising from production. Therefore, depending on the level of potential exposures, certain radiation control measures may be required to provide for an adequate degree of protection for both employees and the public.

In general, radiation hazards to workers arise in the mining and processing of heavy minerals through three principal pathways, namely external irradiation, inhalation and ingestion. The specific potential exposure pathways are:

- External exposure from the ore body during mining of ores or during separation of heavy minerals, or from stockpiled ore or mineral concentrates;
- External exposure during transport of ore or mineral concentrates;
- Internal exposure from the inhalation of dust containing elevated levels of radioactivity;
- Internal exposure from the inhalation of radon gas released from minerals during mining and processing operations or from stockpiled material; and
- Direct ingestion of material during handling of ores and heavy mineral concentrates and products.

Potential exposure pathways to members of the public include off-site releases of dusts or radon gas, contamination of food and water supplies due to the migration of radionuclides from the mine site during mining operations or following the disposal of tailings. Radioactivity associated with the various heavy minerals or tailings may also have the potential to be dispersed in the environment during processing operations.

3. LEGISLATION, REGULATORY REQUIREMENTS, GUIDELINES AND STANDARDS

This chapter discusses the regulation of radiation within NSW and supporting guidelines and standards.

The radiological aspects of the Balranald Project are controlled by the following pieces of NSW legislation:

- *NSW Radiation Control Act 1990 (RC Act); and*
- *NSW Protection of the Environment Operations Act 1997 (PoEO Act); and*
- *NSW Protection of the Environment Operations (Waste) Regulation 2014.*

Figure 3 provides an overview of the guidelines for classification of radioactive ore and wastes containing radioactive material.

The central requirement for radiological protection under the RC Act and PoEO Act is compliance with the '*Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)*', *Radiation Protection Series No. 9 (RPS 9), the (the Code)* (ARPANSA 2005).

Other guidelines and standards of relevant to the Project include the Australian Drinking Water Guidelines (ADWG), World Health Organisation (WHO) Guidelines for Drinking-water Quality and radiation standards set by the International Commission on Radiological Protection (ICRP).

3.1 Radiation Control Act 1990

3.1.1 General

The NSW RC Act includes provisions regulating the use, sale, giving away, disposal, storage, possession, transport, installation, maintenance or repair, remediation or clean-up of regulated material in NSW.

Regulated material includes radioactive substances, ionising radiation apparatus, non-ionising radiation apparatus and sealed source devices. A radioactive substance is defined as:

... any natural or artificial substance whether in solid or liquid form or in the form of a gas or vapour (including any article or compound whether it has or has not been subjected to any artificial treatment or process) which emits ionising radiation spontaneously with a specific activity greater than the prescribed amount and which consists of or contains more than the prescribed activity of any radioactive element whether natural or artificial.

The prescribed activity of radioactive substances are contained in Schedule 1 of the NSW Radiation Control Regulation 2013 (RC Regulation).

Under Section 6 of the RC Act, a person responsible for regulated material must hold a radiation management licence in respect of the regulated material and must comply with any conditions to which the licence is subject.

Section 6(1) of the RC Act states that:

For the purposes of this Act each of the following persons is a person responsible for regulated material:

- (a) the owner of the regulated material,
- (b) any person who is storing, selling or giving away the regulated material,
- (c) any person who has possession of the regulated material, other than:
 - (i) a person who is the holder of a radiation user licence in respect of the regulated material and who has possession of the regulated material only for the purposes of using the regulated material, or
 - (ii) a person who has possession of the regulated material only for the purposes of transporting the regulated material.

Iluka would be required to obtain licences under sections 6 and 7 of the RC Act for the handling and use of regulated material.

Section 7 of the RC Act states that a person who uses regulated material must hold a radiation user licence and must comply with any conditions to which the licence is subject.

A person responsible for regulated material must also hold a radiation management licence in respect of the regulated material and must comply with any conditions to which the licence is subject.

The purpose of a management licence is to regulate, restrict or prohibit the *possession, sale, storage, giving away, and disposal of regulated material to protect the community and the environment from exposure to radiation. A management licence to possess, store, sell or giving away regulated material is valid for one year.

Notwithstanding the above, under Part 2 of the RC Regulation, persons are exempt from radiation management and radiation user licences for managing and using radioactive ores that are at any place to which the NSW Mine Health and Safety Act 2004. This legislation has been repealed and replaced with the NSW Work Health and Safety (Mines) Act 2013 (WH&S Mines Act). No exemptions are provided in the RC Act, RC Regulation or WH&S Mines Act for holding radiation management and radiation user licences.

Further discussion regarding the applicable sections and clauses of this legislation is provided in Section 6 where an assessment in accordance with the requirements of the legislation has been detailed.

3.1.2 Classification in accordance with requirements

The RC Act provides for the regulation and control of radioactive substances, radioactive sources and radiation apparatus in NSW. The RC Act prescribes material as a “radioactive ore” or a “radioactive substance” and details licensing and registration requirements.

Radioactive Ore

Section 4(1) of the RC Act defines a radioactive ore as follows:

radioactive ore means an ore or mineral containing more than the concentration of uranium or thorium prescribed for the purposes of this definition.

Clause 4 of the NSW Radiation Control Regulation 2013 (RC Regulation) defines the prescribed concentrations of uranium and thorium referred to above as:

4 Definition of “radioactive ore”: section 4

(1) For the purposes of the definition of **radioactive ore** in section 4 (1) of the Act, the prescribed concentrations of uranium and thorium are:

- (a) in the case of an ore that contains uranium but not thorium, 0.02 per cent by weight of uranium, or
- (b) in the case of an ore that contains thorium but not uranium, 0.05 per cent by weight of thorium, or
- (c) in the case of an ore that contains both uranium and thorium, a percentage by weight of uranium and thorium such that the expression:

$$U / 0.02 + Th / 0.05$$

is equal to, or greater than, one.

(2) In the expression referred to in subclause (1)(c):

U represents the percentage by weight of uranium.

Th represents the percentage by weight of thorium.

Radioactive Substance

Section 4(1) of the RC Act defines a “radioactive substance” as follows:

radioactive substance means any natural or artificial substance whether in solid or liquid form or in the form of a gas or vapour (including any article or compound whether it has or has not been subjected to any artificial treatment or process) which emits ionising radiation spontaneously with a specific activity greater than the prescribed amount and which consists of or contains more than the prescribed activity of any radioactive element whether natural or artificial.

Clause 5 of the RC Regulation defines the “prescribed amount” and “prescribed activity” referred to above as:

5 Definition of “radioactive substance”: section 4

(1) For the purposes of the definition of **radioactive substance** in section 4 (1) of the Act:

- (a) the prescribed amount is 100 becquerels per gram, and

(b) a substance has the prescribed activity if the expression:

$$A1/40 + A2/400 + A3/4000 + A4/40000$$

is equal to, or greater than, one.

(2) In the expression referred to in subclause (1)(b):

A1 represents the total activity, in kilobecquerels, of the Group 1 radionuclides contained in the substance.

A2 represents the total activity, in kilobecquerels, of the Group 2 radionuclides contained in the substance.

A3 represents the total activity, in kilobecquerels, of the Group 3 radionuclides contained in the substance.

A4 represents the total activity, in kilobecquerels, of the Group 4 radionuclides contained in the substance.

3.2 Protection of the Environment Operations Act, 1997 and Protection of the Environment Operations (Waste) Regulation 2014

In NSW, industrial wastes are regulated under the PoEO Act and the *Protection of the Environment Operations (Waste) Regulation (2014)*.

The *NSW Waste Classification Guidelines* were prepared by the NSW Government Department of Environment, Climate Change and Water to provide guidance on the implementation of sampling, analytical and classification protocols and the management of industrial wastes.

The sections contained within the NSW waste classification guidelines that are relevant to the classification of the Hamilton MBPs include:

- *Classifying Waste (Part 1)* (NSW Department of Environment and Climate Change, 2008) ; and
- *Waste Containing Radioactive Material (Part 3)* (NSW Department of Environment and Climate Change, 2008).

The PoEO Act provides for the classification and management of waste in NSW. Schedule 1 of the PoEO Act provides waste classification definitions, including:

Hazardous waste means waste (other than special waste or liquid waste) that includes any of the following:

(a) anything that is classified as:

(i) a substance of Class 1, 2, 5 or 8 within the meaning of the *Transport of Dangerous Goods Code*, or

- (ii) a substance to which Division 4.1, 4.2, 4.3 or 6.1 of the Transport of Dangerous Goods Code applies,
- (b) containers, having previously contained:
- (i) a substance of Class 1, 3, 4, 5 or 8 within the meaning of the Transport of Dangerous Goods Code, or
- (ii) a substance to which Division 6.1 of the Transport of Dangerous Goods Code applies, from which residues have not been removed by washing or vacuuming,
- (c) coal tar or coal tar pitch waste (being the tarry residue from the heating, processing or burning of coal or coke) comprising more than 1% (by weight) of coal tar or coal tar pitch waste,
- (d) lead-acid or nickel-cadmium batteries (being waste generated or separately collected by activities carried out for business, commercial or community services purposes),
- (e) lead paint waste arising otherwise than from residential premises or educational or child care institutions,
- (f) anything that is classified as hazardous waste pursuant to an EPA Gazettal notice,
- (g) anything that is hazardous waste within the meaning of the Waste Classification Guidelines,
- (h) a mixture of anything referred to in paragraphs (a)–(g).

Restricted solid waste means any waste (other than special waste, hazardous waste or liquid waste) that includes any of the following:

- (a) anything that is restricted solid waste within the meaning of the Waste Classification Guidelines, ...

Hazardous Waste Definition (a) – Transport of Dangerous Goods Classification

The Australian Code for the Transport of Dangerous Goods by Road and Rail (National Transport Commission Australia, 2011) (the Transport of Dangerous Goods Code) defines the following relevant classes:

- Class 1 – Explosives;
- Class 2 – Gases;
- Class 5 – Oxidizing substances and organic peroxides; and
- Class 8 – Corrosive substances.

In addition, the Transport of Dangerous Goods Code defines the following relevant divisions:

- Division 4.1 – Flammable solids, self-reactive substances and solid desensitized explosives;
- Division 4.2 – Substances liable to spontaneous combustion;
- Division 4.3 – Substances which in contact with water emit flammable gases; and
- Division 6.1 – Toxic substances.

Hazardous Waste Definition (f) – NSW Government Gazette

No additional waste types have been classified as “hazardous” in the NSW Government Gazette. “Hazardous waste” definition (f) has therefore not been considered further.

Hazardous Waste Definition (g) – Waste Classification Guidelines

The *Waste Classification Guidelines, Part 3: Waste Containing Radioactive Material* (NSW Department of Environment and Climate Change, 2008) provide a guide for the classification of wastes containing radioactive substances (our underlining):

Step 1

The radioactivity of the waste must be assessed in accordance with the Radiation Control Act 1990 and the Radiation Control Regulation 2013.

Step 2

Liquid or non-liquid wastes with a specific activity greater than 100 becquerels per gram and consisting of, or containing more than, the prescribed activity of a radioactive element in Schedule 1 of the Radiation Control Regulation 2013, whether natural or artificial, must be classified as hazardous wastes.

Step 2 of the Waste Classification Guidelines outlines the process for determining if a waste is a “hazardous waste”. If the specific activity of the waste is above 100 Bq/g it may be a “hazardous waste”.

Step 3

For liquid or non-liquid wastes with a specific activity of 100 becquerels per gram or less and/or consisting of, or containing, the prescribed activity or less of a radioactive element in Schedule 1 of the Radiation Control Regulation 2013, whether natural or artificial, the total activity ratio and specific activity ratio must be calculated according to the mathematical expressions below:

Total activity ratio is calculated using the expression:

$$\text{Total activity ratio} = (A1 \times 10^{-3}) + (A2 \times 10^{-4}) + (A3 \times 10^{-5}) + (A4 \times 10^{-6})$$

where A1 to A4 are the total activity of Group 1 to Group 4 radionuclides, as set out in Column 1 of Schedule 1 of the Radiation Control Regulation 2013.

Specific activity ratio is calculated using the expression:

$$\text{Specific activity ratio} = SA1 + (SA2 \times 10^{-1}) + (SA3 \times 10^{-2}) + (SA4 \times 10^{-3})$$

where SA1 to SA4 are the specific activity (of the material) of Group 1 to Group 4 radionuclides, as set out in Column 1 of Schedule 1 of the Radiation Control Regulation 2013.

Step 4

Where the specific activity ratio or total activity ratio is greater than one, the waste must be classified as follows:...

Non-liquid wastes must be classified as restricted solid waste ...

Further details regarding the classification of the materials associated with the Balranald Project (with regard to Part 3 of the NSW Waste Classification Guidelines) are provided in Section 6.2.)

3.3 The Code

The central requirement for radiological protection under both the RC Act and PoEO Act discussed above, is compliance with the 'Code of Practice and Safety Guide on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)', Radiation Protection Series No. 9 (RPS 9), the (the Code) (ARPANSA 2005).

The following discussion identifies the Code's requirements and the way it is implemented to ensure that workers, members of the public and the environment are protected from the potentially harmful effects of radiation.

The Code has three central requirements:

- Compliance with the Radiation Protection Standards, set by ICRP;
- Development of a radiation management plan (RMP) and radioactive waste management plan (RWMP) for approval by the regulatory authority; and
- Authorisation from the regulatory authorities before construction or operation of the project facility

Overall, the RMP and the RWMP and the associated approvals provide the mechanism for the detailed oversight of the operations radiological aspects by the regulatory authorities.

3.3.1 Radiation management plan

The RMP provides for the control of radiation exposure to employees and members of the public arising from the operation. It requires regulatory approval and would be implemented before the operation started.

The RMP is expected to include the following:

- significant exposure sources and pathways;
- measures to control radiation exposures, including engineered controls and administrative measures, such as control of access to potentially high-exposure areas. Other measures include training in the radiological aspect of work, and supervision to ensure that controls are properly used;
- estimates of doses that would arise from the operations;
- a radiation monitoring program designed to determine the effectiveness of controls, including monitoring of exposures from all sources (i.e. external gamma, radon decay products and radioactive dust), to workers and members of the public;

- details on how the RMP would be implemented, including commitments to adequate staffing, equipment and resources; and
- a quality assurance program, including ongoing assessment, review and revision of the program to ensure continued compliance with the ALARA principle, and updating to incorporate any changes to the operations.

The RMP is expected to demonstrate that the ALARA principle has been properly considered in the development of controls on radiation exposure.

3.3.2 Radiation waste management plan

The management of waste, including radioactive waste, is an integral part of the operation and is addressed from the inception of project planning. A radioactive waste management plan (RWMP) would be developed and implemented to provide for the management of waste to protect people and the environment from the potential effects of radioactive wastes.

The development of the RWMP and the design of waste management would take into account a number of factors, including:

- the nature of the waste, including their radionuclide content, and their chemical and physical states,
- the particular environment into which the waste would be discharged or may escape (e.g. climate, topography, hydrology and ecology)
- the pathways by which radionuclides in the waste may travel through the environment,
- estimated concentration of radioactive contaminants in the environment,
- estimated doses to members of the public as a result of the waste management,
- the potential for, and consequences of, failure of waste management facilities, and contingency measures to be put in place in such circumstances,
- a monitoring program to monitor the systems operations (e.g. quantities of waste stored or discharged) and effect of the environment (e.g. radionuclide concentrations),
- details of the operations of the waste management system, including commitments to provision of adequate staff and resources and
- a quality assurance program to ensure that the system is being operated and performed within its design parameters, together with a system of ongoing review and revision.

As in the case of the RMP, the RWMP is expected to demonstrate that the ALARA principle has been properly considered in the development of the waste management system.

3.4 Australian Drinking Water Guidelines

The Australian Drinking Water Guidelines (ADWG) have been developed by the National Health and Medical Research Council (NHMRC, 2011) and are designed to provide a reference on what defines safe, good quality water, how it can be achieved and how it can be assured.

The ADWG adopts a 10 step process for the determination of the radiological quality of water beginning with Step 1 by adopting a screening activity level for both gross alpha and gross beta (this is not a criterion). If screening levels are not exceeded there is no requirement for further assessment. If either or both screening levels are exceeded then it is

necessary to identify the specific radionuclides and their activities. The annual dose rate from such radionuclides must then be calculated.

Further details regarding the classification of the existing groundwater quality (within the project area) against the screening levels within the ADWG are provided in Section 6.2.

3.5 World Health Organisation Guidelines for Drinking-water Quality

The World Health Organisation (WHO) Guidelines for Drinking-water Quality (3rd edition, 2008) have been developed primarily to assist water and health regulators, policy makers and their advisors to assist in the development of national standards. They provide details on a quality of water that is acceptable for lifelong consumption and can be used as a source of information on water quality and health and of effective management approaches.

Further details regarding the classification existing groundwater against the screening levels within the WHO guidelines are provided in Section 6.2.

3.6 Radiation Standards and Limits

3.6.1 Sources of standards

The premier international body for radiation protection is the ICRP. The limits recommended by the ICRP have generally been adopted around the world. The recommended dose limits have changed over time as more information on the health effects of radiation has become available. However there has been only one major change to the recommended limits to worker in the past 50 years, in 1990 (International Commission of Radiological Protection 1990).

The ICRP recommendations are not themselves legally binding in Australia, but Commonwealth, states and territories have adopted them into their own legislation. Currently it is the 1990 recommendation, as set out in ICRP Publication 60 (International Commission on Radiological Protection 1990) that are adopted, but it is expected that the latest recommendations will be adopted where necessary.

3.6.2 International Commission on Radiological Protection

Dose limits form only part of the ICRP radiation protection system. The three key elements of this system are:

- **Justification** – a practice involving exposure to radiation should be adopted only if the benefits of the practice outweigh the risk associated with the radiation exposure.
- **Optimisation** – radiation doses received should be as low as reasonably, economic and social factors being taken into account (the ALARA or as low as reasonably achievable principle).
- **Limitations** – individuals should not receive radiation doses greater than the recommended limits.

3.6.2.1 Dose limitations

The risks associated with radiation are mostly known and quantified. The objective of radiation protection is to limit the exposure to radiation by the application of comprehensive programs of measurements of all significant radiation sources to ensure that no employee or member of the public are exposed to levels exceeding those prescribed by legislation. Dose limits for occupational exposed persons and members of the public are provided in Table 2.

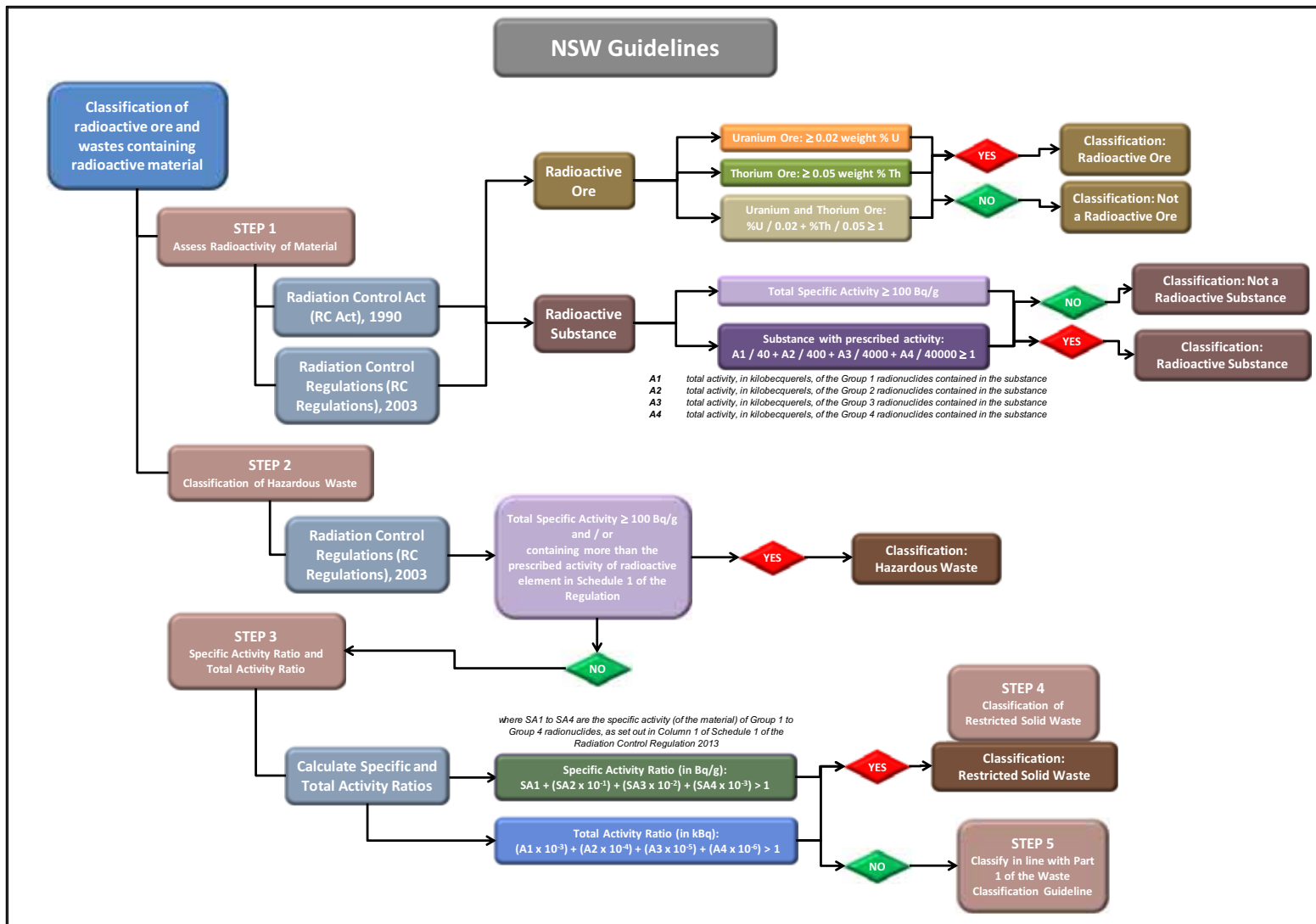
Table 2: Dose Limits for Occupational Exposed Persons and Members of the Public

Application	Dose Limit Occupational Exposed Person	Dose Limit Members of the public
Effective dose	20 mSv per year averaged over a period of 5 consecutive calendar years ^{4,5,6}	1 mSv in a year ⁷
Equivalent dose to:		
(a) Lens of the eye	20 mSv per year averaged over a period of 5 consecutive calendar years ^{4,5,6}	15 mSv in a year
(b) Skin ⁸	500 mSv in a year	50 mSv in a year
(c) The hands and feet	500 mSv in a year	No limit specified
<p>Note 1: The limit apply to the sum of the relevant doses from external exposure in the specified period and the committed dose from intakes in the same period. In this Note, committed dose means the dose of radiation, arising from the intake of radioactive material accumulated by the body over 50 years following the intake (except in the case if intakes by children, where it is the dose accumulated until the age of 70)</p>		
<p>Note 2: Any dose resulting from medical diagnosis should not be taken into account</p>		
<p>Note 3: Any dose attributable to normal naturally occurring background levels of radiation should not be taken into account.</p>		
<p>Note 4: With the further provision that the effective dose must not exceed 50mSv in a single year</p>		
<p>Note 5: When a female employee declares a pregnancy, the embryo or foetus should be afforded the same level of protection as a member of the public</p>		
<p>Note 6: When, in exceptional circumstances, a temporary change in the dose limit requirements is approved by the Authority, one of the following conditions applies:</p> <ul style="list-style-type: none"> (a) The effective dose limit must not exceed 50mSv per year for the period, that must not exceed 5 years, for which the temporary change is approved, and (b) The period for which the 20mSv per year average applies must not exceed 10 consecutive years and the effective dose must not exceed 50mSv in any single year 		
<p>Note 7: In special circumstances, a higher value of effective dose could be allowed in a single year,</p>		

Application	Dose Limit Occupational Exposed Person	Dose Limit Members of the public
provided that the average over 5 years does not exceed 1mSv per year		
Note 8: The equivalent dose limit for the skin applies to the dose averaged over any 1 square centimetre of skin, regardless of the total area exposed.		

The doses received may be averaged over five years, but the dose to a worker in any one year must not exceed 50 mSv. These limits apply to total dose received from operational sources including external gamma exposure and inhalation of radon decay products and dust (with the doses from natural background being excluded). There are no exposure limits for the individual dose components. Likewise there are also no specific dose limits set for shorter periods (less than a year). This is because the likely health effects depend only on the total dose accumulated over a long period (possibly decades). In an operational situation, investigation and action levels are set for each pathway at levels that ensure continued exposure will not lead to doses above these long-term limits.

Figure 3 NSW Guidelines for classification of radioactive ore and wastes containing radioactive material



4. PROJECT DESCRIPTION

4.1 Project schedule

The Balranald Project will have a life of approximately 15 years, including construction, mining, backfilling of all overburden material, rehabilitation and decommissioning.

Construction of the Balranald Project will commence at the West Balranald mine, and is expected to take about 2.5 years. Operations will commence at the West Balranald mine in Year 1 of the operational phase, which will overlap with approximately the last six months of the construction. The operational phase includes mining and associated ore extraction, processing and transport activities, and will be approximately nine years in duration. This will include completion of backfilling overburden into the pits at both the West Balranald and Nepean mines. Construction of infrastructure at the Nepean mine will commence in approximately Year 5 of the operational phase, with mining of ore starting in Year 6 and commencing in approximately Year 8.

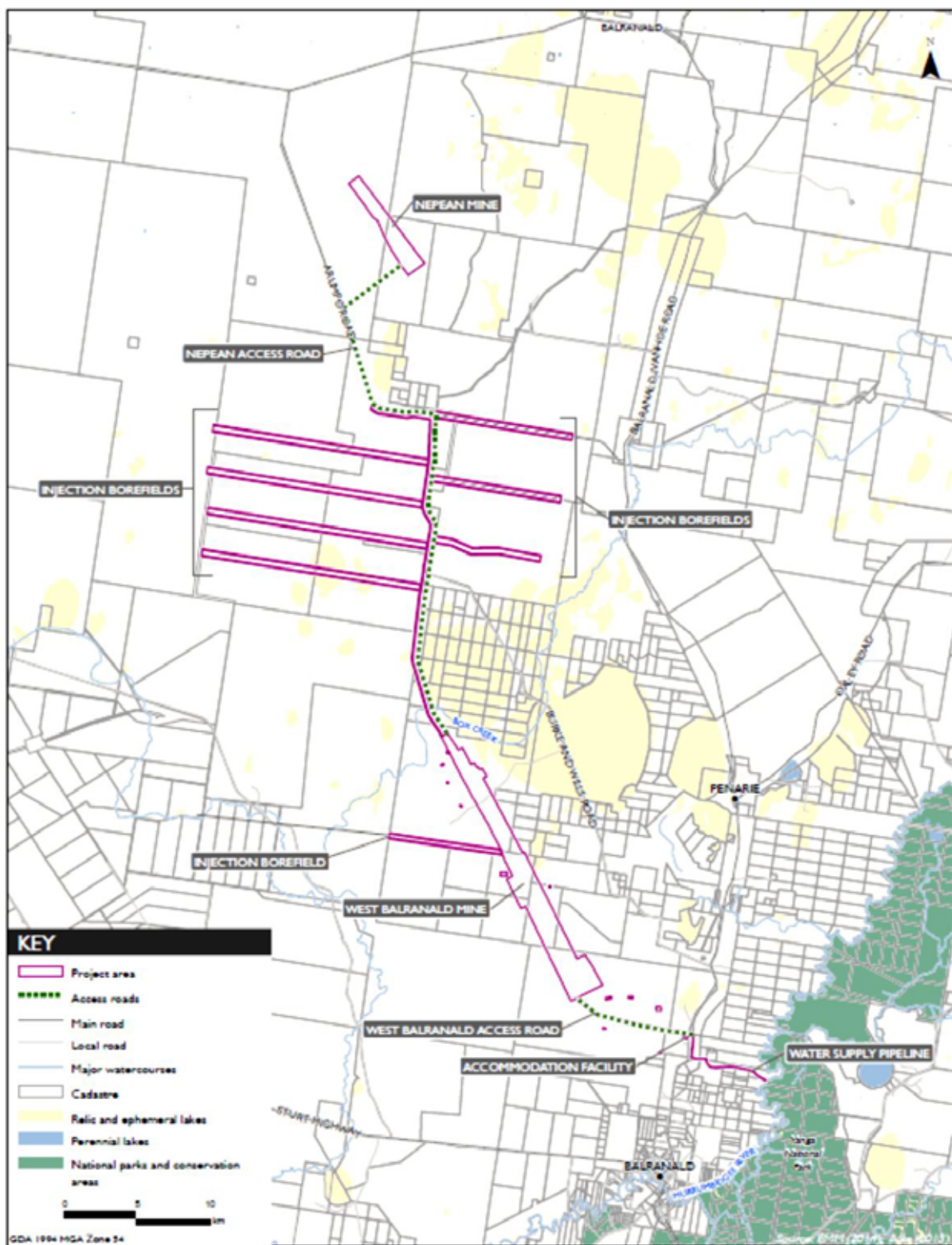
Rehabilitation and decommissioning is expected to take a further two to five years following Year 9 of the operational phase.

4.2 Project area

All development for the Balranald Project that is the subject of the SSD application is within the project area (see Figure 4). The project area is approximately 9,964 ha, and includes the following key project elements:

- West Balranald and Nepean mines;
- West Balranald access road;
- Nepean access road;
- injection borefields;
- gravel extraction;
- water supply pipeline (from the Murrumbidgee River); and
- accommodation facility.

Figure 4: Project features



Source: EMM 2015

4.2.1 West Balranald and Nepean mines

The West Balranald and Nepean mines include:

- open cut mining areas (i.e. pit/mine void) that would be developed using conventional dry mining methods to extract the ore;
- soil and overburden stockpiles;
- ore stockpiles and mining unit plant (MUP) locations;
- a processing area (at the West Balranald mine), including a mineral processing plant, tailings storage facility (TSF), maintenance areas and workshops, product stockpiles, truck load-out area, administration offices and amenities;
- groundwater management infrastructure, including dewatering, injection and monitoring bores and associated pumps and pipelines;
- surface water management infrastructure;
- services and utilities infrastructure (e.g. electricity infrastructure);
- haul roads for heavy machinery and service roads for light vehicles; and
- other ancillary equipment and infrastructure.

The location of infrastructure at the West Balranald and Nepean mines would vary over the life of the Balranald Project according to the stage of mining.

The mining method proposed is a truck and shovel open cut mining method. This involves excavating and mining an active pit area that advances along the deposit. After ore is removed from an area it is progressively backfilled. The result is a pit that moves from south-east to north-west along the deposits.

To maintain dry mining conditions groundwater abstraction is required, the majority of abstracted groundwater will then be reinjected off path. Dewatering of the Formations overlying and surrounding the ore body would be required ahead of mining operations. Groundwater abstraction and injection will occur in the Loxton-Parilla Sands. Abstraction will occur within and adjacent to the pit, while water will be injected off hydraulic gradient, either on path (down gradient at the West Balranald deposit) or in the injection borefield. Prior to injection water will be treated with UV light to remove possible bacteria.

It is estimated that dewatering will commence six months in advanced of mining operations and will continue during the mining phase, and while the West Balranald deposit is being backfilled. A dry pit is required at the West Balranald deposit for a further two years after mining whilst the final pit void, located at the northern end of the deposit, is backfilled. The necessary abstraction volumes needed to maintain dry pit conditions during the backfilling of West Balranald and mining at Nepean are substantially reduced when compared to those required during active mining operations at West Balranald.

4.2.2 Access roads

There are two primary access roads within the project area to provide access to the Balranald Project:

- West Balranald access road – a private access road to be constructed from the Balranald Ivanhoe Road to the West Balranald mine.

- Nepean access road – a route comprising private access roads and existing public roads. A private access road would be constructed from the southern end of the West Balranald mine to the Burke and Wills Road. The middle section of the route would be two public roads, Burke and Wills Road and Arumpo Road. A private access road would be constructed from Arumpo Road to the Nepean mine.

The West Balranald access road would be the primary access point to the project area, and would be used by heavy vehicles transporting HMC and ilmenite. The Nepean access road would primarily be used by heavy vehicles transporting ore mined at the Nepean mine to the processing area at the West Balranald mine.

During the initial construction phase, existing access tracks through the project area from the local road network may also be used temporarily until the West Balranald and Nepean access roads and internal access roads within the project are established.

4.2.3 Accommodation facility

An accommodation facility would be constructed for the Balranald Project workforce. It would operate throughout the construction and operation phases of the project. It would be located adjacent to the West Balranald mine near the intersection of the West Balranald access road with the Balranald Ivanhoe Road.

4.2.4 Gravel extraction

Gravel would be required during the construction and operational phases of the Balranald Project. Local sources of gravel (borrow pits) have been included in the project area to provide gravel during the construction phase. During the construction phase, gravel would be required for the construction of the West Balranald access road, internal haul roads and service roads, and hardstand areas for infrastructure. Processing operations, such as crushing and screening activities (if required) would also be undertaken at the borrow pits. Gravel for the operational phase would be obtained from external sources.

4.3 Mine processing

Following removal of ore from the mine, mineral processing will be undertaken at the processing plant. The processing plant will concentrate the ore to generate two primary product streams; HMC and ilmenite. Annual average production rates of HMC and ilmenite are 500,000 tpa and 650,000 tpa respectively. HMC and ilmenite will be stockpiled at the processing plant prior to offsite transport.

The processing plant has a number of components including the Primary Concentrator Plant (PCP), Wet Concentrator Plant (WCP), Wet High Intensity Magnetic Separation (WHIMS) plant and Ilmenite Separation Plant (ISP). Water requirements for the processing plant will be fed from the process water dam, except for the ISP, which will be fed from a fresh water supply.

The processing plant is described below. Figure 5 provides detail on the conceptual layout of the area and a process flow diagram is shown in Figure 6.

4.3.1 Pre-concentrator plant

The PCP utilises desliming cyclones for fines removal and gravity spirals to concentrate the heavy mineral within the ore. Wet gravity processing methods will separate light minerals (such as quartz) from heavy minerals (such as rutile and zircon), and remove mining by-products such as slimes and sand.

The PCP will receive slurried ore via pipeline from the MUP, and will process ore at a nominal rate of 440 tph. The slurried ore is initially pumped to the PCP vibrating screen which will remove material 2.5 mm or larger. The PCP then separates fines (-45 µm) from coarser ore, and concentrates the heavy mineral in the ore to a grade suitable for the WCP.

The fines fraction (-45 µm) is pumped to desliming cyclones where fines are further separated. The fines are sent to the cyclone overflow and are gravity fed to a thickener unit, where flocculent is added to create thickened fines by-product stream, known as thickener underflow (or slimes).

The PCP circuit produces a concentrated heavy mineral stream and a sand by-product stream. The concentrated heavy mineral either goes directly to the WCP as a slurry, or to the decoupling stacker. The sand by-product stream is diverted to a sand tails stacker and stockpiled. Once the sand by-product stockpile has reached capacity it is trucked to the mine void for disposal.

The PCP will be track mounted and comprises thickeners, a spirals building, flocculant units, a cyclone stacker, pump stations and a mining by-product handling plant. The PCP requires water, which will be supplied by the process water dam.

4.3.2 Wet concentrator plant

The WCP will further upgrade the heavy mineral content of the concentrate stream (from the PCP) to between 95 and 98% heavy mineral. Wet gravity processing methods further separate light and heavy minerals.

The WCP processes an upgraded HMC product at a nominal rate of 150 tph. The WCP comprises a decoupling plant with a PCP heavy mineral stockpile, a constant density tank and structure, a spirals building consisting of six spiral stages, screens and associated stockpiles and pipelines, pump stations and water storage dams. The WCP is typically divided into a primary and secondary concentrating circuit where the primary circuit contains gravity spirals which upgrades the PCP concentrate to 95% heavy mineral. The secondary WCP consists of the WHIMS circuit and the up-current classifier circuit. The upgraded ore is feed through the WHIMS plant.

4.3.3 Wet high intensity magnetic separation plant

The WHIMS plant is a series of high strength magnets which separate magnetic material (ilmenite) from non-magnetic material (HMC). The WHIMS plant is a wet process that splits the product into two streams (HMC product stream and magnetic ilmenite stream) with different destinations and beneficiation process routes.

The WHIMS plant includes five primary and two secondary processing units with the primary unit feed rate approximately 150 tph. Each of the five units will process approximately 30 tph.

The secondary WHIMS units will receive approximately 30 tph dry solids. These units will further recover entrained ilmenite from the non-magnetic WHIMS stream (approximately 40% recovery rate). The secondary WHIMS magnetic stream is combined with the primary magnetic stream and feed to the ISP.

The non-magnetic stream is HMC, which is stockpiled in the processing area.

4.3.4 Ilmenite separation plant

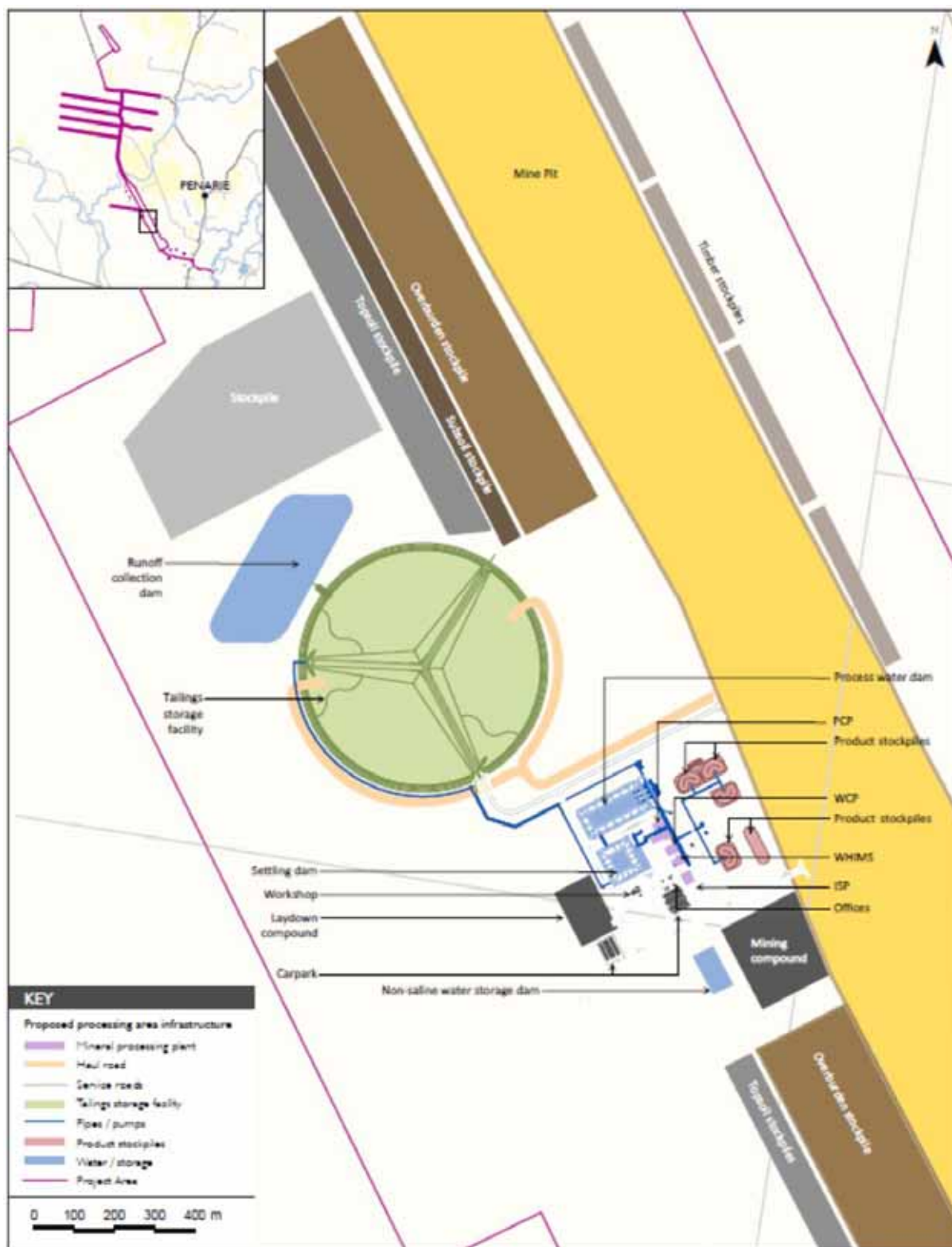
The ISP separates the WHIMS magnetic stream from the WCP into two saleable ilmenite products. The ISP produces sulphate and chloride ilmenite products. The ISP will have a feed rate of approximately 90 tph (dry) and include a stockpile reclaim system to feed the ISP, a wash plant to remove dissolved salts from the mineral surfaces and a dry separation plant comprising rare earth drum roll magnetic separators to magnetically fractionate the mineral.

The ISP non-magnetic stream would be directed to the non-magnetic tank bin, while the magnetic streams of sulphate ilmenite and chloride ilmenite reports to the sulphate and chloride bins respectively.

4.3.5 Product stockpiles

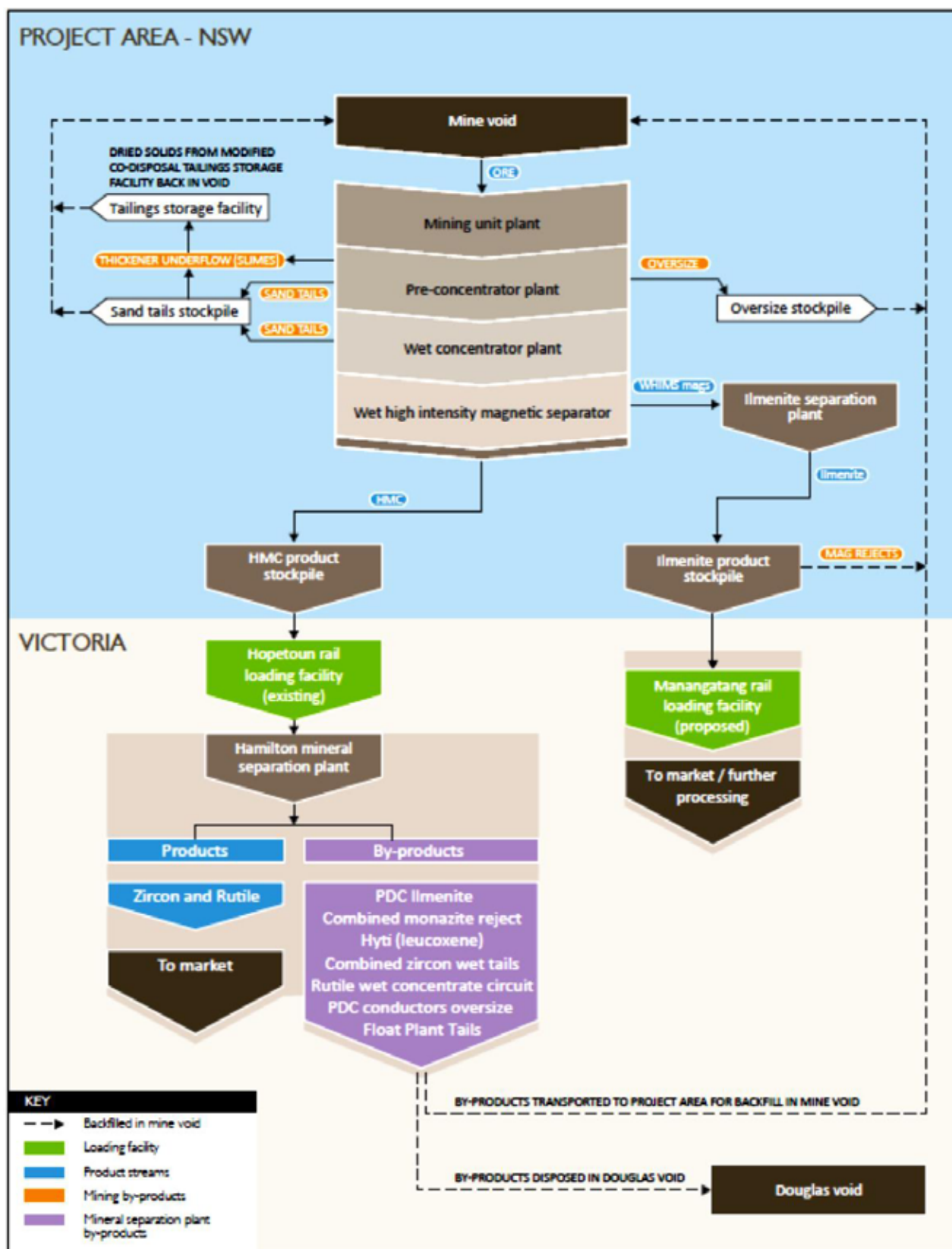
Product stockpiles will be located at the processing area, as shown in Figure 5.

Figure 5: Processing area conceptual layout



Source: EMM 2015

Figure 6: Mineral processing flow diagram



Source: EMM 2015

4.4 Tailings and mining by-products management

4.4.1 Tailings storage facility

Management of tailings and mining by-products associated with processing will be by modified co-disposal. Modified co-disposal will involve slurring sand tails from the WCP with slimes (thickener underflow) from the PCP, and placement in the TSF. The sand and thickener underflow mixture is referred to as ModCod.

The TSF will be located within the processing area (Figure 5). The TSF will be approximately 30 ha in area with a tailings volume in the order of 1,000,000 m³, lined with clay and divided into a number of individual cells. The ModCod will be pumped into a single cell of the TSF. Once a cell is at capacity, the ModCod will be directed to the next empty cell while the first cell dries and consolidates. Once the ModCod has dried sufficiently, the cell will be excavated and the dried material transported by truck back to the mine pit for disposal. Cells that have been excavated will then become available to refill. The cycle from slurry to consolidation to recovery is estimated to take 12 months per cell; every four months the process will discharge into a new cell.

Water will be recovered from the TSF via decant or an in cell pontoon pump and either gravity fed or pumped to the settling dam.

Sand tailings that are not required for the ModCod will be pumped to a sand stacking pad located adjacent to the ROM stockpile at the MUP. Once the sand tails are dried they will be backfilled into the mine void.

4.4.2 Mining by-products from Hamilton mineral separation plant

The Hamilton Mineral Separation Plant (MSP) will generate waste during processing of HMC from the Balranald Project. This will include the following waste streams as detailed on Figure 6:

- Primary Dry Circuit (PDC) Ilmenite;
- Combined monazite reject material;
- HyTi (leucoxene)
- Combined zircon wet tails
- Rutile wet concentrate circuit tails
- PDC conductors oversize (+410 µm)
- Float plant tails

Currently non-saleable by-products materials from the Hamilton MSP are received by Iluka's Douglas operations site. Iluka is currently seeking approval from the Victorian Minister for Planning for the continued disposal of Hamilton MSP by-products at Douglas.

Approximately 155,000 tpa of Hamilton MSP by-products are generated and would be required to be managed as part of Iluka's existing Victorian operations or returned to be placed in the West Balranald void as part of backfilling activities.

4.5 Transport

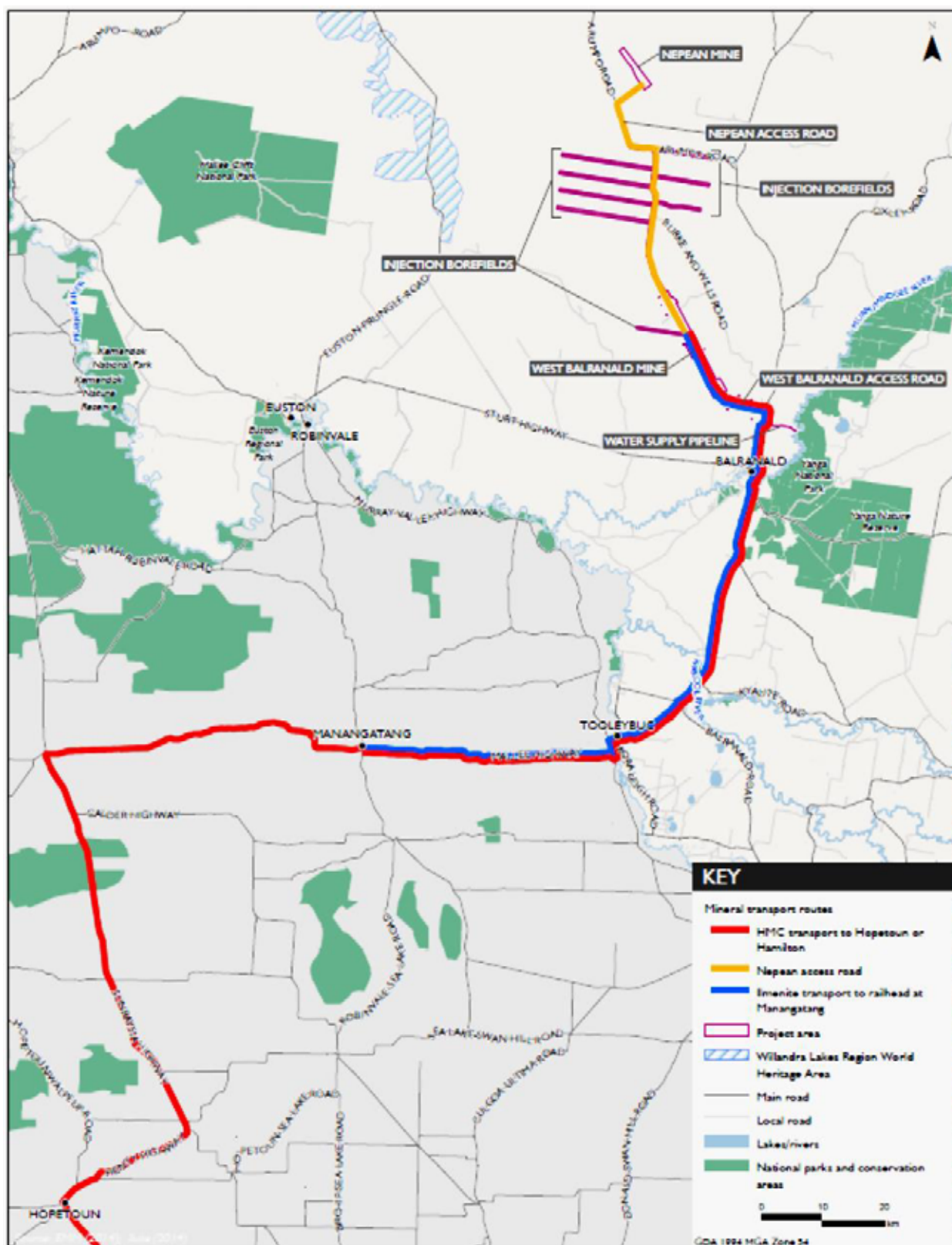
4.5.1 Product Transport

HMC and ilmenite would be transported by trucks from West Balranald mine. Trucks would travel along the Balranald-Ivanhoe Road to the Sturt Highway, and along the Mallee Highway. Transport of HMC would be by B-double vehicle to Iluka's existing rail facility at Hopetoun in Victoria. HMC would be transported from the Sturt Highway south of Balranald to the Mallee Highway, through Tooleybuc and then west into Victoria and south to the Hopetoun rail facility. Transport of ilmenite would be by either B-double (in bulk) or containerised on flat-bed trucks. Ilmenite would be transported to a new rail loading facility in Manangatang, Victoria. The transport route for HMC and ilmenite in NSW is shown in Figure 7. Transport of HMC would generate approximately 37 trucks per day to transport product to Hopetoun, Victoria, and 50 trucks per day for the transport of ilmenite to Manangatang, Victoria.

4.5.2 Back-loaded mining by-product

Non-saleable by-products associated with the processing of HMC at the Hamilton MSP would continue to be managed as part of Iluka's Murray Basin operations in Victoria, which includes placement of by-products from the Hamilton MSP in the mine void of Iluka's Douglas mine. However, where this is not possible, the non-saleable by-products would be transported back to the Balranald Project area by road for placement in the mine void (Figure 6).

Figure 7: Transport route for HMC and ilmenite



Source: EMM 2015

5. BASELINE CONDITIONS

5.1 Radionuclide content of soil in the Project area

Earth Systems^[4] (Appendix A) undertook a preliminary assessment of the radioactive properties and behaviour of mine overburden, wastes and ore from Iluka's West Balranald Mineral Sands deposit. The mine materials were sampled during a sonic drilling and core extraction program of the existing in-situ mine materials from 25 June to 1 July 2014. The sample program was designed to collect information on five distinctive lithologies. In order of increasing age and depth in the deposit these materials were:

- Surface soils (SS)
- Non-saline overburden (NSOB)
- Saline overburden (SOB)
- Organic overburden (OOB)
- Minerals sands ore (ore)

Figure 8 provides details on the locations of these materials within the mining profile and how they will be placed following ore extraction.

Laboratory based radiation activity and full secular equilibrium decay chain analysis were undertaken by Australian Nuclear Science and Technology Organisation (ANSTO) at their Lucas Heights Laboratory in NSW. Table 3 provides the results for the secular equilibrium determination for Th-232, U-238 and U-235 in each lithology.

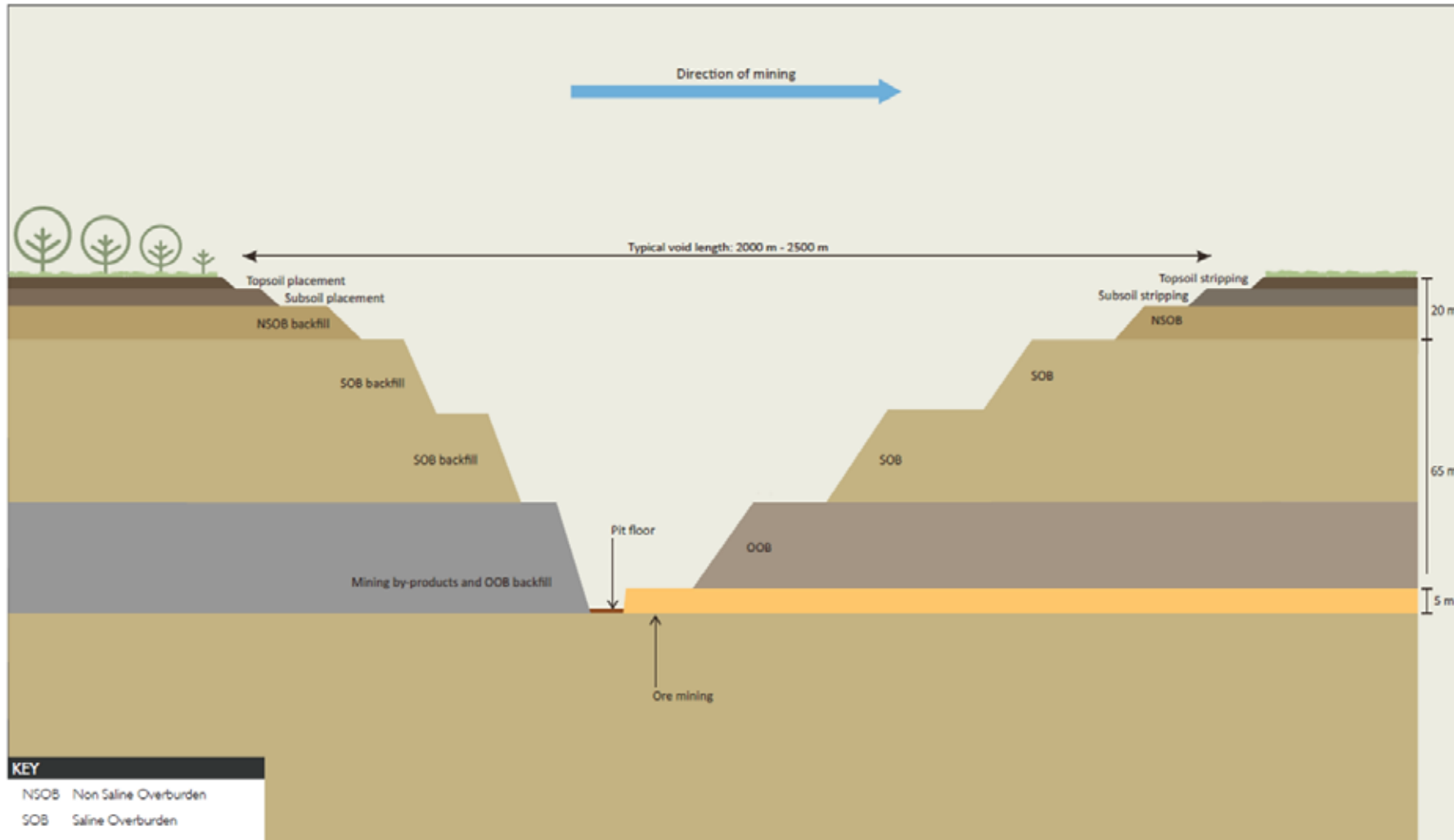
Table 3: Radionuclide Decay Chain Results in Th-232, U-238 and U-235 for Mine Materials

Radionuclide Results (Bq/g)	Balranald Mine Materials				
	SS	NSOB	SOB	OOB	ORE
U (ppm)	4.4 ± 0.2	4.8 ± 0.2	1.5 ± 0.1	11.2 ± 0.3	45.0 ± 0.6
U (Bq/g) [#]	0.055	0.060	0.019	0.139	0.56
Th (ppm)	7.8 ± 0.7	15 ± 1	4.5 ± 0.5	5.1 ± 0.4	310 ± 20
Th (Bq/g) [@]	0.032	0.061	0.018	0.021	1.258
Th-232 Decay Chain					
Th-232	0.031 ± 0.003	0.059 ± 0.005	0.018 ± 0.002	0.021 ± 0.002	1.25 ± 0.09
Ra-228	0.033 ± 0.004	0.058 ± 0.006	0.020 ± 0.002	0.010 ± 0.001	1.3 ± 0.1
Th-228	0.034 ± 0.003	0.057 ± 0.006	0.017 ± 0.002	0.013 ± 0.001	1.3 ± 0.1
U-238 Decay Chain					
U-238	0.055 ± 0.003	0.060 ± 0.003	0.019 ± 0.002	0.139 ± 0.004	0.538 ± 0.008
Th-230	< 0.11 [^]	< 0.12 [^]	< 0.062 [^]	< 0.57 [^]	0.7 ± 0.1
Ra-226	0.022 ± 0.002	0.042 ± 0.004	0.013 ± 0.001	0.015 ± 0.002	0.57 ± 0.06
Pb-210	< 0.017	0.054 ± 0.006	0.022 ± 0.004	< 0.0084	0.46 ± 0.05
Po-210 [*]	0.32 ± 0.04	0.064 ± 0.04	0.021 ± 0.04	0.047 ± 0.04	0.22 ± 0.04
U-235 Decay Chain					
U-235 ^{&}	0.0025 ^{&}	0.0028 ^{&}	0.00087 ^{&}	0.0064 ^{&}	0.026 ± 0.005
Pa-231	< 0.036	< 0.036	< 0.026	< 0.020	< 0.044
Ac-227	< 0.0067	< 0.0064	< 0.0046	< 0.0041	< 0.031
Th-227	< 0.0067	< 0.0064	< 0.0046	< 0.0041	< 0.031
Potassium-40					
K-40	0.34 ± 0.03	0.61 ± 0.06	0.14 ± 0.01	0.13 ± 0.01	0.14 ± 0.01
Total contained activity[‡]	1.5	1.9	0.57	1.0	20.9^π

Notes: (ANSTO 2014) * Po-210 concentration on the count date of 19 September 2014. ^ No gamma peak was detected in the gamma spectrum. Less than values quoted are statistically determined by the gamma analysis software. & No gamma peak was detected in the gamma spectrum. U-235 concentration calculated from the measured U-238 concentration. ‡ Including K-40. Less than values assume zero concentration for those particular radionuclides in the calculations. π Assumes the concentration of Po-210 is 0.56 Bq/g.

‡ Includes the contribution from all radionuclides (long- and short-lived) in each of the respective decay chains and K-40. Less than values assume zero concentration for those particular radionuclides in the calculation [ANSTO]

Figure 8: Conceptual mining cross section showing overburden materials



Source: EMM 2015

5.2 Radionuclide in groundwater

Land & Water Consulting Pty Ltd (LWC) was engaged to undertake a Pre-Mining Radionuclide Groundwater Monitoring Event for the Balranald Mineral Sands Project (Appendix B). The Radionuclide Groundwater Monitoring Event (GME) was undertaken between 2 and 5 June 2014.

The key objective of pre-mining groundwater monitoring for the proposed Balranald Mineral Sands project is to obtain suitable and representative baseline groundwater elevation, field parameter and water quality data from the underlying groundwater system/s observed within the Project area (and surrounds) for the purpose of:

- understanding temporal/spatial trends in the overburden and ore; and
- future comparison against any changes brought about as a result of mining operations.

The underlining basis of this objective is to protect the surrounding water resources and existing groundwater users during and post future mining operations. Baseline monitoring data will therefore represent the natural radiological composition and distribution in groundwater beneath the study area and surrounds and becomes a control against any measured impact of the future mining operations and activities.

The following sampling program was to be adopted for both the West Balranald and Nepean deposits:

- One bore as close to the ore body as possible to be sampled for full radionuclide analysis including U-238, Th-232 and U-235 and respective decay chains.
- One bore up gradient of the ore body (and outside of the mining pathway which is considered to represent background) to be sampled for U-238, Th-232 and U-235 and respective decay chains.
- Targeted sampling of other bores within the mining extent and surrounds with groundwater to be sampled for uranium, radium-228 and radium-226.

The West Balranald ore deposit within the Loxton-Parilla Sands is situated around 46 to 53 m below ground level (bgl) in the centre of the defined deposit. The Nepean deposit is also located within the Loxton-Parilla Sands, but with a shallower average depth of 48 m bgl.

The location of the bores monitored as part of the monitoring event is shown on Figure 9. Table 4 provides a summary of the radionuclide analysis undertaken during the sampling program. A summary of the hydrogeochemical parameters sampled during the program is provided in Table 5 while Table 6 and 7 provide a summary of radionuclide analysis for West Balranald and Nepean mines (respectively).

Figure 9: Groundwater Well Location Plan

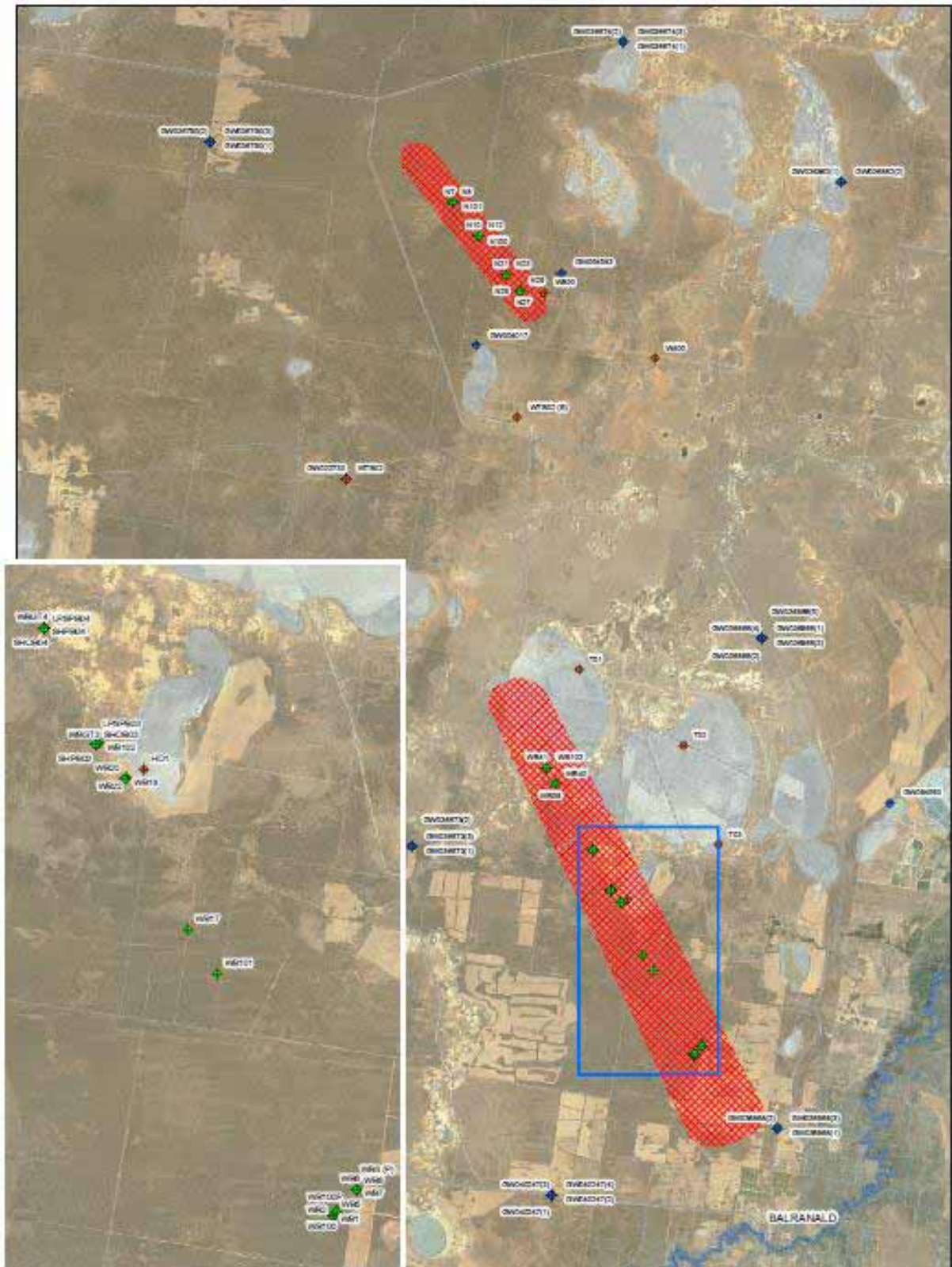


Table 4: Summary of Groundwater Monitoring Well Analysis

Zone	Function	Groundwater Well	Analysis	
			Full Decay Chain (Alpha & Gamma Spectrometry)	Gamma Spectrometry & ICP-MS Activity Conversion
West Balranald	Near the ore body	WB28, WB40 or WB41	Choice of one of these three wells for full uranium and thorium decay chain.	The remaining two wells being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
	Up-Gradient / Outside of the Mining Pathway	GW036868(2) or GW036673(2)	GW036868(2) & GW036673(2)	N/A
	Other Bores within the Mining Extent / Down hydraulic gradient.	WB5, WB17 and WB20	Choice of one of these three wells for full uranium and thorium decay chain.	The remaining two wells being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
Nepean	Near the ore body	N10 and GW036790-2	Choice of one of these two wells for full uranium and thorium decay chain.	The remaining well being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
	Up-Gradient / Outside of the Mining Pathway	GW036674(1) or GW036866(2)	Choice of one of these two wells for full uranium and thorium decay chain.	The remaining well being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
	Other Bores within the Mining Extent	N7 and N28	Choice of two of these three wells for full uranium and thorium decay chain.	The remaining well being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.

Table 5: Summary of Hydrogeochemical Parameters

Zone	Function	Groundwater Well	pH	EC (uS/cm)	Redox (mV)	Temp. °C
West Balranald	Near the ore body	WB28	6.34	51,818	-107.1	20.6
		WB40	6.21	47,326	-64.1	21.3
		WB41	6.15	45,982	-90.9	21.2
	Up-Gradient / Outside of the Mining Pathway	GW036868(2)	7.69	24,427	-185.2	20.6
		GW036673(2)	7.02	50,192	-91.5	21.2
	Other Bores within the Mining Extent / Down hydraulic gradient.	WB5	6.6	29,983	-155.3	20.1
		WB17	6.21	55,090	-74.6	20.4
WB20*		6.78	51,007	-102.2	17.6	
Nepean	Near the ore body	N10	6.55	48,729	-78.0	22.5
		GW036790-2	6.62	42,250	103.8	22.9
	Up-Gradient / Outside of the Mining Pathway	GW036674(1)	6.86	22,107	-22.9	22.7
		GW036866(2)	6.92	20,900	-63.3	20.4
	Other Bores within the Mining Extent	N7	6.33	46,258	-51.7	21.5
		N28	6.61	29,112	-226.0	21.8

*Table 2.1 in LWC 2015 incorrectly identifies this bore as WB25. The correct well identification is WB20

Table 6: Summary of Radionuclide Analysis for West Balranald Bores

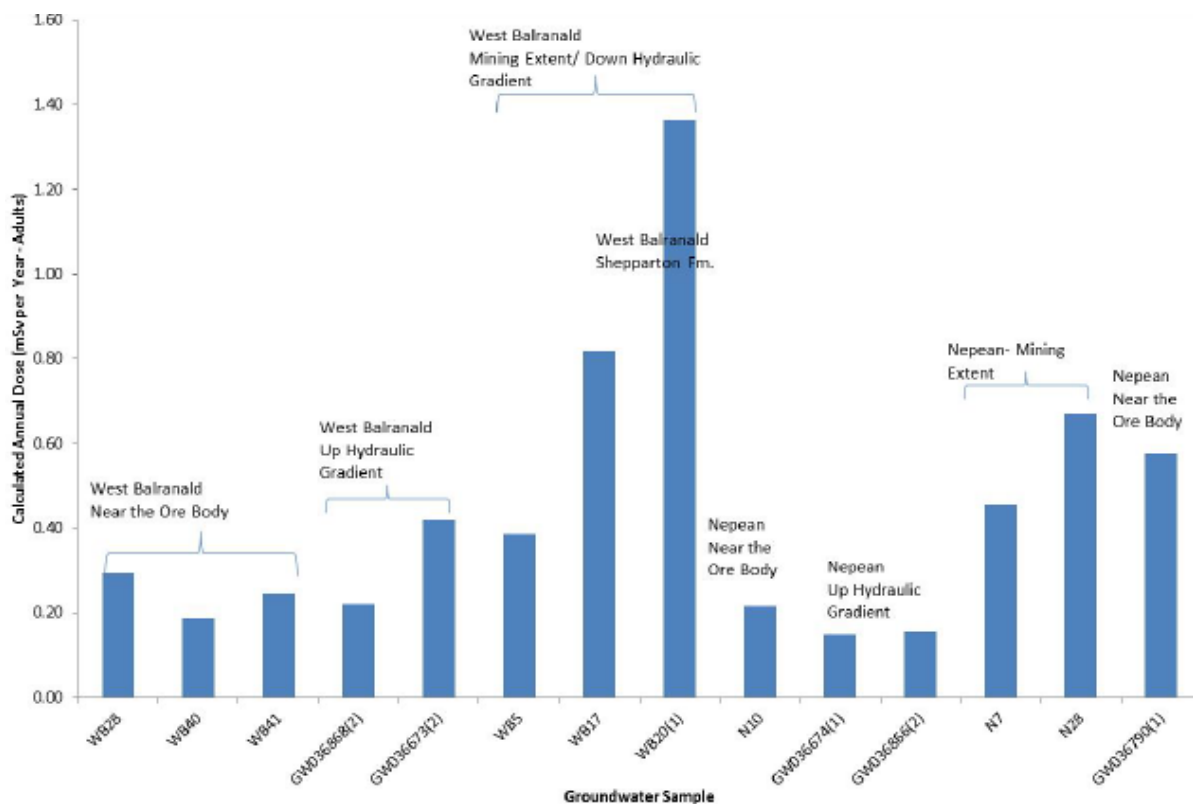
Analyte	West Balranald								
	Near the Ore Body			Up-Hydraulic Gradient		Mining Extent / Down Hydraulic Gradient			
	WB28	WB40	WB41	GW036868(2)	GW036673(2)	WB5	WB17	WB20(1)	WB20(2)
Naturally Occurring U-238 Series (Bq/L)									
U-238		<0.02	<0.02			<0.02		2.6	2.7
Th-234	<0.17	<0.13	<0.15	<0.14	<0.45	<0.43	0.12	2.2	
Ra-226	0.104	0.091	0.123	0.109	0.06	0.151	1.82	0.5	
Pb-210	<0.16	<0.13	<0.13	<0.15	<0.6	<0.4	<0.17	<0.61	
Po-210	<0.013			0.0124	0.0034		0.0054		
Naturally Occurring Thorium Series (Bq/L)									
Th-232		0.01	0.014			<0.005		<0.005	<0.005
Ra-228	0.325	0.194	0.297	0.206	0.189	0.298	0.683	1.72	
Th-228	<0.039	<0.029	<0.036	<0.037	<0.039	<0.038	<0.030	<0.034	
Naturally Occurring Uranium Radioisotopes (Bq/L)									
U-238	0.053			0.012	0.0099		0.0509		
U-235	0.0113			0.00105	<0.0017		0.0055		
U-234	0.083			0.012	0.0109		0.0569		
Naturally Occurring Thorium Radioisotopes (Bq/L)									
Th-232	<0.013			<0.0034	<0.0019		<0.0045		
Th-230	0.036			0.0261	0.0212		0.0157		
Th-228	0.019			0.0112	0.0128		0.0189		
Th-227	0.022			<0.0071	<0.017		<0.0086		

Table 7: Summary of Radionuclide Analysis for Nepean Bores

Analyte	Nepean					
	Near the Ore Body		Up-Hydraulic Gradient		Mining Extent / Down Hydraulic Gradient	
	N10	GW036790(2)	GW036674(1)	GW036866(2)	N7	N28
Naturally Occurring U-238 Series (Bq/L)						
U-238				<0.02		<0.02
Th-234	<0.18	<0.13	0.09	<0.14	<0.47	<0.45
Ra-226	0.114	1.87	0.082	<0.053	0.202	1.064
Pb-210	<0.16	<0.14	<0.13	<0.14	<0.61	<0.42
Po-210	<0.0044	0.025	0.0131		0.0081	
Naturally Occurring Thorium Series (Bq/L)						
Th-232				<0.005		<0.005
Ra-228	0.194	0.162	0.097	<0.14	0.185	0.472
Th-228	<0.032	<0.034	<0.017	<0.033	0.036	<0.043
Naturally Occurring Uranium Radioisotopes (Bq/L)						
U-238	0.0568	0.151	0.0136		0.0358	
U-235	0.0046	0.0174	0.0025		0.0027	
U-234	0.066	0.154	0.0134		0.0609	
Naturally Occurring Thorium Radioisotopes (Bq/L)						
Th-232	0.0054	<0.0095	0.0038		<0.0036	
Th-230	0.0172	0.035	0.021		0.00243	
Th-228	0.0099	<0.0098	0.0109		0.0049	
Th-227	<0.008	0.017	<0.006		<0.0076	

Figure 10 provides details on the calculated annual dose of radionuclides through the ingestion of groundwater within the project area. The calculation is based solely on radionuclide content and does not consider whether the groundwater is suitable for human consumption. Results provided in Table 5.3 indicate that the salinity (EC) of the waters is notably elevated, and thus salinity precludes the use of the water for abstraction and potable use (without considerable treatment).

Figure 10: Calculated Annual Dose through ingestion of groundwater per zone



Key findings of the radionuclide monitoring event included the following:

- With respect to human health screening (i.e. ingestion of water), only one water sample (sampled from WB20) exceeded the Australian Drinking Water Guideline (ADWG) dose threshold of 1 mSv per year, largely driven by uranium-238, and radium-228 from the thorium series. Notwithstanding the activity, it is not expected that such water would be suitable for potable use due to salinity.
- Radium 228 appears to be generally elevated in all waters sampled, relevant to World Health Organisation (WHO) radium 228 screening criterion for drinking waters (0.1 Bq/L), independent of zones / domains.

6. MATERIALS CHARACTERISATION AND CLASSIFICATION

6.1 Characterisation

The scope for the mine materials included an assessment of laboratory data against activity and transport guidelines for radiation management. Laboratory based radiation activity and full secular equilibrium decay chain analysis were undertaken by ANSTO at their Lucas Heights Laboratory in NSW. Decay chain analysis was employed to allow for determination of secular equilibrium for long-lived decay progeny of Th-232, U-235 and U-238 in the mine materials.

The following analysis techniques were undertaken:

- Gamma spectrometry for U-238 and Th-232 decay progeny and U-235 and its decay progeny;
- Delayed neutron activation (DNA) analysis for parent U-238;
- Neutron activation analysis (NAA) analysis for parent Th-232;
- Alpha spectrometry for Po-210; and
- X-Ray Fluorescence Spectrometry (XRF) analysis for elemental content. This data is used for self-absorption corrections in gamma spectrometry.

Earth Systems[5] was also engaged to conduct a laboratory test-work program to classify the Hamilton MSP MBPs from processing of Balranald HMC in accordance with NSW government waste classification guidelines (Appendix C).

Samples of each of the Hamilton MBP streams were prepared at Iluka's pilot scale metallurgical test facility. The MBPs and the percentage that each waste stream represents of the total MBP mass produced at the Hamilton MSP are provided in Table 8. All samples were submitted for radionuclide and chemical analyses.

Table 8: Hamilton MBPs, sample mass and the percentage that each by-product represents of the total waste produced at the Hamilton MSP

MBP	Percentage of total waste produced (wt.%) ¹
PDC Ilmenite	53
Combined monazite reject	10.5
Hyti	11.7
Combined zircon wet tails	8.6
Rutile wet concentrate circuit	0.9
PDC conductors oversize (+410 µm) ²	-
Float Tails	11.3

1: The remaining 4 % of waste material is recycled through the Hamilton MSP.

2: This stream represents 0.1 wt.% of the Hamilton MSP feed and may not be produced as it makes very little difference to the grade of the products.

A representative sub-sample of each of the MBPs was also submitted to ANSTO for analysis and classification in accordance with Part 3 of the waste classification guidelines. Analyses conducted include:

- Gamma spectrometry for U-238 and Th-232 decay progeny and U-235 and its decay progeny;
- DNA analysis or fusion / acid digest followed by ICP-MS for parent U-238 (method depends on available mass of sample material);
- NAA or fusion / acid digest followed by ICP-MS for parent Th-232 (method depends on available mass of sample material);
- Alpha spectrometry for Po-210; and
- XRF analysis for elemental content for self-absorption corrections in gamma spectrometry.

6.1.1 Mine Materials

Table 5.1 summarises the radionuclide results on the mine materials for the secular equilibrium determination for Th-232, U-238 and U-235.

The conversion factors for uranium and thorium from ppm to Bq/g (Specific Activity) were calculated as follows (conversion factors are provided in Table 9):

$$\text{Specific Activity (SA)} = \lambda N \quad (\text{Bq/g})$$

Where λ = decay constant (s^{-1}) = $\ln 2 / t_{1/2} = 0.693 / t_{1/2}$
 $t_{1/2}$ = half live of nuclide (s)
 N = number of atoms (g^{-1}) = N_A / A
 N_A = Avogadro Constant = number of atoms in one mole
 $= 6.023 \times 10^{23}$ atoms
 A = Atomic weight of nuclide in one mole

Table 9: U-238 and Th-232 Specific Activity Conversion Factors

Nuclide	Atomic Mass (A)	Half-life of individual Radionuclides		Decay Constant	Specific Activity Conversion Factor
	gram / mole	Years	sec	$\lambda = \ln 2 / T_{1/2}$ (s)	
U238	238.03	4.47 billion	1.40903E+17	4.92E-18	12.441
Th232	232.04	14.05 billion	4.43081E+17	1.56E-18	4.059

6.1.2 Mining By-Products

Table 10 summarises the radionuclide results on the MBPs for the secular equilibrium determination for Th-232, U-238 and U-235.

Table 10: Radionuclide Decay Chain Results in Th-232, U-238 and U-235 for MBPs

Radionuclide Results (Bq/g)	PDC Ilmenite	Combined Monazite Reject	HyTi	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	Float Tails Sample	PDC Conductors O/S + 410 micron
Th-232 Decay Chain							
Th-232	0.22	77	1.3	0.56	1	0.3	0.89
Ra-228	0.22	68	1.2	0.3	0.91	0.27	0.86
Th-228	0.19	75	1.3	0.3	0.9	0.27	0.86
U-238 Decay Chain							
U-238	0.11	14	0.42	1.01	0.58	0.48	0.81
Th-230	0.12	17	0.5	0.78	0.51	<0.3	0.9
Ra-226	0.12	13	0.47	0.83	0.58	0.39	0.82
Pb-210	0.14	13	0.42	0.72	0.47	0.33	0.68
Po-210	0.03	8	0.34	0.3	0.16	0.25	0.31
U-235 Decay Chain							
U-235	0.0051	0.65	0.0194	0.0466	0.0268	0.0222	0.037
Pa-231	<0.026	0.8	<0.069	<0.039	<0.043	<0.064	<0.13
Ac-227	<0.0053	1	0.028	0.046	0.03	0.019	0.047
Th-227	<0.0053	1	0.028	0.045	0.03	0.019	0.047
Potassium-40							
K-40	0.026	<0.32	0.1	<0.024	0.07	<0.044	0.3
Total contained activity[‡]	3.7	938	19.4	15.7	17.2	8.2	20.5
Specific Activity - Group 1	1.7	460	9.3	7.0	8.1	3.5	9.5
Specific Activity - Group 2	1.6	375	7.9	6.4	7.0	3.5	8.5
Specific Activity - Group 3	0.32	89	1.8	1.2	1.5	0.7	1.7
Specific Activity - Group 4	0.12	15	0.4	1.1	0.6	0.5	0.8

[‡] Including K-40. Less than values assume zero concentration for those particular radionuclides in the calculations

6.2 Classification Summary

6.2.1 Mine Materials

A summary of the classification of mine materials is provided in Table 11 below.

Table 11: Classification of Mine Materials under the RC Act

Radionuclide Results	West Balranald Mine Materials				
	SS	NSOB	SOB	OOB	ORE
U (ppm)	4.4	4.8	1.5	11.2	45
Weight % U	0.0004	0.0005	0.0002	0.0011	0.0045
Th (ppm)	7.8	15	4.5	5.1	310
Weight % Th	0.0008	0.0015	0.0005	0.0005	0.0310
Weight% U / 0.02	0.022	0.024	0.0075	0.056	0.225
Weight% Th / 0.05	0.0156	0.03	0.009	0.0102	0.62
U / 0.02 + Th / 0.05	0.0376	0.054	0.0165	0.0662	0.845
Radioactive Ore	NO	NO	NO	NO	NO
Total contained activity‡	1.5	1.9	0.57	1	20.9
Radioactive Substance	NO	NO	NO	NO	NO

As all five lithologies (mine materials) would include both uranium and thorium, clause 4(1)(c) of the RC Regulation is the relevant method to determine if the ore would be a “radioactive ore”. None of the mine materials are classified as “radioactive ore”, since: ‘weight % U / 0.02 + weight % Th / 0.05 < 1’ for all lithologies.

The first step to determining if a material is a “radioactive substance” is to check its specific activity is below the prescribed amount of 100 Bq/g. As the specific activity (Total contained activity as per Table 6.5) of all five lithologies (mine materials) would be less than 100 Bq/g, as such these materials would not be classified as a “radioactive substance” under the RC Act.

6.2.2 Mining By-Products

The sections contained within the NSW waste classification guidelines that are relevant to the classification of the Hamilton MBPs include:

- *Classifying Waste* (Part 1); and
- *Waste Containing Radioactive Material* (Part 3).

As discussed in Section 3, only Part 3 of the Guideline is relevant to the radiation classification of the mining by-product waste material. Further details regarding classification of the materials in accordance with Part 1 of the NSW waste classification guidelines are contained in Earth Systems[6].

Relevant strategies and regulations that are referred to in the NSW Guidelines include:

- RC Act; and
- RC Regulation.

Part 3 of the NSW Guidelines outlines the classification requirements for solid and liquid wastes containing radionuclides. Radioactive waste is regulated in accordance with the RC Act and the RC Regulation. Part 3 of the guidelines stipulate that wastes with a specific activity greater than 100 Bq/g and consisting of, or containing more than, the prescribed activity of a radioactive element in Schedule 1 of the Radiation Control Regulation (2003) must be classified as hazardous waste. The Specific Activity and Total Activity ratios are then used to determine whether the waste is classified as 'restricted solid waste' or whether it is to be classified in accordance with Part 1 of the NSW Guidelines. If the Specific Activity or Total Activity ratios are greater than one, then non-liquid wastes must be classified as 'restricted solid waste' unless:

- Other characteristics of the waste mean that the waste must be classified as 'hazardous waste' (e.g. via Step 3 of Part 1 of the NSW Guidelines); or
- It may contain chemical contaminants that will lead to its assessment as 'hazardous waste' (e.g. via Step 5 of Part 1 of the NSW Guidelines).

Where the Specific Activity and Total Activity ratios are equal to or less than one, the waste must be classified according to its other characteristics in line with Part 1 of the NSW Guidelines.

Table 12 summarises the classification of MBPs under the RC Act.

Table 12: Classification of Mining By-Products under the RC Act

Radionuclide Results	West Balranald Mining By-Products						
	PDC Ilmenite	Combined Monazite Reject	HyTi	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	Float Tails Sample	PDC Conductors O/S + 410 micron
Bq/g U-238	0.11	14	0.42	1.01	0.58	0.48	0.81
U (ppm)	9	1125	34	81	47	39	65
Weight % U	0.0009	0.1125	0.0034	0.0081	0.0047	0.0039	0.0065
Bq/g Th-232	0.22	77	1.3	0.56	1	0.3	0.89
Th (ppm)	54	18970	320	138	246	74	219
Weight % Th	0.0054	1.8970	0.0320	0.0138	0.0246	0.0074	0.0219
Weight% U / 0.02	0.044	5.627	0.169	0.406	0.233	0.193	0.326
Weight% Th / 0.05	0.11	37.94	0.64	0.28	0.49	0.15	0.44
U / 0.02 + Th / 0.05	0.15	43.57	0.81	0.68	0.73	0.34	0.76
Radioactive Ore	NO	YES	NO	NO	NO	NO	NO
Total contained activity#	3.7	938.1	19.4	15.7	17.2	8.2	20.5
Radioactive Substance	NO	YES	NO	NO	NO	NO	NO

To be classified as a “radioactive substance”, the material specific activity needs to be above the prescribed amount of 100 Bq/g. For the mining by-products, only the ‘combined monazite reject’ has a total contained activity (Table 12) greater than 100 Bq/g and is therefore classified as a “radioactive substance” under the RC Act.

Table 13 summarises the classification of MBPs under the NSW waste classification guidelines.

Table 13: Classification of Mining By-Product Materials under the NSW Guidelines

Radionuclide Results (Bq/g)	PDC Ilmenite	Combined Monazite Reject	HyTi	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	Float Tails Sample	PDC Conductors O/S + 410 micron
Total contained activity [‡]	3.7	938	19.4	15.7	17.2	8.2	20.5
Radioactive Substance	NO	YES	NO	NO	NO	NO	NO
Specific Activity - Group 1	1.7	460	9.3	7.0	8.1	3.5	9.5
Specific Activity - Group 2	1.6	375	7.9	6.4	7.0	3.5	8.5
Specific Activity - Group 3	0.32	89	1.8	1.2	1.5	0.7	1.7
Specific Activity - Group 4	0.12	15	0.4	1.1	0.6	0.5	0.8
Specific Activity Ratio	1.9	498	10.1	7.7	8.8	3.8	10.3
Classification	Restricted Solid	Hazardous	Restricted Solid	Restricted Solid	Restricted Solid	Restricted Solid	Restricted Solid

From Table 13, only the ‘Combined Monazite Reject’ material is classified as “hazardous waste” according to Schedule 1 of the RC Regulation. All other MBP materials are classified as “restricted solid waste”.

7. RADIOLOGICAL IMPACT ASSESSMENT

This section describes the potential radiological impacts associated with the Balranald Project and provides management measures for these activities. Each of the potential impact mechanisms described has the potential to result in impacts on the environment and human health if not appropriately managed. The management of materials containing radioactive components at the Balranald Project would be detailed in a RMP in accordance with the Code.

The RMP would include details of best practicable technology to minimise potential occupational and member of public doses, and would describe monitoring proposed for the Balranald Project. A summary of the proposed radiation monitoring program is provided in Table 14.

Table 14: Radiation Monitoring Program

Project Component	Location	Method	Primary Purpose
Balranald & Nepean mines	Mine path	Environmental gamma monitoring	Once-off survey prior to mining to record baseline radiation levels.
		Environmental gamma monitoring	Regular surveys to confirm radiation levels at surface are equivalent to baseline radiation levels.
	HMC stockpiles & MSP waste disposal sites	Personal thermoluminescent dosimeter TLD; Personal Air Samplers (representative samples)	Occupational dose assessment
Mineral Concentrate & MSP Process Waste Transport	Trucks/Train	Locational dose rate measurements using hand held gamma radiation monitors inside driver's cabin.	Operational control.
		Gamma radiation readings taken outside of the containers and at 1 m from the truck/train.	Operational control.

In addition to the RMP, the following management plans would also be prepared for the Project:

- Radioactive Waste Management Plan (RWMP);
- Mineral Concentrate and MSP Process Waste Transport Management Plan.

7.1 Dose delivery pathways to employees and members of the public

Potential dose delivery pathways for employees and members of the public resulting from the Project would include:

- irradiation by gamma radiation;
- inhalation of dusts containing long lived alpha emitting radionuclides (LLAE);
- inhalation of the decay products of radon (Rn222 and Rn220); and
- ingestion of radionuclides.

These potential dose delivery pathways could occur during the following project activities:

- handling and stockpiling of HMC, mineral concentrates, MSP process waste and blended process waste at the Balranald Mine;
- transporting (via road) mineral concentrates and MSP process waste between the Balranald Mine and the Hamilton MSP;

A discussion of the potential impacts at each of these Project components is provided below.

7.1.1 Balranald & Nepean Mine

The long-term accrual of radiation dose (via irradiation, inhalation and/or ingestion) of employees and/or members of the public during the handling and stockpiling of HMC, mineral concentrates, MSP process waste and blended process waste at the Balranald Mine could cause potential doses in excess of relevant limits (Section 2.3) in the absence of management measures. Table 15 provides a summary of the potential activities and associated dose delivery pathways that would potentially occur at the Balranald Mine.

Management of HMC, mineral concentrates, MSP process waste at the Balranald Mine would be conducted as described in Section 4.4. With the implementation of these management measures, the risk of harm to employees, members of the public and the environment from the handling and stockpiling of the HMC, mineral concentrates, MSP process waste and blended process waste would be negligible.

Table 15: Potential Dose Delivery Pathways associated with the Balranald Project

Activity	Potential Dose Delivery Pathway	Mitigation Measures
Handling and stockpiling HMC, mineral concentrates and MSP process waste.	<ul style="list-style-type: none"> • Inhalation or ingestion of LLAE in dust during handling and stockpiling activities. • Doses of gamma radiation through close proximity to the mineral concentrates and MSP process waste. 	<ul style="list-style-type: none"> • Radiation Monitoring Programme • Stockpile Management Standard • Radiation Management Standard • Dust suppression measures implemented including water carts, shade cloths, sprinkler systems, speed limits enforcement, minimisation of open area.
Loading of mineral concentrates onto haulage vehicles.	<ul style="list-style-type: none"> • Inhalation or ingestion of LLAE in dust during loading activities. • Doses of gamma radiation through close proximity to the mineral concentrates. 	<ul style="list-style-type: none"> • Radiation Monitoring Programme • Stockpile Management Standard • Radiation Management Standard • Dust suppression measures implemented including water carts, shade cloths, sprinkler systems, speed limits enforcement, minimisation of open area.
Unloading of MSP process waste from haulage vehicles.	<ul style="list-style-type: none"> • Inhalation or ingestion of LLAE in dust during unloading activities. • Doses of gamma radiation through close proximity to the MSP process waste. 	<ul style="list-style-type: none"> • Radiation Monitoring Programme • Stockpile Management Standard • Radiation Management Standard • Dust suppression measures implemented including water carts, shade cloths, sprinkler systems, speed limits enforcement, minimisation of open area.
Mixing of MSP process waste with sand residues and coarse rejects.	<ul style="list-style-type: none"> • Inhalation or ingestion of LLAE in dust through activities associated with loading MSP process waste prior to mixing. • Doses of gamma radiation through close proximity to the MSP process waste. 	<ul style="list-style-type: none"> • Radiation Monitoring Programme • Dust suppression measures implemented including water carts, shade cloths, sprinkler systems.

Activity	Potential Dose Delivery Pathway	Mitigation Measures
Deposition of blended process waste.	<ul style="list-style-type: none"> Very little risk of either gamma radiation or dust generation as the blended process waste is wet and material has been blended with non-radioactive material. 	<ul style="list-style-type: none"> Radiation Monitoring Programme
Incident or accident resulting in loss of containment of material.	<ul style="list-style-type: none"> Inhalation of LLAE in dust or doses of gamma radiation. Environmental exposure to radioactive material. 	<ul style="list-style-type: none"> <i>Emergency Response Plan (ERP)</i> This plan would provide emergency response objectives, site roles and responsibilities and a series of detailed response procedures for a range of potential emergencies. Emergency response procedures in place to respond to leaks and spills including assessment, clean-up and treatment procedures.

7.1.2 Mineral Concentrate and MSP Process Waste Transport

Table 16 provides a summary of the potential activities and associated potential dose delivery pathways that would potentially occur during transport of mineral concentrates and MSP process waste.

Management of the transport of mineral concentrates and MSP process waste for the Balranald Project would be conducted as described in Section 4.4. With the implementation of these management measures, the risk of harm to employees, members of the public and the environment from the transport of mineral concentrates and MSP process waste would be negligible.

Table 16: Potential Dose Delivery during Transport of Mineral Concentrates and MSP Process Waste

Activity	Potential Dose Delivery Pathway	Mitigation Measures
Transport of mineral concentrates and MSP process waste.	<ul style="list-style-type: none"> Doses of gamma radiation through close proximity to the road haulage vehicles and rail wagons containing mineral concentrates or MSP process waste. 	<ul style="list-style-type: none"> Truck tubs are covered. Haul truck operator training. Contractor Management Standard. Radiation Monitoring Programme
Wind-blown dust during the transport of mineral concentrates and MSP process waste.	<ul style="list-style-type: none"> Inhalation or ingestion of LLAE in dust dispersed from haulage vehicles or rail wagons. Doses of gamma radiation through close proximity to the mineral concentrates or MSP process waste. Environmental exposure to radioactive material. 	<ul style="list-style-type: none"> Truck tubs are covered. Haul truck operator training. Contractor Management Standard. Radiation Monitoring Programme Emergency response procedures in place to respond to leaks and spills including assessment, clean-up and treatment procedures.

Activity	Potential Dose Delivery Pathway	Mitigation Measures
Incident or accident resulting in loss of containment of mineral concentrates or MSP process waste.	<ul style="list-style-type: none"> • Inhalation or ingestion of LLAE in dust or doses of gamma radiation following loss of intended containment of material as a result of collision, failure of containment component, or interference by unauthorised personnel. • Environmental exposure to radioactive material. 	<ul style="list-style-type: none"> • <i>Emergency Response Plan (ERP)</i> – This plan would provide emergency response objectives, site roles and responsibilities and a series of detailed response procedures for a range of potential emergencies. • Emergency response procedures in place to respond to leaks and spills including assessment, clean-up and treatment procedures.

7.1.3 Environment

An incident or accident resulting in the loss of containment of HMC, mineral concentrates, MSP process waste or blended process waste (e.g. accident along the transport route) could potentially result in local contamination of land or surface waters. In the event of a loss of containment event, there would be limited radiological consequences, as the heavy nature of the radioactive material (i.e. monazite) and its insolubility in water, would limit the potential for dispersal and therefore the extent of contamination (Radiation Advice & Solutions, 2006). The coarse heavy nature of the radioactive material would also limit the potential for the

material to become airborne. In addition, the RWMP would include a plan for dealing with incidents, accidents and emergencies to respond to these events in order to limit the potential for land and surface water contamination.

Section 3.6.6 of the Mining and Processing Code states that:

For the purposes of the Code it is assumed that by achieving adequate protection of human health, an acceptable level of protection will be afforded to the environment. However, this assumption may not be valid in all circumstances and specific additional control measures may be required.

It is therefore considered appropriate to afford protection of the environment through the application of human health exposure criteria. As the Balranald Project is expected to address the human health exposure criteria, it is considered that there would be no significant radiological impact on the environment.

8. CONCLUSIONS

8.1 Baseline radionuclide content of soil and mine materials

From the baseline conditions on the radionuclide content of soil in the Balranald Project area was found that the head of chain (U & Th) specific activities and the total contained activities (sum of activities of all radionuclides present) of the five lithologies (mine materials) is summarised in Table 17.

Table 17: Specific head-of-chain and total contained activities of mine materials

Radionuclide Results (Bq/g)	West Balranald Mine Materials				
	Surface Soils (SS)	Non-Saline overburden (NSOB)	Saline overburden (SOB)	Organic overburden (OOB)	Mineral Sands Ore (ore)
Head of Chain Specific Activity: U & Th (Bq/g)	0.087	0.121	0.037	0.16	1.818
Total contained activity	1.5	1.9	0.57	1.0	20.9

None of the mine materials: surface soils; non-saline overburden; saline overburden; organic overburden or mineral sands ore are classified as “radioactive ore”, or as “radioactive substances” under the RC Act.

8.2 Baseline radionuclide content of groundwater

Key findings from the baseline conditions on the radionuclide content of groundwater in the Balranald Project included the following:

- With respect to human health screening (i.e. ingestion of water), only one water sample (sampled from WB20) exceeded the ADWG dose threshold of 1 mSv per year, largely driven by uranium-238, and radium-228 from the thorium series. Notwithstanding the activity, it is not expected that such water would be suitable for potable use due to salinity.
- Radium 228 appears to be generally elevated in all waters sampled, relevant to WHO radium 228 screening criterion for drinking waters (0.1 Bq/L), independent of zones / domains.

8.3 Classification of Hamilton Mineral Separation Plant materials

Key conclusions from the classification test-work of the MBP samples include:

- Based on Part 3 of the NSW Guidelines relating to wastes containing radioactive material, the Combined Monazite Reject is likely to be classified as Hazardous Solid Waste.
- Based on Part 3 of the NSW Guidelines relating to wastes containing radioactive material, the PDC Ilmenite, Hyti, Combined Zircon Wet Tails, Rutile Wet Concentrate

Circuit, PDC Conductors Oversize and Float Tails MBP streams are likely to be classified as Restricted Solid Waste.

8.4 Risk to human health and the environment

Table 18 summarises the radiological risks to human health and the environment associated with the Balranald Project.

Table 18: Summary of the radiological risks to human health and the environment associated with the Balranald Project

Project element	Risk to human health and the environment
Balranald and Nepean mine operations	With the implementation of identified management measures (Table 7.2) the risk of harm to employees, members of the public and the environment from the handling and stockpiling of the HMC, mineral concentrates, MSP process waste and blended process waste is considered to be negligible.
Transport of mineral concentrates and MSP process wastes	With the implementation of identified management measures (Table 7.3) the risk of harm to employees, members of the public and the environment from the transport to mineral concentrates and MSP process waste is considered to be negligible.

8.5 Conclusion summary

Based on the existing environment baseline information collected for the Balranald Project, waste characterisation work and results from the completed radiological risk assessment it is considered that with the implementation of the identified mitigation measures, the Project will present a negligible radiological risk to human health and the environment.

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APPENDIX A

West Balranald Mineral Sands Project Preliminary Mine Materials Radiation Assessment

prepared for

Iluka Resources Limited

by



EARTH SYSTEMS

Environment | Water | Sustainability

May 2015

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This report is not to be used for purposes other than that for which it was intended. Environmental conditions change with time. The site conditions described in this report are based on observations made only from the laboratory results obtained for this study. Earth Systems Pty Ltd does not imply that the site conditions described in this report are representative of past or future conditions. Where this report is to be made available, either in part or in its entirety, to a third party, Earth Systems Pty Ltd reserves the right to review the information and documentation contained in the report and revisit and update findings, conclusions and recommendations.



EXECUTIVE SUMMARY

Iluka Resources Limited (Iluka) engaged Earth Systems to undertake a preliminary assessment of naturally occurring radiative materials, radiation and radionuclides in the mine materials to be encountered at Iluka's Balranald Mineral Sands Project. Typical mine materials were sampled during a sonic drilling program from 25 June to 1 July 2014. The sample program was designed to collect information on five distinctive groups of mine materials present in the soil lithology at the site.

The five groups of mine materials included (in order of depth from the surface):

1. Surface soils (SS)
2. Non-saline overburden (NSOB)
3. Saline overburden (SOB)
4. Organic overburden (OOB)
5. Minerals sands ore (ore)

Analysis of the overall activity levels of each of the mine materials shows that all samples analysed were very low to low in activity, with levels approaching the limits of detection for many of the decay chain isotopes. Of the mine materials analysed, only the ore sample displayed activity levels above the ARPANSA (2014) 1 Bq/g limit for radioactivity and this was generated in the Th-232 decay chain.

The key findings from this report are:

- The ore material is classified as radioactive material at 1.3 Bq/g when compared to ARPANSA (2014) guidelines of 1.0 Bq/g.
- All materials tested (SS, NSOB, SOB, OOB and ore) are considered exempt material for the purposes of transport and handling.
- The ore material appears to be at secular equilibrium with respect to Th-232 in its unprocessed state, giving confidence to the results.
- The overburden materials including SS, NSOB, SOB and OOB are below ARPANSA (2014) limits and are not considered radioactive materials for purposes of management or handling.



RECOMMENDATIONS

The key recommendations are as follows:

1. Compare ore mineralogy content to activity levels and develop a mineralogy activity model for the purposes of future mine site material management.
2. Develop radiation management plans for occupational health and safety, mine management and storage of ore.
3. Conduct radiation studies for dust and groundwater in contact with ore mine materials associated with the West Balranald site.

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ATTACHMENTS

Attachment A: ANSTO Proposal and Report.



1.0 Introduction

Iluka Resources Limited (Iluka) engaged Earth Systems to undertake a preliminary assessment of the radioactive properties and behaviour of mine overburden, wastes and ore from its West Balranald Mineral Sands deposit which is proposed to be mined as part of the Balranald Mineral Sands Project. . The mine materials were sampled during a sonic drilling and core extraction program of the existing in-situ mine materials from 25 June to 1 July 2014 as part of the West Balranald Minerals Sand deposit geochemical assessment program. This program did not include material from the Nepean deposit. The sample program was designed to collect information on five distinctive lithologies. In order of increasing age and depth in the deposit these materials were:

1. Surface soils (SS)
2. Non-saline overburden (NSOB)
3. Saline overburden (SOB)
4. Organic overburden (OOB)
5. Minerals sands ore (ore)

2.0 Background

Mineral sands deposits occur naturally throughout the world, and are being commercially exploited in countries such as Australia, Brazil, India, South Africa and China. Common commercial mineral components within these deposits can include ilmenite (FeTiO_3), rutile, anatase and occasionally phases such as brookite and akaogiite (TiO_2), zircon (ZrSiO_4), monazite ((Ce, La Th) PO_4) and leucoxene (an iron depleted/weathered form of Ilmenite). Both monazite and zircon generally contain radioactive elements (U, Th) that form part of a natural solid solution series. Hence it is a routine requirement for geochemical assessments of mine wastes and ore from mineral sand deposits to include a radioactivity and radionuclide assessment.

2.1 Geology

Figure 1 shows the location of the deposits in relation to the ground surface. The geology of the West Balranald LPS system is described by Iluka (2013):

“The proposed Stage 3 Hydrogeological Program is located within the centre of the Murray Basin, which is a large structurally controlled depression which has filled with Tertiary marine and non-marine sediments. This sequence has subsequently been overlain by Quaternary aged aeolian, fluvial and lacustrine sediments.

The mineralised heavy mineral strands identified at West Balranald are hosted in a typical sequence of Loxton Parilla Sand (LPS), which is a marine sequence comprising of (moving upward through the sedimentary pile): a basal unit of fine-grained to silty sands; coarse sands and gravels; fine to medium and even grained well rounded quartz sand. These sediments are interpreted to represent (respectively) the off-shore, lower shore face, and upper shore face (mineralized) facies of the LPS.

Overlying these sediments is another marine sequence which essentially comprises the same facies as the underlying sequence. The two marine sequences are approximately 40 m thick. Overlying the marine sands is the Shepparton Formation which is a fluvio-lacustrine sequence comprising silts, sands and clays. This Formation is up to 33 m thick in places.”

This unit forms a thick sequence of marine sands which were deposited during two marine regressions... The sequence typically consists of three facies: beach – foreshore, – surf zone and – lower shore... At the southern end of the deposit there is a lagoonal deposit consisting of black carbonaceous clays and sands... These sands comprise well to very well sorted medium grained sands.

The base of the [lower LPS] at West Balranald is situated on the Geera Clay unit and its position varies from approximately 95 m below surface in the south to 110 m in the north.”

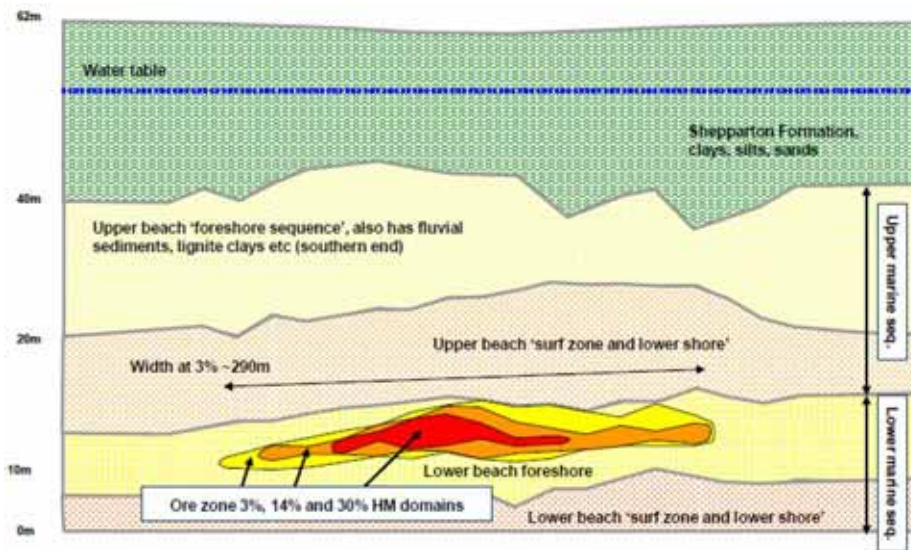


Figure 1: Stylised cross section looking to the North through the West Balranald deposit.

2.2 Hydrogeology

A brief description of the West Balranald site hydrogeology and groundwater salinity is provided below to assist with the radiation assessment of the mine materials. There are several radiation related issues that can potentially be affected by groundwater salinity and its effects on the soil matrix:

- Radium and Radon solubility and transport are influenced groundwater salinity.
- Analytical procedures for radionuclide activity may demonstrate interference related to matrix salinity levels.

Details on the hydrogeology of the region surrounding the deposit are extracted from Iluka (2013).

Groundwater salinity in the Shepparton Formation ranges from 350 to 5300 mg/L total dissolved solids (TDS)(URS 2012). The underlying LPS aquifer is regionally saline, with TDS typically between 14,000 and 100,000 mg/L (Kellett 1991).

URS (2012) suggested that there was different salinity in each formation associated with the West Balranald mine. The changes in salinity concentration were seen as evidence for an aquitard that limits hydraulic connection between the Shepparton Formation and LPS and the underlying Lower Renmark Aquifer. Additionally, regional groundwater displays lower salinity near the Murrumbidgee River and even more so near the Murray River.

More recent groundwater salinity data for each formation related to the mineral sand deposits are provided in Table 1.

Table 1: Summary of groundwater salinity in key geological formations (LWC 2014).

Unit	Lower Salinity (mS/cm)	Upper Salinity (mS/cm)
Shepparton	36.3	68.6
Loxton Parilla Sands	14.6	65.7
Upper Renmark	8.5	28.2
Lower Renmark	4.1	10.9



LWC (2014) suggested that at the upper range of groundwater salinity results reported, it is possible some level of analytical matrix interference would occur for radionuclide analysis of groundwaters.



3.0 Scope of Works

Earth Systems was engaged to undertake a radioactivity assessment of representative material types to be excavated from the West Balranald deposit. The work program included:

- Design of a sampling program.
- Sample collection.
- Development and implementation of the analytical program.
- Assessment of laboratory data against activity and transport guidelines (see Section 4.3.3) for radiation management.
- Report compilation.

4.0 Method

The radiation samples subject to analysis in this report were collected in conjunction as part of the Earths Systems geochemical assessment program. The field work methods are discussed further in the Field Testwork Program Results section of Earth Systems (2014a).

The methodology for the design of the representative sampling program, and reporting is described further below.

4.1 Data Review and Gap Analysis

Existing radiation data (LWC 2014) and the latest mine plans were reviewed by Earth Systems and a field and laboratory testwork programme was developed to fill the data gaps required to meet the objectives of this study.

4.1.1 Data Review

Key data reviewed to develop the work programme were:

- Definitive Feasibility Study (DFS) mining schedules.
- Existing drill hole logs from previous investigations.
- Existing geology and lithology models.
- Existing hydrogeological model data including groundwater radiation test results and standing water levels.
- Site plans.

It was identified that radiation and radionuclide activity testing had been previously undertaken on groundwater and ore-based mining by products and was also required on the in-situ ore, and overburden materials OOB, SOB, NSOB, and SS.

4.1.2 Field Work Program

The work programme comprised:

- Drilling and logging of three sonic drill holes along strike of the West Balranald mine.
- Collection of representative sub-samples of the various overburden formations and identified strata for radiation activity testing.
- Collection of representative surface soil samples from across the mining area
- Storage and preservation of radiation samples.

The following sections describe the sample collection, analytical program and representative sub-sampling methods for the material collected during the field work program.

4.2 Sampling Program

4.2.1 Drill Hole Samples

A meeting was held with Iluka specialists (Earth Systems 2014b) to identify target materials and formulate a radiation sampling plan for these five key groups of mine materials.

Three drill hole locations were agreed upon by Iluka and Earth Systems, located along the strike of the West Balranald mine to provide subsurface core samples of the five mine materials previously identified for investigation. Drilling was conducted by Star Drilling using a sonic drill rig which utilises high frequency (~10 kHz) vibrations and rotation to drive a casing and core sleeve into the ground (see Figure 2). Core samples were recovered in Polytetrafluoroethylene bags. Cores were geologically logged and subdivided into known lithologies / material domains.



Figure 2: Sonic drill rig at WBGEC-1 bore hole site.

The coordinates for bore holes WBGEC1, WBGEC2, WBGEC3 are provided in Table 2 below and their location shown in Figure 3.

From each drill hole, core samples were collected at approximately 2 m intervals or more frequently where there was a natural break in lithology. Sub samples of these intersections were collected from the centre of each core from the full 2 m interval to avoid contamination from drilling muds and viscosifiers. Sub samples were thoroughly mixed then collected in sealed air tight plastic 200 mL sample containers with no head space (300-400 g) for transport and temporary storage at Earth Systems' laboratory. Plastic sample containers were stored in eskies with ice packs for transport to the laboratory.

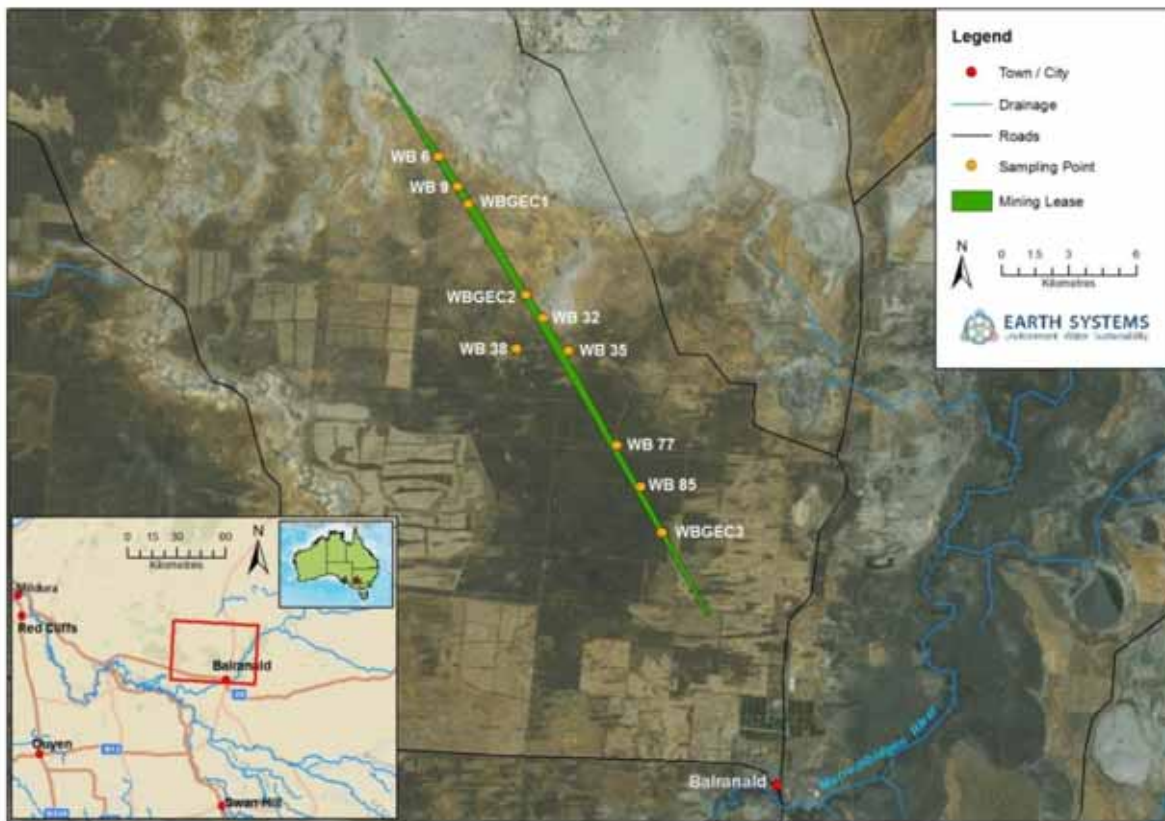


Figure 3: Site location and map of drill holes and surface soil sample sites.

Table 2: Coordinates of drill holes and surface soil sampling sites.

Drill Hole ID	Material collected	Easting	Northing
WB GEC1*	SS, NSOB, SOB, OOB, ore	722743	6190645
WB GEC2*	SS, NSOB, SOB, OOB, ore	725068	6186437
WB GEC3*	SS, NSOB, SOB, OOB, ore***	730483	6175525
WB 6**	SS	721546	6192840
WB 9**	SS	722294	6191455
WB 32**	SS	725760	6185367
WB 35**	SS	726802	6183831
WB 38**	SS	724503	6184062
WB 77**	SS	728705	6179553
WB 85**	SS	729666	6177623

Notes: * Geographic coordinate system was UTM1984, Zone 55S, ** GDA94 MGA 55, *** not analysed in the current radiation program, used for geochemistry only.

4.2.2 Mine Material Composite Sampling

A composite sampling strategy was designed to create one representative subsample of each mine material type based on the relative volume of the material indicated in borehole cores.

Four 500g composite mine materials samples were generated on a weighted mass basis, calculated from the material volume as a percentage of total depth of each type of mine material from the depth data of the bore log. The weighted subsampling program and diagrammatic bore logs for WBEC1 and 2 are shown below in Table 3.

Each mine material composite sample of 500 g was then thoroughly mixed and placed into a glass 250 mL sample jar. All sample bottles were filled to ensure no headspace and capped tightly to ensure airtight seals. The NSOB 250mL composite sample is shown as an example in Figure 4 below prior to sealing and chilled transport to the Australian Nuclear Science and Technology Organisation (ANSTO) analytical laboratory.



Figure 4: Example of composite sample - NSOB Composite prior to sealing and dispatch.

Mine material from WBGEC1 and WBGEC2 were used to generate composite samples. Bore hole WBGEC3 was considered outside of the mining area based on the latest mine planning and design information, so the subsurface materials composite samples were not collected from this bore. The bore logs and material sampling program for WBGEC1 and WBGEC2 is shown in Table 3 below.

4.2.3 Surface Samples

Sunraysia Environmental provided seven additional surface soils samples from the surface soil characterisation program they undertook at the site. Table 2 also provides the coordinates for the surface soil sampling sites WB 6, WB 9, WB 32, WB 35, WB 38, WB 77 and WB 85. The Sunraysia Environmental samples were collected from the top 100 mm of soil at each location in a sealed 200 mL plastic sample jar. Additionally, Earth Systems collected two surface soil samples, WBGEC-1-1 (0-400 mm) and WBGEC-1-2 (400-900mm), from the WBGEC1 sonic drill core also in sealed 200 mL plastic sample jars.

All of the sampling sites for surface soils are shown on the plan of the West Balranald site (Figure 3).

Each of the seven surface soil samples provided by Sunraysia Environmental were sub-sampled into equal representative volumes of 27.8 mL, to produce a composite 250 mL sample. This composite sample was placed in a glass 250mL sample jar with no head space, sealed and refrigerated.



Table 3: Summary geological logs and sample collection data.

Bore Log WBGEC1				Bore Log WBGEC2			
Mine Material	Sample Depth (m)	Subsample mass (g)	Sample Number	Mine Material	Sample Depth (m)	Subsample mass (g)	Sample Number
Surface Soil	0 - 0.4	27.8 mL	WBGEC-1-1	Non Saline Overburden (NSOB)	1.0	n/s	no sample
	0.9	27.8 mL	WBGEC-1-2		3.0	56.5	WBGEC-2-1
Non-Saline Overburden (NSOB)	3.2	44.3	WBGEC-1-3		5.2	41.4	WBGEC-2-2
	4.5	24.5	WBGEC-1-4		5.6	7.5	WBGEC-2-3
	5.3	15.1	WBGEC-1-5		6.3	13.2	
	6.0	13.2	WBGEC-1-6		8.1	33.9	WBGEC-2-4
	7.2	22.6			10.0	35.8	WBGEC-2-5
	8.0	15.1	WBGEC-1-7		11.0	18.8	
	9.0	18.8	WBGEC-1-8		13.0	42.5	WBGEC-2-6
	12.5	65.9			13.4	n/s	no sample
14.0	28.2	14.7		10.1	WBGEC-2-7		
Saline Overburden (SOB)	16.5	19.5	WBGEC-1-9	15.5		6.2	
	17.7	9.3	WBGEC-1-10	17.0	11.7	WBGEC-2-8	
	19.5	14.0	WBGEC-1-11	20.5	27.3	WBGEC-2-9	
	22.0	19.5	WBGEC-1-12	21.8	10.1	WBGEC-2-10	
	24.0	15.6	WBGEC-1-13	23.9	16.4	WBGEC-2-11	
	26.0	15.6	WBGEC-1-14	24.9	7.8		
	28.0	15.6	WBGEC-1-15	25.9	7.8	WBGEC-2-12	
	29.0	7.8	WBGEC-1-16	29.0	24.1	WBGEC-2-13	
	32.0	23.4	WBGEC-1-17	31.0	15.6	WBGEC-2-14	
	34.7	21.0	WBGEC-1-18	33.1	16.4	WBGEC-2-15	
	38.0	25.7	WBGEC-1-19	34.5	10.9	WBGEC-2-16	
	40.0	15.6	WBGEC-1-20	34.6	0.8		
Organic Overburden (OOB)	44.0	31.2	WBGEC-1-21	37.2	20.2	WBGEC-2-17	
	47.0	12.0	WBGEC-1-22	38.0	6.2	WBGEC-2-18	
		12.0	WBGEC-1-23	38.4	3.1		
	49.8	39.5	WBGEC-1-24	39.2	6.2		
	50.6	11.3	WBGEC-1-25	40.0	6.2	WBGEC-2-19	
	52.2	22.6	WBGEC-1-26	41.0	7.8		
	53.0	11.3		43.6	20.2	WBGEC-2-20	
	56.0	42.4	WBGEC-1-27	44.6	7.8	WBGEC-2-21	
	60.1	27.0	WBGEC-1-28	OOB	47.0	33.9	WBGEC-2-22
27.0		WBGEC-1-29	51.6		32.5	WBGEC-2-23	

Bore Log WBGEC1				Bore Log WBGEC2			
Mine Material	Sample Depth (m)	Subsample mass (g)	Sample Number	Mine Material	Sample Depth (m)	Subsample mass (g)	Sample Number
	62.0	26.8	WBGEC-1-30			32.5	WBGEC-2-24
	63.6	22.6	WBGEC-1-31		53.0	19.8	WBGEC-2-25
	63.8	2.8			55.1	29.7	WBGEC-2-26
	64.4	8.5			55.8	9.9	WBGEC-2-27
	65.0	8.5	WBGEC-1-32		56.7	12.7	WBGEC-2-28
	65.5	7.1			59.0	32.5	WBGEC-2-29
	68.0	35.3	WBGEC-1-33		Ore	59.5	28.1
Ore	69.5	84.3	WBGEC-1-34	60.7		67.4	
	71.1	89.9	WBGEC-1-35	61.0		16.9	
	71.3	11.2		63.5		140.4	WBGEC-2-31
	72.4	61.8			65.0	n/s	WBGEC-2-32
	74.0	n/s	WBGEC-1-36				

Notes: n/s - not sampled

4.3 Analytical Program

4.3.1 Major Element Chemistry

Major element chemistry was undertaken on the five representative composite samples taken from the drill holes by ANSTO at their Lucas Heights Laboratory in NSW (refer to Attachment A). A key purpose of this was to investigate the potential for elevated major element concentrations which had the potential to produce background interference in the radioactive analytical work.

4.3.2 Radiation Analysis

Laboratory based radiation activity and full secular equilibrium decay chain analysis on representative composite samples was also undertaken by ANSTO.

Decay chain analysis was employed to allow for determination of secular equilibrium for long-lived decay progeny (Earth Systems 2014b) of Th-232, U-235 and U-238 in the mine materials. The three decay chains analysed are illustrated in Figure 5 below, with Radon progeny highlighted in dark grey.

The definition of secular equilibrium is the point at which daughter isotopes are producing activity rates at the same rate as the decay chain parent, due to the comparatively long decay half-life of the progenitor, and the short half-life of the daughter isotopes. Secular equilibrium is important to radiation management as modification of materials containing radioactive nuclides, such as during minerals processing, can disrupt equilibrium.

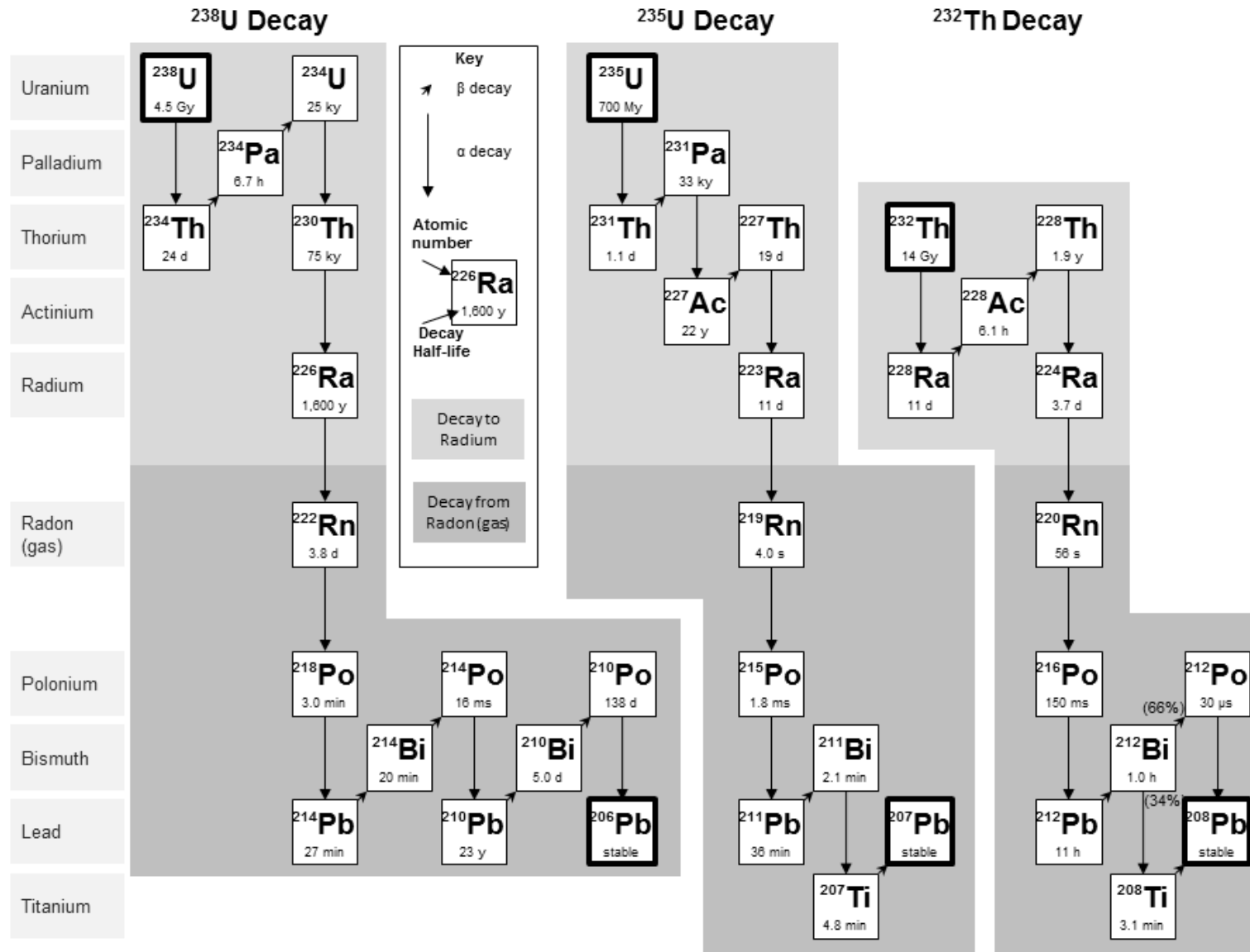


Figure 5: Radionuclide decay chains U-238, U-235 and Th-232.

The analytical techniques undertaken were based on the ANSTO Minerals Analysis Program proposal dated 20/8/2014. See Attachment A for a copy of the document. The following analysis techniques were undertaken:

- Gamma spectrometry for U-238 and Th-232 decay progeny and U-235 and its decay progeny;
- Delayed neutron activation (DNA) analysis for parent U-238;
- Neutron activation analysis (NAA) analysis for parent Th-232;
- Alpha spectrometry for Po-210;
- X-Ray Fluorescence Spectrometry (XRF) analysis for elemental content. This data is used for self-absorption corrections in gamma spectrometry.

4.3.3 Guideline Comparison

Guidelines for management of radiation exist at State and Federal level for the determination of what activity levels constitute a radioactive material. Radioactive materials and the requirements for management response potentially include Radiation Management Plans, Occupational Health and Safety Plans, Waste Disposal and Transport Management Plans. The guidelines used for determination of mine material activity levels include:

- *National Directory for Radiation Protection Radiation Protection Series Publication No. 6* (ARPANSA 2014);
- *Management of Naturally Occurring Radioactive Material (NORM) Radiation Protection Series Publication No. 15* (ARPANSA 2008a);
- *Safe Transport of Radioactive Material - Radiation Protection Series Publication No. 2* (ARPANSA 2008b);
- *Code of Practice and Safety Guide Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing Radiation Protection Series Publication No. 9* (ARPANSA 2005);
- *Guidance for Licensing of Mineral-sand Mining that Generates Radioactive Residues* (DECC 2009); and
- *Waste Classification Guidelines Part 3: Waste Containing Radioactive Material* (DECC 2008).

Several quantitative guideline values are provided for assessment purposes within these documents:

- Section 3.1 of ARPANSA (2014) provides exclusions to regulation for materials containing radionuclides of natural origin, such as mineral sands, where the concentration of each radionuclide is below 1 Bq/g.
- Section 1.2 of ARPANSA (2008a) suggests background levels for NORM materials to be 0.03 – 0.05 Bq/g for U-238 and 0.04 – 0.06 Bq/g for Th-232.
- Section 401 of ARPANSA (2008b) lists activity concentrations for exempt materials for the purposes of transport:



Table 4: Activity concentrations of exempt materials for the purposes of transport (ARPANSA 2008a).

Material	Activity concentration for transport exemption (Bq/g)
Natural Thorium, Th (nat)	1 (b)
Th-232	10
Natural Uranium, U (nat)	1 (b)
U-235	10 (b)
U-238	10 (b)

Note: (b) guideline requires secular equilibrium in parent nuclides and their progeny

5.0 Results

The ANSTO laboratory analytical results were provided on 21 November 2014 and are shown below. The major elemental concentrations for each mine material are shown in Table 5 below.

Table 5: Major Elemental Concentrations for West Balranald Mine Materials Composite Samples.

Major Elemental Concentrations (wt. %)	Al	Ca	Cr	Fe	K	Mg	Na	S	Si	Ti	Zr	Pb ¹
Surface soil	4.9	4.7	0.004	2.1	1.1	0.97	0.37	0.029	31.1	0.3	0.025	-
NSOB	6.3	0.17	0.006	2.5	1.9	0.44	0.81	0.045	35	0.39	0.034	-
SOB	2.5	0.001	0.012	0.6	0.3	0.094	0.24	0.019	42.7	0.23	0.015	0.00005
OOB	1.3	0.002	0.01	0.39	0.39	0.069	0.28	0.37	43.3	0.095	0.015	0.00012
ore	1.2	0.025	0.23	9.5	0.16	0.43	0.18	0.99	21.8	15.2	3.2	0.0022

Notes: ¹ additional data from Earth Systems (2014a)

The results display elevated levels of Iron (Fe), Titanium (Ti) and Zirconium (Zr) in the ore composite sample which are expected in mineral sand deposits. Elevated Ti and Zr levels can provide background interference in a mineral matrix with respect to radiation activity detection.

The radionuclide results for the secular equilibrium determination for Th-232, U-238 and U-235 in each mine material are shown in Table 6 below.

Table 6: Radionuclide Decay Chain Results in Th-232, U-238 and U-235 for each Sampled Mine Material.

Radionuclide Results	West Balranald Mine Materials				
	SS	NSOB	SOB	OOB	ore
U (ppm)	4.4 ± 0.2	4.8 ± 0.2	1.5 ± 0.1	11.2 ± 0.3	45.0 ± 0.6
Th (ppm)	7.8 ± 0.7	15 ± 1	4.5 ± 0.5	5.1 ± 0.4	310 ± 20
Th-232 Decay Chain (Bq/g)					
Th-232	0.031 ± 0.003	0.059 ± 0.005	0.018 ± 0.002	0.021 ± 0.002	1.25 ± 0.09
Ra-228	0.033 ± 0.004	0.058 ± 0.006	0.020 ± 0.002	0.010 ± 0.001	1.3 ± 0.1
Th-228	0.034 ± 0.003	0.057 ± 0.006	0.017 ± 0.002	0.013 ± 0.001	1.3 ± 0.1
U-238 Decay Chain (Bq/g)					
U-238	0.055 ± 0.003	0.060 ± 0.003	0.019 ± 0.002	0.139 ± 0.004	0.538 ± 0.008
Th-230	< 0.11 [^]	< 0.12 [^]	< 0.062 [^]	< 0.57 [^]	0.7 ± 0.1
Ra-226	0.022 ± 0.002	0.042 ± 0.004	0.013 ± 0.001	0.015 ± 0.002	0.57 ± 0.06
Pb-210	< 0.017	0.054 ± 0.006	0.022 ± 0.004	< 0.0084	0.46 ± 0.05
Po-210*	0.32 ± 0.04	0.064 ± 0.04	0.021 ± 0.04	0.047 ± 0.04	0.22 ± 0.04
U-235 Decay Chain (Bq/g)					
U-235 ^{&}	0.0025 ^{&}	0.0028 ^{&}	0.00087 ^{&}	0.0064 ^{&}	0.026 ± 0.005
Pa-231	< 0.036	< 0.036	< 0.026	< 0.020	< 0.044
Ac-227	< 0.0067	< 0.0064	< 0.0046	< 0.0041	< 0.031
Th-227	< 0.0067	< 0.0064	< 0.0046	< 0.0041	< 0.031



Radionuclide Results	West Balranald Mine Materials				
	SS	NSOB	SOB	OOB	ore
K-40	0.34 ± 0.03	0.61 ± 0.06	0.14 ± 0.01	0.13 ± 0.01	0.14 ± 0.01
Total contained activity[‡]	1.5	1.9	0.57	1.0	20.9^π

Notes: (ANSTO 2014) * Po-210 concentration on the count date of 19 September 2014. ^ No gamma peak was detected in the gamma spectrum. Less than values quoted are statistically determined by the gamma analysis software. & No gamma peak was detected in the gamma spectrum. U-235 concentration calculated from the measured U-238 concentration. ‡ Including K-40. Less than values assume zero concentration for those particular radionuclides in the calculations. π Assumes the concentration of Po-210 is 0.56 Bq/g.

Analysis of the overall activity level results of each of the overburden mine materials in Table 6 shows that all samples analysed were low to very low in activity, with levels approaching the limits of detection for many of the decay chain isotopes. Out of the mine materials analysed, only the ore sample displayed activity levels at 1.3 Bq/g, which is above guideline levels of 1 Bq/g (ARPANSA 2014), and this was confined to the Th-232 decay chain results.

The ore was not elevated in activity for the U-238 or U-235 decay chain analysis.

The other mine materials including the SS, NSOB, SOB were 10 to 100 times lower in activity levels than the ore for Th-232 decay chain radionuclides.

Table 7: U-238 Decay Chain Disequilibrium in Iluka Samples (ANSTO 2014).

U-238 Decay Chain Disequilibrium in Iluka Samples	
Mine Material	State of Disequilibrium
SS	high U-238; higher Po-210
NSOB	low Ra-226
SOB	low Ra-226
OOB	high U-238; low Ra-226
ore	Po-210

6.0 Conclusions

Earth Systems has undertaken a preliminary assessment of the radioactive properties and behaviour of mine overburden, wastes and ore from its West Balranald Mineral Sands Project. The mine overburden materials at the West Balranald site display low radionuclide activity levels, and are activity levels similar to background. Ore materials are higher in activity levels than the mine overburden materials.

The key findings from this report are:

- The ore material is classified as radioactive material at 1.3 Bq/g when compared to ARPANSA (2014) guidelines of 1.0 Bq/g.
- All overburden and mine materials tested (SS, NSOB, SOB, OOB and ore) are considered exempt material under ARPANSA (2014) for the purposes of transport and handling.
- The ore material appears to be at secular equilibrium with respect to Th-232 in its unprocessed state, giving confidence to the results.

The West Balranald site will therefore require radiation management plans for occupational health and safety, mine management and storage of ore. Some mineral sand processing techniques are known to have the potential to cause secular disequilibrium, which may cause changes in total activity. Operational phase monitoring will be required to determine appropriate management requirements if ore processing creates disequilibrium. Radiation management plans for ore by-products may also be required depending on the fate of the radioactive components of the ore. Additional radiation management measures for dust and groundwater may also be required.

Waste products from ore materials will require radiation assessment to ensure appropriate waste management, handling and final disposal.

Due to the composite sampling strategy adopted in this study, these results show bulk activity but do not provide information on the spatial distribution of radionuclides, which may be significant for management particularly since the measured activity levels are only just above the guideline levels. For example, if the ore mineralogy changes significantly along strike it is possible that the ore materials may also reduce in activity, potentially requiring less management.



7.0 Recommendations

The key recommendations are as follows:

1. Compare ore mineralogy content to activity levels and develop a mineralogy activity model for the purposes of future mine site material management.
2. Develop radiation management plans for occupational health and safety, mine management and storage of ore.
3. Conduct radiation studies for dust and groundwater in contact with ore mine materials associated with the West Balranald site.

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Attachment A

ANSTO Proposal and Report

MEMORANDUM

The major elemental concentrations are summarised in **Table 2**. The samples were found to contain primarily Al, Fe, K and Si. The ore composite sample (ES-250814-5) also contained Ti and Zr.

TABLE 2
Major Elemental Concentrations in Iluka Samples (wt%)

	Al	Ca	Cr	Fe	K	Mg	Na	S	Si	Ti	Zr
ES-250814-1	4.9	4.7	0.004	2.1	1.1	0.97	0.37	0.029	31.1	0.30	0.025
ES-250814-2	6.3	0.17	0.006	2.5	1.9	0.44	0.81	0.045	35.0	0.39	0.034
ES-250814-3	2.5	0.001	0.012	0.60	0.30	0.094	0.24	0.019	42.7	0.23	0.015
ES-250814-4	1.3	0.002	0.010	0.39	0.39	0.069	0.28	0.37	43.3	0.095	0.015
ES-250814-5	1.2	0.025	0.23	9.5	0.16	0.43	0.18	0.99	21.8	15.2	3.2

The radionuclide results are given in **Table 3**. The results show that the ore composite sample (ES-250814-5) contains 1.3 Bq/g of Th-232 decay chain radionuclides in secular equilibrium. The U-238 decay chain radionuclides in this sample, with the exception of Po-210, are also considered to be in secular equilibrium. The Po-210 concentration was low (0.22 Bq/g) in comparison to the rest of the U-238 decay chain (average concentration 0.54 Bq/g). Polonium-210 is determined by alpha spectrometry, which is a very sensitive technique, however, because of its volatile nature, high temperature dissolution processes (e.g. fusion) cannot be used. Fusion/acid digestion procedures are preferred for dissolution of samples containing Ti and Zr and so, the low Po-210 result for this sample indicates that some of the sample did not dissolve in the standard acid digestion procedure used for Po-210 analysis. Since Po-210 will reach equilibrium with its parent, Pb-210, in ~2 years, in the geological timeframe, there is no reason to assume that Po-210 is not in secular equilibrium with the rest of the U-238 decay chain radionuclides.

The Th-232 decay chain radionuclides in samples ES-250814- to 3 are considered to be in secular equilibrium. The Th-232 concentration in sample ES-250814-4 is higher than those for Ra-228 and Th-228. While Ra-228 and Th-228 are considered to be in secular equilibrium, the Th-232 decay chain overall is not in secular equilibrium. The concentrations of radionuclides in the U-238 decay chain are low in all non-ore samples, however, the samples display varying degrees of disequilibrium, as shown in **Table 4**.

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TABLE 3
Radionuclide Results – Iluka Samples (Bq/g)

ANSTO ID	ES-250814-1	ES-250814-2	ES-250814-3	ES-250814-4	ES-250814-5
Client ID	Surface Soil	Non-Saline O/B	Saline O/B	Organic O/B	Ore
<i>Th-232 Decay Chain</i>					
Th (ppm)	7.8 ± 0.7	15 ± 1	4.5 ± 0.5	5.1 ± 0.4	310 ± 20
Th-232	0.031 ± 0.003	0.059 ± 0.005	0.018 ± 0.002	0.021 ± 0.002	1.25 ± 0.09
Ra-228	0.033 ± 0.004	0.058 ± 0.006	0.020 ± 0.002	0.010 ± 0.001	1.3 ± 0.1
Th-228	0.034 ± 0.003	0.057 ± 0.006	0.017 ± 0.002	0.013 ± 0.001	1.3 ± 0.1
<i>U-238 Decay Chain</i>					
U (ppm)	4.4 ± 0.2	4.8 ± 0.2	1.5 ± 0.1	11.2 ± 0.3	45.0 ± 0.6
U-238	0.055 ± 0.003	0.060 ± 0.003	0.019 ± 0.002	0.139 ± 0.004	0.538 ± 0.008
Th-230	< 0.11 ^b	< 0.12 ^b	< 0.062 ^b	< 0.57 ^b	0.5 ± 0.1
Ra-226	0.022 ± 0.002	0.042 ± 0.004	0.013 ± 0.001	0.015 ± 0.002	0.57 ± 0.06
Pb-210	< 0.017	0.054 ± 0.006	0.022 ± 0.004	< 0.0084	0.56 ± 0.06
Po-210 ^a	0.32 ± 0.04	0.064 ± 0.04	0.021 ± 0.04	0.047 ± 0.04	0.22 ± 0.04
<i>U-235 Decay Chain</i>					
U-235	0.0025 ^c	0.0028 ^c	0.00087 ^c	0.0064 ^c	0.026 ± 0.005
Pa-231	< 0.036	< 0.036	< 0.026	< 0.020	< 0.044
Ac-227	< 0.0067	< 0.0064	< 0.0046	< 0.0041	< 0.031
Th-227	< 0.0067	< 0.0064	< 0.0046	< 0.0041	< 0.031
K-40	0.34 ± 0.03	0.61 ± 0.06	0.14 ± 0.01	0.13 ± 0.01	0.14 ± 0.01
Total contained activity ^d	1.5	1.9	0.57	1.0	20.9 ^e

^a Po-210 concentration on the count date of 19 September 2014.

^b No gamma peak was detected in the gamma spectrum. Less than values quoted are statistically determined by the gamma analysis software.

^c No gamma peak was detected in the gamma spectrum. U-235 concentration calculated from the measured U-238 concentration.

^d Including K-40. Less than values assume zero concentration for those particular radionuclides in the calculations.

^e Assumes the concentration of Po-210 is 0.56 Bq/g.

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TABLE 4
U-238 Decay Chain Disequilibrium in Iluka Samples

Sample Identification	ANSTO ID	State of Disequilibrium
Surface soil comp 3	ILU-250514-1	high U-238; higher Po-210
Non-saline O/B comp	ILU-250514-2	low Ra-226
Saline O/B comp	ILU-250814-3	low Ra-226
Organic O/B comp	ILU-250814-4	high U-238; low Ra-226
Ore comp	ILU-250814-5	Po-210

The solubility and transport of radionuclides in groundwaters, particularly U and Ra isotopes, has been studied extensively and is important in understanding the geology of Th and U deposits [1-3]. Radium isotopes, for example, are soluble in saline groundwaters and information supplied by the client¹ on the geochemistry of the region may explain why the concentrations of both Ra-228 and Ra-226 are lower in these four samples.

Under the ARPANSA National Directory², a material is deemed to be radioactive if the concentration of any radionuclide in the Th-232, U-238 and U-235 decay chains exceeds 1 Bq/g. The ore composite sample (ES-250814-5) is therefore considered to be radioactive with respect to this definition.

For the transport of radioactive material, a limit of 10 Bq/g of U_{nat} and Th_{nat} applies. The ore composite sample (ES-250814-5) would not be considered radioactive for transport.

Detection Limits in Gamma Spectrometry

Detection limits in gamma spectrometry depend on a number of variables. The Compton background in a given spectrum is created by all the gamma emitting peaks in a sample. It is both energy and activity dependent. In any sample, the Compton background depends on which gamma emitting radionuclides are present in the sample (identity and quantity) and generally, at higher energies, the Compton background is lower.

All gamma emitting radionuclides emit gamma rays which have a characteristic energy and abundance. Many radionuclides emit multiple gamma peaks each with a characteristic energy and abundance. The detection limit for any given radionuclide is

¹ Phone conversation 7 November 2014 between D. Dettrick and S. Brown.

² RPS No. 6 – National Directory for Radiation Protection (NDRP) July 2011 (www.arpansa.gov.au).

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dependent on both energy and abundance. For example, Bi-214 has an energy of 609 keV (46% abundance) and Th-230 has an energy of 67.8 keV (0.38% abundance). The detection limit for Bi-214 is therefore much lower than that for Th-230.

Gamma detectors have relative efficiencies in the range of 10 to 65%. The detection limit for any given radionuclide in a given sample is lower if counted using a more efficient detector.

The sample matrix can affect the gamma spectrum, especially when materials contain percent levels of non-radioactive elements, as is common in the minerals industry. The presence and amount of certain elements (e.g Zr) can alter the background and also make it more difficult for the gamma rays to reach the detector. Self-absorption corrections, based on the measured elemental content of a sample, are used to correct for matrix elements. In some cases, x-rays from matrix elements also affect the gamma spectrum.

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APPENDIX B



NSW WASTE CLASSIFICATION OF HAMILTON MINING BY-PRODUCTS

Prepared for

ILUKA RESOURCES LIMITED

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INTRODUCTION

The Balranald Project is comprised of two linear mineral sands deposits, the West Balranald and Nepean deposits, which are located ~12 km and 66 km north-west of Balranald, NSW, respectively. It is proposed that the two deposits will be mined for heavy minerals, primarily rutile (TiO₂) over an expected mine life of approximately 8 years. A heavy mineral concentrate (HMC) produced at the Balranald process plant will be transported to Hamilton, Victoria, for further processing at Iluka's Hamilton mineral separation plant (MSP). It is understood that mining by-products (MBPs), including reactive pyritic material, will be generated as waste during open cut mining and mineral processing at the Balranald Project and the Hamilton MSP.

Non-saleable MBPs associated with the processing of HMC at the Hamilton MSP are expected to be managed as part of Iluka's Murray Basin operations in Victoria, which includes placement of MBPs from the Hamilton MSP in the mine void of Iluka's Douglas Mine (EMGA, 2015). However, if this is not possible, the MBPs will be transported back to the Balranald mine site by road for placement in the West Balranald mine void (EMGA, 2015).

The NSW Department of Planning and Environment (DPE) Secretary's Environmental Assessment Requirements (SEARs) for the Environmental Impact Statement (EIS) for the Balranald Project outline a requirement to assess the MBPs against the NSW Environment Protection Authority (NSW EPA) *Waste Classification Guidelines* (hereafter referred to as the *NSW Guidelines*).

Earth Systems was engaged by Iluka Resources Ltd. to conduct a laboratory testwork program to classify the Hamilton MBPs in accordance with New South Wales (NSW) government waste classification guidelines.

RELEVANT NSW LEGISLATION, GUIDELINES AND STANDARDS

In NSW, industrial wastes are regulated under the amended *Protection of the Environment Operations Act (1997)* and the *Protection of the Environment Operations (Waste) Regulation (2014)*. The *NSW Guidelines* were prepared by the NSW Government Department of Environment, Climate Change and

Water to provide guidance on the implementation of sampling, analytical and classification protocols and the management of industrial wastes.

The sections contained within the *NSW Guidelines* that are relevant to the classification of the Hamilton MBPs include:

- *Classifying Waste* (Part 1); and
- *Waste Containing Radioactive Material* (Part 3).

Relevant strategies and regulations that are referred to in the *NSW Guidelines* include:

- *Radiation Control Act (1990)*; and
- *Radiation Control Regulation (2013)*.

Under Part 1 of the *NSW Guidelines*, 'Special Wastes', 'Liquid Waste' and 'Pre-classified' wastes do not require any further assessment.

Part 1, Step 5 (*Determining a waste's classification using chemical assessment*) of the *NSW Guidelines* outlines the procedure for determining a solid waste's classification using chemical assessment. The analytical requirements include:

- Specific contaminant concentration (SCC) of any chemical contaminant in the waste, expressed as mg/kg; and
- Leachable concentration of any chemical contaminant using the toxicity characteristic leaching procedure (TCLP), expressed in mg/L.

To establish the waste's classification using both SCC and TCLP tests, the analytical results are compared with the threshold values outlined in Tables A1 and A2 of the *NSW Guidelines* (Attachment A). If either the SCC or TCLP threshold values for a contaminant are exceeded for 'general solid waste', the waste must be classified as 'restricted solid waste'. If either the SCC or TCLP threshold values for a contaminant are exceeded for 'restricted solid waste', the waste must be classified as 'hazardous solid waste'. In the absence of TCLP data, a solid waste may also be classified against more conservative (ie. lower) SCC threshold values as outlined in Table 1 of Part 1 of the *NSW Guidelines*.

Part 3 of the *NSW Guidelines* outlines the classification requirements for solid and liquid wastes containing radionuclides. Radioactive waste is regulated in accordance with the *Radiation Control Act (1990)* and the *Radiation Control Regulation (2003)*. Part 3 of the guidelines stipulate that wastes with a specific activity greater than 100 Bq/g and consisting of, or containing more than, the prescribed activity of a radioactive element in Schedule 1 of the *Radiation Control Regulation (2003)* must be classified as hazardous waste. The Specific Activity and Total Activity ratios are then used to determine whether the waste is classified as 'restricted solid waste' or whether it is to be classified in accordance with Part 1 of the *NSW Guidelines*. If the Specific Activity or Total Activity ratios are greater than one, then non-liquid wastes must be classified as 'restricted solid waste' unless:

- Other characteristics of the waste mean that the waste must be classified as 'hazardous waste' (eg. via Step 3 of Part 1 of the *NSW Guidelines*); or
- It may contain chemical contaminants that will lead to its assessment as 'hazardous waste' (eg. via Step 5 of Part 1 of the *NSW Guidelines*).

Where the Specific Activity and Total Activity ratios are equal to or less than one, the waste must be classified according to its other characteristics in line with Part 1 of the *NSW Guidelines*.

METHOD

Samples of each of the Hamilton MBP streams were provided to Earth Systems from Iluka's pilot scale metallurgical testwork. The MBPs and the percentage that each waste stream represents of the total MBP mass produced at the Hamilton MSP are provided in Table 1.

All samples were submitted for radionuclide and chemical analyses.

Table 1: Hamilton MBPs, sample mass and the percentage that each by-product represents of the total waste produced at the Hamilton MSP.

MBP	Percentage of total waste produced (wt.%) ¹
PDC Ilmenite	53
Combined monazite reject	10.5
Hyti	11.7
Combined zircon wet tails	8.6
Rutile wet concentrate circuit	0.9
PDC conductors oversize (+410 µm) ²	-
Float Tails	11.3

1: The remaining 4 % of waste material is recycled through the Hamilton MSP.

2: This stream represents 0.1 wt.% of the Hamilton MSP feed and may not be produced as it makes very little difference to the grade of the products.

Radionuclide Analytical Testwork

A representative sub-sample of each of the MBPs was also submitted to Australian Nuclear Science and Technology Organisation (ANSTO) Minerals Department for analysis and classification in accordance with Part 3 of the *NSW Guidelines*. Analyses conducted include:

- Gamma spectrometry for U-238 and Th-232 decay progeny and U-235 and its decay progeny;
- Delayed neutron activation (DNA) analysis or fusion / acid digest followed by ICP-MS for parent U-238 (method depends on available mass of sample material);
- Neutron activation analysis (NAA) or fusion / acid digest followed by ICP-MS for parent Th-232 (method depends on available mass of sample material);
- Alpha spectrometry for Po-210; and
- X-ray fluorescence spectrometry (XRF) analysis for elemental content for self-absorption corrections in gamma spectrometry.

The Specific Activity was determined for each of the MBPs and for MBPs with a specific activity of <100 Bq/g, the Total Activity ratio and Specific Activity ratios were calculated using the following expressions:

$$\text{Total Activity ratio} = (A1 \times 10^{-3}) + (A2 \times 10^{-4}) + (A3 \times 10^{-5}) + (A4 \times 10^{-6})$$

Where A1 to A4 are the total activity of Group 1 to Group 4 radionuclides, as set out in Column 1 of Schedule 1 of the Radiation Control Regulation (2013).

$$\text{Specific Activity ratio} = \text{SA1} + (\text{SA2} \times 10^{-1}) + (\text{SA3} \times 10^{-2}) + (\text{SA4} \times 10^{-3})$$

Where SA1 to SA4 are the specific activity (of the material) of Group 1 to Group 4 radionuclides, as set out in Column 1 of Schedule 1 of the Radiation Control Regulation (2013).

Chemical Analytical Testwork

The samples were also submitted to a NATA accredited laboratory for the following analyses (detection limits in brackets) in accordance with Step 5 of the *NSW Guidelines* (Part 1):

- Total concentrations of:
 - Metals including arsenic (5 mg/kg), beryllium (1 mg/kg), cadmium (1 mg/kg), chromium (VI) (0.5 mg/kg), lead (5 mg/kg), mercury (0.1 mg/kg), molybdenum (2 mg/kg), nickel (2 mg/kg), selenium (5 mg/kg) and silver (2 mg/kg).
 - Total fluoride (40 mg/kg).
 - Cyanide including weak acid dissociable (1 mg/kg) and total cyanide (1 mg/kg).
 - Total polychlorinated biphenyls (PCB) (0.1 mg/kg).
 - Triazines including atrazine (0.05 mg/kg) (NSW parameter only) and simazine (0.05 mg/kg).
 - Fipronil (0.05 mg/kg) and fenitrothion (0.05 mg/kg).
 - Monocyclic aromatic hydrocarbons including benzene (0.2 mg/kg), toluene (0.5 mg/kg), ethylbenzene (0.5 mg/kg), meta- & para-xylene (0.5 mg/kg), ortho-xylene (0.5 mg/kg), total xylenes (calculated) and styrene (0.5 mg/kg).
 - Polynuclear aromatic hydrocarbons including naphthalene (0.5 mg/kg), acenaphthylene (0.5 mg/kg), acenaphthene (0.5 mg/kg), fluorene (0.5 mg/kg), phenanthrene (0.5 mg/kg), anthracene (0.5 mg/kg), fluoranthene (0.5 mg/kg), pyrene (0.5 mg/kg), benz(a)anthracene (0.5 mg/kg), chrysene (0.5 mg/kg), benzo (b+j) & benzo(k)fluoranthene (0.5 mg/kg), benzo(a)pyrene (0.5 mg/kg), indeno(1.2.3.cd)pyrene (0.5 mg/kg), dibenz(a,h)anthracene (0.5 mg/kg) and benzo(g,h,i)perylene (0.5 mg/kg).
 - C6-C9 petroleum hydrocarbons (10 mg/kg).
 - C10-C36 petroleum hydrocarbons (50 mg/kg).
 - 2-butanone (methyl ethyl ketone) (5 mg/kg).
 - Halogenated aliphatic compounds including vinyl chloride (4 mg/kg), 1,1-dichloroethylene (0.5 mg/kg), methylene chloride (dichloromethane) (0.5 mg/kg), 1,1,1-trichloroethane (0.5 mg/kg), carbon tetrachloride (0.5 mg/kg), 1,2-dichloroethane (0.5 mg/kg), trichloroethylene (0.5 mg/kg), 1,1,2-trichloroethane (0.5 mg/kg) (NSW parameter only), tetrachloroethylene (0.5 mg/kg), 1,1,1,2-tetrachloroethane (0.5 mg/kg), and 1,1,2,2-tetrachloroethane (0.5 mg/kg).
 - Chlorobenzene (0.5 mg/kg).
 - Chloroform (0.5 mg/kg).
 - Isodrin (0.5 mg/kg).

- Phenolic compounds including phenol (0.5 mg/kg), 2-methylphenol (o-cresol) (0.5 mg/kg), 3 (m-cresol) - & 4- (p-cresol) methylphenol (0.5 mg/kg), 4-chloro-3-methylphenol (0.5 mg/kg), 2-chlorophenol (0.5 mg/kg), 2,4,5-trichlorophenol (0.5 mg/kg), 2,4,6-trichlorophenol (0.5 mg/kg), 2,3,4,6-tetrachlorophenol (0.5 mg/kg) and pentachlorophenol (0.5 mg/kg).
- Plasticiser compounds including bis(2-ethylhexyl)phthalate (0.5 mg/kg).
- Nitroaromatics and ketones including nitrobenzene (0.5 mg/kg), 2,4-dinitrotoluene (0.5 mg/kg).
- Chlorinated aromatic hydrocarbons including 1,2-dichlorobenzene (0.5 mg/kg), 1,4-dichlorobenzene (0.5 mg/kg), 1,2,4-trichlorobenzene (0.5 mg/kg), 1,3,5-trichlorobenzene (0.5 mg/kg), 1,2,3-trichlorobenzene (0.5 mg/kg), 1,2,3,4-tetrachlorobenzene (0.5 mg/kg), 1,2,3,5- & 1,2,4,5-tetrachlorobenzene (0.5 mg/kg) and pentachlorobenzene (0.5 mg/kg).
- Organochlorine pesticides including hexachlorobenzene (0.05 mg/kg), alpha-BHC (0.05 mg/kg), beta-BHC (0.05 mg/kg), gamma-BHC (0.05 mg/kg), delta-BHC (0.05 mg/kg), heptachlor (0.05 mg/kg), aldrin (0.05 mg/kg), heptachlor epoxide (0.05 mg/kg), alpha-endosulfan (0.05 mg/kg), beta-endosulfan (0.05 mg/kg), endosulfan sulfate (0.05 mg/kg), total endosulfan (calculated), 4,4`-DDE (0.05 mg/kg), trans-chlordane (0.05 mg/kg), cis-chlordane (0.05 mg/kg), total chlordane (calculated), dieldrin (0.05 mg/kg), endrin (0.05 mg/kg), endrin aldehyde (0.05 mg/kg), 4,4`-DDD (0.05 mg/kg), and 4,4`-DDT (0.2 mg/kg).
- Organophosphorus pesticides including dichlorvos (0.05 mg/kg), dimethoate (0.05 mg/kg), chlorpyrifos-methyl (0.05 mg/kg), malathion (0.05 mg/kg), fenthion (0.05 mg/kg), parathion-methyl (0.2 mg/kg), chlorpyrifos (0.05 mg/kg) and ethion (0.05 mg/kg).
- Synthetic pyrethroids including bifenthrin (0.05 mg/kg), lambda-cyhalothrin (0.05 mg/kg), permethrin (0.05 mg/kg), cyfluthrin (0.05 mg/kg), cypermethrin (0.05 mg/kg), deltamethrin & tralomethrin (0.05 mg/kg).
- Hexachlorophene (10 µg/kg).
- Thiodicarb (0.02 mg/kg).
- Phenoxyacetic acid herbicides including 2,4-D (0.02 mg/kg), triclopyr (0.02 mg/kg) , 2,4,5-TP (0.02 mg/kg), 2,4,5-T (0.02 mg/kg), picloram (0.02 mg/kg), fluroxypyr (0.02 mg/kg).
- Glyphosate (0.5 mg/kg).
- Leachable concentrations (after TCLP) of the following analytes:
 - The initial pH of the sample leach was determined using 5 g of the waste material and 96.5 mL of deionised water to determine the leaching protocol to be used in the TCLP. This pH value was also used to assess the approximate pH of the waste solids.
 - Metals including arsenic (0.1 mg/L), beryllium (0.05 mg/L), cadmium (0.05 mg/L), chromium (VI) (0.01 mg/L), lead (0.1 mg/L), mercury (0.001 mg/L), molybdenum (0.1 mg/L), nickel (0.1 mg/L), selenium (0.05 mg/L) and silver (0.1 mg/L).

- Total fluoride (0.1 mg/L);
- Cyanide including weak acid dissociable (0.004 mg/L) and total cyanide (0.004 mg/L).
- Monocyclic aromatic hydrocarbons including benzene (0.001 mg/L), toluene (0.002 mg/L), ethylbenzene (0.002 mg/L), meta- & para-xylene (0.002 mg/L), ortho-xylene (0.002 mg/L), total xylenes (calculated) and styrene (0.005 mg/L).
- 2-butanone (methyl ethyl ketone) (0.05 mg/L).
- Halogenated aliphatic compounds including vinyl chloride (0.05 mg/L), 1,1-dichloroethylene (0.005 mg/L), methylene chloride (dichloromethane) (0.005 mg/L), 1,1,1-trichloroethane (0.005 mg/L), carbon tetrachloride (0.005 mg/L), 1,2-dichloroethane (0.005 mg/L), trichloroethylene (0.005 mg/L), 1,1,2-trichloroethane (0.005 mg/L), tetrachloroethylene (0.005 mg/L), 1,1,1,2-tetrachloroethane (0.005 mg/L), and 1,1,2,2-tetrachloroethane (0.005 mg/L).
- Chlorobenzene (0.005 mg/L).
- Chloroform (0.005 mg/L).
- Phenolic compounds including phenol (0.002 mg/L), 2-methylphenol (o-cresol) (0.002 mg/L), 3 (m-cresol) - & 4- (p-cresol) methylphenol (0.002 mg/L), 2-chlorophenol (0.002 mg/L), 2,4,5-trichlorophenol (0.002 mg/L) and 2,4,6-trichlorophenol (0.002 mg/L).
- Plasticiser compounds including bis(2-ethylhexyl)phthalate (0.005 mg/L).
- Nitroaromatics and ketones including nitrobenzene (0.002 mg/L), 2,4-dinitrotoluene (0.004 mg/L).
- Chlorinated aromatic hydrocarbons including 1,2-dichlorobenzene (0.002 mg/L), 1,4-dichlorobenzene (0.002 mg/L), 1,2,4-trichlorobenzene (0.002 mg/L), 1,3,5-trichlorobenzene (0.002 mg/L) and 1,2,3,4-tetrachlorobenzene (0.0002 mg/L).
- Organochlorine pesticides including alpha-endosulfan (0.0005 mg/L), beta-endosulfan (0.0005 mg/L), endosulfan sulfate (0.0005 mg/L), total endosulfan (calculated).
- Organophosphorus pesticides including chlorpyrifos (0.0005 mg/L).
- Synthetic pyrethroids including bifenthrin (0.0005 mg/L), lambda-cyhalothrin (0.0005 mg/L), permethrin (0.0005 mg/L), cyfluthrin (0.0005 mg/L), cypermethrin (0.0005 mg/L), deltamethrin and tralomethrin (0.0005 mg/L).
- Phenoxyacetic acid herbicides including 2,4-D (0.01 mg/L), triclopyr (0.01 mg/L), picloram (0.01 mg/L), fluroxypyr (0.01 mg/L).
- Tebuconazole (0.00001 mg/L).

Classification

The MBP samples were assumed to be solid wastes, and were then classified based on the results of the analytical testwork, the threshold values for chemical classification of solid wastes (Attachment A) and the threshold values for waste containing radioactive material outlined in the *Relevant NSW Legislation, Guidelines and Standards* Section of this report.

MBP CLASSIFICATION

Table 2 outlines the classification of the Hamilton MBPs against Part 1, Step 5 (ie. chemical classification) and Part 3 (ie. radioactivity classification) of the *NSW Guidelines*. Results are described in the sections below.

Table 2: Classification of Hamilton MBPs against Part 1, Step 5 and Part 3 of the *NSW Guidelines*.

MBP Stream	Preliminary Waste Classification	Clause Triggering Waste Classification
PDC Ilmenite	Restricted Solid Waste	PDC Ilmenite sample had a Specific Activity Ratio of 1.9, exceeding the threshold value of 1 outlined in Part 3 of the <i>NSW Guidelines</i> .
Combined monazite reject	Hazardous Solid Waste	Combined monazite reject sample had a Specific Activity of 938 Bq/g and a waste disposal mass of 87 g would result in a Prescribed Activity, of a radioactive element in Schedule 1 of the Radiation Control Regulation (2013), greater than 40 kBq. These exceed the threshold values outlined in Part 3 of the <i>NSW Guidelines</i> .
Hyti	Restricted Solid Waste	Hyti sample had a Specific Activity Ratio of 10, exceeding the threshold value of 1 outlined in Part 3 of the <i>NSW Guidelines</i> .
Combined zircon wet tails	Restricted Solid Waste	Combined zircon wet tails sample had a Specific Activity Ratio of 7.7, exceeding the threshold value of 1 outlined in Part 3 of the <i>NSW Guidelines</i> . Combined zircon wet tails sample had a total fluoride concentration of 3,980 mg/kg, exceeding the threshold value of 1,000 mg/kg for 'General Solid Waste' outlined in Part 1, Step 5 of the <i>NSW Guidelines</i> .
Rutile wet concentrate circuit	Restricted Solid Waste	Rutile wet concentrate circuit sample had a Specific Activity Ratio of 8.8, exceeding the threshold value of 1 outlined in Part 3 of the <i>NSW Guidelines</i> .
PDC conductors oversize (+410 µm)	Restricted Solid Waste	PDC conductors oversize sample had a Specific Activity Ratio of 10, exceeding the threshold value of 1 outlined in Part 3 of the <i>NSW Guidelines</i> . PDC conductors oversize sample had a total nickel concentration of 50 mg/kg, exceeding the threshold value (for classification without TCLP) of 40 mg/kg for 'General Solid Waste' outlined in Part 1, Step 5 of the <i>NSW Guidelines</i> .
Float Tails	Restricted Solid Waste	Float tails sample had a Specific Activity Ratio of 3.8, exceeding the threshold value of 1 outlined in Part 3 of the <i>NSW Guidelines</i> .



Comparison of results with radionuclide thresholds

The results of the analysis of the Hamilton MBPs against *NSW Guidelines* for radioactive material are provided in Attachment B. Key results include (ANSTO Minerals, 2015):

- The Specific Activity for all MBP streams, with the exception of the combined monazite reject, was below the 100 Bq/g threshold value for the *NSW Guidelines*.
- The Specific Activity for the combined monazite reject (938 Bq/g) exceeded the 100 Bq/g threshold value. The Total Activity of the Group 1 radionuclides was 460 Bq/g, meaning a waste disposal mass of ≥ 87 g will also exceed the Prescribed Activity for Group 1 radionuclides in Schedule 1 of the *Radiation Control Regulation 2013* (40 kBq), resulting in a Hazardous Solid Waste classification.
- The Specific Activity ratios of the PDC ilmenite (1.9), Hyti (10), Combined zircon wet tails (7.7), rutile wet circuit concentrate (8.8), float tails (3.8) and PDC conductors oversize (+410 μm) were greater than 1 resulting in a Restricted Solid Waste classification under the *NSW Guidelines*.

Comparison of results with SCC thresholds

The results of the analysis of the Hamilton MBPs against specific contaminant concentration thresholds are provided in Table A1 (Attachment A). Key results include:

- Total fluoride concentrations for the combined zircon wet tails sample were 3,980 mg/kg, exceeding the specific contaminant concentration threshold value of 1,000 mg/kg for General Waste.
- As leachate data is not available for the PDC Conductor's Oversize (+410 μm) waste stream, this was assessed against the maximum contaminant threshold values for classification without TCLP. All reported values were below the specific contaminant concentration threshold values for general waste with the exception of nickel at 50 mg/kg, which was above the maximum contaminant concentration threshold value of 40 mg/kg for 'General Waste'.
- All other reported values were below the specific contaminant concentration threshold values for general waste.
- Total arsenic concentrations (454 mg/kg) for the rutile wet concentrate circuit are close to, but do not exceed, the specific contaminant concentration threshold value for general waste (500 mg/kg).
- The NSW EPA requires chemical classification testwork for the contaminants that are expected to be present in the samples. The following analytes were not reported by the analytical laboratory and are not expected to be present in the sample solids based on the source material composition and an assessment of the process flow diagram for the Hamilton MSP:
 - » Some of the moderately harmful pesticide contaminants;
 - » Di-2-ethyl-hexyl adipate; and
 - » Tebuconazole.

Comparison of results with TCLP thresholds

The results of the analysis of the Hamilton MBPs against leachable contaminant concentration thresholds are provided in Table A2 (Attachment A). Key results include:



- pH values for a deionised water leach of the MBPs (5 g sample to 96.5 mL of deionised water) were around 4, above the pH 2 threshold value which results in classification of the material as corrosive and hazardous under the *Australian Code for the Transport of Dangerous Goods by Road & Rail* (2014).
- No reported values were above the leachable contaminant concentration threshold values for general waste.
- Although total fluoride concentrations of 3,980 mg/kg for the combined zircon wet tails material exceed the specific contaminant concentration threshold value for general waste of 1,000 mg/kg, leachable concentrations of fluoride (0.3 mg/L) were well below the leachable contaminant concentration threshold value for general waste (150 mg/L).
- The following analytes were not reported by the analytical laboratory, however are not expected to be present in the sample leachate based on an assessment of the process flow diagram for the Hamilton MSP:
 - Di-2-ethyl-hexyl adipate; and
 - 1,2,3,4-tetrachlorobenzene.

CONCLUSIONS

Key conclusions from the classification testwork of the MBP samples include:

1. Based on Part 3 of the *NSW Guidelines* relating to wastes containing radioactive material, the Combined Monazite Reject is likely to be classified as Hazardous Solid Waste.
2. Based on Part 3 of the *NSW Guidelines* relating to wastes containing radioactive material, the PDC Ilmenite, Hyti, Combined Zircon Wet Tails, Rutile Wet Concentrate Circuit, PDC Conductors Oversize and Float Tails MBP streams are likely to be classified as Restricted Solid Waste.
3. Notwithstanding the classification of the Hamilton MBPs by the *NSW Guidelines* relating to wastes containing radioactive material:
 - a. Based on Part 1, Step 5 of the *NSW Guidelines* relating to chemical classification of solid wastes, the Combined Zircon Wet Tails would be classified as Restricted Solid Waste.
 - b. Based on Part 1, Step 5 of the *NSW Guidelines* relating to chemical classification of solid wastes, the PDC Conductors Oversize would be classified as Restricted Solid Waste.

REFERENCES

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- EMGA Mitchell McLennan (2015). *Balranald Mineral Sands Project Environmental Impact Statement: Chapter 4 Project Description*. Prepared for Iluka Resources, 5 January 2015.
- Department of Environment, Climate Change and Water (2009). *Waste Classification Guidelines: Part 1: Classifying Waste*. New South Wales State Government.
- Department of Environment, Climate Change and Water (2009). *Waste Classification Guidelines: Part 3: Waste Containing Radioactive Material*. New South Wales State Government.



Attachment A

NSW Waste Classification Analytical Laboratory Results



Table A1: Hamilton MBPs specific contaminant concentrations against the general and restricted solid waste thresholds (DECCW, 2009). Yellow shading indicates an exceedance of general solid waste threshold and brown shading indicates an exceedance of both general and restricted solid waste thresholds (light and dark shading respectively if printed in black and white).

Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
Arsenic		500	2,000	<5	16	31	<5	454	79	357
Benzene	71-43-2	18	72	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Benzo(a)pyrene ³	50-32-8	10	23	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.5
Beryllium		100	400	<1	<1	<1	<1	<1	<1	<1
Cadmium		100	400	<1	<1	<1	<1	<1	<1	<1
Carbon tetrachloride	56-23-5	18	72	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chlorobenzene	108-90-7	3,600	14,400	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chloroform	67-66-3	216	864	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chlorpyrifos	2921-88-2	8	30	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Chromium (VI) ⁶		1,900	7,600	<0.5	0.7	<0.5	<0.5	<0.5	<0.5	<0.5
m-cresol	108-39-4	7,200	28,800	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
o-cresol	95-48-7	7,200	28,800	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
p-cresol	106-44-5	7,200	28,800	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cresol (total)	1319-77-3	7,200	28,800	-	-	-	-	-	-	-
Cyanide (amenable) ^{7,8}		300	1,200	<1	<1	<1	<1	<1	<1	<1
Cyanide (total) ⁷		5,900	23,600	<1	<1	<1	<1	<1	<1	<1
2,4-D	94-75-7	360	1,440	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.04



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
1,2-Dichlorobenzene	95-50-1	155	620	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1,4-Dichlorobenzene	106-46-7	270	1,080	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1,2-Dichloroethane	107-06-2	18	72	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1,1-Dichloroethylene	75-35-4	25	100	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Dichloromethane	75-09-2	310	1,240	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2,4-Dinitrotoluene	121-14-2	5	19	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.5
Endosulfan ⁹		108	432							
<i>alpha-endosulfan</i>	959-98-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>beta-endosulfan</i>	33213-65-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Endosulfan-sulfate</i>	1031-07-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Ethylbenzene	100-41-4	1,080	4,320	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Fluoride		1,000	40,000	<40	550	<40	3,980	<40	<40	<40
Fluroxypyr	69377-81-7	75	300	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.04
Lead		1,500	6,000	28	17	133	<5	412	49	288
Mercury		50	200	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Methyl ethyl ketone	78-93-3	7,200	28,800	<5	<5	<5	<5	<5	<5	<5
Moderately Harmful Pesticides ¹¹		250	1,000							
<i>Atrazine</i>	1912-24-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Azoxystrobin</i>	131860-33-8			NR	NR	NR	NR	NR	NR	NR



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
<i>Bifenthrin</i>	82657-04-3			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Brodifacoum</i>	56073-10-0			NR	NR	NR	NR	NR	NR	NR
<i>Carboxin</i>	5234-68-4			NR	NR	NR	NR	NR	NR	NR
<i>Copper naphthenate</i>	1338-02-9			NR	NR	NR	NR	NR	NR	NR
<i>Cyfluthrin</i>	68359-37-5			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Cyhalothrin</i>	68085-85-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Cypermethrin</i>	52315-07-08			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Deltamethrin</i>	52918-63-5			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Dichlofluanid</i>	1085-98-9			NR	NR	NR	NR	NR	NR	NR
<i>Dichlorvos</i>	62-73-7			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Difenoconazole</i>	119446-68-3			NR	NR	NR	NR	NR	NR	NR
<i>Dimethoate</i>	60-51-5			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Diquat dibromide</i>	85-00-7			NR	NR	NR	NR	NR	NR	NR
<i>Emamectin benzoate</i>	137515-75-4 & 155569-918			NR	NR	NR	NR	NR	NR	NR
<i>Ethion</i>	563-12-2			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Fenthion</i>	55-38-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Fenitrothion</i>	122-14-5			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Fipronil</i>	120068-37-3			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
<i>Fluazifop-P-butyl</i>	79241-46-6			NR	NR	NR	NR	NR	NR	NR
<i>Fluidioxonil</i>	131341-86-1			NR	NR	NR	NR	NR	NR	NR
<i>Glyphosate</i>	1071-83-6			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Imidacloprid</i>	138261-41-3			NR	NR	NR	NR	NR	NR	NR
<i>Indoxacarb</i>	173584-44-6			NR	NR	NR	NR	NR	NR	NR
<i>Malathion</i>	121-75-5			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Metalaxyl</i>	57837-19-1			NR	NR	NR	NR	NR	NR	NR
Metalaxyl-M	70630-17-0			NR	NR	NR	NR	NR	NR	NR
Methidathion	950-37-8			NR	NR	NR	NR	NR	NR	NR
<i>3-Methyl-4-chlorophenol</i>	59-50-7			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Methyl chlorpyrifos</i>	5598-13-0			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>N-Methyl pyrrolidone</i>	872-50-4			NR	NR	NR	NR	NR	NR	NR
<i>2-octylthiazol-3-one</i>	26530-20-1			NR	NR	NR	NR	NR	NR	NR
<i>Oxyfluorfen</i>	42874-03-3			NR	NR	NR	NR	NR	NR	NR
<i>Paraquat dichloride</i>	1910-42-5			NR	NR	NR	NR	NR	NR	NR
<i>Parathion methyl</i>	298-00-0			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<i>Permethrin</i>	52645-53-1			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	NR
<i>Profenofos</i>	41198-08-7			NR	NR	NR	NR	NR	NR	NR
<i>Prometryn</i>	7287-19-6			NR	NR	NR	NR	NR	NR	NR
<i>Propargite</i>	2312-35-8			NR	NR	NR	NR	NR	NR	NR
<i>Pentachloronitrobenzene</i>	82-68-8			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
<i>Simazine</i>	122-34-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Thiabendazole</i>	148-79-8			NR	NR	NR	NR	NR	NR	NR
<i>Thiamethoxam</i>	153719-23-4			NR	NR	NR	NR	NR	NR	NR
<i>Thiodicarb</i>	59669-26-0			<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
<i>Thiram</i>	137-26-8			NR	NR	NR	NR	NR	NR	NR
Molybdenum		1000	4000	<2	<2	<2	<2	6	<2	4
Nickel		1050	4200	9	3	31	<2	38	50	50
Nitrobenzene	98-95-3	72	288	<0.5	<0.50	<0.5	<0.5	<0.5	<0.5	<0.5
C6-C9 petroleum hydrocarbons ¹³		650	2600	<10	<10	<10	<10	<10	<10	<10
C10-C36 petroleum hydrocarbons ¹³		10000	40000	<50	<50	<50	<50	<50	<50	<50
Phenol (non-halogenated)	108-95-2	518	2073	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Picloram	1918-02-1	110	440	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.04
Plasticiser compounds ¹⁵		600	2,400							
<i>di-2-ethyl hexyl phthalate</i>	117-81-7	---	---	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>di-2-ethyl hexyl adipate</i>	103-23-1			NR	NR	NR	NR	NR	NR	NR
Polychlorinated biphenyls ¹²	1336-36-3	<50	<50	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Polycyclic aromatic hydrocarbons (total) ¹⁶		200	800							
<i>Acenaphthene</i>	83-32-9			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Acenaphthylene</i>	208-96-8			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
<i>Anthracene</i>	120-12-7			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Benzo(a)anthracene</i>	56-55-3			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Benzo(a)pyrene</i>	50-32-8			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Benzo(b)fluoranthene</i>	205-99-2			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.05
<i>Benzo(ghi)perylene</i>	191-24-2			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Benzo(k)fluoranthene</i>	207-08-9			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Chrysene</i>	218-01-9			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Dibenzo(a,h)anthracene</i>	53-70-3			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Fluoranthene</i>	206-44-0			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Fluorene</i>	86-73-7			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Indeno(1,2,3-cd)pyrene</i>	193-39-5			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Naphthalene</i>	91-20-3			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Phenanthrene</i>	85-01-8			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Pyrene</i>	129-00-0			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Scheduled Chemicals ¹⁷		<50	<50							
<i>Aldrin</i>	309-00-2			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Alpha-BHC</i>	319-84-6			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Beta-BHC</i>	319-85-7			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Gamma-BHC</i>	58-89-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
<i>Delta-BHC</i>	319-86-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>trans-chlordane</i>	5103-74-2			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>cis-chlordane</i>	5103-71-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>DDD</i>	72-54-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>DDE</i>	72-55-9			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>DDT</i>	50-29-3			<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<i>Dieldrin</i>	60-57-1			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Endrin</i>	72-20-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Endrin aldehyde</i>	7421-93-4			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Heptachlor</i>	76-44-8			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Heptachlor epoxide</i>	1024-57-3			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Hexachlorobenzene</i>	118-74-1			<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<i>Hexachlorophene</i>	70-30-4			<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
<i>Isodrin</i>	465-73-6			<3	<3	<3	<3	<3	<3	<0.5
<i>Pentachlorobenzene</i>	608-93-5			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Pentachloronitrobenzene</i>	82-68-8			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>Pentachlorophenol</i>	87-86-5			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>1,2,4,5-Tetrachlorobenzene</i>	95-94-3			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>2,3,4,6 Tetrachlorophenol</i>	58-90-2			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>1,2,4-Trichlorobenzene</i>	120-82-1			<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
<i>2,4,5-Trichlorophenoxyacetic acid, salts and esters</i>	93-76-5			<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.04



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
Selenium		50	200	<5	<5	<5	<5	<5	<5	<5
Silver		180	720	<2	<2	<2	<2	<2	<2	<2
Styrene (vinyl benzene)	100-42-5	108	432	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tebuconazole	107534-96-3	230	920	NR	NR	NR	NR	NR	NR	NR
1,2,3,4-tetrachlorobenzene	634-66-2	18	72	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.5
1,1,1,2-tetrachloroethane ⁵	630-20-6	360	1440	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1,1,2,2-tetrachloroethane ⁵	79-34-5	46.8	187.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tetrachloroethylene	127-18-4	25.2	100.8	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Toluene	108-88-3	518	2073	<0.5	<0.5	0.6	<0.5	<0.5	<0.5	<0.5
1,1,1-trichloroethane	71-55-6	1080	4320	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
1,1,2-trichloroethane	79-00-5	43.2	172.8	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Trichloroethylene	79-01-6	18	72	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2,4,5-trichlorophenol	95-95-4	14400	57600	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
2,4,6-trichlorophenol	88-06-2	72	288	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Triclopyr	55335-06-3	75	300	<0.02	<0.02	<0.04	<0.02	<0.02	<0.02	<0.04
Vinyl chloride	75-01-4	7.2	28.8	<4	<4	<4	<4	<4	<4	<4
Xylenes (total)	1330-20-7	1800	7200							
<i>meta- & para-xylene</i>				<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Contaminant Concentration (mg/kg)						
		SCC1 (mg/kg)	SCC2 (mg/kg)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
<i>ortho-xylene</i>				<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

- Values are the same for general solid waste (putrescible) and general solid waste (nonputrescible).
- See Hazardous Waste Management System: Identification and Listing of Hazardous Waste – Toxicity Characteristics Revisions, Final Rule (USEPA 1990) for TCLP levels.
- There may be a need for the laboratory to concentrate the sample to achieve the TCLP limit value for benzo(a)pyrene with confidence. Waste Classification Guidelines 20 Part 1: Classifying waste (December 2009)
- Calculated from Hazardous Waste: Identification and Listing – Proposed Rule (USEPA 1995)
- Calculated from 'Beryllium' in The Health Risk Assessment and Management of Contaminated Sites (DiMarco & Buckett 1996)
- These limits apply to chromium in the +6 oxidation state only.
- Taken from the Land Disposal Restrictions for Newly Identified and Listed Hazardous Wastes and Hazardous Soil: Proposed Rule (USEPA 1993)
- Analysis for cyanide (amenable) is the established method used to assess the potentially leachable cyanide. DECCW may consider other methods if it can be demonstrated that these methods yield the same information.
- Endosulfan (CAS Registry Number 115-29-7) means the total of Endosulfan I (CAS Registry Number 959-98-8), Endosulfan II (CAS Registry Number 891-86-1) and Endosulfan sulfate (CAS Registry Number 1031-07-8).
- Calculated from Australian Drinking Water Guidelines (NHMRC 1994)
- The following moderately harmful pesticides (CAS Registry Number) are to be included
in the total values specified: Atrazine (1912-24-9), Azoxystrobin (131860-33-8), Bifenthrin (82657-04-3), Brodifacoum (56073-10-0), Carboxin (5234-68-4), Copper naphthenate (1338-02-9), Cyfluthrin (68359-37-5), Cyhalothrin (68085-85-8), Cypermethrin (52315-07-08), Deltamethrin (52918-63-5), Dichlofluanid (1085-98-9), Dichlorvos (62-73-7), Difenconazole (119446-68-3), Dimethoate (60-51-5), Diquat dibromide (85-00-7), Emamectin benzoate (137515-75-4 & 155569-91-8), Ethion (563-12-2), Fenthion (55-38-9), Fenitrothion (122-14-5), Fipronil (120068-37-3), Fluazifop-P-butyl (79241-46-6), Fludioxonil (131341-86-1), Glyphosate (1071-83-6), Imidacloprid (138261-41-3), Indoxacarb (173584-44-6), Malathion (Maldison) (121-75-5), Metalaxyl (57837-19-1), Metalaxyl-M (70630-17-0), Methidathion (950-37-8), 3-Methyl-4-chlorophenol (59-50-7), Methyl chlorpyrifos (5598-13-0), N-Methyl pyrrolidone (872-50-4), 2-octylthiazol-3-one (26530-20-1), Oxyfluorfen (42874-03-3), Paraquat



dichloride (1910-42-5), Parathion methyl (298-00-0), Permethrin (52645-53-1), Profenofos (41198-08-7), Prometryn (7287-19-6), Propargite (2312-35-8), Pentachloronitrobenzene (Quintozene) (82-68-8), Simazine (122-34-9), Thiabendazole (148-79-8), Thiamethoxam (153719-23-4), Thiodicarb (59669-26-0) and Thiram (137-26-8).

12. No TCLP analysis is required. Moderately harmful pesticides, petroleum hydrocarbons, polychlorinated biphenyls, polycyclic aromatic hydrocarbons and scheduled chemicals are assessed using SCC1 and SCC2.

13. Approximate range of petroleum hydrocarbon fractions: petrol C6-C9, kerosene C10-C18, diesel C12-C18, and lubricating oils above C18. Laboratory results are reported as four different fractions: C6-C9, C10-C14, C15-C28 and C29-C36. The results of total petroleum hydrocarbons (C10-C36) analyses are reported as a sum of the relevant three fractions. Please note that hydrocarbons are defined as molecules that only contain carbon and hydrogen atoms. Prior to TPH (C10-C36) analysis, cleanup may be necessary to remove non-petroleum hydrocarbon compounds. Where the presence of other materials that will interfere with the analysis may be present, such as oils and fats from food sources, you are advised to treat the extract that has been solvent exchanged to hexane with silica gel as described in USEPA Method 1664A (USEPA 1999).

14. Proposed level for phenol and toluene in Hazardous Waste Management System: Identification and Listing of Hazardous Waste – Toxicity Characteristics Revisions, Final Rule (USEPA 1990)

15. Plasticiser compounds means the total of di-2-ethyl hexyl phthalate (CAS Registry Number 117-81-7) and di-2-ethyl hexyl adipate (CAS Registry Number 103-23-1) contained within a waste.

16. The following polycyclic aromatic hydrocarbons (CAS number) are assessed as the total concentration of 16 USEPA Priority Pollutant PAHs, as follows: Polycyclic aromatic hydrocarbons (total) (PAH name, CAS Registry Number) Acenaphthene 83-32-9 Chrysene 218-01-9 Acenaphthylene 208-96-8 Dibenzo(a,h)anthracene 53-70-3 Anthracene 120-12-7 Fluoranthene 206-44-0 Benzo(a)anthracene 56-55-3 Fluorene 86-73-7 Benzo(a)pyrene 50-32-8 Indeno(1,2,3-cd)pyrene 193-39-5 Benzo(b)fluoranthene 205-99-2 Naphthalene 91-20-3 Benzo(ghi)perylene 191-24-2 Phenanthrene 85-01-8 Benzo(k)fluoranthene 207-08-9 Pyrene 129-00-0

17. The following Scheduled Chemicals (CAS Registry Number) are to be included in the total values specified: Aldrin (309-00-2), Alpha-BHC (319-84-6), Beta-BHC (319-85-7), Gamma-BHC (Lindane) (58-89-9), Delta-BHC (319-86-8), Chlordane (57-74-9), DDD (72-54-8), DDE (72-55-9), DDT (50-29-3), Dieldrin (60-57-1), Endrin (72-20-8), Endrin aldehyde (7421-93-4), Heptachlor (76-44-8), Heptachlor epoxide (1024-57-3), Hexachlorobenzene (118-74-1), Hexachlorophene (70-30-4), Isodrin (465-73-6), Pentachlorobenzene (608-93-5), Pentachloronitrobenzene (82-68-8), Pentachlorophenol (87-86-5), 1,2,4,5-Tetrachlorobenzene (95-94-3), 2,3,4,6 Tetrachlorophenol (58-90-2), 1,2,4-Trichlorobenzene (120-82-1), 2,4,5-Trichlorophenoxyacetic acid, salts and esters (93-76-5).

18. Calculated from Guidelines for Drinking Water Quality (WHO 1993).

NR Parameter not reported by analytical laboratory.



Table A2: Hamilton MBPs leachable contaminant concentrations against the general and restricted solid waste thresholds (DECCW, 2009). Yellow shading indicates an exceedance of general solid waste threshold and brown shading indicates an exceedance of both general and restricted solid waste thresholds (light and dark shading respectively if printed in black and white).

Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Leachable Contaminant Concentration (mg/L)						
		TCLP1 (mg/L)	TCLP22 (mg/L)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
pH ¹⁹	-	-	-	4.3	3.7	3.7	4.6	3.5	4.2	3.6
Arsenic		5.0 ²	20	<0.1	<0.1	<0.1	<0.1	<0.1	INS	<0.1
Benzene	71-43-2	0.5 ²	2	<0.001	< 0.001	< 0.001	< 0.001	< 0.001	INS	INS
Benzo(a)pyrene ³	50-32-8	0.04 ²	0.16	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
Beryllium		1 ⁵	4	<0.05	<0.05	<0.05	<0.05	<0.05	INS	<0.05
Cadmium		1 ²	4	<0.05	<0.05	<0.05	<0.05	<0.05	INS	<0.05
Carbon tetrachloride	56-23-5	0.5 ²	2	<0.005	< 0.005	< 0.005	< 0.005	< 0.005	INS	INS
Chlorobenzene	108-90-7	100 ²	400	<0.005	< 0.005	< 0.005	< 0.005	< 0.005	INS	INS
Chloroform	67-66-3	6 ²	24	<0.005	< 0.005	< 0.005	< 0.005	< 0.005	INS	INS
Chlorpyrifos	2921-88-2	0.2	0.8	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	INS	<0.0005
Chromium (VI) ⁶		5 ²	20	<0.01	<0.01	<0.01	<0.01	<0.01	INS	<0.01
m-cresol	108-39-4	200 ²	800	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
o-cresol	95-48-7	200 ²	800	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
p-cresol	106-44-5	200 ²	800	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
Cresol (total)	1319-77-3	200 ²	800							
Cyanide (amenable) ^{7,8}		3.5 ⁷	14	<0.004	<0.004	<0.004	<0.004	<0.004	INS	NR



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Leachable Contaminant Concentration (mg/L)						
		TCLP1 (mg/L)	TCLP22 (mg/L)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
Cyanide (total) ⁷		16 ⁷	64	<0.004	<0.004	<0.004	<0.004	<0.004	INS	NR
2,4-D	94-75-7	10 ²	40	<0.01	<0.01	<0.01	<0.01	<0.01	INS	<0.01
1,2-Dichlorobenzene	95-50-1	4.3 ²	17.2	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
1,4-Dichlorobenzene	106-46-7	7.5 ²	30	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
1,2-Dichloroethane	107-06-2	0.5 ²	2	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
1,1-Dichloroethylene	75-35-4	---	---	<0.005	<0.005	<0.005	<0.005	<0.006	INS	INS
Dichloromethane	75-09-2	8.6 ²	34.4	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
2,4-Dinitrotoluene	121-14-2	0.13 ²	0.52	<0.004	<0.004	<0.004	<0.004	<0.004	INS	<0.004
Endosulfan ⁹		3	12							
<i>alpha-endosulfan</i>	959-98-8			<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
<i>beta-endosulfan</i>	33213-65-9			<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
<i>Endosulfan-sulfate</i>	1031-07-8			<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005	<0.0005
Ethylbenzene	100-41-4	30 ¹⁰	120	<0.002	<0.002	<0.002	<0.002	<0.002	INS	INS
Fluoride		150 ¹⁰	600	0.3	0.2	0.3	0.3	0.2	INS	0.1
Fluroxypyr	69377-81-7	2	8	<0.01	<0.01	<0.01	<0.01	<0.01	INS	<0.01
Lead		5 ²	20	<0.1	<0.1	<0.1	<0.1	<0.1	INS	<0.1
Mercury		0.2 ²	0.8	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	INS	<0.0010
Methyl ethyl ketone	78-93-3	200 ²	800	<0.05	<0.05	<0.05	<0.05	<0.05	INS	INS
Molybdenum		5 ¹⁰	20	<0.1	<0.1	<0.1	<0.1	<0.1	INS	<0.1



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Leachable Contaminant Concentration (mg/L)						
		TCLP1 (mg/L)	TCLP22 (mg/L)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
Nickel		2 ¹⁰	8	<0.1	0.1	0.4	<0.1	0.1	INS	0.3
Nitrobenzene	98-95-3	2 ²	8	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
Phenol (non-halogenated)	108-95-2	14.4 ¹⁴	57.6	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
Picloram	1918-02-1	3	12	<0.01	<0.01	<0.01	<0.01	<0.01	INS	<0.01
Plasticiser compounds ¹⁵		1	4							
<i>di-2-ethyl hexyl phthalate</i>	<i>117-81-7</i>	---	---	0.006	<0.005	<0.005	0.026	<0.005	INS	<0.005
di-2-ethyl hexyl adipate	103-23-1			NR	NR	NR	NR	NR	NR	NR
Selenium		1 ²	4	<0.05	<0.05	<0.05	<0.05	<0.05	INS	<0.05
Silver		5 ²	20	<0.1	<0.1	<0.1	<0.1	<0.1	INS	<0.1
Styrene (vinyl benzene)	100-42-5	3 ¹⁰	12	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
Tebuconazole	107534-96-3	6.4	25.6	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001	INS	<0.01
1,2,3,4-tetrachlorobenzene	634-66-2	0.5	2	<0.01	NR	NR	NR	NR	INS	INS
1,1,1,2-tetrachloroethane ⁵	630-20-6	10 ²	40	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
1,1,2,2-tetrachloroethane ⁵	79-34-5	1.3 ²	5.2	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
Tetrachloroethylene	127-18-4	0.7 ²	2.8	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
Toluene	108-88-3	14.4 ¹⁴	57.6	<0.002	<0.002	0.006	<0.002	<0.002	INS	INS
1,1,1-trichloroethane	71-55-6	30 ²	120	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS



Contaminant	CAS Registry Number	General Solid Waste	Restricted Solid Waste	Hamilton Mining By-Product Leachable Contaminant Concentration (mg/L)						
		TCLP1 (mg/L)	TCLP22 (mg/L)	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	PDC Conductors O/size +410µm	Float Tails
1,1,2-trichloroethane	79-00-5	1.2 ²	4.8	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
Trichloroethylene	79-01-6	0.5 ²	2	<0.005	<0.005	<0.005	<0.005	<0.005	INS	INS
2,4,5-trichlorophenol	95-95-4	400 ²	1600	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
2,4,6-trichlorophenol	88-06-2	2 ²	8	<0.002	<0.002	<0.002	<0.002	<0.002	INS	<0.002
Triclopyr	55335-06-3	2	8	<0.01	<0.01	<0.01	<0.01	<0.01	INS	<0.01
Vinyl chloride	75-01-4	0.2 ²	0.8	<0.05	<0.05	<0.05	<0.05	<0.05	INS	INS
Xylenes (total)	1330-20-7	50 ¹⁸	200							
<i>meta- & para-xylene</i>	108-38-3 106-42-3			<0.002	<0.002	<0.002	<0.002	<0.002	INS	INS
<i>ortho-xylene</i>	95-47-6			<0.002	<0.002	<0.002	<0.002	<0.002	INS	INS

1. Values are the same for general solid waste (putrescible) and general solid waste (nonputrescible).
2. See Hazardous Waste Management System: Identification and Listing of Hazardous Waste – Toxicity Characteristics Revisions, Final Rule (USEPA 1990) for TCLP levels.
3. There may be a need for the laboratory to concentrate the sample to achieve the TCLP limit value for benzo(a)pyrene with confidence. Waste Classification Guidelines 20 Part 1: Classifying waste (December 2009)
4. Calculated from Hazardous Waste: Identification and Listing – Proposed Rule (USEPA 1995)
5. Calculated from 'Beryllium' in The Health Risk Assessment and Management of Contaminated Sites (DiMarco & Buckett 1996)
6. These limits apply to chromium in the +6 oxidation state only.
7. Taken from the Land Disposal Restrictions for Newly Identified and Listed Hazardous Wastes and Hazardous Soil: Proposed Rule (USEPA 1993)
8. Analysis for cyanide (amenable) is the established method used to assess the potentially leachable cyanide. DECCW may consider other methods if it can be demonstrated that these methods yield the same information.

9. Endosulfan (CAS Registry Number 115-29-7) means the total of Endosulfan I (CAS Registry Number 959-98-8), Endosulfan II (CAS Registry Number 891-86-1) and Endosulfan sulfate (CAS Registry Number 1031-07-8).
10. Calculated from Australian Drinking Water Guidelines (NHMRC 1994)
11. The following moderately harmful pesticides (CAS Registry Number) are to be included
in the total values specified: Atrazine (1912-24-9), Azoxystrobin (131860-33-8), Bifenthrin (82657-04-3), Brodifacoum (56073-10-0), Carboxin (5234-68-4), Copper naphthenate (1338-02-9), Cyfluthrin (68359-37-5), Cyhalothrin (68085-85-8), Cypermethrin (52315-07-08), Deltamethrin (52918-63-5), Dichlofluanid (1085-98-9), Dichlorvos (62-73-7), Difenoconazole (119446-68-3), Dimethoate (60-51-5), Diquat dibromide (85-00-7), Emamectin benzoate (137515-75-4 & 155569-91-8), Ethion (563-12-2), Fenthion (55-38-9), Fenitrothion (122-14-5), Fipronil (120068-37-3), Fluzifop-P-butyl (79241-46-6), Fludioxonil (131341-86-1), Glyphosate (1071-83-6), Imidacloprid (138261-41-3), Indoxacarb (173584-44-6), Malathion (Maldison) (121-75-5), Metalaxyl (57837-19-1), Metalaxyl-M (70630-17-0), Methidathion (950-37-8), 3-Methyl-4-chlorophenol (59-50-7), Methyl chlorpyrifos (5598-13-0), N-Methyl pyrrolidone (872-50-4), 2-octylthiazol-3-one (26530-20-1), Oxyfluorfen (42874-03-3), Paraquat dichloride (1910-42-5), Parathion methyl (298-00-0), Permethrin (52645-53-1), Profenofos (41198-08-7), Prometryn (7287-19-6), Propargite (2312-35-8), Pentachloronitrobenzene (Quintozene) (82-68-8), Simazine (122-34-9), Thiabendazole (148-79-8), Thiamethoxam (153719-23-4), Thiodicarb (59669-26-0) and Thiram (137-26-8).
12. No TCLP analysis is required. Moderately harmful pesticides, petroleum hydrocarbons, polychlorinated biphenyls, polycyclic aromatic hydrocarbons and scheduled chemicals are assessed using SCC1 and SCC2.
13. Approximate range of petroleum hydrocarbon fractions: petrol C6-C9, kerosene C10-C18, diesel C12-C18, and lubricating oils above C18. Laboratory results are reported as four different fractions: C6-C9, C10-C14, C15-C28 and C29-C36. The results of total petroleum hydrocarbons (C10-C36) analyses are reported as a sum of the relevant three fractions. Please note that hydrocarbons are defined as molecules that only contain carbon and hydrogen atoms. Prior to TPH (C10-C36) analysis, cleanup may be necessary to remove non-petroleum hydrocarbon compounds. Where the presence of other materials that will interfere with the analysis may be present, such as oils and fats from food sources, you are advised to treat the extract that has been solvent exchanged to hexane with silica gel as described in USEPA Method 1664A (USEPA 1999).
14. Proposed level for phenol and toluene in Hazardous Waste Management System: Identification and Listing of Hazardous Waste – Toxicity Characteristics Revisions, Final Rule (USEPA 1990)
15. Plasticiser compounds means the total of di-2-ethyl hexyl phthalate (CAS Registry Number 117-81-7) and di-2-ethyl hexyl adipate (CAS Registry Number 103-23-1) contained within a waste.
16. The following polycyclic aromatic hydrocarbons (CAS number) are assessed as the total concentration of 16 USEPA Priority Pollutant PAHs, as follows: Polycyclic aromatic hydrocarbons (total) (PAH name, CAS Registry Number) Acenaphthene 83-32-9 Chrysene 218-01-9 Acenaphthylene 208-96-8 Dibenzo(a,h)anthracene 53-70-3 Anthracene 120-12-7 Fluoranthene 206-44-0 Benzo(a)anthracene 56-55-3 Fluorene 86-73-7 Benzo(a)pyrene 50-32-8 Indeno(1,2,3-cd)pyrene 193-39-5 Benzo(b)fluoranthene 205-99-2 Naphthalene 91-20-3 Benzo(ghi)perylene 191-24-2 Phenanthrene 85-01-8 Benzo(k)fluoranthene 207-08-9 Pyrene 129-00-0
17. The following Scheduled Chemicals (CAS Registry Number) are to be included in the total values specified: Aldrin (309-00-2), Alpha-BHC (319-84-6), Beta-BHC (319-85-7), Gamma-BHC (Lindane) (58-89-9), Delta-BHC (319-86-8), Chlordane (57-74-9), DDD (72-54-8), DDE (72-55-9), DDT (50-29-3), Dieldrin (60-57-1), Endrin (72-20-8), Endrin aldehyde (7421-93-4), Heptachlor (76-44-8), Heptachlor



epoxide (1024-57-3), Hexachlorobenzene (118-74-1), Hexachlorophene (70-30-4), Isodrin (465-73-6), Pentachlorobenzene (608-93-5), Pentachloronitrobenzene (82-68-8), Pentachlorophenol (87-86-5), 1,2,4,5-Tetrachlorobenzene (95-94-3), 2,3,4,6 Tetrachlorophenol (58-90-2), 1,2,4-Trichlorobenzene (120-82-1), 2,4,5-Trichlorophenoxyacetic acid, salts and esters (93-76-5).

18. Calculated from Guidelines for Drinking Water Quality (WHO 1993)

19. Initial pH of the sample determined using 5 g of the waste material and 96.5 mL of deionised water.

NR Parameter not reported by analytical laboratory.

INS Insufficient sample available to report parameter.



Attachment B

Analytical Laboratory Reports

CERTIFICATE OF ANALYSIS

Work Order : EB1514565 Client : EARTH SYSTEMS PTY LTD Contact : MR ROBERT PICCININ Address : 14 Church St Hawthorn VIC, AUSTRALIA 3122 E-mail : robert.piccinin@earthsystems.com.au Telephone : +61 03 9810 7500 Facsimile : +61 03 9853 5030 Project : ILUKA1405 Order number : ---- C-O-C number : ---- Sampler : ROBERT PICCININ Site : ---- Quote number : ----	Page : 1 of 4 Laboratory : Environmental Division Brisbane Contact : Customer Services EB Address : 2 Byth Street Stafford QLD Australia 4053 E-mail : ALSEnviro.Brisbane@alsglobal.com Telephone : +61-7-3243 7222 Facsimile : +61-7-3243 7218 QC Level : NEPM 2013 Schedule B(3) and ALS QCS3 requirement Date Samples Received : 12-Mar-2015 09:00 Date Analysis Commenced : 16-Mar-2015 Issue Date : 18-Mar-2015 09:29 No. of samples received : 7 No. of samples analysed : 7
---	--

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results



NATA Accredited Laboratory 825

Accredited for compliance with
ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
Kim McCabe	Senior Inorganic Chemist	Brisbane Acid Sulphate Soils



General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
^ = This result is computed from individual analyte detections at or above the level of reporting
∅ = ALS is not NATA accredited for these tests.

- ASS: EA013 (ANC) Fizz Rating: 0- None; 1- Slight; 2- Moderate; 3- Strong; 4- Very Strong; 5- Lime.



Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)				Client sample ID				
Client sampling date / time				PDC Ilmenite	Combined Monazite Reject	Hyti	Combine Zircon Wet Tails	Rutile Wet Circuit Concentrate
30-Dec-2014 00:00				30-Dec-2014 00:00	30-Dec-2014 14:00	30-Dec-2014 14:00	30-Dec-2014 14:00	30-Dec-2014 14:00
Compound	CAS Number	LOR	Unit	EB1514565-001	EB1514565-002	EB1514565-003	EB1514565-004	EB1514565-005
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
^ Net Acid Production Potential	----	0.5	kg H2SO4/t	31.5	4.3	284	11.0	661
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	<0.5	<0.5	<0.5	<0.5	<0.5
^ ANC as CaCO3	----	0.1	% CaCO3	<0.1	<0.1	<0.1	<0.1	<0.1
Fizz Rating	----	0	Fizz Unit	0	0	0	0	0
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	0.781	0.058	7.26	0.206	16.7
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	1.03	0.14	9.27	0.36	21.6



Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)		Client sample ID		Float tails	PDC Conductors o/size +410µm	----	----	----
Client sampling date / time		30-Dec-2014 14:00		30-Dec-2014 14:00	----	----	----	----
Compound	CAS Number	LOR	Unit	EB1514565-006	EB1514565-007	-----	-----	-----
				Result	Result	Result	Result	Result
EA009: Nett Acid Production Potential								
^ Net Acid Production Potential	----	0.5	kg H2SO4/t	618	428	----	----	----
EA013: Acid Neutralising Capacity								
ANC as H2SO4	----	0.5	kg H2SO4 equiv./t	<0.5	<0.5	----	----	----
^ ANC as CaCO3	----	0.1	% CaCO3	<0.1	<0.1	----	----	----
Fizz Rating	----	0	Fizz Unit	0	0	----	----	----
EA026 : Chromium Reducible Sulfur								
Chromium Reducible Sulphur	----	0.005	%	15.4	11.2	----	----	----
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	20.2	14.0	----	----	----

CERTIFICATE OF ANALYSIS

Work Order	: EM1413773	Page	: 1 of 15
Amendment	: 1		
Client	: EARTH SYSTEMS PTY LTD	Laboratory	: Environmental Division Melbourne
Contact	: MR NIC BOURGEOT	Contact	: Client Services
Address	: SUITE 17 79-83 HIGH STREET KEW VIC, AUSTRALIA 3101	Address	: 4 Westall Rd Springvale VIC Australia 3171
E-mail	: nic.bourgeot@earthsystems.com.au	E-mail	: Melbourne.Enviro.Services@alsglobal.com
Telephone	: +61 03 9810 7500	Telephone	: +61-3-8549 9600
Facsimile	: +61 03 9853 5030	Facsimile	: +61-3-8549 9601
Project	: ILUKA1485	QC Level	: NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Order number	: ----		
C-O-C number	: ----	Date Samples Received	: 24-DEC-2014
Sampler	: NB	Issue Date	: 10-FEB-2015
Site	: ----		
Quote number	: MEBQ/112/14	No. of samples received	: 1
		No. of samples analysed	: 1

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results
- Surrogate Control Limits



General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.

LOR = Limit of reporting

^ = This result is computed from individual analyte detections at or above the level of reporting

- **ASS: EA033 (CRS Suite): ANC not required because pH KCl less than 6.5**
- **ASS: EA033 (CRS Suite): Liming rate is calculated and reported on a dry weight basis assuming use of fine agricultural lime (CaCO₃) and using a safety factor of 1.5 to allow for non-homogeneous mixing and poor reactivity of lime. For conversion of Liming Rate from 'kg/t dry weight' to 'kg/m³ in-situ soil', multiply 'reported results' x 'wet bulk density of soil in t/m³'.**
- **Benzo(a)pyrene Toxicity Equivalent Quotient (TEQ) is the sum total of the concentration of the eight carcinogenic PAHs multiplied by their Toxicity Equivalence Factor (TEF) relative to Benzo(a)pyrene. TEF values are provided in brackets as follows: Benz(a)anthracene (0.1), Chrysene (0.01), Benzo(b+j) & Benzo(k)fluoranthene (0.1), Benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), Dibenz(a,h)anthracene (1.0), Benzo(g,h,i)perylene (0.01). Less than LOR results for 'TEQ Zero' are treated as zero, for 'TEQ 1/2LOR' are treated as half the reported LOR, and for 'TEQ LOR' are treated as being equal to the reported LOR. Note: TEQ 1/2LOR and TEQ LOR will calculate as 0.6mg/Kg and 1.2mg/Kg respectively for samples with non-detects for all of the eight TEQ PAHs.**
- **Benzo(a)pyrene Toxicity Equivalent Quotient (TEQ) is the sum total of the concentration of the eight carcinogenic PAHs multiplied by their Toxicity Equivalence Factor (TEF) relative to Benzo(a)pyrene. TEF values are provided in brackets as follows: Benz(a)anthracene (0.1), Chrysene (0.01), Benzo(b+j) & Benzo(k)fluoranthene (0.1), Benzo(a)pyrene (1.0), Indeno(1.2.3.cd)pyrene (0.1), Dibenz(a,h)anthracene (1.0), Benzo(g,h,i)perylene (0.01). Less than LOR results for 'TEQ Zero' are treated as zero.**
- **Due to insufficient sample ZHE Leach Prep (EN33Za) and Leachate Volatile Compounds (EP074) was not able to be reported.**
- **EP075: 'Sum of PAH' is the sum of the USEPA 16 priority PAHs**
- **EP202: Particular samples required dilution due to matrix interferences. LOR values have been adjusted accordingly.**
- **EP202: Poor matrix spike recoveries due to matrix effects.**
- **Fluoride (EK040T) conducted by ALS Newcastle, NATA accreditation no. 825, site no 1656.**
- **This report has been amended and re-released to allow the reporting of additional analytical data. 5/2/15**
- **ZHE Leach Prep (EN33Za), Leachate Volatile Compounds (EP074), Semi-Volatiles Compounds (EP075k/76), Hexachlorophene (EP132), Thiodicarb (EP201), Glyphosate (EP204), Herbicides (EP202), PCB (EP066), Triazines (EP068) and Tebuconazole (EP234) conducted by ALS Sydney, NATA accreditation no. 825, site no 10911.**



NATA Accredited Laboratory 825

Accredited for compliance with
ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
Dilani Fernando	Senior Inorganic Chemist	Melbourne Inorganics
Gaston Allende	R&D Chemist	Sydney Organics
Kim McCabe	Senior Inorganic Chemist	Brisbane Inorganics
Phalak Inthakesone	Laboratory Manager - Organics	Sydney Organics
Ryan Story	2IC Organic Instrument Chemist	Brisbane Organics
Satishkumar Trivedi	2 IC Acid Sulfate Soils Supervisor	Brisbane Acid Sulphate Soils



Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
EA033-A: Actual Acidity								
pH KCl (23A)	----	0.1	pH Unit	3.4	----	----	----	----
Titrateable Actual Acidity (23F)	----	2	mole H+ / t	73	----	----	----	----
sulfidic - Titrateable Actual Acidity (s-23F)	----	0.02	% pyrite S	0.12	----	----	----	----
EA033-B: Potential Acidity								
Chromium Reducible Sulfur (22B)	----	0.005	% S	15.7	----	----	----	----
acidity - Chromium Reducible Sulfur (a-22B)	----	10	mole H+ / t	9800	----	----	----	----
EA033-D: Retained Acidity								
KCl Extractable Sulfur (23Ce)	----	0.02	% S	0.48	----	----	----	----
HCl Extractable Sulfur (20Be)	----	0.02	% S	0.75	----	----	----	----
Net Acid Soluble Sulfur (20Je)	----	0.02	% S	0.28	----	----	----	----
acidity - Net Acid Soluble Sulfur (a-20J)	----	10	mole H+ / t	129	----	----	----	----
sulfidic - Net Acid Soluble Sulfur (s-20J)	----	0.02	% pyrite S	0.21	----	----	----	----
EA033-E: Acid Base Accounting								
ANC Fineness Factor	----	0.5	-	1.5	----	----	----	----
Net Acidity (sulfur units)	----	0.02	% S	16.0	----	----	----	----
Net Acidity (acidity units)	----	10	mole H+ / t	10000	----	----	----	----
Liming Rate	----	1	kg CaCO3/t	750	----	----	----	----
EA055: Moisture Content								
Moisture Content (dried @ 103°C)	----	1.0	%	<1.0	----	----	----	----
ED042T: Total Sulfur by LECO								
Sulfur - Total as S (LECO)	----	0.01	%	18.2	----	----	----	----
EG005T: Total Metals by ICP-AES								
Antimony	7440-36-0	5	mg/kg	<5	----	----	----	----
Arsenic	7440-38-2	5	mg/kg	357	----	----	----	----
Barium	7440-39-3	10	mg/kg	20	----	----	----	----
Beryllium	7440-41-7	1	mg/kg	<1	----	----	----	----
Boron	7440-42-8	50	mg/kg	<50	----	----	----	----
Cadmium	7440-43-9	1	mg/kg	<1	----	----	----	----
Copper	7440-50-8	5	mg/kg	37	----	----	----	----
Lead	7439-92-1	5	mg/kg	288	----	----	----	----
Molybdenum	7439-98-7	2	mg/kg	4	----	----	----	----
Nickel	7440-02-0	2	mg/kg	50	----	----	----	----
Selenium	7782-49-2	5	mg/kg	<5	----	----	----	----



Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
----------	------------	-----	------	---------------	-----	-----	-----	-----

EG005T: Total Metals by ICP-AES - Continued

Silver	7440-22-4	2	mg/kg	<2	---	---	---	---
Zinc	7440-66-6	5	mg/kg	62	---	---	---	---

EG035T: Total Recoverable Mercury by FIMS

Mercury	7439-97-6	0.1	mg/kg	<0.1	---	---	---	---
---------	-----------	-----	-------	------	-----	-----	-----	-----

EG048: Hexavalent Chromium (Alkaline Digest)

Hexavalent Chromium	18540-29-9	0.5	mg/kg	<0.5	---	---	---	---
---------------------	------------	-----	-------	------	-----	-----	-----	-----

EK026SF: Total CN by Segmented Flow Analyser

Total Cyanide	57-12-5	1	mg/kg	<1	---	---	---	---
---------------	---------	---	-------	----	-----	-----	-----	-----

EK028SF: Weak Acid Dissociable CN by Segmented Flow Analyser

Weak Acid Dissociable Cyanide	---	1	mg/kg	<1	---	---	---	---
-------------------------------	-----	---	-------	----	-----	-----	-----	-----

EK040T: Fluoride Total

Fluoride	16984-48-8	40	mg/kg	<40	---	---	---	---
----------	------------	----	-------	-----	-----	-----	-----	-----

EN33: TCLP Leach

Initial pH	---	0.1	pH Unit	3.6	---	---	---	---
Extraction Fluid Number	---	1	-	1	---	---	---	---
Final pH	---	0.1	pH Unit	4.9	---	---	---	---

EP066: Polychlorinated Biphenyls (PCB)

Total Polychlorinated biphenyls	---	0.1	mg/kg	<0.1	---	---	---	---
---------------------------------	-----	-----	-------	------	-----	-----	-----	-----

EP068C: Triazines

Atrazine	1912-24-9	0.05	mg/kg	<0.05	---	---	---	---
Simazine	122-34-9	0.05	mg/kg	<0.05	---	---	---	---

EP071 SG: Total Recoverable Hydrocarbons - NEPM 2013 Fractions - Silica gel cleanup

>C10 - C16 Fraction	>C10_C16	50	mg/kg	<50	---	---	---	---
>C16 - C34 Fraction	---	100	mg/kg	<100	---	---	---	---
>C34 - C40 Fraction	---	100	mg/kg	<100	---	---	---	---
^ >C10 - C40 Fraction (sum)	---	50	mg/kg	<50	---	---	---	---

EP071 SG-S: Total Petroleum Hydrocarbons in Soil - Silica gel cleanup

C10 - C14 Fraction	---	50	mg/kg	<50	---	---	---	---
C15 - C28 Fraction	---	100	mg/kg	<100	---	---	---	---
C29 - C36 Fraction	---	100	mg/kg	<100	---	---	---	---
^ C10 - C36 Fraction (sum)	---	50	mg/kg	<50	---	---	---	---

EP074A: Monocyclic Aromatic Hydrocarbons

Benzene	71-43-2	0.2	mg/kg	<0.2	---	---	---	---
---------	---------	-----	-------	------	-----	-----	-----	-----



Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
EP074A: Monocyclic Aromatic Hydrocarbons - Continued								
Toluene	108-88-3	0.5	mg/kg	<0.5	---	---	---	---
Ethylbenzene	100-41-4	0.5	mg/kg	<0.5	---	---	---	---
meta- & para-Xylene	108-38-3 106-42-3	0.5	mg/kg	<0.5	---	---	---	---
Styrene	100-42-5	0.5	mg/kg	<0.5	---	---	---	---
ortho-Xylene	95-47-6	0.5	mg/kg	<0.5	---	---	---	---
EP074B: Oxygenated Compounds								
2-Butanone (MEK)	78-93-3	5	mg/kg	<5	---	---	---	---
EP074E: Halogenated Aliphatic Compounds								
Vinyl chloride	75-01-4	4	mg/kg	<4	---	---	---	---
1.1-Dichloroethene	75-35-4	0.5	mg/kg	<0.5	---	---	---	---
Methylene chloride	75-09-2	0.5	mg/kg	<0.5	---	---	---	---
1.1.1-Trichloroethane	71-55-6	0.5	mg/kg	<0.5	---	---	---	---
Carbon Tetrachloride	56-23-5	0.5	mg/kg	<0.5	---	---	---	---
1.2-Dichloroethane	107-06-2	0.5	mg/kg	<0.5	---	---	---	---
Trichloroethene	79-01-6	0.5	mg/kg	<0.5	---	---	---	---
1.1.2-Trichloroethane	79-00-5	0.5	mg/kg	<0.5	---	---	---	---
Tetrachloroethene	127-18-4	0.5	mg/kg	<0.5	---	---	---	---
1.1.1.2-Tetrachloroethane	630-20-6	0.5	mg/kg	<0.5	---	---	---	---
1.1.2.2-Tetrachloroethane	79-34-5	0.5	mg/kg	<0.5	---	---	---	---
EP074F: Halogenated Aromatic Compounds								
Chlorobenzene	108-90-7	0.5	mg/kg	<0.5	---	---	---	---
EP074G: Trihalomethanes								
Chloroform	67-66-3	0.5	mg/kg	<0.5	---	---	---	---
EP075K: Miscellaneous Compounds								
Isodrin	465-73-6	0.5	mg/kg	<0.5	---	---	---	---
EP076A: Phenolic Compounds (Chlorinated)								
2-Chlorophenol	95-57-8	0.5	mg/kg	<0.5	---	---	---	---
Phenol	108-95-2	0.5	mg/kg	<0.5	---	---	---	---
2-Methylphenol	95-48-7	0.5	mg/kg	<0.5	---	---	---	---
3- & 4-Methylphenol	1319-77-3	0.5	mg/kg	<0.5	---	---	---	---
2.4-Dichlorophenol	120-83-2	0.5	mg/kg	<0.5	---	---	---	---
4-Chloro-3-methylphenol	59-50-7	0.5	mg/kg	<0.5	---	---	---	---
2.4.5-Trichlorophenol	95-95-4	0.5	mg/kg	<0.5	---	---	---	---



Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
EP076A: Phenolic Compounds (Chlorinated) - Continued								
2,4,6-Trichlorophenol	88-06-2	0.5	mg/kg	<0.5	---	---	---	---
2,3,4,6-Tetrachlorophenol	58-90-2	0.5	mg/kg	<0.5	---	---	---	---
Pentachlorophenol	87-86-5	0.5	mg/kg	<0.5	---	---	---	---
EP076B: Polynuclear Aromatic Hydrocarbons								
Naphthalene	91-20-3	0.5	mg/kg	<0.5	---	---	---	---
Acenaphthylene	208-96-8	0.5	mg/kg	<0.5	---	---	---	---
Acenaphthene	83-32-9	0.5	mg/kg	<0.5	---	---	---	---
Fluorene	86-73-7	0.5	mg/kg	<0.5	---	---	---	---
Phenanthrene	85-01-8	0.5	mg/kg	<0.5	---	---	---	---
Anthracene	120-12-7	0.5	mg/kg	<0.5	---	---	---	---
Fluoranthene	206-44-0	0.5	mg/kg	<0.5	---	---	---	---
Pyrene	129-00-0	0.5	mg/kg	<0.5	---	---	---	---
Benzo(a)anthracene	56-55-3	0.5	mg/kg	<0.5	---	---	---	---
Chrysene	218-01-9	0.5	mg/kg	<0.5	---	---	---	---
Benzo(b+j) & Benzo(k)fluoranthene	205-99-2 207-08-9	0.5	mg/kg	<0.5	---	---	---	---
Benzo(a)pyrene	50-32-8	0.50	mg/kg	<0.50	---	---	---	---
Indeno(1.2.3.cd)pyrene	193-39-5	0.5	mg/kg	<0.5	---	---	---	---
Dibenz(a,h)anthracene	53-70-3	0.5	mg/kg	<0.5	---	---	---	---
Benzo(g,h,i)perylene	191-24-2	0.5	mg/kg	<0.5	---	---	---	---
EP076C: Phthalate Esters								
bis(2-ethylhexyl) phthalate	117-81-7	0.5	mg/kg	<0.5	---	---	---	---
EP076E: Nitroaromatics and Ketones								
Nitrobenzene	98-95-3	0.5	mg/kg	<0.5	---	---	---	---
2,4-Dinitrotoluene	121-14-2	0.5	mg/kg	<0.5	---	---	---	---
Pentachloronitrobenzene	82-68-8	0.5	mg/kg	<0.5	---	---	---	---
EP076G: Chlorinated Hydrocarbons								
Hexachlorobutadiene	87-68-3	0.05	mg/kg	<0.05	---	---	---	---
EP076G: Chlorinated Hydrocarbons (Aromatic)								
1,4-Dichlorobenzene	106-46-7	0.5	mg/kg	<0.5	---	---	---	---
1,2-Dichlorobenzene	95-50-1	0.5	mg/kg	<0.5	---	---	---	---
1,3,5-Trichlorobenzene	108-70-3	0.5	mg/kg	<0.5	---	---	---	---
1,2,4-Trichlorobenzene	120-82-1	0.5	mg/kg	<0.5	---	---	---	---
1,2,3-Trichlorobenzene	87-61-6	0.5	mg/kg	<0.5	---	---	---	---



Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
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EP076G: Chlorinated Hydrocarbons (Aromatic) - Continued

1.2.3.4-Tetrachlorobenzene	634-66-2	0.5	mg/kg	<0.5	---	---	---	---
1.2.3.5- & 1.2.4.5-Tetrachlorobenzene	634-90-2/95-94-3	0.5	mg/kg	<0.5	---	---	---	---
Pentachlorobenzene	608-93-5	0.5	mg/kg	<0.5	---	---	---	---

EP076I: Organochlorine Pesticides

Hexachlorobenzene (HCB)	118-74-1	0.05	mg/kg	<0.05	---	---	---	---
alpha-BHC	319-84-6	0.05	mg/kg	<0.05	---	---	---	---
beta-BHC	319-85-7	0.05	mg/kg	<0.05	---	---	---	---
gamma-BHC	58-89-9	0.05	mg/kg	<0.05	---	---	---	---
delta-BHC	319-86-8	0.05	mg/kg	<0.05	---	---	---	---
Heptachlor	76-44-8	0.05	mg/kg	<0.05	---	---	---	---
Aldrin	309-00-2	0.05	mg/kg	<0.05	---	---	---	---
Heptachlor epoxide	1024-57-3	0.05	mg/kg	<0.05	---	---	---	---
alpha-Endosulfan	959-98-8	0.05	mg/kg	<0.05	---	---	---	---
4.4'-DDE	72-55-9	0.05	mg/kg	<0.05	---	---	---	---
trans-Chlordane	5103-74-2	0.05	mg/kg	<0.05	---	---	---	---
Dieldrin	60-57-1	0.05	mg/kg	<0.05	---	---	---	---
Endrin	72-20-8	0.05	mg/kg	<0.05	---	---	---	---
cis-Chlordane	5103-71-9	0.05	mg/kg	<0.05	---	---	---	---
beta-Endosulfan	33213-65-9	0.05	mg/kg	<0.05	---	---	---	---
4.4'-DDD	72-54-8	0.05	mg/kg	<0.05	---	---	---	---
Endosulfan sulfate	1031-07-8	0.05	mg/kg	<0.05	---	---	---	---
4.4'-DDT	50-29-3	0.2	mg/kg	<0.2	---	---	---	---
Endrin aldehyde	7421-93-4	0.05	mg/kg	<0.05	---	---	---	---

EP076J: Organophosphorus Pesticides

Dichlorvos	62-73-7	0.05	mg/kg	<0.05	---	---	---	---
Dimethoate	60-51-5	0.05	mg/kg	<0.05	---	---	---	---
Chlorpyrifos-methyl	5598-13-0	0.05	mg/kg	<0.05	---	---	---	---
Malathion	121-75-5	0.05	mg/kg	<0.05	---	---	---	---
Fenthion	55-38-9	0.05	mg/kg	<0.05	---	---	---	---
Parathion-methyl	298-00-0	0.2	mg/kg	<0.2	---	---	---	---
Chlorpyrifos	2921-88-2	0.05	mg/kg	<0.05	---	---	---	---
Ethion	563-12-2	0.05	mg/kg	<0.05	---	---	---	---



Analytical Results

Sub-Matrix: **SOIL** (Matrix: **SOIL**)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
EP080/071: Total Petroleum Hydrocarbons								
C6 - C9 Fraction	---	10	mg/kg	<10	---	---	---	---
EP080/071: Total Recoverable Hydrocarbons - NEPM 2013 Fractions								
C6 - C10 Fraction	C6_C10	10	mg/kg	<10	---	---	---	---
EP132A: Phenolic Compounds								
Hexachlorophene	70-30-4	10	µg/kg	<10	---	---	---	---
EP201: Carbamate Pesticides by LCMS								
Thiodicarb	59669-26-0	0.02	mg/kg	<0.02	---	---	---	---
EP202A: Phenoxyacetic Acid Herbicides by LCMS								
2.4-D	94-75-7	0.02	mg/kg	<0.04	---	---	---	---
Triclopyr	55335-06-3	0.02	mg/kg	<0.04	---	---	---	---
2.4.5-TP (Silvex)	93-72-1	0.02	mg/kg	<0.04	---	---	---	---
2.4.5-T	93-76-5	0.02	mg/kg	<0.04	---	---	---	---
Picloram	1918-02-1	0.02	mg/kg	<0.04	---	---	---	---
Fluroxypyr	69377-81-7	0.02	mg/kg	<0.04	---	---	---	---
EP204: Glyphosate and AMPA								
Glyphosate	1071-83-6	0.5	mg/kg	<0.5	---	---	---	---
EP066S: PCB Surrogate								
Decachlorobiphenyl	2051-24-3	0.1	%	108	---	---	---	---
EP068S: Organochlorine Pesticide Surrogate								
Dibromo-DDE	21655-73-2	0.1	%	72.8	---	---	---	---
EP068T: Organophosphorus Pesticide Surrogate								
DEF	78-48-8	0.1	%	71.2	---	---	---	---
EP074S: VOC Surrogates								
1.2-Dichloroethane-D4	17060-07-0	0.1	%	83.4	---	---	---	---
Toluene-D8	2037-26-5	0.1	%	86.7	---	---	---	---
4-Bromofluorobenzene	460-00-4	0.1	%	86.7	---	---	---	---
EP076S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	0.1	%	114	---	---	---	---
Phenol-d6	13127-88-3	0.1	%	90.6	---	---	---	---
2-Chlorophenol-D4	93951-73-6	0.1	%	94.6	---	---	---	---
2.4.6-Tribromophenol	118-79-6	0.1	%	106	---	---	---	---
EP076T: Base-Neutral Surrogate Compounds								
Nitrobenzene-D5	4165-60-0	0.1	%	108	---	---	---	---



Analytical Results

Sub-Matrix: SOIL (Matrix: SOIL)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

23-DEC-2014 15:00

Compound	CAS Number	LOR	Unit	EM1413773-001	----	----	----	----
EP076T: Base-Neutral Surrogate Compounds - Continued								
1,2-Dichlorobenzene-D4	2199-69-1	0.1	%	95.9	----	----	----	----
2-Fluorobiphenyl	321-60-8	0.1	%	104	----	----	----	----
Anthracene-d10	1719-06-8	0.1	%	109	----	----	----	----
4-Terphenyl-d14	1718-51-0	0.1	%	130	----	----	----	----
EP080S: TPH(V)/BTEX Surrogates								
1,2-Dichloroethane-D4	17060-07-0	0.1	%	90.0	----	----	----	----
Toluene-D8	2037-26-5	0.1	%	88.4	----	----	----	----
4-Bromofluorobenzene	460-00-4	0.1	%	82.1	----	----	----	----
EP132S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	0.1	%	91.8	----	----	----	----
Phenol-d6	13127-88-3	0.1	%	97.1	----	----	----	----
2-Chlorophenol-D4	93951-73-6	0.1	%	89.9	----	----	----	----
2,4,6-Tribromophenol	118-79-6	0.1	%	110	----	----	----	----
EP132T: Base/Neutral Extractable Surrogates								
2-Fluorobiphenyl	321-60-8	0.1	%	102	----	----	----	----
Anthracene-d10	1719-06-8	0.1	%	75.0	----	----	----	----
4-Terphenyl-d14	1718-51-0	0.1	%	91.9	----	----	----	----
EP201S: Carbamate Surrogate								
4-Bromo-3,5-dimethylphenyl-N-methylcarbamate	672-99-1	0.1	%	103	----	----	----	----
EP202S: Phenoxyacetic Acid Herbicide Surrogate								
2,4-Dichlorophenyl Acetic Acid	19719-28-9	0.1	%	121	----	----	----	----



Analytical Results

Sub-Matrix: TCLP LEACHATE (Matrix: WATER)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

06-JAN-2015 12:00

Compound	CAS Number	LOR	Unit	EM1413773-001	---	---	---	---
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EG005C: Leachable Metals by ICPAES

Aluminium	7429-90-5	0.1	mg/L	0.1	---	---	---	---
Antimony	7440-36-0	0.01	mg/L	<0.01	---	---	---	---
Arsenic	7440-38-2	0.1	mg/L	<0.1	---	---	---	---
Barium	7440-39-3	0.1	mg/L	0.4	---	---	---	---
Beryllium	7440-41-7	0.05	mg/L	<0.05	---	---	---	---
Boron	7440-42-8	0.1	mg/L	0.2	---	---	---	---
Cadmium	7440-43-9	0.05	mg/L	<0.05	---	---	---	---
Chromium	7440-47-3	0.01	mg/L	0.01	---	---	---	---
Cobalt	7440-48-4	0.01	mg/L	0.2	---	---	---	---
Copper	7440-50-8	0.01	mg/L	0.02	---	---	---	---
Iron	7439-89-6	0.01	mg/L	0.6	---	---	---	---
Lead	7439-92-1	0.1	mg/L	<0.1	---	---	---	---
Manganese	7439-96-5	0.01	mg/L	0.3	---	---	---	---
Nickel	7440-02-0	0.1	mg/L	0.3	---	---	---	---
Selenium	7782-49-2	0.05	mg/L	<0.05	---	---	---	---
Silver	7440-22-4	0.1	mg/L	<0.1	---	---	---	---
Strontium	7440-24-6	0.1	mg/L	0.2	---	---	---	---
Tin	7440-31-5	0.01	mg/L	<0.01	---	---	---	---
Titanium	7440-32-6	0.01	mg/L	0.02	---	---	---	---
Vanadium	7440-62-2	0.01	mg/L	<0.01	---	---	---	---
Zinc	7440-66-6	0.1	mg/L	0.8	---	---	---	---
Molybdenum	7439-98-7	0.1	mg/L	<0.1	---	---	---	---

EG035C: Leachable Mercury by FIMS

Mercury	7439-97-6	0.0010	mg/L	<0.0010	---	---	---	---
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EG050G: Hexavalent Chromium by Discrete Analyser

Hexavalent Chromium	18540-29-9	0.01	mg/L	<0.01	---	---	---	---
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EK040P: Fluoride by PC Titrator

Fluoride	16984-48-8	0.1	mg/L	0.1	---	---	---	---
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EP068A: Organochlorine Pesticides (OC)

alpha-Endosulfan	959-98-8	0.5	µg/L	<0.5	---	---	---	---
beta-Endosulfan	33213-65-9	0.5	µg/L	<0.5	---	---	---	---
Endosulfan sulfate	1031-07-8	0.5	µg/L	<0.5	---	---	---	---

EP068B: Organophosphorus Pesticides (OP)



Analytical Results

Sub-Matrix: TCLP LEACHATE (Matrix: WATER)

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

06-JAN-2015 12:00

Compound	CAS Number	LOR	Unit	EM1413773-001	----	----	----	----
EP068B: Organophosphorus Pesticides (OP) - Continued								
Chlorpyrifos	2921-88-2	0.5	µg/L	<0.5	----	----	----	----
EP075A: Phenolic Compounds								
Phenol	108-95-2	2	µg/L	<2	----	----	----	----
2-Chlorophenol	95-57-8	2	µg/L	<2	----	----	----	----
2-Methylphenol	95-48-7	2	µg/L	<2	----	----	----	----
3- & 4-Methylphenol	1319-77-3	2	µg/L	<2	----	----	----	----
2,4-Dichlorophenol	120-83-2	2	µg/L	<2	----	----	----	----
2,4,6-Trichlorophenol	88-06-2	2	µg/L	<2	----	----	----	----
2,4,5-Trichlorophenol	95-95-4	2	µg/L	<2	----	----	----	----
EP075B: Polynuclear Aromatic Hydrocarbons								
Benzo(a)pyrene	50-32-8	2	µg/L	<2	----	----	----	----
EP075C: Phthalate Esters								
bis(2-ethylhexyl) phthalate	117-81-7	5	µg/L	<5	----	----	----	----
EP075E: Nitroaromatics and Ketones								
Nitrobenzene	98-95-3	2	µg/L	<2	----	----	----	----
2,4-Dinitrotoluene	121-14-2	4	µg/L	<4	----	----	----	----
EP075G: Chlorinated Hydrocarbons								
1,4-Dichlorobenzene	106-46-7	2	µg/L	<2	----	----	----	----
1,2-Dichlorobenzene	95-50-1	2	µg/L	<2	----	----	----	----
Hexachlorobutadiene	87-68-3	2	µg/L	<2	----	----	----	----
EP202A: Phenoxyacetic Acid Herbicides by LCMS								
2,4-D	94-75-7	10	µg/L	<10	----	----	----	----
Triclopyr	55335-06-3	10	µg/L	<10	----	----	----	----
Picloram	1918-02-1	10	µg/L	<10	----	----	----	----
Fluroxypyr	69377-81-7	10	µg/L	<10	----	----	----	----
EP234E: Conazole and Aminopyrimidine Fungicides								
Tebuconazole	107534-96-3	0.01	µg/L	<0.01	----	----	----	----
EP068S: Organochlorine Pesticide Surrogate								
Dibromo-DDE	21655-73-2	0.1	%	117	----	----	----	----
EP068T: Organophosphorus Pesticide Surrogate								
DEF	78-48-8	0.1	%	134	----	----	----	----
EP075S: Acid Extractable Surrogates								
2-Fluorophenol	367-12-4	0.1	%	104	----	----	----	----



Analytical Results

Sub-Matrix: **TCLP LEACHATE (Matrix: WATER)**

Client sample ID

3785 Flot Conc RSV's

Client sampling date / time

06-JAN-2015 12:00

Compound	CAS Number	LOR	Unit	EM1413773-001	----	----	----	----
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EP075S: Acid Extractable Surrogates - Continued

Phenol-d6	13127-88-3	0.1	%	32.8	----	----	----	----
2-Chlorophenol-D4	93951-73-6	0.1	%	85.6	----	----	----	----
2,4,6-Tribromophenol	118-79-6	0.1	%	104	----	----	----	----

EP075T: Base/Neutral Extractable Surrogates

Nitrobenzene-D5	4165-60-0	0.1	%	87.5	----	----	----	----
1,2-Dichlorobenzene-D4	2199-69-1	0.1	%	90.4	----	----	----	----
2-Fluorobiphenyl	321-60-8	0.1	%	111	----	----	----	----
Anthracene-d10	1719-06-8	0.1	%	123	----	----	----	----
4-Terphenyl-d14	1718-51-0	0.1	%	134	----	----	----	----

EP202S: Phenoxyacetic Acid Herbicide Surrogate

2,4-Dichlorophenyl Acetic Acid	19719-28-9	0.1	%	93.0	----	----	----	----
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Surrogate Control Limits

Sub-Matrix: SOIL		Recovery Limits (%)	
Compound	CAS Number	Low	High
EP066S: PCB Surrogate			
Decachlorobiphenyl	2051-24-3	39	149
EP068S: Organochlorine Pesticide Surrogate			
Dibromo-DDE	21655-73-2	49	147
EP068T: Organophosphorus Pesticide Surrogate			
DEF	78-48-8	35	143
EP074S: VOC Surrogates			
1,2-Dichloroethane-D4	17060-07-0	64	130
Toluene-D8	2037-26-5	66	136
4-Bromofluorobenzene	460-00-4	60	122
EP076S: Acid Extractable Surrogates			
2-Fluorophenol	367-12-4	25	121
Phenol-d6	13127-88-3	24	113
2-Chlorophenol-D4	93951-73-6	23	134
2,4,6-Tribromophenol	118-79-6	19	122
EP076T: Base-Neutral Surrogate Compounds			
Nitrobenzene-D5	4165-60-0	23	120
1,2-Dichlorobenzene-D4	2199-69-1	32	129
2-Fluorobiphenyl	321-60-8	30	115
Anthracene-d10	1719-06-8	27	133
4-Terphenyl-d14	1718-51-0	18	137
EP080S: TPH(V)/BTEX Surrogates			
1,2-Dichloroethane-D4	17060-07-0	72.8	133.2
Toluene-D8	2037-26-5	73.9	132.1
4-Bromofluorobenzene	460-00-4	71.6	130.0
EP132S: Acid Extractable Surrogates			
2-Fluorophenol	367-12-4	25	121
Phenol-d6	13127-88-3	24.6	121
2-Chlorophenol-D4	93951-73-6	21.3	137
2,4,6-Tribromophenol	118-79-6	19	122
EP132T: Base/Neutral Extractable Surrogates			
2-Fluorobiphenyl	321-60-8	26.9	131
Anthracene-d10	1719-06-8	35	139
4-Terphenyl-d14	1718-51-0	29.7	164
EP201S: Carbamate Surrogate			
4-Bromo-3,5-dimethylphenyl-N-methylcarbamate	672-99-1	59	137
EP202S: Phenoxyacetic Acid Herbicide Surrogate			
2,4-Dichlorophenyl Acetic Acid	19719-28-9	45	139



Sub-Matrix: TCLP LEACHATE		Recovery Limits (%)	
Compound	CAS Number	Low	High
EP068S: Organochlorine Pesticide Surrogate			
Dibromo-DDE	21655-73-2	40.4	134.4
EP068T: Organophosphorus Pesticide Surrogate			
DEF	78-48-8	41.8	143.3
EP075S: Acid Extractable Surrogates			
2-Fluorophenol	367-12-4	10.0	126.5
Phenol-d6	13127-88-3	10.0	128.8
2-Chlorophenol-D4	93951-73-6	20.3	138.1
2,4,6-Tribromophenol	118-79-6	13.7	162.7
EP075T: Base/Neutral Extractable Surrogates			
Nitrobenzene-D5	4165-60-0	34.0	139.3
1,2-Dichlorobenzene-D4	2199-69-1	10.0	128.7
2-Fluorobiphenyl	321-60-8	18.7	145.1
Anthracene-d10	1719-06-8	32.7	160.2
4-Terphenyl-d14	1718-51-0	31.5	177.3
EP202S: Phenoxyacetic Acid Herbicide Surrogate			
2,4-Dichlorophenyl Acetic Acid	19719-28-9	64	140

MEMORANDUM

TO: Rob Piccinin and David Dettrick, Earth Systems **DATE:** 4 February 2015
FROM: Sue Brown, ANSTO Minerals **No. of Pages:** 12 inclusive
SUBJECT: Waste Classification of Mining By-Products

Earth Systems requested¹ ANSTO Minerals (AM) to undertake radioactivity analysis of mining by-products (MBP's). Seven (7) samples were received on 5 January 2015. The sample identifications, together with corresponding AM numbers, are given in **Table 1**.

Table 1
Sample Identification

Client ID	AM ID
PDC Ilmenite	ES-050115-1
Combined Monazite Reject	ES-050115-2
Hyti	ES-050115-3
Combined Zircon Wet Tails	ES-050115-4
Rutile Wet Circuit Concentrate	ES-050115-5
Float tails sample	ES-050115-6
PDC Conductors O/size +410 µm	ES-050115-7

The samples were dried to constant weight and then pulverised for assay. The following techniques were used in the analysis, depending upon the elemental content:

- Gamma spectrometry for U-238 and Th-232 decay progeny and U-235 and its decay progeny
- Delayed neutron activation (DNA) analysis or fusion/acid digest followed by ICPMS for parent U-238
- Neutron activation analysis (NAA) analysis or fusion/acid digest followed by ICPMS for parent Th-232
- Alpha spectrometry for Po-210
- X-Ray Fluorescence Spectrometry (XRF) analysis for elemental content. This data was used for self-absorption corrections in gamma spectrometry.

¹ Email dated 18 December 2014 from D. Dettrick to S. Brown.

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The radionuclide results are given in **Table 2**. The Po-210 concentrations were low in comparison to other radionuclides in the U-238 decay chain for all samples, although the concentration of 0.34 Bq/g for the Hiti sample is within the analytical error. Polonium-210 is determined by alpha spectrometry, which is a very sensitive technique, however, because of its volatile nature, high temperature dissolution processes (e.g. fusion) cannot be used. Fusion/acid digestion procedures are preferred for dissolution of samples containing Ti and Zr and so, the low Po-210 results indicate that the samples did not completely dissolve in the standard acid digestion procedure used for Po-210 analysis. Since Po-210 will reach equilibrium with its parent, Pb-210, in ~2 years, in the geological timeframe, there is no reason to assume that Po-210 is not in secular equilibrium with its parent, Pb-210.

Table 2
Radionuclide Results (Bq/g)

Client ID	PDC Ilmenite	Combined Monazite Reject	Hyti	Combined Zircon Wet Tails	Rutile Wet Circuit Concentrate	Float Tails Sample	PDC Conductors O/size +410 µm
ANSTO ID	ES-050115-1	ES-050115-2	ES-050115-3	ES-050115-4	ES-050115-5	ES-050115-6	ES-050115-7
<i>Th-232 Decay Chain</i>							
Th-232	0.22 ± 0.02	77 ± 8	1.3 ± 0.2	0.56 ± 0.06	1.0 ± 0.1	0.30 ± 0.03	0.89 ± 0.09
Ra-228	0.22 ± 0.02	68 ± 7	1.2 ± 0.1	0.30 ± 0.03	0.91 ± 0.09	0.27 ± 0.03	0.86 ± 0.09
Th-228	0.19 ± 0.02	75 ± 8	1.3 ± 0.1	0.30 ± 0.03	0.90 ± 0.09	0.27 ± 0.03	0.86 ± 0.09
<i>U-238 Decay Chain</i>							
U-238	0.11 ± 0.05	14 ± 1	0.42 ± 0.01	1.01 ± 0.02	0.58 ± 0.02	0.48 ± 0.02	0.81 ± 0.03
Th-230	0.12 ± 0.02	17 ± 4	0.5 ± 0.1	0.78 ± 0.08	0.51 ± 0.08	< 0.30	0.9 ± 0.2
Ra-226	0.12 ± 0.01	13 ± 1	0.47 ± 0.05	0.83 ± 0.08	0.58 ± 0.06	0.39 ± 0.04	0.82 ± 0.08
Pb-210	0.14 ± 0.02	13 ± 1	0.42 ± 0.04	0.72 ± 0.07	0.47 ± 0.05	0.33 ± 0.03	0.68 ± 0.07
Po-210	0.03 ± 0.02	8.0 ± 0.7	0.34 ± 0.08	0.30 ± 0.06	0.16 ± 0.04	0.25 ± 0.07	0.31 ± 0.07
<i>U-235 Decay Chain</i>							
U-235	0.0051 ± 0.0023	0.65 ± 0.05	0.0194 ± 0.0005	0.0466 ± 0.0009	0.0268 ± 0.0009	0.0222 ± 0.0009	0.037 ± 0.0014
Pa-231	< 0.026	0.8 ± 0.2	< 0.069	< 0.039	< 0.043	< 0.064	< 0.13
Ac-227	< 0.0053	1.0 ± 0.1	0.028 ± 0.005	0.046 ± 0.005	0.030 ± 0.003	0.019 ± 0.003	0.047 ± 0.008
Th-227	< 0.0053	1.0 ± 0.1	0.028 ± 0.005	0.045 ± 0.005	0.030 ± 0.003	0.019 ± 0.003	0.047 ± 0.008
K-40	0.026 ± 0.007	< 0.32	0.10 ± 0.02	< 0.024	0.07 ± 0.01	< 0.044	0.30 ± 0.05

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The radionuclide results were then used to assess the MBP's in accordance with the requirements of the NSW EPA Waste Classification Guidelines, Part 3: Waste containing radioactive material (radioactive waste), based on AM understanding and interpretation of said Guidelines. It is recommended that the client confirm these classifications with the Regulator at the appropriate time.

MBP's classified as hazardous wastes² were identified according to Step 2 of the Guidelines.

MBP's not classified as hazardous wastes were assessed according to Step 3 of the Guidelines – *“For liquid or non-liquid wastes with a specific activity of 100 becquerels per gram or less and/or consisting of, or containing, the prescribed activity or less of a radioactive element in Schedule 1 of the Radiation Control Regulation 2013, whether natural or artificial, the total activity ratio and specific activity ratio must be calculated according to the mathematical expressions below:*

$$\text{Total activity ratio} = (A1 \times 10^{-3}) + (A2 \times 10^{-4}) + (A3 \times 10^{-5}) + (A4 \times 10^{-6})$$

where A1 to A4 are the total activity³ of Group 1 to Group 4 radionuclides, as set out in Column 1 of Schedule 1 of the Radiation Control Regulation 2013; and

$$\text{Specific activity ratio} = SA1 + (SA2 \times 10^{-1}) + (SA3 \times 10^{-2}) + (SA4 \times 10^{-3})$$

where SA1 to SA4 are the specific activity (of the material) of Group 1 to Group 4 radionuclides, as set out in Column 1 of Schedule 1 of the Radiation Control Regulation 2013”.

However, because no information was supplied by the client for the total masses of the respective MBP's to be disposed of, the total activities, and hence total activity ratios, could not be determined. Classification for MBP's with a specific activity < 100 Bq/g was, therefore, made based on the respective specific activity ratios. It should be noted that for one (1) gram of material, the total activities of the Group 1 to 4 radionuclides

² Non-liquid wastes with a specific activity greater than 100 becquerels per gram and consisting of, or containing more than, the prescribed activity of a radioactive element in Schedule 1 of the Radiation Control Regulation 2013, whether natural or artificial.

³ Total activity of a material means the activity of the whole of the material in which the radionuclides are essentially uniformly distributed (determined using 1-kilogram representative samples of the whole material).

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(A1, A2, A3, A4) are the same as the specific activities of the Group 1 to 4 radionuclides (SA1, SA2, SA3, SA4).

It should also be noted that in all calculations, the concentration of Po-210 has been assumed to be the same as that of its parent, Pb-210.

Table 3 summarises the waste classification for each MBP. A detailed assessment for each MBP is given in **Appendix 1**. The combined monazite reject was the only sample that contained a specific activity (of the material) of > 100 Bq/g. The Guidelines (Step 2) state that *“Liquid or non-liquid wastes with a specific activity greater than 100 becquerels per gram and consisting of, or containing more than, the prescribed activity of a radioactive element in Schedule 1 of the Radiation Control Regulation 2013, whether natural or artificial, must be classified as hazardous wastes.”* Since the total activity of the Group 1 radionuclides (\equiv SA1) is 460 Bq/g in this sample, a material weight for disposal in excess of 87 g exceeds the prescribed activity for Group 1 radionuclides in Schedule 1 of the Radiation Control Regulation 2013 (40 kBq). The combined monazite reject was classified as hazardous.

Table 3
Waste Classification for Mining By-Products

Client ID	Classification	Specific Activity Ratio
PDC Ilmenite	restricted solid	1.9
Combined Monazite Reject	hazardous (if > 87 g is being disposed of)	-
Hyti	restricted solid	10
Combined Zircon Wet Tails	restricted solid	7.7
Rutile Wet Circuit Concentrate	restricted solid	8.8
Float tails sample	restricted solid	3.8
PDC Conductors O/size +410 μ m	restricted solid	10

The remaining six MBP samples were classified as restricted solids because the respective specific activity ratios for the MBP's were > 1. The Guidelines state in Step 4 that *“Where the specific activity ratio or total activity ratio is greater than one, the waste must be classified as follows: Non-liquid wastes must be classified as restricted solid waste.”*

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APPENDIX 1

Assessment of Waste Classification for Mining By-Products

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				PDC Ilmenite			
				ES-050115-1			
	Emission	Group	Bq/g			Factor	Bq/g
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	0.22 ± 0.02	Specific Activity (material)			3.7
Ra-228	beta	1	0.22 ± 0.02				
Ac-228	beta	2	0.22 ± 0.02				
Th-228	alpha	1	0.19 ± 0.02				
Ra-224	alpha	2	0.19 ± 0.02	Specific Activity - Group 1	SA1	1	1.7
Rn-220	alpha	3	0.19 ± 0.02	Specific Activity - Group 2	SA2	10 ⁻¹	1.6
Po-216	alpha	1	0.19 ± 0.02	Specific Activity - Group 3	SA3	10 ⁻²	0.31
Pb-212	beta	2	0.19 ± 0.02	Specific Activity - Group 4	SA4	10 ⁻³	0.12
Bi-212 (64.07%)	beta	2	0.12 ± 0.02	Specific Activity Ratio			1.9
Bi-212 (35.93%)	alpha	1	0.07 ± 0.02	Classification			restricted solid
Po-212 (64.07%)	alpha	1	0.12 ± 0.02				
Tl-208 (35.93%)	beta	2	0.07 ± 0.02				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	0.11 ± 0.05				
Th-234	beta	2	0.11 ± 0.05				
Pa-234	beta	2	0.11 ± 0.05				
U-234	alpha	1	0.11 ± 0.05				
Th-230	alpha	1	0.12 ± 0.02				
Ra-226	alpha	1	0.12 ± 0.01				
Rn-222	alpha	3	0.12 ± 0.01				
Po-218	alpha	1	0.12 ± 0.01				
Pb-214	beta	2	0.12 ± 0.01				
Bi-214	beta	2	0.12 ± 0.01				
Po-214	alpha	1	0.12 ± 0.01				
Pb-210	beta	1	0.14 ± 0.02				
Bi-210	beta	2	0.14 ± 0.02				
Po-210	alpha	2	0.14 ± 0.02				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.005 ± 0.002				
Th-231	beta	3	0.005 ± 0.002				
Pa-231	alpha	1	< 0.026				
Ac-227	beta	1	< 0.0053				
Th-227 (98.62%)	alpha	1	< 0.0053				
Fr-223 (1.38%)	alpha	1	< 0.0053				
Ra-223	alpha	1	< 0.0053				
Rn-219	alpha	1	< 0.0053				
Po-215	alpha	1	< 0.0053				
Pb-211	beta	2	< 0.0053				
Bi-211	alpha	1	< 0.0053				
Tl-207	beta	2	< 0.0053				
K-40	beta	2	0.026 ± 0.007				

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				Combined Monazite Reject			
				ES-050115-2			
	Emission	Group	Bq/g			Factor	Bq/g
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	77 ± 8	Specific Activity (material)			938
Ra-228	beta	1	68 ± 7				
Ac-228	beta	2	68 ± 7				
Th-228	alpha	1	75 ± 8				
Ra-224	alpha	2	75 ± 8	Specific Activity - Group 1	SA1	1	460
Rn-220	alpha	3	75 ± 8	Specific Activity - Group 2	SA2	10 ⁻¹	375
Po-216	alpha	1	75 ± 8	Specific Activity - Group 3	SA3	10 ⁻²	89
Pb-212	beta	2	75 ± 8	Specific Activity - Group 4	SA4	10 ⁻³	15
Bi-212 (64.07%)	beta	2	48 ± 8	Specific Activity Ratio			498
Bi-212 (35.93%)	alpha	1	27 ± 8	Classification			hazardous
Po-212 (64.07%)	alpha	1	48 ± 8				
Tl-208 (35.93%)	beta	2	27 ± 8				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	14 ± 1				
Th-234	beta	2	14 ± 1				
Pa-234	beta	2	14 ± 1				
U-234	alpha	1	14 ± 1				
Th-230	alpha	1	17 ± 4				
Ra-226	alpha	1	13 ± 1				
Rn-222	alpha	3	13 ± 1				
Po-218	alpha	1	13 ± 1				
Pb-214	beta	2	13 ± 1				
Bi-214	beta	2	13 ± 1				
Po-214	alpha	1	13 ± 1				
Pb-210	beta	1	13 ± 1				
Bi-210	beta	2	13 ± 1				
Po-210	alpha	2	13 ± 1				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.65 ± 0.05				
Th-231	beta	3	0.65 ± 0.05				
Pa-231	alpha	1	0.8 ± 0.2				
Ac-227	beta	1	1.0 ± 0.1				
Th-227 (98.62%)	alpha	1	1.0 ± 0.1				
Fr-223 (1.38%)	alpha	1	0.014 ± 0.001				
Ra-223	alpha	1	1.0 ± 0.1				
Rn-219	alpha	1	1.0 ± 0.1				
Po-215	alpha	1	1.0 ± 0.1				
Pb-211	beta	2	1.0 ± 0.1				
Bi-211	alpha	1	1.0 ± 0.1				
Tl-207	beta	2	1.0 ± 0.1				
K-40	beta	2	< 0.32				

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	Emission	Group	Hyti				Bq/g
			ES-050115-3				
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	1.3 ± 0.2	Specific Activity (material)		Factor	19
Ra-228	beta	1	1.2 ± 0.1				
Ac-228	beta	2	1.2 ± 0.1				
Th-228	alpha	1	1.3 ± 0.1				
Ra-224	alpha	2	1.3 ± 0.1	Specific Activity - Group 1	SA1	1	9.3
Rn-220	alpha	3	1.3 ± 0.1	Specific Activity - Group 2	SA2	10 ⁻¹	7.9
Po-216	alpha	1	1.3 ± 0.1	Specific Activity - Group 3	SA3	10 ⁻²	1.8
Pb-212	beta	2	1.3 ± 0.1	Specific Activity - Group 4	SA4	10 ⁻³	0.44
Bi-212 (64.07%)	beta	2	0.8 ± 0.1	Specific Activity Ratio			10
Bi-212 (35.93%)	alpha	1	0.5 ± 0.1	Classification			restricted solid
Po-212 (64.07%)	alpha	1	0.8 ± 0.1				
Tl-208 (35.93%)	beta	2	0.5 ± 0.1				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	0.42 ± 0.01				
Th-234	beta	2	0.42 ± 0.01				
Pa-234	beta	2	0.42 ± 0.01				
U-234	alpha	1	0.42 ± 0.01				
Th-230	alpha	1	0.5 ± 0.1				
Ra-226	alpha	1	0.47 ± 0.05				
Rn-222	alpha	3	0.47 ± 0.05				
Po-218	alpha	1	0.47 ± 0.05				
Pb-214	beta	2	0.47 ± 0.05				
Bi-214	beta	2	0.48 ± 0.05				
Po-214	alpha	1	0.47 ± 0.05				
Pb-210	beta	1	0.42 ± 0.04				
Bi-210	beta	2	0.42 ± 0.04				
Po-210	alpha	2	0.42 ± 0.04				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.0194 ± 0.0005				
Th-231	beta	3	0.0194 ± 0.0005				
Pa-231	alpha	1	< 0.069				
Ac-227	beta	1	0.028 ± 0.005				
Th-227 (98.62%)	alpha	1	0.028 ± 0.005				
Fr-223 (1.38%)	alpha	1	4E-04 ± 7E-05				
Ra-223	alpha	1	0.028 ± 0.005				
Rn-219	alpha	1	0.028 ± 0.005				
Po-215	alpha	1	0.028 ± 0.005				
Pb-211	beta	2	0.028 ± 0.005				
Bi-211	alpha	1	0.028 ± 0.005				
Tl-207	beta	2	0.028 ± 0.005				
K-40	beta	2	0.10 ± 0.02				

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				Combined Zircon Wet Tails			
				ES-050115-4			
	Emission	Group				Factor	Bq/g
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	0.56 ± 0.06	Specific Activity (material)			16
Ra-228	beta	1	0.30 ± 0.03				
Ac-228	beta	2	0.30 ± 0.03				
Th-228	alpha	1	0.30 ± 0.03	Specific Activity - Group 1	SA1	1	7.0
Ra-224	alpha	2	0.30 ± 0.03	Specific Activity - Group 2	SA2	10 ⁻¹	6.4
Rn-220	alpha	3	0.30 ± 0.03	Specific Activity - Group 3	SA3	10 ⁻²	1.2
Po-216	alpha	1	0.30 ± 0.03	Specific Activity - Group 4	SA4	10 ⁻³	1.1
Pb-212	beta	2	0.30 ± 0.03	Specific Activity Ratio			7.7
Bi-212 (64.07%)	beta	2	0.19 ± 0.03				
Bi-212 (35.93%)	alpha	1	0.11 ± 0.03	Classification			restricted solid
Po-212 (64.07%)	alpha	1	0.19 ± 0.03				
Tl-208 (35.93%)	beta	2	0.11 ± 0.03				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	1.01 ± 0.02				
Th-234	beta	2	1.01 ± 0.02				
Pa-234	beta	2	1.01 ± 0.02				
U-234	alpha	1	1.01 ± 0.02				
Th-230	alpha	1	0.78 ± 0.08				
Ra-226	alpha	1	0.83 ± 0.08				
Rn-222	alpha	3	0.83 ± 0.08				
Po-218	alpha	1	0.83 ± 0.08				
Pb-214	beta	2	0.84 ± 0.08				
Bi-214	beta	2	0.83 ± 0.08				
Po-214	alpha	1	0.83 ± 0.08				
Pb-210	beta	1	0.72 ± 0.07				
Bi-210	beta	2	0.72 ± 0.07				
Po-210	alpha	2	0.72 ± 0.07				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.0466 ± 0.0009				
Th-231	beta	3	0.0466 ± 0.0009				
Pa-231	alpha	1	< 0.039				
Ac-227	beta	1	0.046 ± 0.005				
Th-227 (98.62%)	alpha	1	0.045 ± 0.005				
Fr-223 (1.38%)	alpha	1	6E-04 ± 6E-05				
Ra-223	alpha	1	0.046 ± 0.005				
Rn-219	alpha	1	0.046 ± 0.005				
Po-215	alpha	1	0.046 ± 0.005				
Pb-211	beta	2	0.046 ± 0.005				
Bi-211	alpha	1	0.046 ± 0.005				
Tl-207	beta	2	0.046 ± 0.005				
K-40	beta	2	< 0.024				

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				Rutile Wet Circuit Concentrate			
				ES-050115-5			
	Emission	Group				Factor	Bq/g
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	1.0 ± 0.1	Specific Activity (material)			17
Ra-228	beta	1	0.91 ± 0.09				
Ac-228	beta	2	0.91 ± 0.09				
Th-228	alpha	1	0.90 ± 0.09	Specific Activity - Group 1	SA1	1	8.1
Ra-224	alpha	2	0.90 ± 0.09	Specific Activity - Group 2	SA2	10 ⁻¹	7.0
Rn-220	alpha	3	0.90 ± 0.09	Specific Activity - Group 3	SA3	10 ⁻²	1.5
Po-216	alpha	1	0.90 ± 0.09	Specific Activity - Group 4	SA4	10 ⁻³	0.61
Pb-212	beta	2	0.90 ± 0.09	Specific Activity Ratio			8.8
Bi-212 (64.07%)	beta	2	0.58 ± 0.09				
Bi-212 (35.93%)	alpha	1	0.32 ± 0.09	Classification			restricted solid
Po-212 (64.07%)	alpha	1	0.58 ± 0.09				
Tl-208 (35.93%)	beta	2	0.32 ± 0.09				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	0.58 ± 0.02				
Th-234	beta	2	0.58 ± 0.02				
Pa-234	beta	2	0.58 ± 0.02				
U-234	alpha	1	0.58 ± 0.02				
Th-230	alpha	1	0.51 ± 0.08				
Ra-226	alpha	1	0.58 ± 0.06				
Rn-222	alpha	3	0.58 ± 0.06				
Po-218	alpha	1	0.58 ± 0.06				
Pb-214	beta	2	0.58 ± 0.06				
Bi-214	beta	2	0.58 ± 0.06				
Po-214	alpha	1	0.58 ± 0.06				
Pb-210	beta	1	0.47 ± 0.05				
Bi-210	beta	2	0.47 ± 0.05				
Po-210	alpha	2	0.47 ± 0.05				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.0268 ± 0.0009				
Th-231	beta	3	0.0268 ± 0.0009				
Pa-231	alpha	1	< 0.043				
Ac-227	beta	1	0.030 ± 0.003				
Th-227 (98.62%)	alpha	1	0.030 ± 0.003				
Fr-223 (1.38%)	alpha	1	4E-04 ± 4E-05				
Ra-223	alpha	1	0.030 ± 0.003				
Rn-219	alpha	1	0.030 ± 0.003				
Po-215	alpha	1	0.030 ± 0.003				
Pb-211	beta	2	0.030 ± 0.003				
Bi-211	alpha	1	0.030 ± 0.003				
Tl-207	beta	2	0.030 ± 0.003				
K-40	beta	2	0.07 ± 0.01				

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				Float Tails Sample			
				ES-050115-6			
	Emission	Group				Factor	Bq/g
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	0.30 ± 0.03	Specific Activity (material)			8.2
Ra-228	beta	1	0.27 ± 0.03				
Ac-228	beta	2	0.27 ± 0.03				
Th-228	alpha	1	0.27 ± 0.03	Specific Activity - Group 1	SA1	1	3.5
Ra-224	alpha	2	0.27 ± 0.03	Specific Activity - Group 2	SA2	10 ⁻¹	3.5
Rn-220	alpha	3	0.27 ± 0.03	Specific Activity - Group 3	SA3	10 ⁻²	0.68
Po-216	alpha	1	0.27 ± 0.03	Specific Activity - Group 4	SA4	10 ⁻³	0.50
Pb-212	beta	2	0.27 ± 0.03	Specific Activity Ratio			3.8
Bi-212 (64.07%)	beta	2	0.17 ± 0.03				
Bi-212 (35.93%)	alpha	1	0.10 ± 0.03	Classification			restricted solid
Po-212 (64.07%)	alpha	1	0.17 ± 0.03				
Tl-208 (35.93%)	beta	2	0.10 ± 0.03				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	0.48 ± 0.02				
Th-234	beta	2	0.48 ± 0.02				
Pa-234	beta	2	0.48 ± 0.02				
U-234	alpha	1	0.48 ± 0.02				
Th-230	alpha	1	< 0.30				
Ra-226	alpha	1	0.39 ± 0.04				
Rn-222	alpha	3	0.39 ± 0.04				
Po-218	alpha	1	0.39 ± 0.04				
Pb-214	beta	2	0.39 ± 0.04				
Bi-214	beta	2	0.39 ± 0.04				
Po-214	alpha	1	0.39 ± 0.04				
Pb-210	beta	1	0.33 ± 0.03				
Bi-210	beta	2	0.33 ± 0.03				
Po-210	alpha	2	0.33 ± 0.03				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.0222 ± 0.0009				
Th-231	beta	3	0.0222 ± 0.0009				
Pa-231	alpha	1	< 0.064				
Ac-227	beta	1	0.019 ± 0.003				
Th-227 (98.62%)	alpha	1	0.019 ± 0.003				
Fr-223 (1.38%)	alpha	1	3E-04 ± 5E-05				
Ra-223	alpha	1	0.019 ± 0.003				
Rn-219	alpha	1	0.019 ± 0.003				
Po-215	alpha	1	0.019 ± 0.003				
Pb-211	beta	2	0.019 ± 0.003				
Bi-211	alpha	1	0.019 ± 0.003				
Tl-207	beta	2	0.019 ± 0.003				
K-40	beta	2	< 0.044				

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				PDC Conductors O/size +410 µm			
				ES-050115-7			
	Emission	Group				Factor	Bq/g
<i>Th-232 Decay Chain</i>							
Th-232	alpha	1	0.89 ± 0.09	Specific Activity (material)			21
Ra-228	beta	1	0.86 ± 0.09				
Ac-228	beta	2	0.86 ± 0.09				
Th-228	alpha	1	0.86 ± 0.09	Specific Activity - Group 1	SA1	1	9.5
Ra-224	alpha	2	0.86 ± 0.09	Specific Activity - Group 2	SA2	10 ⁻¹	8.5
Rn-220	alpha	3	0.86 ± 0.09	Specific Activity - Group 3	SA3	10 ⁻²	1.7
Po-216	alpha	1	0.86 ± 0.09	Specific Activity - Group 4	SA4	10 ⁻³	0.85
Pb-212	beta	2	0.86 ± 0.09	Specific Activity Ratio			10
Bi-212 (64.07%)	beta	2	0.55 ± 0.09				
Bi-212 (35.93%)	alpha	1	0.31 ± 0.09	Classification			restricted solid
Po-212 (64.07%)	alpha	1	0.55 ± 0.09				
Tl-208 (35.93%)	beta	2	0.31 ± 0.09				
<i>U-238 Decay Chain</i>							
U-238	alpha	4	0.81 ± 0.03				
Th-234	beta	2	0.81 ± 0.03				
Pa-234	beta	2	0.81 ± 0.03				
U-234	alpha	1	0.81 ± 0.03				
Th-230	alpha	1	0.9 ± 0.2				
Ra-226	alpha	1	0.82 ± 0.08				
Rn-222	alpha	3	0.82 ± 0.08				
Po-218	alpha	1	0.82 ± 0.08				
Pb-214	beta	2	0.81 ± 0.08				
Bi-214	beta	2	0.83 ± 0.08				
Po-214	alpha	1	0.82 ± 0.08				
Pb-210	beta	1	0.68 ± 0.07				
Bi-210	beta	2	0.68 ± 0.07				
Po-210	alpha	2	0.68 ± 0.07				
<i>U-235 Decay Chain</i>							
U-235	alpha	4	0.037 ± 0.001				
Th-231	beta	3	0.037 ± 0.001				
Pa-231	alpha	1	<0.13				
Ac-227	beta	1	0.048 ± 0.008				
Th-227 (98.62%)	alpha	1	0.047 ± 0.008				
Fr-223 (1.38%)	alpha	1	7E-04 ± 1E-04				
Ra-223	alpha	1	0.048 ± 0.008				
Rn-219	alpha	1	0.048 ± 0.008				
Po-215	alpha	1	0.048 ± 0.008				
Pb-211	beta	2	0.048 ± 0.008				
Bi-211	alpha	1	0.048 ± 0.008				
Tl-207	beta	2	0.048 ± 0.008				
K-40	beta	2	0.30 ± 0.05				

APPENDIX C

**Pre-Mining Radionuclide
Groundwater Monitoring
Event (June 2014)**

**Balranald Minerals Sands
Project, Murray Basin,
New South Wales**

**Iluka Trim Reference:
1706898**

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1 INTRODUCTION

Land & Water Consulting Pty Ltd (LWC) was engaged by Iluka Resources Limited (Iluka) to undertake a Pre-Mining Radionuclide Groundwater Monitoring Event for the Balranald Mineral Sands Project ('Site'), Balranald, New South Wales, Australia. A site locality plan is presented as Figure 1.

The Radionuclide Groundwater Monitoring Event (GME) was undertaken in accordance with the Pre-Mining Groundwater Management Plan (GMP) (LWC, 2013) which describes the framework and activities which Iluka will undertake in order to establish suitable baseline groundwater elevation and water quality data beneath the Site and surrounds prior to submitting the application for future mining operations at the Site.

1.1 PROJECT BACKGROUND

Iluka recently completed a Pre-Feasibility Study (PFS) to assess the potential for mining two rutile-rich mineral sands deposits in the northern Murray Basin, New South Wales. The deposits contain heavy minerals, including rutile, zircon. The mining operation will include development of an open cut mine and associated infrastructure with the intent to transport the processed ore to a mineral separation plant in Victoria.

Following completion of the PFS, the Balranald project has now proceeded to the next stage, being the definitive feasibility study (DFS) which consists of further detailed hydrogeological modelling through to the installation of bores and a long term pump and re-injection trials.

The two deposits include the West Balranald Deposit located approximately 13 km northwest of the township of Balranald in New South Wales and the Nepean Deposits located a further 40 km north-northwest of the West Balranald deposit. A map detailing the study area is provided as Figure 2.

As major dewatering will be required during mining the assessment of potential hydrogeological impacts during operations is currently of particular significance moving forward with the definitive feasibility study. An operating scenario which involves the location of an off-path re-injection bore-field is currently being explored to manage the volume of groundwater estimated to be removed as part of dewatering in the study area. The bore field and re-injection program is currently being implemented along with injection pilot trials.

A baseline groundwater monitoring program has been developed and implemented since early 2012 and included (1) monthly field parameter sampling/ elevation and pressure head gauging at nominated locations across the designated mining area/surrounds and (2) three monthly water quality assessment utilising select monitoring wells. Figure 3 details the current groundwater well network implemented across the study area.

While a quantity of data has been collected across the study area, with the exception of that required to develop the initial site numerical groundwater model, prior to the development of the GMP (LWC, 2013) no detailed analysis of the records was undertaken to identify trends and/or opportunities to optimise the current baseline monitoring program. The GMP document formalised a scope, methodology and reporting structure for recording and reviewing of collected data and assessment of the quality and appropriateness of infield monitoring practices.

Consistent with regulatory requirements, analysis of radionuclides in groundwater is required in order to establish baseline concentrations prior to any mining operations and associated activities occurring.



Following communication with Iluka, the following sampling program was to be adopted for both the West Balranald and Nepean deposits:

- One bore as close to the ore body as possible to be sampled for full radionuclide analysis including U-238, Th-232 and U-235 and respective decay chains.
- One bore up gradient of the ore body (and outside of the mining pathway which is considered to represent background) to be sampled for U-238, Th-232 and U-235 and respective decay chains.
- Targeted sampling of other bores within the mining extent and surrounds with groundwater to be sampled for uranium, radium-228 and radium-226.

Based on information provided to LWC, it is understood that the West Balranald ore deposit within the Loxton-Parilla Sands unit is situated around 46 to 53 m below ground level (bgl) in the centre of the defined deposit. The Nepean deposit is also located within the Loxton-Parilla Sands formation, but with a shallower average depth of 48 m bgl.

Following a number of discussions with Iluka and with radiochemistry laboratories, it is evident that there might be little benefit in scheduling samples for gross alpha and beta analysis based on the upper range of salinity (total dissolved solids) reported in groundwater across all units (refer Table 1-1), which may cause some level of analytical matrix interference. Subsequently, the radionuclide schedule was refined to comprise gamma spectrometry, inductively coupled plasma mass spectrometry (ICP-MS) and alpha spectrometry for the heads of the two naturally occurring radioactive material chains U-238 and Th-232.

Table 1-1 – Summary of Salinity per Unit

Unit	Lower Salinity (mS/cm)	Upper Salinity (mS/cm)
Shepparton	36.3	68.6
Loxton Parilla Sands	14.6	65.7
Upper Renmark	8.5	28.2
Lower Renmark	4.1	10.9

1.2 OBJECTIVES

The key objective of pre-mining groundwater monitoring for the proposed Balranald Mineral Sands project is:

- To obtain suitable and representative baseline groundwater elevation, field parameter and water quality data from the underlying groundwater system/s observed within the study area (and surrounds) for the purpose of (1) understanding temporal/spatial trends and (2) for future comparison against any changes brought about as a result of mining operations.

The underlining basis of this objective is to protect the surrounding water resources and existing groundwater users during and post future mining operations.



Baseline monitoring data will therefore represent the natural radiological composition and distribution in groundwater beneath the study area and surrounds and becomes a control against any measured impact of the future mining operations and activities.

1.3 SCOPE OF WORKS

The scope of works for the radionuclide GME included the following:

- Groundwater sampling of targeted monitoring wells installed across the proposed mining area at both West Balranald Deposit Area and Nepean Deposit Area's.
- Provision of report detailing the results of the monitoring event, assessment of the quality of groundwater with respect to identified beneficial uses of groundwater, comparison to previous historical data and an assessment of the suitability of the data to be used as a basis of interpretation.

In summary, the suggested approach targeted the three relevant hydrogeochemical domains (i.e. up hydraulic gradient, ore body and down hydraulic gradient) for full uranium and thorium decay chain (i.e. a representative sample per domain) backed by gamma spectrometry/ ICP-MS in an additional one or more wells per domain.



2 APPROACH

2.1 OVERVIEW

The approach to the radionuclide background screening event is summarised below:

- High salinity should not significantly affect gamma ray spectrometry, although detection limits and uncertainties may be increased somewhat. The following radionuclides are most commonly obtained by gamma ray spectrometry: Th-234, Ra-226, Pb-210, Ra-228 and Th-228 (note that others are also possible, such as the U-235 chain radionuclides U-235, Th-227 and Ra-223 but this is rarely necessary for environmental water samples).
- The heads of the two main naturally occurring radioactive material chains U-238 and Th-232 cannot be measured directly by gamma ray spectrometry. These are commonly obtained by activity conversion after ICP-MS based analysis for elemental U and Th.
- A further method with respect to assessing the decay chain sequence which is not obtainable by the above methods is to analyse principal radionuclides of the U-238, U-235 and Th-232 chains by alpha spectrometry. This is generally the most sensitive method and can be used to assess radionuclides that cannot be analysed easily or at all by other methods (e.g. Th-230, U-234 and Po-210). There are three main alpha spectrometry analytical suites: Th isotopes (Th-230, Th-232, Th-228 and Th-227), U isotopes (U-238, U-234 and U-235) and Po-210. The use of alpha spectrometry is at a significant increase in cost however.
- The combined use of gamma spectrometry and ICP-MS is considered to provide good value, with a proportion of samples (representative of each 'domain') scheduled for full decay chain analysis (i.e. a combination of gamma spectrometry and alpha spectrometry) for baseline assessment only, in the first instance.
- It is considered that obtaining full decay chain information from each 'domain' at baseline is an expensive but necessary process, noting that if not undertaken, and queries arise during operational phase, it will be difficult if not impossible to retrospectively obtain such information representative of baseline from both the ore 'domain' and the down-hydraulic gradient 'domain'.
- It is envisaged that following the collection of full decay chain information at baseline, that general operational monitoring would include gamma spectrometry and ICP-MS activity conversion.

2.2 THE SAMPLING AND ANALYSIS SCHEDULE

A summary of the schedule is presented in Table 2-1. Note that the assessment targets the Loxton Parilla Sands Formation (LPS) with the exception of groundwater monitoring well WB20. However, anecdotal information from Iluka indicates that this well is potentially screening the LPS (unconfirmed – further assessment recommended). Water sampled from this well has consistently reported uranium above the Australian Drinking Water Guideline (ADWG) criterion of 0.017 mg/L. Given the potential ambiguity of the screened zone and the consistently elevated uranium concentration, WB20 was sampled and analysed for radionuclides.

The WB20 was field-split with two samples (WB20(1) and WB20(2)) being submitted to the primary laboratory for analysis of uranium and thorium. Sample WB20(1) was filtered and sample WB20(2) was



unfiltered; the objective of this action was to assess uranium content in filtered and unfiltered sample noting that uranium is redox sensitive and will be predominantly in solution in oxidised conditions (as U(VI)) and sparingly soluble in reduced conditions (as U(IV) – less environmentally mobile).

Table 2-1 – Summary of Groundwater Monitoring Well Analysis

Zone	Function	Groundwater Well	Analysis	
			Full Decay Chain (Alpha & Gamma Spectrometry)	Gamma Spectrometry & ICP-MS Activity Conversion
West Balranald	Near the ore body	WB28, WB40 or WB41	Choice of one of these three wells for full uranium and thorium decay chain.	The remaining two wells being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
	Up-Gradient/ Outside of the Mining Pathway	GW036868(2) or GW036673(2)	GW036868(2) & GW036673(2)	N/A
	Other Bores within the Mining Extent/ Down hydraulic gradient.	WB5, WB17 and WB25	Choice of one of these three wells for full uranium and thorium decay chain.	The remaining two wells being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
Nepean	Near the Ore Body	N10 and GW036790-2	Choice of one of these two wells for full uranium and thorium decay chain,	The remaining well being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
	Up-Gradient/ Outside the Mining Pathway	GW036674(1) or GW036866(2)	Choice of one of these two wells for full uranium and thorium decay chain.	The remaining well being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.
	Other Bores within the Mining Extent	N7 and N28	Choice of two of these three wells for full uranium and thorium decay chain.	The remaining well being analysed for gamma spectrometry suite and ICP-MS U & Th activity conversion.



3 METHODOLOGY

3.1 GROUNDWATER GAUGING AND SAMPLING

Based on the industry standard guidelines (consistent with NSW guidelines and standard best practices) the following table details the methodology implemented for the radionuclide GME program.

Table 3-1 - Summary of Groundwater Sampling Methodology

Activity/ Item	Details
Water Level Gauging	<p>Monitoring wells targeted for the assessment were gauged for water level elevations using a calibrated electronic water level probe prior to commencement of sampling.</p> <p>Water levels were gauged from the top of the casing.</p>
Well Purging and Sampling Process	<p>All groundwater monitoring wells were purged using industry standard low flow sampling techniques with dedicated LDPE Teflon tubing used per location. The low flow sampling method included placement of the pump at the midpoint of the slotted screen interval and pumping at the flow rate where the groundwater level did not decline significantly (i.e. greater than 10cm). Each well was pumped to a maximum rate of 0.5 L/min which is within the recommended in industry standard guidelines (i.e. between 0.1 to 0.5 L/min).</p> <p>Prior to collection of field parameters, a flush through of groundwater entering the tubing material was undertaken and was conservatively based on on 1 litre per 10 metres of tubing.</p> <p>Groundwater elevation gauging during sampling was undertaken to ensure groundwater extracted from the well is fresh groundwater obtained from the adjacent formation and not stagnant water contained in the well water column.</p>
Monitoring Parameters	<p>Measurement of field water parameters were undertaken until field quality parameters had stabilised (i.e. within 3% EC, 0.05 pH, 10% DO and 10m V redox and 0.5 C temperature). Parameter measurements were obtained every 5 minutes until field parameters over two consecutive readings had stabilised, thereafter sampling proceeded. A minimum of four readings was undertaken at each monitoring well. Field chemical parameters were recorded to ensure stable geochemical conditions existed prior to the collection of the groundwater sample.</p> <p>The pH, redox, electrical conductivity, dissolved oxygen and temperature meters were calibrated prior to the commencement of purging – i.e. at the start of each day of purging/ sampling (and recorded into a calibration record book).</p>
Decontamination Procedure	<p>Decontamination of all groundwater sampling equipment between locations was undertaken with monitoring equipment (water level probe and submersible pump) decontaminated according to the following procedure:</p> <ul style="list-style-type: none"> ▪ Decontaminate equipment away from the sampling location. ▪ Wash with Decon 90 or similar decontaminant/ water solution and rinse. ▪ Triple wash with laboratory supplied clean deionised water. ▪ Equipment should be air dried (if possible) before use of sampling. <p>As a matter of course the flow cell for measuring field parameters was also rinsed with clean water between locations.</p>
Sample Method and Preservation	<p>Targeted monitoring wells were purged and sampled using dedicated low flow LDPE Teflon tubing (per monitoring well) prior to sampling.</p> <p>Following stabilisation of field parameters, samples were placed into laboratory supplied bottles containing appropriate preservations for the selected analytical testing.</p> <p>Samples were immediately chilled and stored at a temperature of 4C or less prior to transit to the laboratory.</p>



Activity/ Item	Details
Analytical Laboratories	<p>Groundwater samples were placed in laboratory cleaned bottles containing appropriate preservatives, and then placed into a chilled esky for transport to the primary laboratory, SGS Australian Radiation Services Pty Ltd (SGS). Intra-duplicate and inter-duplicate groundwater samples were also collected and sent to SGS and Australian Laboratory Services (ALS) (another NATA registered laboratory).</p> <p>Laboratory limits of reporting were below the adopted relevant guideline values for each targeted analysis with the exception of lead (Pb) 210 (discussed in later Sections).</p>
Quality Assurance/ Quality Control	<p>QA/QC samples were collected and analysed in accordance Australian Standard and NEPM (1999 – amended 2013). QA/QC samples collected for quality control purposes included the following:</p> <ul style="list-style-type: none"> ▪ intra-laboratory field duplicates; ▪ inter-laboratory field triplicates; and ▪ rinsate blanks (pump equipment only) per each day of sampling to ensure appropriate decontamination processes occurred. <p>The frequency of QA/QC samples included the following:</p> <ul style="list-style-type: none"> ▪ 1 in 20 groundwater samples are required for intra and inter laboratory field duplicate analysis. ▪ 1 rinsate blank from the decontaminated pump obtained for key water quality analytes (heavy metals) per day.
Sample Nomenclature	Sampling nomenclature was consistent with the previous monitoring well nomenclature.
Field Records/ Documentation	<p>During each monitoring event:</p> <ul style="list-style-type: none"> ▪ Groundwater levels and pressure heads were recorded for each targeted monitoring event (see Table 1). ▪ Field purge and sampling sheets were filled in per well per monitoring event (refer to Appendix A). ▪ Chain of custody document for all samples were sent for laboratory analysis to be maintained for quality assurance checking (refer to Appendix B).

3.2 GROUNDWATER ANALYTICAL SCHEDULE

The following laboratory analysis was undertaken for the June 2014 monitoring event:

Analysis	Groundwater Wells	# of Samples excl. QA/ QC
Uranium and Thorium Decay Chain	WB28	1
Alpha Spectrometry	GW036868(2) and GW036673(2)	2
U-238, U-234, U-235	WB17	1
Th-232, Th-230, Th-228, Th-227	N10	1
Po-210	GW036674(1)	1
Gamma Spectrometry	N7 and GW036790(1)	2



Analysis	Groundwater Wells	# of Samples excl. QA/ QC
Th-234, Ra-226, Pb-210, Ra-228, Th-228		Total of 8 Samples
Gamma Spectrometry & ICP-MS	WB40 and WB41	2
Gamma Spectrometry	WB5 and WB20 (1 and 2)	3
Th-234, Ra-226, Pb-210, Ra-228, Th-228	GW036866(2)	1
ICP-MS	N28	1
U and Th (activity conversion)		Total of 7 Samples

3.3 ASSESSMENT CRITERIA AND GUIDELINES

The adopted assessment criteria and guidelines were based on the site setting and potential beneficial uses of groundwater (LWC, 2013) beneath and surrounding the proposed mine site, and included the following:

For Human Health Screening (selected from the following hierarchy unless a criterion provided in a lower hierarchy is significantly lower and/ or for establishing a benchmark):

1. Australian Drinking Water Guidelines (ADWG, NHMRC 2011).
 - Note that the ADWG adopt a screen for radiological parameters (gross alpha and gross beta) which is not a criterion.
 - Exceedance of the screen requires detailed analysis of the nature of activity.
 - Note that the analysis undertaken in the first instance provides detailed analysis of the nature of activity.
 - The ADWG then requires a calculation of annual dose (total) associated with the water.
 - The ADWG total annual dose threshold is encompassing of all radionuclides, is overarching and supersedes all other criteria in this assessment.
2. World Health Organisation Guidelines for Drinking Water (3rd Edition, 2008).
3. Guidelines for Canadian Drinking Water Quality (2008).

For Ecosystem Protection:

- No provision of criterion in the ANZECC (2000) Guidelines for Freshwater Ecosystem (95% Protection).



For Irrigation and Stock Watering:

- ANZECC (2000) Guidelines for Stock Water.
- ANZECC (2000) Guidelines for Irrigation.

In accordance with the National Environment Measure Protection, beneficial uses of groundwater are those uses that could be supported by the background groundwater quality and is based on the inherent ability of the aquifer to support those uses. Based on historical salinity measurements observed in groundwater sampled from monitoring wells installed within and surrounding the West Balranald and Nepean deposits include the following:

- Shepparton Formation Aquifer– 24,700 to 41,500 mg/L.
- Loxton-Parilla Sand Aquifer – 1,400 to 42,400 mg/L.
- Upper Renmark Aquifer – 4,300 to 29,600 mg/L.
- Lower Renmark – 1,700 to 8,100 mg/L.

The high saline groundwater of the Shepparton and Loxton-Parilla Sands aquifer suggests the beneficial use of groundwater is limited to industrial water use and maintenance of ecosystems in a saline environment. At the lower end of the salinity range for the Loxton-Parilla Sands, groundwater is also marginally suitable (based on salinity alone) for stock-water use and primary contact (i.e. bathing/ swimming). This is also consistent with the beneficial use of groundwater at the lower end of the salinity range for the Upper Renmark Formation.

It is noted that in addition to the beneficial use being limited in the Shepparton Formation, it is also low yielding due to the discontinuous nature of the sands within the formation and therefore would preclude use for industrial purposes.

Groundwater salinity observed in the Lower Renmark Formation suggests groundwater beneath the area is suitable for maintenance of ecosystems (fresh water), stock water, industrial water use and primary contact/ recreation (i.e. bathing/ swimming). At the lower end of the salinity range, groundwater is also potentially suitable for potable mineral water supply and agriculture/ parks and gardens.



4 RESULTS

The June radionuclide 2014 monitoring program was undertaken between 2 and 5 June 2014.

4.1 GROUNDWATER ELEVATIONS

A summary of the groundwater elevations as identified per aquifer unit during the May/June quarterly monitoring event is presented in Table 4-1.

Table 4-1 - Summary of Groundwater Elevations Ranges Observed per Relevant Aquifer Unit (m below top of PVC*) – May/June 2014

Aquifer Unit	West Balranald Deposit Area		Nepean Deposit Area	
	Within the Proposed Extent of Mining	Surrounding Proposed Mining Area	Within the Proposed Extent of Mining	Surrounding Proposed Mining Area
Shepparton Aquifer	12.3 mTOC (WB20) to 18.9 (WB1)	11.38 (GW040247-1) to 14.7 mTOC (GW036673-1)	23.5 (N27)	14.0 mTOC (GW036862-1)
Loxton-Parilla Sands Aquifer	12.1 (WB17) to 17.8 (WB2)	10.0 mTOC (GW036868-1) to 14.5 (GW036673-2)	24.5 (N28) to 43.3 (N10)	13.2 mTOC (GW036674-1)

*Units specified are m below top of PVC unless otherwise specified to be m below Top of Casing (TOC)

4.2 HYDRO-GEOCHEMICAL CONDITIONS

Groundwater field parameter results for this sampling event are summarised in Table 4-2 and the groundwater purge sheets are presented in Appendix A.




Table 4-2 – Summary of Hydrogeochemical Parameters

Zone	Function	Groundwater Well	pH	EC (uS/cm)	Redox (mV)	Temp. °C
West Balranald	Near the ore body	WB28	6.34	51,818	-107.1	20.6
		WB40	6.21	47,326	-64.1	21.3
		WB41	6.15	45,982	-90.9	21.2
	Up-Gradient/ Outside of the Mining Pathway	GW036868(2)	7.69	24,427	-185.2	20.6
		GW036673(2)	7.02	50,192	-91.5	21.2
	Other Bores within the Mining Extent/ Down hydraulic gradient.	WB5	6.60	29,983	-155.3	20.1
		WB17	6.21	55,090	-74.6	20.4
		WB20	6.78	51,007	-102.2	17.6
	Nepean	Near the Ore Body	N10	6.55	48,729	-78.0
GW036790(2)			6.62	42,250	103.8	22.9
Up-Gradient/ Outside the Mining Pathway		GW036674(1)	6.86	22,107	-22.9	22.7
		GW036866(2)	6.92	20,900	-63.3	20.4
Other Bores within the Mining Extent		N7	6.33	46,258	-51.7	21.5
		N28	6.61	29,112	-226.0	21.8

4.3 GROUNDWATER ANALYTICAL RESULTS

A summary of the analytical results is presented with respect to Tier 1 criteria in Table 1 (at rear). The certified laboratory reports are presented as Appendix B. Please note that where activities are reported with a deviation, the deviation has been added to the reported value to provide a conservative upper value inclusive of deviation. A summary of the findings of the analysis is presented in Table 4-3.

Table 4-3 – Summary of Analytical Findings per Zone/ Function (Drinking Water/ Human Health)

Zone	Function	Groundwater Well	Analysis		Comment
			Full Decay Chain (Alpha & Gamma Spectrometry)	Gamma Spectrometry & ICP-MS Activity Conversion	
West Balranald	Near the ore body	WB28			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.

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Zone	Function	Groundwater Well	Analysis		Comment	
			Full Decay Chain (Alpha & Gamma Spectrometry)	Gamma Spectrometry & ICP-MS Activity Conversion		
		WB40			This water reported gamma emitting radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.	
		WB41			This water reported gamma emitting radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.	
	Up-Gradient/ Outside of the Mining Pathway	GW036868(2)		-	This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.	
		GW036673(2)			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.	
	Other Bores within the Mining Extent/ Down hydraulic gradient.	W5			This water reported gamma emitting radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.	
		WB17			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of radium 226, lead 210 and radium 228.	
		WB20			This water reported gamma emitting radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228. Alpha emitting uranium 238 was reported at 2.6 Bq/L. This is in excess of the adopted screening level of 0.21 Bq/L.	
	Nepean	Near the Ore Body	N10			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.
			GW036790(1)			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of radium 226, lead 210 and radium 228.



Zone	Function	Groundwater Well	Analysis		Comment
			Full Decay Chain (Alpha & Gamma Spectrometry)	Gamma Spectrometry & ICP-MS Activity Conversion	
	Up-Gradient/ Outside the Mining Pathway	GW036674(1)			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of lead 210.
		GW036866(2)			This water reported gamma emitting radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.
	Other Bores within the Mining Extent	N7			This water reported full decay chain radionuclides below adopted drinking water criteria with the exception of lead 210 and radium 228.
		N28			This water reported gamma emitting radionuclides below adopted drinking water criteria with the exception of radium 226, lead 210 and radium 228.

A summary of analytical results exceeding adopted screening criteria for use of groundwater for irrigation and stock watering is presented in Table 4-4.

Table 4-4 – Sampled Groundwater Exceeding Irrigation/ Stock Watering Use Screening Criteria

Zone	Function	Groundwater Well	Analysis		Comment
			Full Decay Chain (Alpha & Gamma Spectrometry)	Gamma Spectrometry & ICP-MS Activity Conversion	
West Balranald	Other Bores within the Mining Extent/ Down hydraulic gradient.	WB20			This water reported gamma emitting radionuclides below adopted irrigation water criteria. Alpha emitting uranium 238 was reported at 2.6 Bq/L. This is in excess of the adopted screening level of 0.2 Bq/L.



4.4 DATA QUALITY ASSESSMENT

Analytical data produced for the radionuclide monitoring event has been assessed with reference to the following issues:

- Sampling technique;
- Preservation and storage of samples upon collection and during transport to the laboratory;
- Sample holding times;
- Analytical procedures;
- Laboratory limits of reporting;
- Field duplicate agreement;
- Laboratory quality assurance/quality control (QA/QC) procedures; and
- The occurrence of apparently unusual or anomalous results.

Laboratory QA/QC procedures and results are detailed in the certified laboratory results contained in Appendix B. A summary of the data quality assessment and a summary of the field duplicate sample relative percentage differences are included as Appendix C.

All samples were collected, stored and transported to the laboratory in accordance with the requirements of Schedule B(2) of the NEPM (NEPC, 1999). Laboratory analysis was undertaken within specified holding times and in accordance with National Association of Testing Authorities (NATA) accepted analytical procedures and the requirements of Schedule B(3) of the NEPM (NEPC, 1999).

Consistent with industry standards, blind coded intra and inter-laboratory groundwater duplicates were undertaken within the required frequency of 1 in 20 for all field investigation program. Two blind-coded inter and intra-laboratory duplicates were sampled from monitoring wells:

- WB5 – Duplicate sample for ICP Analysis/ Conversion (DUP-MAY-RN1-ICP); and
- WB17 – Duplicate sample for full chain analysis (DUP-MAY-RN1-FULL).

A number of elevated relative percentage duplicates (RPD%) were observed above the acceptable 50% difference between the primary and the blind-coded intra and inter-laboratory duplicates. These included:

- Between primary sample WB17 and blind-coded intra-laboratory duplicate (DUP-MAY-RN1-FULL) for thorium 230 (119%).
- Between primary sample WB17 and blind-coded inter-laboratory duplicate (DUP-MAY-RN1-FULL) for uranium 238 (64.8%), uranium 235 (138.5%) and uranium 234 (58.9%). The elevated RPD may be a function of the two differing methodologies applied by the primary and secondary laboratory. SGS used alpha spectrometry for assessment of uranium isotopes whereas ALS used ICP-SFMS.



- Between primary sample WB17 and blind-coded inter-laboratory duplicate (DUP-MAY-RN1-FULL) for polonium 210 (192.7%). This is considered to represent either an erroneous polonium result in the inter-laboratory sample given the agreement between the primary and intra sample, and the magnitude of the remainder of the natural uranium series, or a difference in transition time of polonium-210 to lead 210 (polonium has a half-life of 138 days, an error or difference in time calculation in the laboratory can increase the calculated activity). Similarly, differing methods were used, with SGS using alpha spectrometry and ALS using scintillation with ZnS(Ag). The accuracy of such a technique in notably saline water may have the potential to decrease. International Standards Organisation guideline ISO 13161:2011 recommends use of alpha spectrometry.

The majority of elevated RPD's are not considered significant in terms of the overall interpretation of results as the primary laboratory generally showed good agreement between primary and intra duplicates. The secondary laboratory used ICP-SFMS which may have had some infringement on accuracy due to elevated salinity.

Laboratory quality control information from the primary laboratory indicates an acceptable degree of QA/QC information was collected and reported providing confidence in the accuracy and precision of reported results subject to the limitations discussed in Appendix C.



5 DISCUSSION

5.1 GROUNDWATER LEVELS AND SALINITY

In comparison to historical data the groundwater elevations and salinity values for targeted monitoring wells were generally consistent with that reported historically.

5.2 RADIONUCLIDE ANALYTICAL RESULTS – HUMAN HEALTH SCREENING

Generally, four radionuclides were reported at activities in excess of adopted human health screening criteria, as summarised in Table 5-1. The distribution and magnitude of each of these radionuclides is discussed below.

Table 5-1 – Summary of Radionuclides Reported above Human Health (Ingestion) Screening Criteria

Radionuclide	Screening Criterion (activity, Bq/L)	Location(s)	Zone	Maximum Activity (Bq/L)
Uranium 238	0.21 (adjusted AWDG)	WB20	West Balranald – Within or down hydraulic gradient of the mining extent.	2.7 (WB20(2))
Lead 210	0.1 (WHO)	All Samples	All zones/ domains.	0.61 (WB20 and N7)
Radium 226	1 (WHO)	WB17, N28 and GW036790(1)	West Balranald – Within or down hydraulic gradient of the mining extent; and Nepean near the ore body/ within the mining extent.	1.87 (GW036790(1))
Radium 228	0.1 (WHO)	All Samples except GW036674(1)	All zones/ domains.	0.683 (WB17)
Notes				
The AWDG provides a screen (not a criterion) of 0.5 Bq/L for both gross alpha and gross beta, as well as a chemical toxicity criterion for uranium (total) of 0.017 mg/L. Analysis undertaken supersedes the screen, therefore WHO criteria also adopted. AWDG requires a dose assessment (mSv per year) as detailed below.				



Uranium 238

Uranium-238 was reported above the conservative human health screening criteria (i.e. drinking water criterion) in a single sample obtained from groundwater monitoring well WB20. Water sampled from this well has consistently reported elevated uranium over previous GMEs. The screening criterion adopted in the first instance (0.21 Bq/L) is very conservative. Generally, uranium (total) is screened on a chemical toxicity basis (i.e. mg/L) rather than on an activity basis. The actual activity criterion for uranium (total) given in the Australian Drinking Water Guidelines is 3 Bq/L.

A uranium-238 activity concentration of 3 Bq/L is equivalent to a chemical concentration of natural uranium of 0.24 mg/L. This is considerably greater than the guideline of 0.017 mg/L derived from the chemical toxicity data. The guideline value derived from chemical toxicity data is therefore also protective of radiological effects. Subsequently the 3 Bq/L criterion provided was adjusted down to 0.21 Bq/L to represent 0.017 mg/L.

Note that the activities reported are background activities, pre-mining. Generally uranium may be present in the environment as a result of various sources/ mechanisms (e.g. leaching from soils, rocks and natural deposits, release in mill tailings, combustion of coal and other fuels, and use of phosphate fertilisers).

Naturally occurring uranium comprises of three radionuclides, U-238, U-234, and U-235. U-238 and U-234 decay predominantly by alpha particle emission, whereas U-235 emits both gamma rays and alpha particles. Natural uranium consists almost entirely of the U-238 isotope, the other isotopes being less than 1% abundant.

Studies overseas have reported uranium concentrations in drinking water of generally less than 0.001 mg/L; however, concentrations as high as 0.7 mg/L have been reported in some private water supplies in Canada (NHMRC, 2011).

With respect to the split sample from WB20 (filtered versus unfiltered), the reported similar concentrations in each sample (filtered and unfiltered) indicates that uranium-238 is likely present as soluble oxidised hexavalent uranium (noting the sparing solubility of reduced uranium as uraninite), as previously discussed in project GME reporting.

Radium 226 and 228

Radium isotopes are formed as a result of radioactive decay of uranium-238 and thorium-232, both of which occur naturally in the environment. The two most significant isotopes in this process, in terms of radiological health, are radium-226 (uranium series; note that Radium-226 is an alpha emitter) and radium-228 (thorium series, a beta emitter), which have half-lives of 1,620 years and 5.8 years, respectively.

Of the radionuclides that comprise the natural thorium and uranium series, radium-226 and radium-228 are those most likely to be found in drinking water, and this occurs more commonly in supplies derived from groundwater.

Concentrations in surface water are likely to be extremely low (radium concentrations in Australian surface water supplies are generally below 0.02 Bq/L according to NHMRC, 2011). Concentrations of radium isotopes in groundwater vary according to the type of aquifer minerals and dissolved anions such as chloride, carbonate, and sulfate anions, which tend to increase the mobility of radium.

Radium is widespread in the environment and trace amounts are found in many foods. The average dietary intake is estimated to be 15 Bq per year (UNSCEAR 2000).



In supplies derived from groundwater sources, radium-226 and radium-228 concentrations vary considerably depending on the aquifer, and it is not uncommon in small supplies to find concentrations up to, or exceeding, 0.5 Bq/L.

With respect to the Balranald pre-mining groundwater analysis, radium 226 (uranium series) was reported above the adopted AWDG screening criterion of 0.5 Bq/L in three samples (and in excess of the WHO 1 Bq/L screening criterion in the same three samples).

Radium-228 (thorium series) was reported below the AWDG screening criterion of 0.5 Bq/L in all samples except WB17 but above the WHO 0.1 Bq/L screening criterion in all samples excepting GW036674(1).

An annual dose assessment from waters containing elevated activities is required for screening against ADWG (2011) annual dose thresholds for drinking waters, as discussed below.

Lead 210

Lead-210, like radium-226, is a decay product of the uranium-238 series. Food is the most important route by which lead-210 enters the human body, and the annual intake depends on diet: highest concentrations are found in fish and other aquatic species. Generally, lead-210 concentrations in drinking water are considerably less than concentrations of either radium-226 or radium-228.

There are only limited literature data on concentrations of lead-210 in Australian drinking water supplies. ADWG (2011) reports that lead-210 concentrations are probably below 0.05 Bq/L.

The ADWG criteria does not include a criterion for lead-210 however the WHO prescribes a criterion of 0.1 Bq/L. Lead-210 was reported at limits of reporting however given the conservatism of the screening criterion, all samples failed such criterion.

As with radium 226 and 228; an annual dose assessment from waters containing elevated activities is required for screening against ADWG annual dose thresholds for drinking waters, as discussed below.

Dose Screening Assessment

The AWDG criteria adopts a 10 step flow chart for determination of the radiological quality of water, beginning at Step 1 with a screening activity level of 0.5 Bq/L for both gross alpha/beta. If screening levels are not exceeded then there is no requirement for further assessment. If either or both screening levels are exceeded then it is necessary to identify the specific radionuclides and their activities. The annual dose rate from such radionuclides must then be calculated.

If the sum of the annual doses from all radionuclides is less than 0.5 mSv then no further action is required. If the sum of the annual doses from all radionuclides exceeds 0.5 mSv then (for drinking water supply cases) it is inappropriate to rely on a single analysis to determine annual exposure and therefore radionuclides should be sampled quarterly to obtain an accurate profile of radiological quality (i.e. to account for seasonal variations).

If the total annual dose lies between 0.5 and 1.0 mSv then the guideline intervention has not been exceeded but discussion with the relevant health authority must be undertaken to determine appropriate monitoring strategies.



If the total annual dose exceeds 1.0 mSv then the guideline for intervention has been exceeded. Waters calculated to have an annual dose in excess of 10 mSv are not to be used for drinking water in any circumstance.

Given the prescribed screening approach presented in the ADWG (2011), a total annual dose has been calculated for each of the sampled waters, in order to gauge against annual dose screening values.

Further detailed information on the units of radioactivity and dose measurement can be found in Section 7.5 of the AWDG (NHMRC, 2011). Briefly, the dose arising from the intake of 1 Bq (by ingestion) of a radioisotope in a particular chemical form can be estimated using a dose conversion factor. Data for age related dose conversion factors for ingestion of radionuclides have been published by the International Commission on Radiological Protection (ICRP, 1996). The dose conversion factors used in the total annual dose calculation of Balranald waters is presented in Table 5-2.

Table 5-2 – Summary of Dose per Unit Intake for Adult Members of the Public (ICRP, 1996)

Category	Radionuclide	Dose per unit intake (mSv/Bq)
Natural uranium series	Uranium-238	4.5×10^{-5}
	Uranium-234	4.9×10^{-5}
	Thorium-230	2.1×10^{-4}
	Radium-226	2.8×10^{-4}
	Lead-210	6.9×10^{-4}
	Polonium-210	1.2×10^{-3}
	Thorium-234	3.4×10^{-9}
Natural thorium series	Thorium-232	2.3×10^{-4}
	Radium-228	6.9×10^{-4}
	Thorium-228	7.2×10^{-5}

The annual dose from an individual radionuclide consumed in water is calculated as:

$$\text{Annual dose (mSv/ year)} = \text{dose per unit intake (mSv/Bq)} \times \text{annual water consumption (L/ year)} \\ \times \text{radionuclide concentration (Bq/L)}$$

The WHO (2008) estimate that adults on average consume 2 L of water per day and this figure is believed to be an appropriate figure for Australia, giving an annual consumption of 730 L for each adult Australian.

The calculated annual dose per water sample/ location is presented as Table 3 (at rear¹). A summary of the annual doses above the 'notice' screening threshold of 0.5 mSv per year is presented in Table 5-3. Sampled waters not presented in Table 5-3 are below relevant thresholds.

¹ Note that to facilitate calculations, those activities reporting as '<' are calculated as the reported activity (conservative).



Table 5-3 – Summary of Waters Exceeding Relevant Dose Thresholds

Water	Calculated Mean Annual Dose (mSv/ year) from Ingestion (adults)
WB20 (Shepparton Formation)	1.36
WB17 (Loxton-Parilla Sands)	0.82
N28 (Loxton-Parilla Sands)	0.67
GW036790(2) (Loxton-Parilla Sands)	0.58
Notes (provided in NHMRC, 2011 - provided here for context)	
	0.5 mSv per year Consult with relevant health authorities. Review sampling frequency. Evaluate operational options to reduce exposure.
	1 – 10 mSv per year Consult with relevant health authorities. Review sampling frequency. Evaluate operational options to reduce exposure. Assess management options. Implement management options.

In summary, a single sampled water (WB20, Shepparton Formation – although potentially screening the Loxton Parilla Sands) reported a calculated annual dose above the ADWG threshold of 1 mSv per year, with three waters above the ‘watching brief’ threshold of 0.5mSv per year.

Given some apparent potential for discrete alterations to occur with respect to aquifer hydrogeochemistry, a potential future increase in annual dose in waters sampled from WB17, N28 and GW036790(1) (Loxton Parilla Sands) cannot be ruled out in the first instance (noting dissolved anions such as chloride, carbonate, and sulfate anions tend to increase the mobility of radium – thus increases in such may increase radium mobility in such waters). Equally, localised elevated activities and doses may be apparent in and around operational groundwater well screens in accordance with geochemical equilibration changes and partition/ dissolution kinetics.

However as noted earlier, the salinity of these waters is notably elevated, and thus the salinity precludes the use of such waters for potable use (abstraction).



Table 5-4 – Waters Reporting Elevated Dose and Respective Salinities

Water	Formation	Calculated Mean Annual Dose (mSv/year) from Ingestion (adults)	Approx. Maximum Salinity (TDS, mg/L)	Potable Use TDS Threshold (mg/L) – ADWG (2011) 'unacceptable TDS'	Likely to be Used for Potable Abstraction?
WB20	Shepparton	1.36	34,600	1,200	No
WB17	Loxton Parilla Sands	0.82	35,300	1,200	No
N28	Loxton Parilla Sands	0.67	18,600	1,200	No
GW036790(1)	Loxton Parilla Sands	0.58	27,000	1,200	No

5.3 RADIONUCLIDE ANALYTICAL RESULTS – IRRIGATION & STOCK WATER SCREENING

A comparison of the data to ANZECC screening criteria for irrigation and stock watering indicated that waters sampled from groundwater well WB20 (Shepparton Formation) exceeded the uranium-238 criterion for irrigation and stock watering. It is considered that based on reported salinity that the water would be precluded for use for such purpose.

5.4 RADIONUCLIDE DISTRIBUTION

The calculated annual dose for each of the sampled waters is plotted in Figure 5-1 to indicate annual doses per zone/ domain. The highest doses are those as summarised in Table 5-3 (West Balranald mining extent/ down hydraulic gradient), with elevated doses being calculated for the Nepean mining extent (i.e. within the 0.5 – 1.0 mSv range).

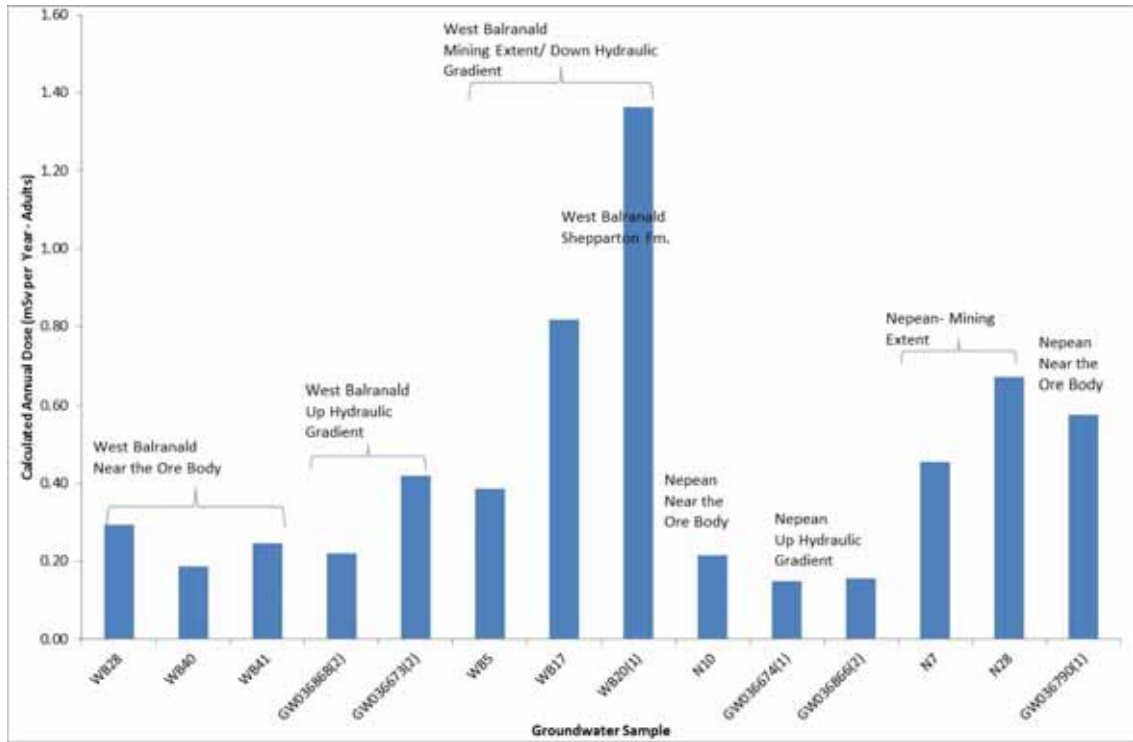


Figure 5-1 – Calculated Annual Dose of Waters per Zone



6 CONCLUSIONS

The June 2014 pre-mining Groundwater Radionuclide Monitoring Event for the Balranald Mineral Sands Project was undertaken for the purpose of providing a baseline background understanding of radionuclide distribution in groundwater relevant to the Site/project and for use as a basis for understanding temporal/spatial trends and for future comparison against any changes brought about as a result of mining operations. Baseline groundwater monitoring data will become a control against any measured impact of the future mining operations and activities.

Key findings of the radionuclide monitoring event included the following:

- With respect to human health screening (i.e. ingestion of water), only one water (sampled from WB20) exceeded the ADWG dose threshold of 1 mSv per year, largely driven by uranium-238, and radium-228 from the thorium series. Notwithstanding the activity, it is not expected that such water would be suitable for potable use due to salinity.
- A split sample from WB20 (filtered versus unfiltered) indicates that uranium-238 is likely present as soluble oxidised hexavalent uranium (noting the sparing solubility of reduced uranium as uraninite), as previously discussed in project GME reporting.
- Three waters were calculated to have an annual dose in the range 0.5 – 1.0 mSv. It is not clear based on current understanding of the system during mining operations (and post operations) whether discrete alterations to the hydrogeochemistry of the groundwater would have potential to increase the annual dose based on phase partitioning, dissolution etc.
- Equally, discrete and localised occurrence of increased activity may occur in and around operational extraction or injection bores (relative to annual dose threshold) due to discrete localised alteration to hydrogeochemistry (i.e. formation and dissolution of ferric oxyhydroxides etc.).
- Radium 228 appears to be generally elevated in all waters sampled, relevant to WHO radium 228 screening criterion for drinking waters (0.1 Bq/L), independent of zones/ domains (although the highest activities were generally associated with waters sampled from bores within or down hydraulic gradient of the West Balranald mining extent).
- Lead 210 exceeded the conservative screening WHO screening criterion of 0.1 Bq/L likely as a function of the limit of reporting being higher than the criterion. Lead-210 was included in dose assessment calculations and is not considered to be a potentially significant issue.
- Polonium-210 was reported as being elevated in the inter laboratory sample. It is noted that the secondary laboratory adopted liquid scintillation for polonium-210 emanation. The accuracy of such a technique with respect to a notably saline water may be potentially compromised. International Standards Organisation guideline ISO 13161:2011 recommends use of alpha spectrometry.



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Tables

Table 1 - Summary of Analytical Results (Drinking Water/ Human Health)

						WEST BALRANALD								NEPEAN								
						Near the Ore Body			Up-Hydraulic Gradient		Mining Extent/ Down Hydraulic Gradient			Near the Ore Body		Up-Hydraulic Gradient		Mining Extent				
						WB28	WB40	WB41	GW036868(2)	GW036673(2)	WB5	WB17	WB20(1)	WB20(2)	N10	GW036790(2)	GW036674(1)	GW036866(2)	N7	N28		
						14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1		
						SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS		
						3.6.14	3.6.14	3.6.14	5.6.14	5.6.14	3.6.14	3.6.14	2.6.14	2.6.14	2.6.14	4.6.14	4.6.14	4.6.14	4.6.14	2.6.14	2.6.14	
														Filtered	Un-filtered							
Analyte	Criteria	Screening Level	SGS LOR (moving detection per method as per ISO11929)	ALS LOR	Units																	
Naturally Occurring U-238 Series																						
uranium 238	AWDG	0.21	<0.02	0.001	Bq/L		<0.02	<0.02			<0.02		2.6	2.7			<0.02			<0.02		
thorium 234	CDWG	20	-	2	Bq/L	<0.17	<0.13	<0.15	<0.14	<0.45	<0.43	0.12	2.2			<0.18	<0.13	0.09	<0.14	<0.47	<0.45	
radium 226	WHO	1	-	0.2	Bq/L	0.104	0.091	0.123	0.109	0.06	0.151	1.82	0.5			0.114	1.87	0.082	<0.053	0.202	1.064	
lead 210	WHO	0.1	-	0.05	Bq/L	<0.16	<0.13	<0.13	<0.15	<0.6	<0.4	<0.17	<0.61			<0.16	<0.14	<0.13	<0.14	<0.61	<0.42	
polonium-210	WHO	0.1	-	0.05	Bq/L	<0.013			0.0124	0.0034		0.0054			<0.0044	0.025	0.0131			0.0081		
Naturally Occurring Thorium Series																						
thorium 232	CDWG	0.1	-	0.001	Bq/L		0.01	0.014			<0.005		<0.005	<0.005			<0.005		<0.005		<0.005	
radium 228	WHO	0.1	-	0.2	Bq/L	0.325	0.194	0.297	0.206	0.189	0.298	0.683	1.72			0.194	0.162	0.097	<0.14	0.185	0.472	
thorium 228	CDWG	2	-	0.2	Bq/L	<0.039	<0.029	<0.036	<0.037	<0.039	<0.038	<0.030	<0.034			<0.032	<0.034	<0.017	<0.033	0.036	<0.043	
Naturally Occurring Uranium Radioisotopes																						
uranium 238	AWDG	0.21	-	0.001	Bq/L	0.053			0.012	0.0099		0.0509			0.0568	0.151	0.0136			0.0358		
uranium-235	AWDG	0.21	-	0.001	Bq/L	0.0113			0.00105	<0.0017		0.0055			0.0046	0.0174	0.0025			0.0027		
uranium-234	AWDG	0.21	-	0.004	Bq/L	0.083			0.012	0.0109		0.0569			0.066	0.154	0.0134			0.0609		
Naturally Occurring Thorium Radioisotopes																						
thorium-232	CDWG	0.1	-	0.001	Bq/L	<0.013			<0.0034	<0.0019		<0.0045			0.0054	<0.0095	0.0038			<0.0036		
thorium-230	CDWG	0.4	-	0.004	Bq/L	0.036			0.0261	0.0212		0.0157			0.0172	0.035	0.021			0.00243		
thorium-228	CDWG	2	-	0.2	Bq/L	0.019			0.0112	0.0128		0.0189			0.0099	<0.0098	0.0109			0.0049		
thorium-227	WHO	10	-	0.2	Bq/L	0.022			<0.0071	<0.017		<0.0086			<0.008	0.017	<0.006			<0.0076		

Table 2 - Summary of Analytical Results (Irrigation/ Stock Watering)

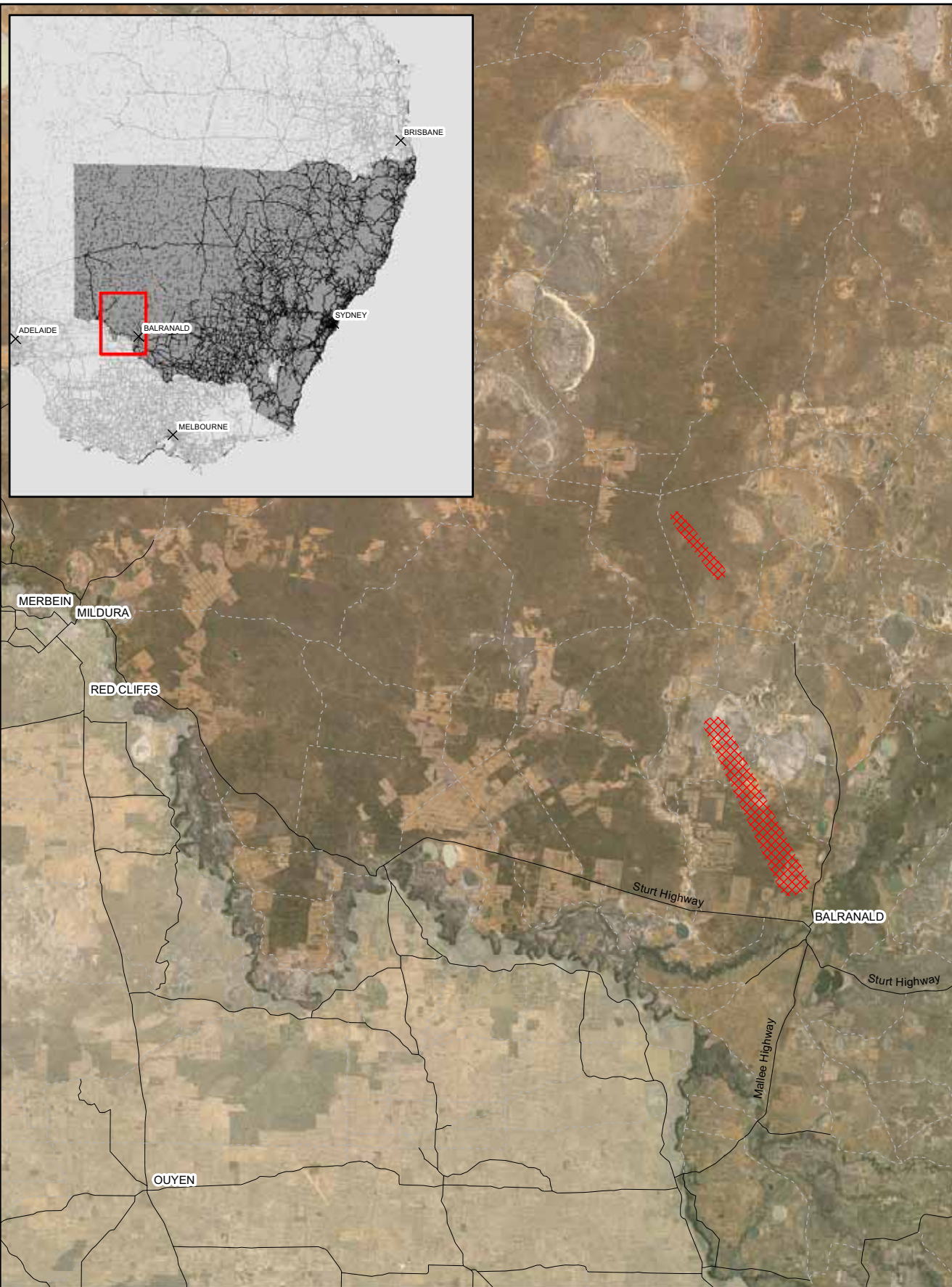
						WEST BALRANALD								NEPEAN								
						Near the Ore Body			Up-Hydraulic Gradient		Mining Extent/ Down Hydraulic Gradient			Near the Ore Body		Up-Hydraulic Gradient		Mining Extent				
						WB28	WB40	WB41	GW036868(2)	GW036673(2)	WB5	WB17	WB20(1)	WB20(2)	N10	GW036790(2)	GW036674(1)	GW036866(2)	N7	N28		
						14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1		
						SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS		
						3.6.14	3.6.14	3.6.14	5.6.14	5.6.14	3.6.14	3.6.14	2.6.14	2.6.14	2.6.14	4.6.14	4.6.14	4.6.14	4.6.14	2.6.14	2.6.14	
														Filtered	Un-filtered							
Analyte	Criteria	Screening Level	SGS LOR (moving detection per method as per ISO11929)	ALS LOR	Units																	
Naturally Occurring U-238 Series																						
uranium 238	ANZECC (2000)	0.2	<0.02	0.001	Bq/L		<0.02	<0.02			<0.02		2.6	2.7				<0.02		<0.02		
thorium 234	-	-	-	2	Bq/L	<0.17	<0.13	<0.15	<0.14	<0.45	<0.43	0.12	2.2		<0.18	<0.13	0.09	<0.14	<0.47	<0.45		
radium 226	ANZECC (2000)	5	-	0.2	Bq/L	0.104	0.091	0.123	0.109	0.06	0.151	1.82	0.5		0.114	1.87	0.082	<0.053	0.202	1.064		
lead 210	-	-	-	0.05	Bq/L	<0.16	<0.13	<0.13	<0.15	<0.6	<0.4	<0.17	<0.61		<0.16	<0.14	<0.13	<0.14	<0.61	<0.42		
polonium-210	-	-	-	0.05	Bq/L	<0.013			0.0124	0.0034		0.0054			<0.0044	0.025	0.0131		0.0081			
Naturally Occurring Thorium Series																						
thorium 232	-	-	-	0.001	Bq/L		0.01	0.014			<0.005		<0.005	<0.005				<0.005		<0.005		
radium 228	ANZECC (2000)	2	-	0.2	Bq/L	0.325	0.194	0.297	0.206	0.189	0.298	0.683	1.72		0.194	0.162	0.097	<0.14	0.185	0.472		
thorium 228	-	-	-	0.2	Bq/L	<0.039	<0.029	<0.036	<0.037	<0.039	<0.038	<0.030	<0.034		<0.032	<0.034	<0.017	<0.033	0.036	<0.043		
Naturally Occurring Uranium Radioisotopes																						
uranium 238	ANZECC (2000)	0.2	-	0.001	Bq/L	0.053			0.012	0.0099		0.0509			0.0568	0.151	0.0136		0.0358			
uranium-235	-	-	-	0.001	Bq/L	0.0113			0.00105	<0.0017		0.0055			0.0046	0.0174	0.0025		0.0027			
uranium-234	-	-	-	0.004	Bq/L	0.083			0.012	0.0109		0.0569			0.066	0.154	0.0134		0.0609			
Naturally Occurring Thorium Radioisotopes																						
thorium-232	-	-	-	0.001	Bq/L	<0.013			<0.0034	<0.0019		<0.0045			0.0054	<0.0095	0.0038		<0.0036			
thorium-230	-	-	-	0.004	Bq/L	0.036			0.0261	0.0212		0.0157			0.0172	0.035	0.021		0.00243			
thorium-228	-	-	-	0.2	Bq/L	0.019			0.0112	0.0128		0.0189			0.0099	<0.0098	0.0109		0.0049			
thorium-227	-	-	-	0.2	Bq/L	0.022			<0.0071	<0.017		<0.0086			<0.008	0.017	<0.006		<0.0076			

Table 3 - Calculated Mean Annual Dose for Adults from Sampled Waters (Ingestion)

Client	Iluka Resources	Location	WB28	WB40	WB41	GW036868(2)	GW036673(2)	WBS	WB17	WB20(1)	N10	GW036674(1)	GW036666(2)	N7	N28	GW036790(1)	WB20(2)		
Project Code	CP-01	Report No.	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1	14-1448-R1		
Criteria	Radionuclide Screen	Laboratory	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS	SGS ARS		
Grey Shade = Exceedance of Criterion		Date	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14	3.6.14		
Analyte	Dose per Unit Intake (mSv/Bq/L)	Annual Water Consumption (L)	Units																
Naturally Occurring U-238 Series																			
uranium 238	4.50E-05	7.30E+02	Bq/L		0.02	0.02			0.02		2.6		0.02		0.02		2.7		
thorium 234*	3.40E-09	7.30E+02	Bq/L	0.17	0.13	0.15	0.14	0.45	0.43	0.12	2.2	0.18	0.09	0.14	0.47	0.45	0.13		
radium 226	2.80E-04	7.30E+02	Bq/L	0.104	0.091	0.123	0.109	0.06	0.151	1.82	0.5	0.114	0.082	0.053	0.202	1.054	1.87		
lead 210	6.90E-04	7.30E+02	Bq/L	0.16	0.13	0.13	0.15	0.6	0.4	0.17	0.61	0.16	0.13	0.14	0.61	0.42	0.14		
Naturally Occurring Thorium Series																			
thorium 232	2.30E-04	7.30E+02	Bq/L		0.01	0.014			0.005		0.005		0.005		0.005		0.005		
radium 228	6.90E-04	7.30E+02	Bq/L	0.325	0.194	0.297	0.206	0.189	0.298	0.683	1.72	0.194	0.097	0.14	0.185	0.472	0.162		
thorium 228	7.20E-05	7.30E+02	Bq/L	0.039	0.029	0.036	0.037	0.039	0.038	0.03	0.034	0.032	0.017	0.033	0.036	0.043	0.034		
Naturally Occurring Uranium Radioisotopes																			
uranium 238	4.50E-05	7.30E+02	Bq/L	0.053			0.012	0.0099		0.0509		0.0568	0.0136		0.0358		0.151		
uranium-235*	4.70E-08	7.30E+02	Bq/L	0.0113			0.00105	0.0017		0.0055		0.0046	0.0025		0.0027		0.0174		
uranium-234	4.90E-05	7.30E+02	Bq/L	0.083			0.012	0.0109		0.0569		0.066	0.0134		0.061		0.154		
Naturally Occurring Thorium Radioisotopes																			
thorium-232	2.30E-04	7.30E+02	Bq/L	0.013			0.0034	0.0019		0.0045		0.0054	0.0038		0.0036		0.0095		
thorium-230	2.10E-04	7.30E+02	Bq/L	0.031			0.0261	0.0212		0.0157		0.0172	0.021		0.00243		0.035		
thorium-228	7.20E-05	7.30E+02	Bq/L	0.019			0.0112	0.0128		0.0189		0.0099	0.0109		0.0049		0.0098		
thorium-227*	8.80E-09	7.30E+02	Bq/L	0.022			0.0071	0.017		0.0086		0.008	0.006		0.0076		0.017		
polonium-210	1.20E-03	7.30E+02	Bq/L	0.013			0.0124	0.0034		0.0054		0.0044	0.0131		0.0081		0.025		
Calculated Total Annual Dose from Water					0.29	0.19	0.25	0.22	0.42	0.39	0.82	1.36	0.22	0.15	0.16	0.46	0.67	0.58	0.09

All dose per unit intake factors from ADWG except (*) from Schedule 2 (Table II-VI) of International Atomic Energy Authority Report 26

Figures



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Legend

 Areas of Interest



Land & Water Consulting Pty Ltd
 Email: enquiries@lwconsulting.com.au
 Web: www.lwconsulting.com.au



Figures in Set 1 of 3

Site Locality Plan

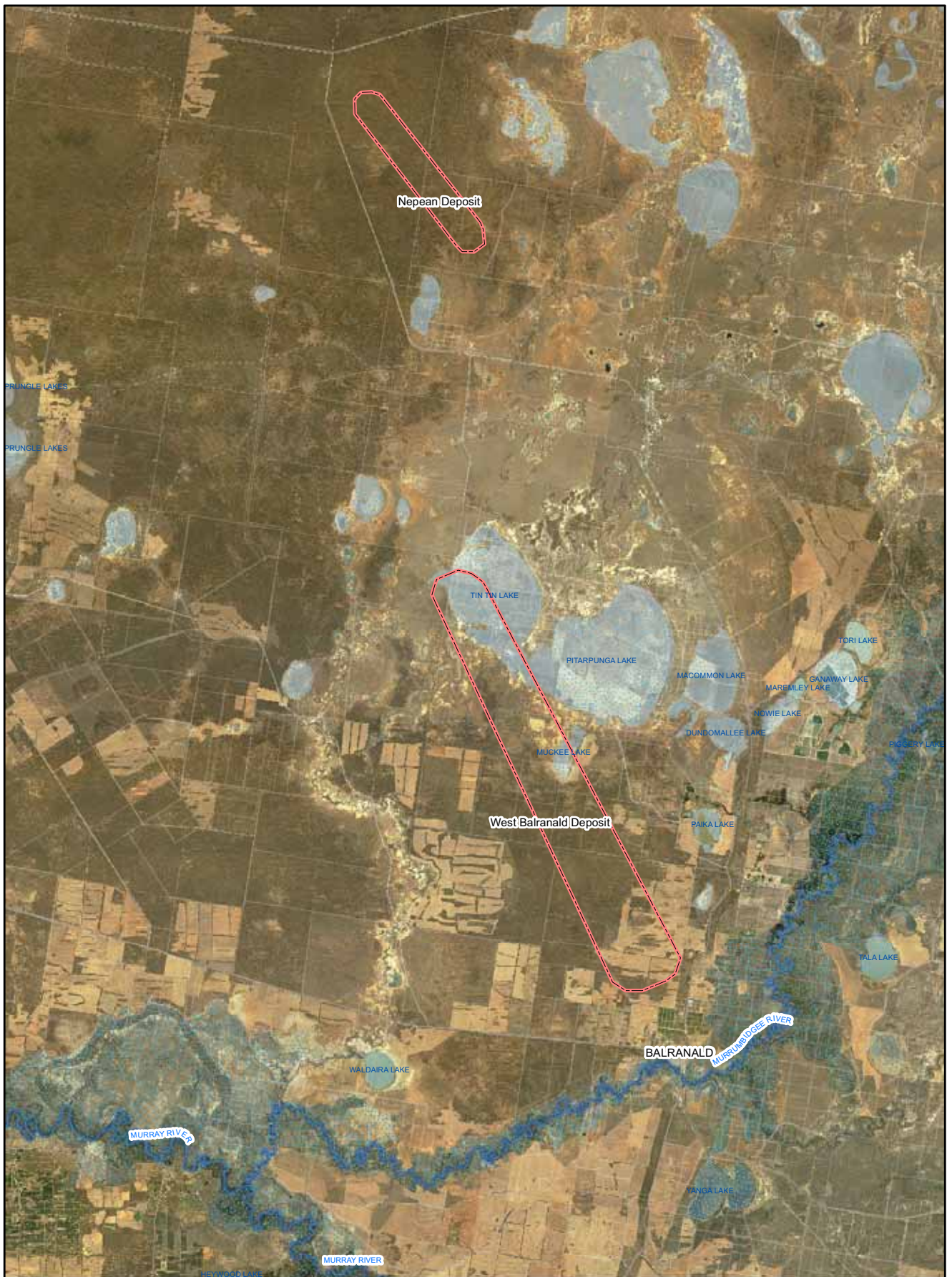
Date: October 2013

Figure

1

Revision

A



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Legend

Extent of Target Ore Bodies

Water Course

Non-Perennial/Intermittent/Fluctuating

Perennial/Permanent



Land & Water Consulting Pty Ltd
 Email: enquiries@lwconsulting.com.au
 Web: www.lwconsulting.com.au

Figures in Set 2 of 3

Location of Ore Deposits and Regional Site Features

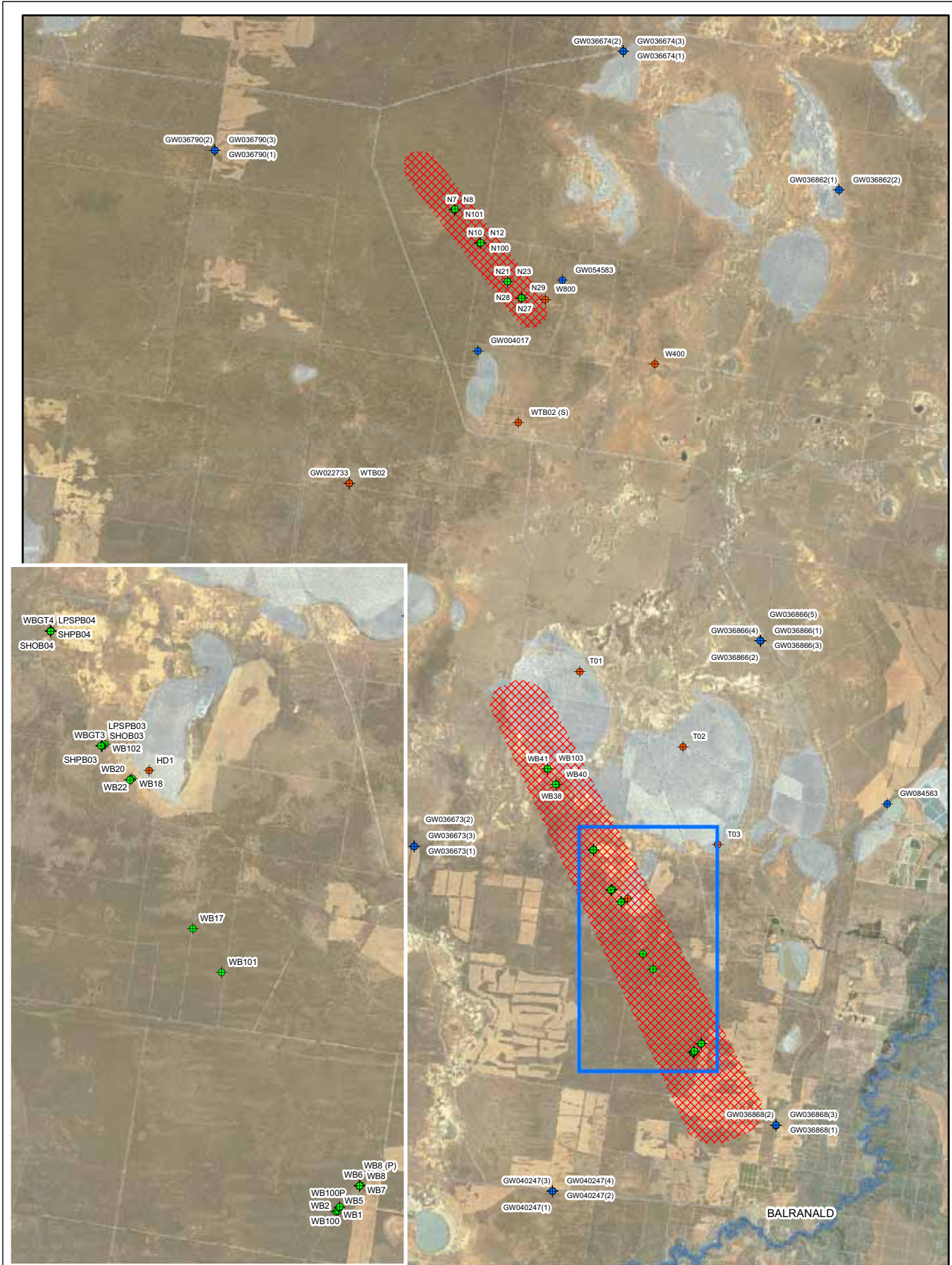
Date: October 2013

Figure


2

Revision

A



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<p>Legend</p> <p>Extent of Target Ore Bodies</p> <p>Water Course</p> <ul style="list-style-type: none"> Non-Perennial/Intermittent/Fluctuating Perennial/Permanent 	<p>Groundwater Wells</p> <ul style="list-style-type: none"> Government Register Monitoring/Mining Private/Stock 	 <p>Land & Water Consulting Pty Ltd Email: enquiries@lwconsulting.com.au Web: www.lwconsulting.com.au</p>	<p>Figures in Set 3 of 3</p> <p>Groundwater Well Location Plan</p> <p>Date: October 2013</p>	<p>Figure 3 Revision A</p>
<p>0 2.5 5 10 15 20 Kilometers</p>				

Appendix A
Groundwater Field Sheets

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions	
Client:	Iulka Resources LTD			Rain:	—
Job Number:	CP-01-01	Bore Locked (Y/N)		Wind Direction:	—
Project:	Mineral Sands Deposit	Well ID No.	WB20	Temperature:	17°
Location:	Bairnseld, NSW	Chem Kit No.		Wind Speed:	—
Depth to Groundwater (m-TOSC):	12.306	Well depth (m-PVC)		Cloud Cover:	10%
Depth to Groundwater (m-PVC):		Free product thickness:		Upwind Activities:	—
Depth to Groundwater (m-BGL):		RL from TOC:		Location Conditions:	Hughdale, Saltbush scrub

Field Comments		
Other Comments and Observations:	r =	H =
- Bore Conditions	R =	h =
- Fate of Tubing, etc. (left in hole/disposal)		
- Purge Volume Calculations in Liters (screened & unscreened sections)		PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$		
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)		
Shepparton formation PV =		

Purging Information							
Date:	2/6/14		Name:	L Wilkins			
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	19m
Start Time:	5.04		Finish Time:	6.05		Pump Speed:	Max 0.5l per min
Purge Volume (L)	6		No times purged:	6		Total Purge Volumes (litres)	18
Time	Volume Removed (L)	pH	E.C. (µS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
5.10	3	6.57	54117	-87.8	20.4	12.360	clear no oil
5.20	3	6.62	53973	-90.1	20.4	12.380	" "
5.30	3	6.65	49896	-95.7	17.0	12.360	" "
5.40	3	6.74	49989	-96.7	17.3	12.380	" "
5.50	3	6.73	50030	-97.7	17.4	12.380	" "
6.00	3	6.78	51007	-102.2	17.6	12.380	" "
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	AL	Signature	Date 17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions	
Client:	Iulka Resources LTD			Rain:	—
Job Number:	CP-01-01	Bore Locked (Y/N)	Y	Wind Direction:	SW
Project:	Mineral Sands Deposit	Well ID No.	GW036790-2	Temperature:	10°C
Location:	Bairnseld, NSW	Chem Kit No.		Wind Speed:	low
Depth to Groundwater (m-TOSC):		Well depth (m-PVC)		Cloud Cover:	High
Depth to Groundwater (m-PVC):		Free product thickness:		Upwind Activities:	—
Depth to Groundwater (m-BGL):		RL from TOC:		Location Conditions:	

Field Comments		
Other Comments and Observations:	r =	H =
- Bore Conditions	R =	h =
- Fate of Tubing, etc. (left in hole/disposal)		
- Purge Volume Calculations in Liters (screened & unscreened sections)		PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$		
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)		
LPS formation PV =		

Purging Information							
Date:	4/6/14		Name:	L Wilkins P Howie RCV			
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	—
Start Time:	12.20		Finish Time:	12.45		Pump Speed:	—
Purge Volume (L)	GRAB		No times purged:	—		Total Purge Volumes (litres)	—
Time	Volume Removed (L)	pH	E.C. (µS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
12.30	GRAB	6.62	42,250	103.8	22.9	N/A	
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	AL	Signature	Date 17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions	
Client:	Xiluka Resources LTD			Rain:	-
Job Number:	CP-01-01	Bore Locked (Y/N):		Wind Direction:	-
Project:	Mineral Sands Deposit	Well ID No.	WB20	Temperature:	20°
Location:	Bairnsald, NSW	Chem Kit No.		Cloud Cover:	-
Depth to Groundwater (m-TOSC):	4.179	Well depth (m-PVC):		Upwind Activities:	-
Depth to Groundwater (m-PVC):		Free product thickness:		Location Conditions:	
Depth to Groundwater (m-BGL):		RL from TOC:		Karra access track adj	

Field Comments	
Other Comments and Observations:	r = H =
- Bore Conditions	R = h =
- Fate of Tubing, etc. (left in hole/disposal)	
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$	
where H = height of water column (m)	R = Bore Radius (m)
h = thickness of saturated filterpack (m)	r = PVC Radius (m)
LPS formation	PV =

Purging Information						
Date:	3/6/14		Name:	L Wilkins		
Method:	Low Flow		Tubing Material:	Teflon		
Start Time:	10.12		Finish Time:	11.21		
Purge Volume (L)	6		No times purged	6		
	Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)
	10.26	7	6.51	51470	-73.4	20.5
	10.36	5	6.48	51430	-79.9	20.8
	10.46	5	6.41	51797	-95.3	20.7
	10.56	5	6.37	51659	-103.9	20.6
	11.06	5	6.36	51704	-104.4	20.6
	11.16	5	6.34	51818	-107.1	20.6
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.						

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	PL	Signature	Date
			17/12/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions	
Client:	Xiluka Resources LTD			Rain:	-
Job Number:	CP-01-01	Bore Locked (Y/N):		Wind Direction:	-
Project:	Mineral Sands Deposit	Well ID No.	WB40	Temperature:	20
Location:	Bairnsald, NSW	Chem Kit No.		Cloud Cover:	100%
Depth to Groundwater (m-TOSC):		Well depth (m-PVC):		Upwind Activities:	-
Depth to Groundwater (m-PVC):	15.738	Free product thickness:		Location Conditions:	
Depth to Groundwater (m-BGL):		RL from TOC:		Karra saltbush	

Field Comments	
Other Comments and Observations:	r = H =
- Bore Conditions	R = h =
- Fate of Tubing, etc. (left in hole/disposal)	
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$	
where H = height of water column (m)	R = Bore Radius (m)
h = thickness of saturated filterpack (m)	r = PVC Radius (m)
LPS formation	PV =

Purging Information						
Date:	3/6/14		Name:	L Wilkins		
Method:	Low Flow		Tubing Material:	Teflon		
Start Time:	2.24		Finish Time:	3.11		
Purge Volume (L)	6		No times purged	4		
	Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)
	2.36	6	6.22	47284	-31.4	21.3
	2.46	5	6.20	47250	-57.9	21.2
	2.56	5	6.20	47323	-58.7	21.3
	3.06	5	6.21	47326	-64.1	21.3
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.						

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	PL	Signature	Date
			17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions			
Client:	Zilka Resources LTD			Rain:	-		
Job Number:	CP-01-01	Bore Locked (Y/N)		Temperature:	20	Wind Direction:	-
Project:	Mineral Sands Deposit	Well ID No.	WB41	Cloud Cover:	50%	Wind Speed:	-
Location:	Bairnald, NSW	Chem Kit No.		Upwind Activities:	-		
Depth to Groundwater (m-TOSC):		Well depth (m-PVC)		Location Conditions:			
Depth to Groundwater (mPVC):	15.310	Free product thickness:					
Depth to Groundwater (m-BGL):		RL from TOC:					

Field Comments			
Other Comments and Observations:	r =	H =	
- Bore Conditions	R =	h =	
- Fate of Tubing, etc. (left in hole/disposal)			
- Purge Volume Calculations in Liters (screened & unscreened sections)		PV =	
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$			
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)			
LPS formation		PV =	

Purging Information									
Date:	3/6/14		Name:	L Wilkins					
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	56m		
Start Time:	3:43		Finish Time:	4:42		Pump Speed:	max 0.5L per min		
Purge Volume (L)	No times purged		5						
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)		
3.57	7	6.17	45944	-43.7	21.2	15.335	clear no o/e		
4.07	5	6.16	45919	-68.8	21.2	15.335	" "		
4.17	5	6.16	45823	-86.1	21.1	15.335	" "		
4.27	5	6.15	46026	-86.4	21.2	15.335	" "		
4.37	5	6.15	45982	-90.9	21.2	15.335	" "		
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.									

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	PH	Signature	Date 17/12/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions			
Client:	Zilka Resources LTD			Rain:	-		
Job Number:	CP-01-01	Bore Locked (Y/N)		Temperature:		Wind Direction:	
Project:	Mineral Sands Deposit	Well ID No.	4WC36868-2	Cloud Cover:		Wind Speed:	
Location:	Bairnald, NSW	Chem Kit No.		Upwind Activities:			
Depth to Groundwater (m-TOSC):	10.529	Well depth (m-PVC)		Location Conditions:			
Depth to Groundwater (mPVC):		Free product thickness:					
Depth to Groundwater (m-BGL):		RL from TOC:					

Field Comments			
Other Comments and Observations:	r =	H =	
- Bore Conditions	R =	h =	
- Fate of Tubing, etc. (left in hole/disposal)			
- Purge Volume Calculations in Liters (screened & unscreened sections)		PV =	
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$			
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)			
LPS formation		PV =	

Purging Information									
Date:	5/6/14		Name:	L Wilkins					
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	76m		
Start Time:	8:04		Finish Time:	9:05		Pump Speed:	max 0.5L per min		
Purge Volume (L)	No times purged		5						
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)		
8.20	8	7.32	24419	-83.4	19.3	10.529			
8.30	5	7.46	24544	-123.1	19.9	10.529			
8.40	5	7.82	24371	-154.8	20.8	10.529			
8.50	5	7.71	24441	-183.4	20.5	10.529			
9.00	5	7.69	24427	-185.2	20.6	10.529			
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.									

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	PH	Signature	Date 17/12/14

Bore Purging and Groundwater Sampling Data Sheet

General Information			Weather Conditions			
Client:	Iuka Resources LTD		Rain:	-		
Job Number:	CP-01-01	Bore Locked (Y/N)	Temperature:	10	Wind Direction:	SW
Project:	Mineral Sands Deposit	Well ID No.	Cloud Cover:	High	Wind Speed:	LOW
Location:	Balranald, NSW	Chem Kit No.	Upwind Activities:	-		
Depth to Groundwater (m-TOSC):	14.450	Well depth (m-PVC)	Location Conditions:			
Depth to Groundwater (m-PVC):		Free product thickness:	Located within tree break			
Depth to Groundwater (m-BGL):		RL from TOC:				

Field Comments		
Other Comments and Observations:	r =	H =
- Bore Conditions	R =	h =
- Fate of Tubing, etc. (left in hole/disposal)		
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =	
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$		
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)		
LPS formation	PV =	

Purging Information							
Date:	5/6/14		Name:	P. HOWIESON			
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	84m
Start Time:	10.02		Finish Time:	10.55		Pump Speed:	max 0.5 L per min
Purge Volume (L)	No times purged		4		Total Purge Volumes (litres)	16.5	
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
10.20	9	7.10	50220	-44.3	21.1	14.450	
10.30	2.5	7.06	50193	-65.6	21.2	14.450	
10.40	2.5	7.02	50194	-82.3	21.1	14.450	
10.50	2.5	7.02	50192	-91.5	21.2	14.450	
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	PH	Signature	Date 17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information			Weather Conditions			
Client:	Iuka Resources LTD		Rain:	-		
Job Number:	CP-01-01	Bore Locked (Y/N)	Temperature:	14	Wind Direction:	-
Project:	Mineral Sands Deposit	Well ID No.	Cloud Cover:	-	Wind Speed:	-
Location:	Balranald, NSW	Chem Kit No.	Upwind Activities:	-		
Depth to Groundwater (m-TOSC):		Well depth (m-PVC)	Location Conditions:			
Depth to Groundwater (m-PVC):	17.121	Free product thickness:	Pinelodge access track adj			
Depth to Groundwater (m-BGL):		RL from TOC:				

Field Comments		
Other Comments and Observations:	r =	H =
- Bore Conditions	R =	h =
- Fate of Tubing, etc. (left in hole/disposal)		
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =	
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$		
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)		
LPS formation	PV =	

Purging Information							
Date:	3/6/14		Name:	L Wilkins			
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	87m
Start Time:	7.38		Finish Time:	8.31		Pump Speed:	max 0.5 L per min
Purge Volume (L)	No times purged		4		Total Purge Volumes (litres)	21	
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
7.56	9	6.64	29986	-137.0	20.0	17.130	cloudy br, no o/d
8.06	4	6.61	29791	-150.2	20.0	17.130	clear, no turb, H ₂ O odour
8.16	4	6.60	29970	-151.7	20.2	17.130	" "
8.26	4	6.60	29983	-155.3	20.1	17.130	" "
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes			
DUP-MAY RN1-ICP			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	PH	Signature	Date 17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions	
Client: Iluka Resources LTD		Bore Locked (Y/N)		Rain: -	Wind Direction: -
Job Number: CP-01-01		Well ID No. WB17		Temperature: 20°	Wind Speed: -
Project: Mineral Sands Deposit		Chem Kit No.		Cloud Cover: 60%	Upwind Activities: -
Location: Balranald, NSW		Free product thickness:		Location Conditions: Hughdale access track rd	
Depth to Groundwater (m-TOSC): 12.160		Well depth (m-PVC)			
Depth to Groundwater (m-PVC): 12.145		RL from TOC:			
Depth to Groundwater (m-BGL):					

Field Comments	
Other Comments and Observations:	r = H =
- Bore Conditions	R = h =
- Fate of Tubing, etc. (left in hole/disposal)	
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$	
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)	
LPS formation	PV =

Purging Information							
Date: 3/6/14		Name: L Wilkins					
Method: Low Flow		Tubing Material: Teflon		Pump Depth: 63m			
Start Time: 12.09		Finish Time: 1.00		Pump Speed: max 0.5 L per min			
Purge Volume (L)		No times purged: 4		Total Purge Volumes (litres): 20			
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
12.25	8	6.19	55179	-38.8	20.4	12.190	clear / b. no o/t
12.35	4	6.19	55008	-64.9	20.3	12.160	" "
12.45	4	6.20	55116	-69.9	20.4	12.160	" "
12.55	4	6.21	55090	-74.6	20.4	12.160	" "
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes		
DUP - MAY RN1 - FULL		
Purger's Name: L Wilkins	Signature	Date
Sampler's Name: L Wilkins	Signature	Date
Checked by: DH	Signature	Date 17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information				Weather Conditions	
Client: Iluka Resources LTD		Bore Locked (Y/N)		Rain: -	Wind Direction: -
Job Number: CP-01-01		Well ID No. N10		Temperature: 20°	Wind Speed: -
Project: Mineral Sands Deposit		Chem Kit No.		Cloud Cover: -	Upwind Activities: -
Location: Balranald, NSW		Free product thickness:		Location Conditions: Neparril access track rd	
Depth to Groundwater (m-TOSC): 43.315		Well depth (m-PVC)			
Depth to Groundwater (m-PVC):		RL from TOC:			
Depth to Groundwater (m-BGL):					

Field Comments	
Other Comments and Observations:	r = H =
- Bore Conditions	R = h =
- Fate of Tubing, etc. (left in hole/disposal)	
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$	
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)	
LPS formation	PV =

Purging Information							
Date: 2/6/14		Name: L Wilkins					
Method: Low Flow		Tubing Material: Teflon		Pump Depth: 55m			
Start Time: 12.37		Finish Time: 1.22		Pump Speed: max 0.5 L per min			
Purge Volume (L)		No times purged: 4		Total Purge Volumes (litres): 17			
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
12.47	5	6.68	48526	-77.1	22.3	43.360	clear, no o/t
12.57	4	6.58	48582	-83.7	22.3	43.360	" "
1.07	4	6.57	48852	-84.0	22.5	43.360	" "
1.17	4	6.55	48729	-78.0	22.5	43.360	" "
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes		
Purger's Name: L Wilkins	Signature	Date
Sampler's Name: L Wilkins	Signature	Date
Checked by: PH	Signature	Date 17/17/14

Bore Purging and Groundwater Sampling Data Sheet

General Information			Weather Conditions	
Client:	Iluka Resources LTD		Rain:	—
Job Number:	CP-01-01	Bore Locked (Y/N)	Temperature:	12°C
Project:	Mineral Sands Deposit	Well ID No.	Cloud Cover:	High
Location:	Bairanald, NSW	Chem Kit No.	Upwind Activities:	—
Depth to Groundwater (m-TOSC):	13.16	Well depth (m-PVC)	Location Conditions:	
Depth to Groundwater (mPVC):		Free product thickness:		
Depth to Groundwater (m-BGL):		RL from TOC:		

Field Comments	
Other Comments and Observations:	r = H =
- Bore Conditions	R = h =
- Fate of Tubing, etc. (left in hole/disposal)	
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$	
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)	
LPS formation	PV =

Purging Information							
Date:	4/6/14		Name:	L Wilkins			
Method:	Low Flow		Tubing Material:	Teflon			
Start Time:	1:58		Finish Time:	2:45			
Purge Volume (L)	No times purged		4		Pump Depth	72.5	
	Total Purge Volumes (litres)		14.9				
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
2:14	3	6.82	22866	32.5	22.6	13.16	
2:30	2.3	6.94	22863	-4.3	22.7	13.16	
2:35	2.3	6.85	22893	-17.1	22.7	13.16	
2:40	2.3	6.86	22107	-22.9	22.7	13.16	
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	DJI	Signature	Date
			17/7/14

Bore Purging and Groundwater Sampling Data Sheet

General Information			Weather Conditions	
Client:	Iluka Resources LTD		Rain:	—
Job Number:	CP-01-01	Bore Locked (Y/N)	Temperature:	10
Project:	Mineral Sands Deposit	Well ID No.	Cloud Cover:	High
Location:	Bairanald, NSW	Chem Kit No.	Upwind Activities:	—
Depth to Groundwater (m-TOSC):	11.095	Well depth (m-PVC)	Location Conditions:	
Depth to Groundwater (mPVC):		Free product thickness:		
Depth to Groundwater (m-BGL):		RL from TOC:		

Field Comments	
Other Comments and Observations:	r = H =
- Bore Conditions	R = h =
- Fate of Tubing, etc. (left in hole/disposal)	
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$	
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)	
LPS formation	PV =

Purging Information							
Date:	4/6/14		Name:	P. HOWIESEN			
Method:	Low Flow		Tubing Material:	Teflon			
Start Time:	4:43		Finish Time:	5:15			
Purge Volume (L)	No times purged		4		Pump Depth	55m	
	Total Purge Volumes (litres)		12.9				
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
4:55	6	6.94	20937	-53.2	20.6	11.095	
5:00	2.3	6.96	20987	-64.4	20.6	11.095	
5:05	2.3	6.90	20924	-66.0	20.5	11.095	
5:10	2.3	6.92	20900	-63.3	20.4	11.095	
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes			
Purger's Name:	L Wilkins	Signature	Date
Sampler's Name:	L Wilkins	Signature	Date
Checked by:	P.H.	Signature	Date
			17/7/14

Bore Purging and Groundwater Sampling Data Sheet

General Information			Weather Conditions	
Client:	Iluka Resources LTD		Rain:	-
Job Number:	CP-01-01	Bore Locked (Y/N)	Temperature:	17°
Project:	Mineral Sands Deposit	Well ID No.	Cloud Cover:	Fog
Location:	Bairnsdell, NSW	Chem Kit No.	Upwind Activities:	-
Depth to Groundwater (m-TOSC):	41.47	Well depth (m-PVC)	Location Conditions:	Nepean scrub
Depth to Groundwater (mPVC):		Free product thickness:		
Depth to Groundwater (m-BGL):		RL from TOC:		

Field Comments		
Other Comments and Observations:	r =	H =
- Bore Conditions	R =	h =
- Fate of Tubing, etc. (left in hole/disposal)		
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =	
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$		
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)		
LPS formation	PV =	

Purging Information							
Date:	2/6/14		Name:	L Wilkins			
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	53m
Start Time:	10.08		Finish Time:	11.13		Pump Speed:	max 0.5L per min
Purge Volume (L)	6		No times purged:	6		Total Purge Volumes (litres)	25
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
10.18	5	6.38	45333	-10.5	21.0	41.470	clear no o/t
10.28	4	6.35	45741	-37.9	21.1	41.490	" "
10.38	4	6.31	46049	-58.9	21.3	41.490	" "
10.48	4	6.30	46144	-50.1	21.4	41.490	" "
10.58	4	6.32	46151	-44.6	21.4	41.490	" "
11.08	4	6.33	46258	-51.7	21.5	41.490	" "
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes		
Purger's Name:	L Wilkins	Signature
Sampler's Name:	L Wilkins	Signature
Checked by:	[Signature]	Signature
Date:	17/7/14	Date

Bore Purging and Groundwater Sampling Data Sheet

General Information			Weather Conditions	
Client:	Iluka Resources LTD		Rain:	-
Job Number:	CP-01-01	Bore Locked (Y/N)	Temperature:	27°
Project:	Mineral Sands Deposit	Well ID No.	Cloud Cover:	-
Location:	Bairnsdell, NSW	Chem Kit No.	Upwind Activities:	-
Depth to Groundwater (m-TOSC):	24.552	Well depth (m-PVC)	Location Conditions:	Nepean scrub paddock
Depth to Groundwater (mPVC):		Free product thickness:		
Depth to Groundwater (m-BGL):		RL from TOC:		

Field Comments		
Other Comments and Observations:	r =	H =
- Bore Conditions	R =	h =
- Fate of Tubing, etc. (left in hole/disposal)		
- Purge Volume Calculations in Liters (screened & unscreened sections)	PV =	
$PV = [(H \times \pi \times r^2) + 0.2(h \times \pi \times (R^2 - r^2))] \times 1000$		
where H = height of water column (m) R = Bore Radius (m) h = thickness of saturated filterpack (m) r = PVC Radius (m)		
LPS Formation	PV =	

Purging Information							
Date:	2/6/14		Name:	L Wilkins			
Method:	Low Flow		Tubing Material:	Teflon		Pump Depth:	53m
Start Time:	2.12		Finish Time:	2.59		Pump Speed:	max 0.5L per min
Purge Volume (L)	4		No times purged:	4		Total Purge Volumes (litres)	18
Time	Volume Removed (L)	pH	E.C. (mS/cm)	Redox (mV)	Temp (Cels)	Water Level (mPVC)	Appearance (Colour / Odour / Turbidity)
2.24	6	6.63	28260	-194.40	21.4	24.590	clear w black
2.34	4	6.66	28709	-218.0	21.4	24.590	particles + H2S odour
2.44	4	6.63	28990	-220.9	21.8	24.590	" "
2.54	4	6.61	29112	-226.0	21.8	24.590	" "
Purging should continue until measurements for pH are within 0.05 pH unit, EC is within 3%, Redox is within 10mV and Temperature is within 0.5 degC of the previous set of parameters.							

Sampling Notes		
Purger's Name:	L Wilkins	Signature
Sampler's Name:	L Wilkins	Signature
Checked by:	[Signature]	Signature
Date:	17/7/14	Date

Appendix B
Certified Laboratory Analytical Reports

Certificate of Analysis

REPORT №: 14-1448-R1
Issue date: 17th July 2014
Client: Land & Water Consulting Pty. Ltd.
Address: Suite 3, 4-8 Goodwood Road
Wayville SA 5034
Contact: Mr. Peter Howieson
Telephone: 0417 585 058
E-mail: Laboratoryresults@lwconsulting.com.au; jfox@lwconsulting.com.au;
phowieson@lwconsulting.com.au
Client reference: Project Reference № CP-01-RN

SAMPLE DETAILS

Sample description or type: Water
Number of samples received: Seventeen
Date received: First batch received 6th June 2014
Second batch received 11th June 2014
Analysis required:
a. Th-234, Ra-226, Pb-210, Ra-228 and Th-228 by high resolution gamma ray spectrometry in fifteen samples.
b. Uranium isotopes (U-238, U-235 and U-234), thorium isotopes (Th-232, Th-230, Th-228 and Th-227) and Po-210 by alpha spectrometry in nine samples.
c. Uranium-238 and thorium-232 by activity conversion of elemental concentrations in eight samples.

SGS AUSTRALIAN RADIATION SERVICES

Authorised signatory:



Name:

Mr. Stephen Rutkowski



Accreditation No. 16987
Accredited for compliance
with ISO/IEC 17025

Position:

Senior Health Physicist

Important Note:

- This report supersedes any previous reports with this reference number.
 - The results in this report apply to the sample(s) as received by SGS Australian Radiation Services
 - This report has been prepared and issued in accordance with NATA's accreditation requirements.
-

RESULTS:
A. Radionuclide activity concentrations by high resolution gamma ray spectrometry and activity conversions from ICPMS
Notes:

- a) Radionuclide or gross radioactivity concentrations are expressed in becquerel per kilogram of dried solid sample or becquerel per litre of water sample unless otherwise specified. The becquerel (Bq) is the SI unit for activity and equals one nuclear transformation per second.
- b) Less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.
- c) The reported uncertainty in each result is the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%.
- d) Uranium-238 activity concentration is calculated from the uranium mass concentration using a conversion factor of 12.445 Bq·mg⁻¹.
- e) Thorium-232 activity concentration is calculated from the thorium mass concentration using a conversion factor of 4.046 Bq·mg⁻¹.
- f) SGS Australian Radiation Services sample 14-1448-17 has been analysed without filtration as requested by Land & Water Consulting Pty. Ltd.

Test method: a. Preparation – ARS-SOP-AS301 – Preparation of liquid samples for measurement by high resolution gamma ray spectrometry.
 b. Measurement – ARS-SOP-AS406 – Measurement by high resolution gamma ray spectrometry.
 MA-1400.WW.09 Dissolved Metals (U-238 and Th-232 for filtered samples)
 MA-1400.WW.10 Total Metals (U-238 and Th-232 for unfiltered sample)

		Radionuclide Concentration						
		Naturally-occurring uranium (U-238) series				Naturally-occurring thorium (Th-232) series		
Client Sample ID (ARS Lab. ID)	Units	Uranium-238	Thorium-234	Radium-226	Lead-210	Thorium-232	Radium-228	Thorium-228
WB28 (14-1448-01)	Bq·L ⁻¹	-	< 0.17	0.084 ± 0.020	< 0.16	-	0.279 ± 0.046	< 0.039
WB40 (14-1448-02)	Bq·L ⁻¹	< 0.02	< 0.13	0.071 ± 0.020	< 0.13	0.008 ± 0.002	0.164 ± 0.030	< 0.029
WB41 (14-1448-03)	Bq·L ⁻¹	< 0.02	< 0.15	0.097 ± 0.026	< 0.13	0.012 ± 0.002	0.252 ± 0.045	< 0.036
GW036868(2) (14-1448-04)	Bq·L ⁻¹	-	< 0.14	0.084 ± 0.025	< 0.15	-	0.172 ± 0.034	< 0.037



Client Sample ID (ARS Lab. ID)	Units	Radionuclide Concentration						
		Naturally-occurring uranium (U-238) series				Naturally-occurring thorium (Th-232) series		
		Uranium-238	Thorium-234	Radium-226	Lead-210	Thorium-232	Radium-228	Thorium-228
GW036673(2) (14-1448-05)	Bq·L ⁻¹	-	< 0.45	0.039 ± 0.021	< 0.60	-	0.156 ± 0.033	< 0.039
WB5 (14-1448-06)	Bq·L ⁻¹	< 0.02	< 0.43	0.120 ± 0.031	< 0.40	< 0.005	0.254 ± 0.044	< 0.038
WB17 (14-1448-07)	Bq·L ⁻¹	-	0.073 ± 0.047	1.69 ± 0.13	< 0.17	-	0.624 ± 0.059	< 0.030
WB20(1) (14-1448-08)	Bq·L ⁻¹	2.4 ± 0.2	1.94 ± 0.26	0.453 ± 0.047	< 0.61	< 0.005	1.58 ± 0.14	< 0.034
N10 (14-1448-09)	Bq·L ⁻¹	-	< 0.18	0.094 ± 0.020	< 0.16	-	0.153 ± 0.041	< 0.032
GW036674(1) (14-1448-10)	Bq·L ⁻¹	-	0.053 ± 0.037	0.069 ± 0.013	< 0.13	-	0.078 ± 0.019	< 0.017
GW036866(2) (14-1448-11)	Bq·L ⁻¹	< 0.02	< 0.14	< 0.053	< 0.14	< 0.005	< 0.14	< 0.033
N7 (14-1448-12)	Bq·L ⁻¹	-	< 0.47	0.175 ± 0.027	< 0.61	-	0.148 ± 0.037	0.021 ± 0.015
N28 (14-1448-13)	Bq·L ⁻¹	< 0.02	< 0.45	0.978 ± 0.086	< 0.42	< 0.005	0.420 ± 0.052	< 0.043
GW036790(2) (14-1448-14)	Bq·L ⁻¹	-	< 0.13	1.74 ± 0.13	< 0.14	-	0.134 ± 0.028	< 0.034
DUP-MAY-RN1 – FULL (14-1448-15)	Bq·L ⁻¹	-	< 0.20	1.68 ± 0.13	< 0.17	-	0.658 ± 0.064	< 0.030
DUP-MAY-RN1 – ICP (14-1448-16)	Bq·L ⁻¹	< 0.02	-	-	-	< 0.005	-	-
WB20(2) (14-1448-17)	Bq·L ⁻¹	2.5 ± 0.2	-	-	-	< 0.005	-	-

B. Radionuclide activity concentrations by alpha spectrometry
Notes:

- a) Radionuclide or gross radioactivity concentrations are expressed in becquerel per kilogram of dried solid sample or becquerel per litre of water sample unless otherwise specified. The becquerel (Bq) is the SI unit for activity and equals one nuclear transformation per second.
- b) Less than (<) values indicate the detection limit for each radionuclide or parameter for the measurement system used. The respective detection limits have been calculated in accordance with ISO 11929.
- c) The reported uncertainty in each result is the expanded uncertainty calculated using a coverage factor of 2, providing a level of confidence of approximately 95%.

Test method:

a. Preparation & measurement –

Uranium isotopes by alpha spectrometry after radiochemical preparation (U-238, U-235, and U-234).

Thorium isotopes by alpha spectrometry after radiochemical preparation (Th-232, Th-230, Th-228, and Th-227).

Polonium-210 by alpha spectrometry after radiochemical separation.

Client Sample ID (ARS Lab. ID)	Unit	Radionuclide concentration							
		Naturally-occurring uranium radioisotopes			Naturally-occurring thorium radioisotopes				Polonium-210
		Uranium-238	Uranium-235	Uranium-234	Thorium-232	Thorium-230	Thorium-228	Thorium-227	
WB28 (14-1448-01)	Bq·L ⁻¹	0.036 ± 0.017	0.0043 ± 0.0070	0.060 ± 0.023	< 0.013	0.021 ± 0.015	0.009 ± 0.010	0.008 ± 0.014	< 0.013
GW036868(2) (14-1448-04)	Bq·L ⁻¹	0.0087 ± 0.0033	0.00035 ± 0.00070	0.0087 ± 0.0033	< 0.0034	0.0189 ± 0.0072	0.0067 ± 0.0045	< 0.0071	0.0077 ± 0.0047
GW036673(2) (14-1448-05)	Bq·L ⁻¹	0.0071 ± 0.0028	< 0.0017	0.0079 ± 0.0030	< 0.0019	0.0147 ± 0.0065	0.0066 ± 0.0062	< 0.017	0.0014 ± 0.0020
WB17 (14-1448-07)	Bq·L ⁻¹	0.0427 ± 0.0082	0.0032 ± 0.0023	0.0481 ± 0.0088	< 0.0045	0.0102 ± 0.0055	0.0126 ± 0.0063	< 0.0086	0.0027 ± 0.0027
N10 (14-1448-09)	Bq·L ⁻¹	0.0473 ± 0.0095	0.0024 ± 0.0022	0.056 ± 0.010	0.0025 ± 0.0029	0.0110 ± 0.0062	0.0053 ± 0.0046	< 0.0080	< 0.0044
GW036674(1) (14-1448-10)	Bq·L ⁻¹	0.0102 ± 0.0034	0.0012 ± 0.0013	0.0100 ± 0.0034	0.0016 ± 0.0022	0.0147 ± 0.0063	0.0067 ± 0.0042	< 0.0060	0.0083 ± 0.0048

Client Sample ID (ARS Lab. ID)	Unit	Radionuclide concentration							
		Naturally-occurring uranium radioisotopes			Naturally-occurring thorium radioisotopes				Polonium-210
		Uranium-238	Uranium-235	Uranium-234	Thorium-232	Thorium-230	Thorium-228	Thorium-227	
N7 (14-1448-12)	Bq·L ⁻¹	0.0290 ± 0.0068	0.0012 ± 0.0015	0.0515 ± 0.0094	< 0.0036	0.0172 ± 0.0071	0.0021 ± 0.0028	< 0.0076	0.0045 ± 0.0036
GW036790(2) (14-1448-14)	Bq·L ⁻¹	0.124 ± 0.027	0.0094 ± 0.0080	0.126 ± 0.028	< 0.0095	0.023 ± 0.012	< 0.0098	0.007 ± 0.010	0.0180 ± 0.0070
DUP-MAY-RN1 – FULL (14-1448-15)	Bq·L ⁻¹	0.065 ± 0.019	< 0.0082	0.052 ± 0.018	0.0015 ± 0.0030	0.045 ± 0.017	0.017 ± 0.011	0.0049 ± 0.0080	0.0020 ± 0.0014

CERTIFICATE OF ANALYSIS

Work Order : ES1412602 Client : LAND & WATER CONSULTING PTY LTD Contact : MR PETER HOWIESON Address : Suite 3 4-8 Goodwood Road WAYVILLE SOUTH AUSTRALIA 5034 E-mail : phowieson@lwconsulting.com.au Telephone : ---- Facsimile : ---- Project : ---- Order number : ---- C-O-C number : ---- Sampler : ---- Site : ---- Quote number : ----	Page : 1 of 3 Laboratory : Environmental Division Sydney Contact : Kieren Burns Address : 277-289 Woodpark Road Smithfield NSW Australia 2164 E-mail : kieren.burns@alsglobal.com Telephone : 61 8 8359 0890 Facsimile : 61 8 8259 0875 QC Level : NEPM 2013 Schedule B(3) and ALS QCS3 requirement Date Samples Received : 06-JUN-2014 Issue Date : 18-JUL-2014 No. of samples received : 2 No. of samples analysed : 2
--	---

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Certificate of Analysis contains the following information:

- General Comments
- Analytical Results



NATA Accredited Laboratory 825

Accredited for compliance with
ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

<i>Signatories</i>	<i>Position</i>	<i>Accreditation Category</i>
Shobhna Chandra	Metals Coordinator	Sydney Inorganics
Wael Saleh	Creation & Committal Coordinator	Sydney External Subcontracting



General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

When sampling time information is not provided by the client, sampling dates are shown without a time component. In these instances, the time component has been assumed by the laboratory for processing purposes.

Where a result is required to meet compliance limits the associated uncertainty must be considered. Refer to the ALS Contact for details.

Key : CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.

LOR = Limit of reporting

^ = This result is computed from individual analyte detections at or above the level of reporting

- **EG020: LOR's have been raised due to matrix interference (High Total Dissolved Solids)**
- **Radiological work undertaken by ALS Laboratory Group (Ceska Lipa) under CAI accreditation No. L1163. Report No.PR1432447 . NATA and CAI accreditations' are both recognised under ILAC.**



Analytical Results

Sub-Matrix: WATER (Matrix: WATER)

Client sample ID

				DUP-MAY RN1-FULL	DUP-MAY RN1-ICP	----	----	----
				03-JUN-2014 15:00	03-JUN-2014 15:00	----	----	----
				ES1412602-001	ES1412602-002	----	----	----
Compound	CAS Number	LOR	Unit					
Radiological Parameters								
Radon 222	----	5.0	Bq/L	22.1	----	----	----	----
EG020F: Dissolved Metals by ICP-MS								
Uranium	7440-61-1	0.001	mg/L	----	<0.010	----	----	----
Thorium	7440-29-1	0.001	mg/L	----	<0.010	----	----	----
Radionuclides / Activity								
Lead 210	----	0.05	Bq/L	0.06	----	----	----	----
Polonium 210	----	0.05	Bq/L	0.29	----	----	----	----
Uranium 238	----	0.001	Bq/L	0.026	----	----	----	----
Thorium 234	----	2.0	Bq/L	<2.0	----	----	----	----
Uranium 235	----	0.001	Bq/L	0.001	----	----	----	----
Uranium 234	----	0.004	Bq/L	0.031	----	----	----	----
Radium 226	----	0.20	Bq/L	1.30	----	----	----	----
Thorium 232	----	0.001	Bq/L	<0.001	----	----	----	----
Thorium 230	----	0.004	Bq/L	<0.004	----	----	----	----
Protactinium 231	----	1.0	Bq/L	<1.0	----	----	----	----
Actinium 227	----	0.20	Bq/L	<0.30	----	----	----	----
Thorium 227	----	0.20	Bq/L	<0.20	----	----	----	----
Radium 223	----	0.20	Bq/L	<0.37	----	----	----	----
Radium 228	----	0.20	Bq/L	0.52	----	----	----	----
Thorium 228	----	0.20	Bq/L	<0.20	----	----	----	----
Potassium 40	13966-00-2	2.0	Bq/L	<2.0	----	----	----	----



QUALITY CONTROL REPORT

Table with 4 columns: Field Name, Value, Field Name, Value. Includes Work Order (ES1412602), Client (LAND & WATER CONSULTING PTY LTD), Laboratory (Environmental Division Sydney), and various contact and project details.

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Quality Control Report contains the following information:

- Laboratory Duplicate (DUP) Report; Relative Percentage Difference (RPD) and Acceptance Limits
• Method Blank (MB) and Laboratory Control Spike (LCS) Report; Recovery and Acceptance Limits
• Matrix Spike (MS) Report; Recovery and Acceptance Limits



NATA Accredited Laboratory 825
Accredited for compliance with ISO/IEC 17025.

Signatories

This document has been electronically signed by the authorized signatories indicated below. Electronic signing has been carried out in compliance with procedures specified in 21 CFR Part 11.

Table with 3 columns: Signatories, Position, Accreditation Category. Lists Shobhna Chandra (Metals Coordinator) and Wael Saleh (Creation & Committal Coordinator).



General Comments

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the USEPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request.

Where moisture determination has been performed, results are reported on a dry weight basis.

Where a reported less than (<) result is higher than the LOR, this may be due to primary sample extract/digestate dilution and/or insufficient sample for analysis.

Where the LOR of a reported result differs from standard LOR, this may be due to high moisture content, insufficient sample (reduced weight employed) or matrix interference.

Key :
Anonymous = Refers to samples which are not specifically part of this work order but formed part of the QC process lot
CAS Number = CAS registry number from database maintained by Chemical Abstracts Services. The Chemical Abstracts Service is a division of the American Chemical Society.
LOR = Limit of reporting
RPD = Relative Percentage Difference
= Indicates failed QC



Laboratory Duplicate (DUP) Report

The quality control term Laboratory Duplicate refers to a randomly selected intralaboratory split. Laboratory duplicates provide information regarding method precision and sample heterogeneity. The permitted ranges for the Relative Percent Deviation (RPD) of Laboratory Duplicates are specified in ALS Method QWI-EN/38 and are dependent on the magnitude of results in comparison to the level of reporting: Result < 10 times LOR:- No Limit; Result between 10 and 20 times LOR:- 0% - 50%; Result > 20 times LOR:- 0% - 20%.

Sub-Matrix: **WATER**

				Laboratory Duplicate (DUP) Report					
Laboratory sample ID	Client sample ID	Method: Compound	CAS Number	LOR	Unit	Original Result	Duplicate Result	RPD (%)	Recovery Limits (%)
EG020F: Dissolved Metals by ICP-MS (QC Lot: 3524696)									
ES1412602-002	DUP-MAY RN1-ICP	EG020B-F: Thorium	7440-29-1	0.001	mg/L	<0.010	<0.010	0.0	No Limit
		EG020B-F: Uranium	7440-61-1	0.001	mg/L	<0.010	<0.010	0.0	No Limit



Method Blank (MB) and Laboratory Control Spike (LCS) Report

The quality control term Method / Laboratory Blank refers to an analyte free matrix to which all reagents are added in the same volumes or proportions as used in standard sample preparation. The purpose of this QC parameter is to monitor potential laboratory contamination. The quality control term Laboratory Control Spike (LCS) refers to a certified reference material, or a known interference free matrix spiked with target analytes. The purpose of this QC parameter is to monitor method precision and accuracy independent of sample matrix. Dynamic Recovery Limits are based on statistical evaluation of processed LCS.

Sub-Matrix: WATER

				Method Blank (MB) Report	Laboratory Control Spike (LCS) Report			
				Result	Spike Concentration	Spike Recovery (%)	Recovery Limits (%)	
Method: Compound	CAS Number	LOR	Unit			LCS	Low	High
EG020F: Dissolved Metals by ICP-MS (QCLot: 3524696)								
EG020B-F: Thorium	7440-29-1	0.001	mg/L	<0.001	----	----	----	----
EG020B-F: Uranium	7440-61-1	0.001	mg/L	<0.001	----	----	----	----

Matrix Spike (MS) Report

The quality control term Matrix Spike (MS) refers to an intralaboratory split sample spiked with a representative set of target analytes. The purpose of this QC parameter is to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

- **No Matrix Spike (MS) Results are required to be reported.**

Matrix Spike (MS) and Matrix Spike Duplicate (MSD) Report

The quality control term Matrix Spike (MS) and Matrix Spike Duplicate (MSD) refers to intralaboratory split samples spiked with a representative set of target analytes. The purpose of these QC parameters are to monitor potential matrix effects on analyte recoveries. Static Recovery Limits as per laboratory Data Quality Objectives (DQOs). Ideal recovery ranges stated may be waived in the event of sample matrix interference.

- **No Matrix Spike (MS) or Matrix Spike Duplicate (MSD) Results are required to be reported.**



INTERPRETIVE QUALITY CONTROL REPORT

Work Order	: ES1412602	Page	: 1 of 5
Client	: LAND & WATER CONSULTING PTY LTD	Laboratory	: Environmental Division Sydney
Contact	: MR PETER HOWIESON	Contact	: Kieren Burns
Address	: Suite 3 4-8 Goodwood Road WAYVILLE SOUTH AUSTRALIA 5034	Address	: 277-289 Woodpark Road Smithfield NSW Australia 2164
E-mail	: phowieson@lwconsulting.com.au	E-mail	: kieren.burns@alsglobal.com
Telephone	: ----	Telephone	: 61 8 8359 0890
Facsimile	: ----	Facsimile	: 61 8 8259 0875
Project	: ----	QC Level	: NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Site	: ----	Date Samples Received	: 06-JUN-2014
C-O-C number	: ----	Issue Date	: 18-JUL-2014
Sampler	: ----	No. of samples received	: 2
Order number	: ----	No. of samples analysed	: 2
Quote number	: ----		

This report supersedes any previous report(s) with this reference. Results apply to the sample(s) as submitted. All pages of this report have been checked and approved for release.

This Interpretive Quality Control Report contains the following information:

- Analysis Holding Time Compliance
- Quality Control Parameter Frequency Compliance
- Brief Method Summaries
- Summary of Outliers



Analysis Holding Time Compliance

This report summarizes extraction / preparation and analysis times and compares each with recommended holding times (USEPA SW 846, APHA, AS and NEPM) based on the sample container provided. Dates reported represent first date of extraction or analysis and preclude subsequent dilutions and reruns. A listing of breaches (if any) is provided herein.

Holding time for leachate methods (e.g. TCLP) vary according to the analytes reported. Assessment compares the leach date with the shortest analyte holding time for the equivalent soil method. These are: organics 14 days, mercury 28 days & other metals 180 days. A recorded breach does not guarantee a breach for all non-volatile parameters.

Holding times for VOC in soils vary according to analytes of interest. Vinyl Chloride and Styrene holding time is 7 days; others 14 days. A recorded breach does not guarantee a breach for all VOC analytes and should be verified in case the reported breach is a false positive or Vinyl Chloride and Styrene are not key analytes of interest/concern.

Matrix: **WATER** Evaluation: * = Holding time breach ; ✓ = Within holding time.

Method Container / Client Sample ID(s)	Sample Date	Extraction / Preparation			Analysis		
		Date extracted	Due for extraction	Evaluation	Date analysed	Due for analysis	Evaluation
EG020F: Dissolved Metals by ICP-MS							
Clear Plastic Bottle - Natural (EG020B-F) DUP-MAY RN1-ICP	03-JUN-2014	---	30-NOV-2014	----	04-JUL-2014	30-NOV-2014	✓



Quality Control Parameter Frequency Compliance

The following report summarises the frequency of laboratory QC samples analysed within the analytical lot(s) in which the submitted sample(s) was(when) processed. Actual rate should be greater than or equal to the expected rate. A listing of breaches is provided in the Summary of Outliers.

Matrix: **WATER** Evaluation: ✖ = Quality Control frequency not within specification ; ✔ = Quality Control frequency within specification.

Quality Control Sample Type	Method	Count		Rate (%)			Quality Control Specification
		QC	Regular	Actual	Expected	Evaluation	
Analytical Methods							
Laboratory Duplicates (DUP)							
Dissolved Metals by ICP-MS - Suite B	EG020B-F	1	9	11.1	10.0	✔	NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Laboratory Control Samples (LCS)							
Dissolved Metals by ICP-MS - Suite B	EG020B-F	1	9	11.1	5.0	✔	NEPM 2013 Schedule B(3) and ALS QCS3 requirement
Method Blanks (MB)							
Dissolved Metals by ICP-MS - Suite B	EG020B-F	1	9	11.1	5.0	✔	NEPM 2013 Schedule B(3) and ALS QCS3 requirement



Brief Method Summaries

The analytical procedures used by the Environmental Division have been developed from established internationally recognized procedures such as those published by the US EPA, APHA, AS and NEPM. In house developed procedures are employed in the absence of documented standards or by client request. The following report provides brief descriptions of the analytical procedures employed for results reported in the Certificate of Analysis. Sources from which ALS methods have been developed are provided within the Method Descriptions.

Analytical Methods	Method	Matrix	Method Descriptions
Radionuclides (Natural) in Water	EA252	WATER	Individual Natural Radionuclides in water by High Resolution Gamma Spectrometry. Analysis is performed by ALS (Czech Republic) who hold technical accreditation #1163 for Gamma Spectrometry under CAI. CAI are a European accreditation body, equivalent to NATA in Australia and recognised internationally by NATA under ILAC.
Polonium 210 by Scintillation with ZnS(Ag)	EA256	WATER	CSN 75 7626: Analysis is performed by ALS (Czech Republic) who hold technical accreditation #1163 for Scintillation under CAI. CAI are a European accreditation body, equivalent to NATA in Australia and recognised internationally by NATA under ILAC.
Lead 210 by LL beta counting	EA257	WATER	CSN ISO 9698: Analysis is performed by low level beta counting using proportion detector after separation with ZnS. This analysis is performed by ALS (Czech Republic) who hold technical accreditation #1163 under CAI. CAI are a European accreditation body, equivalent to NATA in Australia and recognised internationally by NATA under ILAC.
Radon 222	EA259	WATER	Analysis by ALS in the Czech Republic per method W-RN222EMA: Radon 222 by scintillation emanometry.
Natural uranium & thorium isotopes	EA265	WATER	In house (ICP/SFMS): Natural uranium isotopes (U-238, U 235 and U-234) and thorium isotopes (Th-232 and Th-230) by ICP-SFMS. Analysis is performed by ALS (Czech Republic) who hold technical accreditation #1163 for Gamma Spectrometry under CAI. CAI are a European accreditation body, equivalent to NATA in Australia and recognised internationally by NATA under ILAC.
Dissolved Metals by ICP-MS - Suite B	EG020B-F	WATER	(APHA 21st ed., 3125; USEPA SW846 - 6020, ALS QWI-EN/EG020): Samples are 0.45 um filtered prior to analysis. The ICPMS technique utilizes a highly efficient argon plasma to ionize selected elements. Ions are then passed into a high vacuum mass spectrometer, which separates the analytes based on their distinct mass to charge ratios prior to their measurement by a discrete dynode ion detector.



Summary of Outliers

Outliers : Quality Control Samples

The following report highlights outliers flagged in the Quality Control (QC) Report. Surrogate recovery limits are static and based on USEPA SW846 or ALS-QWI/EN/38 (in the absence of specific USEPA limits). This report displays QC Outliers (breaches) only.

Duplicates, Method Blanks, Laboratory Control Samples and Matrix Spikes

- For all matrices, no Method Blank value outliers occur.
- For all matrices, no Duplicate outliers occur.
- For all matrices, no Laboratory Control outliers occur.
- For all matrices, no Matrix Spike outliers occur.

Regular Sample Surrogates

- For all regular sample matrices, no surrogate recovery outliers occur.

Outliers : Analysis Holding Time Compliance

This report displays Holding Time breaches only. Only the respective Extraction / Preparation and/or Analysis component is/are displayed.

- No Analysis Holding Time Outliers exist.

Outliers : Frequency of Quality Control Samples

The following report highlights breaches in the Frequency of Quality Control Samples.

- No Quality Control Sample Frequency Outliers exist.
-

Jacob Waugh

From: James Fox <jfox@lwconsulting.com.au>
Sent: Tuesday, 10 June 2014 11:32 AM
To: Jacob Waugh
Cc: Shirley LeCornu
Subject: RE: samples for Prague

Please proceed as discussed

thanks

From: Jacob Waugh [mailto:Jacob.Waugh@alsglobal.com]
Sent: Tuesday, 10 June 2014 10:59 AM
To: James Fox
Cc: Shirley LeCornu
Subject: RE: samples for Prague

Hi James,

Yes Radium 226 & 228 are included in EA252 but the LOR's are a bit higher than EA251. See below.

For the second sample we can analyse it here in Sydney by ICPMS for Uranium and Thorium but we are unable to do any activity conversions. Please confirm if you are ok to proceed with this option?

EA251

Ra 226 = 0.03 Bq/L

Ra 228 = 0.05 Bq/L

EA252

Ra 226 = 0.2 Bq/L

Ra 228 = 0.2 Bq/L

Jacob Waugh

Laboratory Co-ordinator
ALS | Environmental Division

277-289 Woodpark Road
Smithfield NSW 2164 Australia

How was your customer experience? Please send us your feedback

EnviroMail 80 – Data Management Innovation and Support – Apr 2014

EnviroMail 81 - TRH Silica and Reducing Potential False Positives on TPH

EnviroMail 83 - NSW Waste Classification

EnviroMail 00 – Summary of all EnviroMails by Category

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Appendix C
Data Quality Assessment

APPENDIX C - DATA QUALITY SUMMARY REPORT - GROUNDWATER

Project No: CP-01-01
 Site: Balranald Mineral Sands Project, Murray Basin, New South Wales
 Matrix: GROUNDWATER
 Primary Laboratory: SGS (14-1448-R1)
 Secondary Laboratory: ALS (ES1412602)
 No. of Tests Requested/ Reported: Th-234, Ra-226, Pb-210, a-228 and Th-228 by high res. Gamma spec. in 15 samples. Uranium isotopes (U-238, U-235, U-234) Thorium isotopes (Th-232, 230,228 and 227) and Po-210 by alpha spec. in 9 samples and U-238 and Th-232 by activity conversion from ICP-MS (8 samples)

Frequency of QA/QC undertaken: 1 per 15 samples
 Frequency of QA/QC Required: 1 in 20 samples is required to be duplicated

Data Quality Issue Assessed	Issue Reviewed	Results Acceptable	Comments
Sampling Technique	✓	Y	
Sample Holding Times	✓	Y	See Note 1
Analytical Procedures	✓	Y	See Note 2
Laboratory Limits of Reporting (below relevant guideline value)	✓	Y	See Note 3
Field Duplicate Agreement (RPD%)	✓	Y	See Note 4
Blank Sample Analysis			
Method Blank	NA		
Rinsate Blank	✓	Y	
Trip Blank	NA		
Laboratory Duplicate Agreement (RPD%)	✓	Y	
Matrix Spikes/Matrix Spike Duplicates			
Recovery Percentages	✓	Y	
Duplicate Agreement (RPD%)	✓	Y	
Surrogate Recoveries	✓	Y	
Other Issues	✓	Y	

Notes

Note 1: All results for key analytes were analysed within the technical holding times at both the primary and secondary laboratory.

Note 2: Secondary laboratory used scintillation for Po-210 which may have been interfered with by high salinity. Uranium isotopes were assessed by different methods (alpha spectrometry at the primary and ICP-SFMS at the secondary).

Note 3: The Laboratory Limits of Reporting were lower for Pb-210 than the WHO screening criterion however this is not considered an issue due to inclusion of Pb-210 in dose assessment.

Note 4: Between primary sample WB17 and blind-coded intra-laboratory duplicate (DUP-MAY-RN1-FULL) for thorium 230 (119%). Between primary sample WB17 and blind-coded inter-laboratory duplicate (DUP-MAY-RN1-FULL) for uranium 238 (64.8%), uranium 235 (138.5%) and uranium 234 (58.9%). The elevated RPD may be a function of the two differing methodologies applied by the primary and secondary laboratory. SGS used alpha spectrometry for assessment of uranium isotopes whereas ALS used ICP-SFMS. Between primary sample WB17 and blind-coded inter-laboratory duplicate (DUP-MAY-RN1-FULL) for polonium 210 (192.7%). This is considered to represent either an erroneous polonium result in the inter-laboratory sample given the agreement between the primary and intra sample, and the magnitude of the remainder of the natural uranium series, or a difference in transition time of polonium-210 to lead 210 (polonium has a half-life of 138 days – an error or difference in time calculation in the lab can increase the calculated activity). Similarly, differing methods were used, with SGS using alpha spectrometry and ALS using scintillation with ZnS(Ag). The accuracy of such a technique in notably saline water is suspect. International Standards Organisation guideline ISO 13161:2011 recommends use of alpha spectrometry.

Summary Comments:

Groundwater analytical data can be used as a basis of interpretation, subject to the limitations outlined above.

Recommended Corrective Action:

None



Appendix C - Quality Assurance and Control Summary (Field Duplicates)

Client	Iluka Resources
Project Code	CP-01
Criteria	Radionuclide Screen
Grey Shade = Exceeds 50% RPD Criterion	

Location	WB5	DUP-MAY-RN1-ICP		DUP-MAY-RN1-ICP		WB17	DUP-MAY-RN1-FULL		DUP-MAY-RN1-FULL	
Report No.	14-1448-R1	14-1448-R1	RPD	ES1412602	RPD	14-1448-R1	14-1448-R1	RPD	ES1412602	RPD
Laboratory	SGS ARS	SGS ARS		ALS		SGS ARS	SGS ARS		ALS	
Date	3.6.14	3.6.14		3.6.14		3.6.14	3.6.14		3.6.14	

Analyte	Criteria	Screening Level	SGS LOR	ALS LOR	Units							
Naturally Occurring U-238 Series												
uranium 238	-	-			Bq/L	<0.02	<0.02	0.026				
thorium 234	-	-			Bq/L	<0.43			0.12	<0.2		<2.0
radium 226	-	-			Bq/L	0.151			1.82	1.81	0.55	1.3
lead 210	-	-			Bq/L	<0.4			<0.17	<0.17		0.06
Naturally Occurring Thorium Series												
thorium 232	-	-			Bq/L	<0.005	<0.005	<0.001				
radium 228	-	-			Bq/L	0.298			0.683	0.722	5.55	0.52
thorium 228	-	-			Bq/L	<0.038			<0.030	<0.03		<0.20
Naturally Occurring Uranium Radioisotopes												
uranium 238	-	-			Bq/L				0.0509	0.084	49.1	0.026
uranium-235	-	-			Bq/L				0.0055	<0.0082		0.001
uranium-234	-	-			Bq/L				0.0569	0.07	20.6	0.031
Naturally Occurring Thorium Radioisotopes												
thorium-232	-	-			Bq/L				<0.0045	0.0045		<0.001
thorium-230	-	-			Bq/L				0.0157	0.062	119.2	<0.004
thorium-228	-	-			Bq/L				0.0189	0.028	38.8	<0.20
thorium-227	-	-			Bq/L				<0.0086	0.0129		<0.20
polonium-210	-	-			Bq/L				0.0054	0.0034	45.5	0.29





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