OZ MINERALS LIMITED

Carrapateena Project

Occupational Radiation Assessment

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1. INTRODUCTION

1.1 Aim of This Document

OZ Minerals Limited (OZL) is proposing to develop the Carrapateena deposit in the mid-north of South Australia via an underground mine and metallurgical processing facility. The project involves mining copper ore using the sub level caving method and processing the ore on site to produce a copper concentrate final product that can be exported to smelters around the world.

The Carrapateena ore deposit contains elevated naturally occurring uranium at a reported average concentration of approximately 239 ppm – with concentrations reaching 309 ppm U in the final years of operations. At this concentration, the Carrapateena ore and tailings will be defined as 'radioactive' under the *Radiation Protection and Control Act 1982* (SA). Accordingly, the radiological impacts to workers need to be considered and assessed.

This document provides an assessment of the potential radiation doses to workers and an overview of the proposed management measures.

2. RADIATION AND RADIATION PROTECTION

2.1 Overview of Radiation

This document assumes a basic understanding of radiation protection. For a more detailed discussion on radiation and radiation safety, refer to the *Radiation Workers' Handbook* (http://www.aua.org.au/Content/RadiationSafety.aspx) [Australian Uranium Association, 2011].

2.2 Describing Radiation

Radioactive materials occur naturally in soils, water and the air and are responsible for much of the naturally occurring radiation known as 'background radiation'. Including cosmic radiation, naturally occurring background radiation is variable and causes radiation exposure to people everywhere.

When discussing impacts of radiation on people, it is usual to say that people are 'exposed' to radiation resulting in a 'dose'. The term 'dose' is a standardised measure of radiation impact, reported as 'Sieverts' (Sv), which takes into account the different types of radiation and the way that the particular exposure occurs.

The effects of radiation depend upon the size of the dose received. At high doses, above 1 Sv, a range of radiation effects are *immediately* observable in individuals. At doses between 0.1 and 1 Sv, effects are observable in populations or groups of people, and there is a *probability* that the dose may result in an impact to an individual. Below a dose of 0.1 Sv, it is difficult to observe any effects in populations, however, it is assumed that the probability of an effect still exists.

Naturally occurring background radiation produces doses ranging from 1 to 10 mSv/y in different parts of the world. In Australia, the average dose from background radiation is 2.3 mSv/y (ARPANSA, 2012).

2.3 Framework for Radiation Protection

2.3.1 International Approach

Radiation and its effects have been studied for almost 100 years and there is International consensus on its effects and controls. The main organisations that oversee radiation and radiation protection and provide guidance and standards are:

- The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) which provides a consolidated overview of the effects of radiation by regularly reviewing research and publishing the summaries. UNSCEAR provides the scientific basis for radiation protection.
- The International Commission on Radiological Protection (ICRP) is recognised as the pre-eminent authority on radiation protection and has produced the philosophy around radiation protection and publishes recommendations on radiation protection. ICRP provides the philosophical basis for radiation protection.
- The International Atomic Energy Agency develops and publishes industry 'codes of practice' and provides advice on basic safety precautions when dealing with radiation for both operators and regulators. The IAEA develops operating standards.

In Publication 26 [ICRP, 1977], the ICRP first recommended the 'system of dose limitation' which has become the internationally accepted approach to radiation protection and is universally adopted as the basis of legislative systems for the control of radiation. It is made up of three key elements as follows:

- Justification – this means that a practice involving exposure to radiation should only be adopted if the benefits of the practice outweigh the risks associated with the radiation exposure.
- Optimisation – this means that radiation doses should be As Low As Reasonably Achievable, taking into account economic and social factors. This is also known as the ALARA principle.
- Limitation – this means that individuals should not receive radiation doses greater than the prescribed dose limits.

Within the 'system of dose limitation', the ALARA principle is generally regarded as the most important and the most effective of these elements for the control and management of radiation. In the design stage of a project, ALARA means identifying radiation hazards and making design, engineering and infrastructure decisions to ensure that potential doses are as low as reasonably achievable. In operation, ALARA is similar to continuous improvement, where ongoing efforts are made to ensure that practices, procedures and systems are monitored and reviewed.

While the ALARA principle is the foundation for radiation protection, radiation dose limits have been established to provide an absolute level of protection. The limits apply only to the radiation dose received as a result of a 'practice' and excludes natural background radiation. The limits are:

- 20 mSv/y for a worker (whilst at work), and
- 1 mSv/y for a member of the public (total year).

When assessing compliance with the limits, occupational doses may be averaged over a five-year period and there is an absolute annual limit of 50 mSv in any one year for workers (ICRP, 2007).

2.3.2 Australian Radiation Standards

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the Australian national authority on radiation protection. ARPANSA develops standards and Codes of Practice based on the IAEA codes and standards.

The primary national guidance documents related to radiation protection in the mining or processing of radioactive materials are:

- Fundamentals for Protection Against Ionising Radiation (2014) [ARPANSA, 2014a]
- The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005; known as the Mining Code [ARPANSA, 2005]
- Safety Guide for the Management of Naturally Occurring Radioactive Material [ARPANSA, 2008]
- The Code of Practice for the Safe Transport of Radioactive Material 2014 [ARPANSA, 2014b].

2.3.3 South Australian Requirements

In South Australia, the primary legislation for radiation control is the *Radiation Protection and Control Act 1982* (SA) (the Act) and associated legislation. The Act and regulations refer to permitting processes and the development of a radiation management plan and a radioactive waste management plan. The laws also enact various ARPANSA codes of practice.

3. RADIOLOGICAL ASSESSMENT OF EFFECTS

3.1 Summary of Project

A detailed description of the project is provided elsewhere and the key aspects related to radiation protection are outlined in this section.

3.2 Radiological Characteristics of the Mined Material

The mineralised ore body occurs at a depth of approximately 515 m below ground level (mBGL), extending 950 metres to 1,465 mBGL. Above the ore body there is a non-mineralised cover sequence material (containing less than 5 ppm U). The mineralisation itself lies within a basement rock which is also non-mineralised, but with a higher natural uranium content of approximately 20 ppm. On average, the ore body contains approximately 239 ppm uranium. This is equivalent to approximately 3 Bq/g of U^{238} as head of the U^{238} decay chain. Since the mineralisation is relatively undisturbed, it is highly likely that the radionuclides are in secular equilibrium, which means that the activity concentrations of the U^{238} and its decay products are the same.

For reference the world average uranium content of soils is 2.8 ppm [World Nuclear Association, 2016], and the uranium grade at Olympic Dam is approximately 600 ppm (BHP Billiton, 2009). At uranium concentrations below 600 ppm extraction is not generally considered to be economic.

3.3 Mining

OZL proposes to mine the Carrapateena deposit using the sub level caving mining method. This method is described in detail elsewhere and a summary is provided here. The method requires the development of a number of tunnels through the mineralisation on a number of levels. The area between the drives is successively blasted and the broken rock is reclaimed using load haul dump (LHD) units which transfer broken rock to an ore pass or to a truck for onward delivery to an ore pass. The mine develops in layers progressing downwards. It is planned that underground development be in-cycle fibrecreted for geotechnical purposes. Fibrecrete can reduce exposure to gamma sources as it forms a barrier between the source and the workplace. In order to provide a conservative assessment, and allow operational flexibility, the following occupational radiation exposure assessment has conservatively assumed that no fibrecrete is placed.

The important aspect is that both development and production miners work inside the mineralised area.

Ventilating workplaces in a sub level cave operation can be complex and the overriding principle is to ensure that the mine ventilation delivers fresh air to each of the work places and that contaminated air is exhausted from the mine.

The complete ventilation system makes use of both a primary ventilation circuit, which uses large diameter surface raise bores to push fresh air into the mine itself, and then secondary fans and ducting to move the fresh air to workplaces. The ventilation design criteria requiring fresh air to all working faces is standard in all modern underground mines and requires active management.

3.4 Metallurgical Processing

The proposed metallurgical processing plant would consist of essentially two sections; a concentrator and an impurity removal circuit (also known as the concentrate treatment plant).

The concentrator is a conventional crush, grind and flotation circuit in which broken ore from underground is crushed in a surface crusher (if required) and then ground in a semi autogenous mill. The ground ore slurry would report to the flotation tanks where most of the copper would be removed as a 'concentrate' with the remainder reporting to tailings. The flotation concentrate contains the majority of the copper as a copper sulphide material that was in the ore, but is only approximately 5% of the mass of the original ore. The remaining 95% of the original mass is the tailings. Testwork has shown that the majority of radionuclides report to the tailings, however, the copper concentrate material contains uranium at a concentration similar to that of the original ore and also other impurities. Therefore, the concentrate undergoes further processing in the concentrate treatment plant to remove the uranium and its decay products to levels less than 1 Bq/g, in order for the final product to be defined as 'non-radioactive'. Other impurities are also removed to acceptable levels.

Preliminary testwork has shown that the concentrate treatment plant is able to remove radionuclides and other impurities to required levels and it is anticipated that the radionuclide distribution would be as seen in Table 1.

Table 1: Radionuclide Composition of Process Streams

Material	Uranium Series Radionuclide Concentration[1]
Mineralised ore[2]	approx. 3 Bq/g
Unprocessed copper concentrate	3 Bq/g
Impurity plant residue[3]	approx. 1,000 Bq/L
Tailings	3 Bq/g
Final product (export grade copper concentrate)	< 1 Bq/g

Note 1: Concentration for U^{238} and all decay products assumed to be in secular equilibrium
Note 2: Assumes an average uranium concentration of 239 ppm
Note 3: Assumes 5% mass flow to concentrate and all radionuclides reporting to make up liquor which has a mass ratio of 2 parts liquor to 1 part solids.

4. RADIOLOGICAL IMPACT ASSESSMENT

4.1 Approach

This section provides an assessment of occupational doses. The main work groups have been identified and the exposure pathways assessed.

Estimates of doses have been calculated for:

- mine workers
- processing plant operators and
- administration workers.

Dose assessments consider the main exposure pathways being:

- gamma irradiation
- inhalation of radon decay products (RnDP) and
- inhalation of radionuclides in dust.

A literature search has not revealed any radiation impact assessments of mines using the sub level caving mining method where naturally occurring uranium levels are elevated.

The characteristics of sub level caving means that miners work inside the mineralised areas. The exposures and doses to miners working in similar conditions have been reported in the literature (BHP Billiton, 2009 and Palabora, 2013) and therefore provide a practical indicator of potential conditions when working within a mining area with elevated uranium concentrations.

Results from reported exposures from underground development work undertaken at Olympic Dam during the 1990's are available and have been used, to assess the potential doses for Carrapateena miners. The higher uranium grade at Olympic Dam has been factored into the assessment.

For the processing plant, actual results from the Olympic Dam processing facility have been used to assess worker potential doses.

In undertaking this dose assessment, there has been a large reliance on the published data from Olympic Dam [BHP Billiton, 2009]. This is because it is a source of actual dose information based on measurements in a mine and processing facility which will be similar to that proposed for Carrapateena.

In this assessment, mine worker gamma exposure has been estimated using an alternative method and then cross checked against the results obtained at Olympic Dam.

4.2 Occupational Radiation Doses – Mine Workers

4.2.1 Workgroup Description

For this assessment, specific workgroups were identified and dose estimates were made.

The estimates have been based on the Olympic Dam data, including specific factors for the Carrapateena mineralised material characteristics.

The following mining work groups have been assessed with the noted assumptions:

- LHD Operators
  - The LHD operators work inside mineralised areas and move ore from the draw points along access drives (in mineralisation) to the ore passes or to trucks.
  - Operators spend their whole day on mining equipment.
- Development Miners
  - The sub level caving method requires a significant amount of development which is mainly access drives. A development mining crew, consisting of jumbo operators, charge up and loader and truck drivers would be required to develop the drives. For development of the sub level cave, the work would be inside mineralised material and for other development work (such as general access ways), the development is outside of the mineralisation.
  - For this assessment, it is assumed that 80% of development occurs in mineralisation and 20% occurs in non-mineralised basement rock.
  - Development miners are expected to spend their whole shift on mining equipment.
- Maintenance workers
  - Routine maintenance of mine vehicles would be carried out in a surface workshop facility adjacent to the portal entrance. A small underground workshop facility would be established for minor maintenance works. The underground workshops would be ventilated with fresh air and located out of the mineralisation.
  - Maintenance workers working in the underground workshop would be expected to spend 80% of their time in the workshop and 20% of their time in the mine undertaking repairs.
  - Other work such as maintenance and repair of ventilation infrastructure, power, water and air reticulation, servicing of fixed plant such as the fans, substation would be carried out in the mine workings.

- Mine maintenance workers can work all around the mine and it is assumed that 80% of their time is spent around the mine (equally in mineralised and non-mineralised areas) and 20% in the workshop.

- Service personnel
  - Support services for the mining operations include:
    - Full time underground work (assume 50% of time in mineralisation and 50% of time in non-mineralisation)
      - miscellaneous miners
      - shotcrete crew
    - Part time underground work (assume 25% of time in mineralisation and 25% of time in non-mineralisation, with remainder of time on surface)
      - surveyors
      - supervisors
      - ventilation and radiation safety officers.

4.2.2 Gamma Radiation Exposure Rates

Gamma radiation exposure estimates are based on the work of Thomson and Wilson [Thomson and Wilson 1980] who quote a gamma exposure constant of 65 µSv/h per %U for a 2π exposure situation (which is equivalent to standing on an infinite plane source, that is, being exposed from one side only). To take account of exposure from all sides, a 4π exposure situation is used. This is equivalent to a calculated gamma exposure constant of 130 µSv/h per %U.

Based on this factor, the calculated dose rates for the various materials are as follows:

- Exposure in non-mineralised basement rock (containing 20 ppm of uranium) is 0.26 µSv/h
- Exposure in mineralised rock (containing 239 ppm of uranium) is 3.1 µSv/h.

In practice, mining equipment affords a high degree of protection from gamma radiation through absorption and attenuation. Testwork has shown that totally enclosed work cabins on mining equipment can provide up to 67% attenuation of gamma radiation and partially enclosed cabins can provide 40% attenuation (ERA, 2014). It can reasonably be assumed that large mining equipment offers, on average, a 50% reduction in gamma radiation exposure. In practice, the mining equipment is shielding the operator from gamma radiation from below, thereby turning the exposure geometry into a 2π exposure situation.

For comparison purposes, gamma measurements in development headings in ore gave average unattenuated gamma dose rates of between 5 and 6 µSv/h at Olympic Dam (BHP Billiton, 2009), which is comparable with the estimates based on the work of Thomson and Wilson 1980.

4.2.3 RnDP Exposure

The mine design requires all workplaces to be ventilated with fresh air, with contaminated air exhausted from the mine. In practice, the air that is delivered to the workplaces is relatively free from radon and its decay products and even though the design may be optimised, the actual concentrations of radon decay products in workplaces depends more on the function of the daily controls, such as efficacy of ventilation ducting and the actual mining activities in the area and depends upon the mining situation (such as equipment heat and equipment movement which may interrupt airflows). Therefore, workplaces usually contain concentrations of radon decay products. To estimate the likely RnDP concentrations in and around the sub level caving operations, the reported measured results from Olympic Dam have been used [Kinhill, 1997]. The results give average RnDP concentrations of 0.5 µJ/m^3 in access drives and at draw points ranging up to 1.5 µJ/m^3 at tipping points and at ore passes. Therefore, for the situation where a LHD operator is moving ore from a draw point to a tipping point, it has been assumed that an average RnDP concentration of 1 µJ/m^3 exists.

This average has also been used for miners working at a development heading.

The mineralised material at Olympic Dam has higher concentrations of uranium (average of approximately 600 ppm), compared to Carrapateena (239 ppm) therefore, for Carrapateena it has been assumed that the average mine RnDP concentration is proportionally lower, giving a mine average concentration of 0.3 µJ/m^3.

Kinhill 1997 reports underground workshop RnDP concentrations of 0.07 µJ/m^3. Using a similar proportion approach, the likely average workshop concentrations will be 0.02 µJ/m^3.

4.2.4 Airborne Dust Exposure

Airborne dust exposures can be determined by combining the activity concentration of the airborne dust with the exposure time. The activity concentration can be calculated from the dust mass concentration combined with the known radionuclide composition of the dust.

Based on an average underground dust mass concentration of 3 mg/m^3 (a conservative estimate based on ensuring that dust concentrations underground remain less than the 5 mg/m^3 statutory occupational (inhalable) dust limit for a 12-hour shift (Safe Work Australia 2013)), and an average uranium grade of 239 ppm in the mineralised material in the proposed underground mine, the calculated average U^{238} activity concentration is approximately 10 mBq/m^3. (Note that this is based on the specific activity of U^{238}, which is the dominant radionuclide in naturally occurring uranium. The specific activity of U^{238} is 12,400 Bq/g, which means that in material containing 239 ppm uranium, the activity concentration of U^{238} is approximately 3 Bq/g).

Kinhill 1997 also reports measured average U^{238} activity concentration for various mining tasks including development work of approximately 40 mBq/m^3. When taking into account the different uranium concentrations, this equates to approximately 12 mBq/m^3, which is consistent with the average concentration determined above.

4.2.5 Dose Parameters

For calculating the potential doses to mine workers, the following factors were used:

- worker exposure hours (working year) – 2,000 h/y
- worker breathing rate – 1.2 m^3/h
- RnDP conversion factor 1.4 $mSv.m^3/mJ.h$ (workers) [ARPANSA, 2005]
- 7.2 µSv/αdps [ARPANSA, 2005].

The exposure factors are as follows:

- Gamma
  - Exposure in non-mineralised material (containing 20 ppm of uranium): 0.26 µSv/h
  - Exposure in mineralised material (containing 239 ppm of uranium): 3.1 µSv/h
- RnDP
  - Mine average: 0.3 $\mu J/m^3$
  - Workshop average: 0.02 $\mu J/m^3$
- Radionuclides in Dust
  - Mine average: 0.012 Bq/m^3 (for each radionuclide)

A summary of the exposure assumptions can be seen in Table 2.

Table 2: Estimated Time in Locations in the Mine

Work Group	Percentage of Time (%)			Equipment Protection From Gamma
	Mineralised area	Non Mineralised area	Workshop	
LHD operators	100			Y
Development miners	80	20		Y
Maintenance personnel (workshop)	20		80	N
Maintenance personnel (mine)	40	40	20	N
Service personnel (Full time)	50	50		N
Service personnel (Part time)	25	25		N

The calculated doses are shown in Table 3.

Table 3: Occupational Dose Estimates for Carrapateena Mine Workers

Work Group	Dose (mSv/y)			
	Gamma	RnDP	Dust	Total
LHD operators	3.1	0.9	1.0	5.0
Development miners	2.5	0.9	1.0	4.4
Maintenance personnel (workshop)	1.7	0.2	1.0	2.9
Maintenance personnel (mine)	2.8	0.7	1.0	4.5
Service personnel (Full time)	3.4	0.9	1.0	5.3
Service personnel (Part time)	1.7	0.4	0.5	2.6

Note that the calculation of dose in Table 3 is as follow;

Calculation: Dose = Exposure rate x hours of exposure x dose factor x protection factor

Example: Development Miner Gamma Dose =

3.1 µSv/h x 2000h/y x 0.5 (on equipment) x 0.8 (for mineralised area) +

0.26 µSv/h x 2000h/y x 0.5 (on equipment) x 0.2 (for non-mineralised area)

4.3 Occupational Radiation Doses - Processing Plant Worker Doses

The proposed processing plant consists of three discrete components:

- an ore concentrator including a crush grind and flotation circuit (concentrator)
- an concentrate treatment plant using wet metallurgical processes (impurity removal)
- a tailings storage facility (TSF).

Assessment of the potential doses to workers in each component can be undertaken by considering the first principles and determining the exposure geometries, however, actual measured doses for workers in very similar facilities can be used to provide a reliable estimate.

Doses for workers in the concentrator section has been estimated from exposures received at the existing Olympic Dam concentrator [BHP Billiton, 2009], which is a similar sized operation using similar processing techniques on a similar ore but with a higher uranium grade. The Carrapateena concentrator is likely to behave in an identical manner to the Olympic Dam concentrator. The Olympic Dam ore contains approximately 2.5 times more uranium than the Carrapateena ore, and therefore, it is it is appropriate to scale the Carrapateena dose estimates accordingly.

The details of the Carrapateena concentrate treatment plant have yet to be finalised, although it is based on wet metallurgical processing and therefore the exposure situations can be considered to be similar to the wet processing situations at the Olympic Dam concentrator. It is relevant to note that the material being treated in the concentrate treatment plant will have a higher radionuclide concentration than the ore. Initial test work indicates that the radionuclide concentration will not exceed approximately 10 Bq/g per radionuclide. Therefore, the concentrate is radiologically similar to the concentrate being treated at Olympic Dam.

For this assessment, the actual doses from Olympic Dam [Kinhill, 1997] for concentrator workers will be used to estimate the doses to concentrate treatment plant workers.

The on-site TSF will be used for the disposal of residues from both the concentrator and the impurities removal circuit. For the on-site processing option, both streams will be combined within the processing facility before for final disposal. The radionuclide content of the final tailings is therefore for all practical purposes, identical to the radionuclide concentration of the ore, apart from a minor increase in concentration due to the removal of the copper bearing minerals (approximately 5% by mass). Doses to workers in the TSF area will also be based on the Olympic Dam worker doses.

Table 4 shows the assumptions used for the assessment. The Olympic Dam doses are the average doses from 2001 to 2007 [BHP Billiton, 2009].

Table 4: Assumptions Used in Processing Plant Workers Dose Estimates

Processing Plant Area	**Assumptions**
Concentrator	Use doses received by Olympic Dam concentrator plant workers and scaled
Impurity removal	Use doses received by Olympic Dam concentrator plant workers and not scaled
TSF	Use Olympic Dam results

Based on the assumptions, the dose estimates for the processing plant work areas are shown in Table 5.

Table 5: Occupational Dose Estimates for Carrapateena Processing Plant Operators

Processing Plant Work Area	**Doses (mSv/y)**			
	Gamma	**Dust Inhalation**	**RnDP**	**Total**
Concentrator	0.3	0.3	0.1	**0.7**
Impurity removal	0.8	0.7	0.3	**1.8**
TSF	0.3	0.3	0.1	**0.7**

4.4 Occupational Radiation Doses - Doses to Other Workers

Administration workers would mainly work in offices located adjacent to the processing plant. The work area would be outside of the main processing plant area and workers would not be required to undertake any special requirements for radiation exposure control.

Exposures for administration workers would be as follows:

- Gamma radiation – no close sources of gamma ore, therefore gamma dose expected to be negligible.
- Dust exposure – assume that a dust concentration of 0.5 mg/m^3 of ore dust is present in the workplace (note that this would be considered operationally unacceptable and require mitigation), then using the assumptions in Appendix A, the dose would be approximately dose 0.025 mSv/y.
- RnDP exposure – assume that RnDP exposure is similar to plant workers, being 0.3 mSv/y.

Therefore the estimated total dose is less than 1 mSv/y, considerably less than the radiation worker occupational dose criterion (20 mSv/y). Monitoring would be conducted to confirm this.

Final product copper concentrate is to be transported by road to a shipping transfer point. Since the final product is below the specification for a radioactive material, it is expected that doses to the truck drivers would be less than 1 mSv/y. Monitoring would be conducted to confirm this once operations commence.

4.5 Consideration of Changes in Dose Factors

The ICRP has published a revised dose factor for radon decay products [ICRP, 2015]. The new factor has yet to be adopted in national laws, although it is likely that this would occur in the near future.

The factor is used to convert an exposure to a concentration of RnDP into a dose, which is a standardised measure of detriment that can be used to combine different types of radiation exposure into one overall measure of impact.

Until recently, the RnDP dose factor has been based on data from epidemiological studies of uranium miners from the middle of the last century. The ICRP has decided to standardise its approach to determining detriment and has therefore changed to a dosimetric approach to determining detriment, which is based on modelling.

The new dose factor is 2.4 times higher than the current dose factor. The impact of the change is that for miners, total doses would increase by up to 1 mSv/y. The maximum underground dose would therefore be approximately 6 mSv/y.

4.6 Summary of Radiological Impacts

The assessment has shown that the radiological impacts from the proposed project would be low. Conservative estimates show that doses to all workers would be less than 5 mSv/y, compared to the annual limit of 20 mSv/y.

Special attention needs to be paid to mine ventilation which needs to be installed and maintained to ensure that doses to mine workers from the inhalation of RnDP remain low and well controlled.

5. MANAGEMENT OF RADIATION

5.1 Overall Approach

OZL will comply with the relevant South Australian Regulations on radiation protection and the radiological impacts of the proposed project would be managed and controlled through good design and ongoing operational management systems.

The operational controls will be outlined in the Radiation Management Plan and Radioactive Waste Management Plan which will be submitted to the competent authority in the secondary permitting stage of the project.

This section provides an overview of the main radiation management systems and controls.

5.2 General Site Controls

5.2.1 Classification of Work Areas and Workers

ARPANSA 2005 provides guidance on classification of workplaces for radiological purposes, as follows:

> A 'controlled area' is an area to which access is subject to control and in which employees are required to follow specific procedures aimed at controlling exposure to radiation.
>
> A 'supervised area' is an area in which working conditions are kept under review but in which special procedures to control exposure to radiation are not normally necessary.

OZL has defined the whole of the project area within the proposed mining lease boundary as a 'supervised area'. Within this area, the underground mine would be defined as a 'controlled area' as would the milling and crushing areas and the impurities removal processing area.

Employees working in the controlled areas would be defined as 'designated' radiation workers. Other workers would be defined as 'non-designated' radiation workers. These classifications would be reviewed when sufficient radiation monitoring data has been obtained.

5.2.2 Site Access Control

Access to the site would be through a manned gatehouse and linked to a record keeping system to ensure that all personnel accessing the site have been appropriately inducted.

Vehicle access would be through a main gate, and exit from site would require all vehicles to pass through a wheel wash. Water from the wheel wash and wash-down areas would be collected and settled to remove solids, then treated for re-use at the on-site water treatment plant.

5.2.3 Change-rooms

Designated workers would be required to change into work clothes at the commencement of their shift and then shower and change into 'street clothes' at the end of their shift. This would be a general health and hygiene requirement and not just a radiation requirement.

Dirty clothes would be laundered on site, with waste water sent to the on-site water treatment plant.

5.2.4 Other General Controls

OZL would develop and implement a series of other site-wide operational and administrative controls for radiation protection including:

- pre-employment and routine medical checks
- development of safe work procedures, which include radiation safety aspects
- procedures to segregate, isolate and clean contamination or contaminated equipment
- procedures for equipment or materials leaving the controlled area
- mandatory use of personal hygiene facilities (wash facilities) at entrances to lunch rooms and offices.

5.3 Radiation Control in the Mine

5.3.1 Mine Ventilation System

The role of the underground ventilation system is to ensure that sufficient fresh air is available at all times at all underground workplaces thereby controlling dust, blasting fumes, heat and RnDP.

The mine ventilation system would consist of two systems, a primary and a secondary ventilation system, with the primary system providing bulk quantities of fresh air into the vicinity of the workings and the secondary system distributing this air to workplaces.

The primary ventilation circuit consists of a network of large diameter surface raise bores. Large air fans force fresh air into the mine through a number of these raise bores, while contaminated air exits the mine through the others. This is called a positive pressure mine ventilation system.

The secondary ventilation system would take fresh air from the primary circuit and distribute it to working area through the use of secondary ventilation fans and ducting. The fans would blow fresh air to the workplaces, with the 'contaminated' air flowing back along the drives to the exhaust side of the primary ventilation system. In some cases it would be necessary to extract contaminated air from a work area through more rigid steel ducting. The decline would be a source of fresh air and would be developed through inert cover material.

The sub level caving mining method has restricted opportunity for flow through ventilation therefore careful management of airflows using secondary ventilation will be required.

The exact details of the ventilation system are yet to be developed and OZL is obtaining specialist advice for the design of the underground ventilation system, based on specific radiological engineering design criteria. The main criterion is to ensure that all of the workings are actively ventilated.

The key radiological design requirements of the ventilation systems are as follows:

- a minimum air-flow of 10 m^3/s in all drives
- a one-pass ventilation system, with no re-use of ventilation air
- continuous ventilation of all active drives
- provision of fresh air to all workplaces (where fresh air is air that has not been in contact with the mineralised zone and has not been contaminated by exhaust air).

5.3.2 Other Mine Controls

OZL would implement additional management controls to ensure that doses remain well controlled. These include:

- restricting access to the main mining areas to ensure that only appropriately trained and qualified personnel are able to access the work areas
- ensuring that all heavy mining equipment is air conditioned to reduce exposure to dust and RnDP
- using standard dust suppression techniques
- implementing a systems of ventilation maintenance and repair
- shotcreting of areas where gamma radiation may be elevated (note that shotcreting has been shown to reduce gamma radiation levels by up to 50%)
- installing a separate wash-down pad within the site area for vehicles that have come from the mine area.

5.4 Radiation Control in the Processing Facility

Both wet and dry process material would be handled in the concentrator requiring specific design considerations for dust control and spillage containment. This includes:

- crushers and conveyor systems fitted with appropriate dust control measures such as dust extraction
- use of scrubbers or bag houses where appropriate
- bunding to collect and contain spillages from tanks containing radioactive process slurries, with bunding to capture at least the volume of the tank in the event of a catastrophic failure
- tailings pipeline corridor bunded to control spillage from tailings pipeline failures
- sufficient access and egress for mobile equipment to allow clean-up where there is the possibility for large spillages
- washdown water points and hoses supplied for spillage clean-up.

If the monitoring shows that there are elevated levels of dust in the workplace, respiratory protection would be used until a more permanent means to reduce dust is established.

5.5 Radiation Control in the Concentrate Treatment Plant

Radionuclides and other impurities in the concentrate will be selectively removed from the copper concentrate and recombined with the concentrator tailings prior to disposal in the TSF. The concentrations of radionuclides in the waste slurry are not expected to be high, with all radionuclides less than 10 Bq/g or 1000 Bq/L.

The controls for the concentrate treatment plant would be identical to those for the concentrator with no additional controls necessary.

5.6 Operational and Administrative Controls

In addition to the design controls, administrative controls would be implemented.

5.6.1 Radiation Safety Expertise

OZL would ensure that suitably qualified and experienced radiation safety professionals are available to assist during the design and construction phases of the proposed project.

During operations, OZL would employ a suitable qualified and resourced Radiation Safety Officer (RSO) who would influence the day to day workings of the project, ensure that appropriate radiation safety advice is available to implement the RMP and RWMP and provide ongoing advice to the General Manager.

5.6.2 Induction and Training

All employees and contractors would receive an induction upon commencement (with annual re-induction), informing them of the hazards associated with the workplace. The induction would include an introduction to radiation, radiation safety and responsibilities. Specific training would be provided to personnel involved in the handling of process materials containing elevated levels of radionuclides.

Managers and supervisors would receive additional training in the recognition and management of situations that have the potential to increase a person's exposure to radiation.

A specific radiation safety work permit system would be developed and implemented. Before any non-routine work or maintenance work commences in a potentially high exposure area or situation, such as the return air side of underground ventilation system, a work permit would be issued, outlining the specific radiation protection measures.

5.6.3 Record Keeping

A computer based data management system would be used to store and manage all information relating to radiation management, monitoring and worker doses.

Periodic reports would be prepared from information stored in the electronic database. Dose reports would be provided to workers upon request.

5.7 Radiation Monitoring Program

As part of the ongoing management of radiation, an occupational radiation monitoring program would be developed and implemented.

The Radiation Monitoring Program would also include:

- recognised sampling methodologies that are documented and regularly reviewed
- requirement for appropriately trained and qualified monitoring personnel
- the use of appropriate monitoring equipment
- review of new equipment
- routine instrument calibration programs, including auditing of calibration sources
- instrument maintenance and repair programs
- regular external audits of the monitoring program and system.

An outline of the proposed occupational radiation monitoring program is shown in Table 6.

Table 6: Proposed Occupational Radiation Monitoring Program (Indicative only)

Radiation Exposure Pathway and Monitoring Method	Underground	Surface Workplaces	Administration Area
Gamma radiation Survey with handheld monitor	Monthly areas survey	Monthly areas survey	Annual area survey
Gamma radiation Personal TLD badges	Quarterly TLD badges on selected designated workers	Quarterly TLD badges on selected workers	
Airborne dust Sampling pumps with radiometric and gravimetric analysis of filters	Weekly personal dust sampling for: • LHD operators • development miner • maintenance personnel • general underground worker	Weekly personal and workplace samples in selected work areas	Six monthly area samples
Radon Decay Products Grab sample using the Rolle or Borak method	Twice weekly 'grab' sample in: • extraction level • active development headings • workshop and • occupied areas (such as lunchroom)	Monthly grab samples in concentrator area	
Radon and Radon Decay Products Personal monitoring	Personal monitoring of designated workers using passive radon monitors, including monitoring to determine equilibrium factors		
Surface Contamination	Weekly survey of: • underground offices • workshop • lunchroom	Monthly survey	Six monthly survey

Results of monitoring would be provided to operational personnel for action as necessary.

For routine management control of radiation, OZL would establish a series of action levels to ensure that exposures and doses remain well controlled. Exceeding the action levels would initiate mandatory action by operational personnel. Table 7 provides an overview of the proposed action levels and actions.

Table 7: Proposed Exposure Action Levels and Actions

Radiation Measurement Type	Action Level	Actions
Gamma radiation Handheld Instrument	10 µSv/h	Investigate and identify source. Consider redesign of workplace or tasks to reduce exposure.
Gamma radiation TLD (quarterly result)	1.5 mSv	Investigate and identify source. Redesign workplace or tasks to reduce exposure. Shield if necessary.
Radon Decay Products (underground)	2 µJ/m^3	Fix ventilation – if not fixed by end of shift – do not allow next shift to enter until less than 2 µJ/m^3.
	8 µJ/m^3	Fix ventilation – evacuate area until level below 2 µJ/m^3.
Radon and Radon Decay Products personal	1000 Bq/m^3 Radon	Investigate and identify source. Redesign workplace or tasks to reduce exposure.
Surface contamination (in workshops, control rooms and lunchrooms)	0.4 Bq/cm^2	Immediate cleanup.
Airborne Dust	5 mg/m^3 1 mg/m^3 in the processing plant area	Identify source and suppress (e.g. water suppression, housekeeping and ventilation).

Table 8 provides a list of the radiation monitoring equipment that would be used to implement the proposed occupational radiation monitoring program.

Table 8: List of Equipment required for Occupational Radiation Monitoring

Radiation Measurement Type	Equipment
Gamma radiation	Hand held gamma radiation monitor
TLD (quarterly result)	TLD badges (provided and analysed by service provider)
Surface contamination in workshops, control rooms and lunchrooms	Surface contamination probe and rate-meter
Airborne Dust	2 L/min personal dust pumps fitted with suitable 'inhalable' filter holders Microbalance for weighing of filters Alpha slide drawer assembly and rate-meter
RnDP	2 L/min personal dust pumps fitted with suitable 'inhalable' filter holders Portable alpha slide drawer assembly and rate-meter
Radon	Passive radon detectors Rn/RnDP monitoring equipment

5.8 Radioactive Waste Disposal

There are three main categories of radioactive waste generated by the proposed project:

- tailings from the concentrator and residues from the concentrate treatment plant
- water that may have come into contact with radioactive materials including surface runoff, from areas which contain process material
- miscellaneous wastes that may have become contaminated through contact with ores and process residues (referred to as contaminated waste).

Waste rock from mine overburden is not considered to be radioactive and is to be used for construction purposes or disposed of on a waste rock stockpile with no radiation control measures necessary. Where waste rock contains nominally more than 1 Bq/g (equivalent to 80 ppm of uranium), it will not be used for construction and instead encapsulated in more benign waste rock.

5.8.1 Tailings

There are two main metallurgical processing waste streams that are produced, combined and then disposed in the TSF as follows:

- a slurry residue stream from the flotation circuit
- residues from the concentrate treatment plant.

The tailings are to be thickened and pumped to an on-site valley fill tailings disposal area. The design aims to ensure that tailings are effectively contained in the long-term and that radiation doses from the tailings to the proposed workforce is minimised.

In general, all of the original radionuclides in the ore report to the TSF.

5.8.2 Contaminated Water

Water that has come in contact with mineralised material, such as stormwater runoff from the ore stockpile or processing plant may contain entrained radioactive dusts and sediments. The site is designed so that all surface water is collected and contained and does not flow from the site to surface water landforms. The method of control involves the construction of sedimentation dams, from which water can be reclaimed, and appropriate collection bunds and channels.

Waste water from wash-down areas and clean-up water would also be captured for treatment and evaporation.

5.8.3 Contaminated Waste Control

This material includes contaminated equipment and wastes from operational areas, including equipment, steel, discarded conveyor belts, rubber lining material, pipes, filter media and used protective equipment. OZL would implement a contaminated waste program which aims to minimise waste to be disposed of. Where practical, potentially contaminated waste would be decontaminated and disposed of via normal waste disposal methods. Where this is not possible and depending on the nature of the waste, several disposal options would be available.
These include:

- incorporation into the waste rock stockpile
- disposal into the mine at the end of operations
- disposal in an approved on-site landfill.

A system that retains records of the disposal, including type of material, quantities and locations would be maintained.

6. SUMMARY

The radiation assessment shows that the impacts would be manageable, with potential doses well below the recognised limits. A summary of the radiological impacts of the proposed project can be seen in Table 9.

Table 9: Summary of Radiation Impacts During the Proposed Project

Dose Groups	Expected Dose/Impact (mSv/y)	Dose Limit/Standard (mSv/y)
Workers	<6	20

Appendices

Appendix A: Dose Factors and Assumptions

Appendix B: References

Appendix A: Dose Factors and Assumptions

Conversion of dust mass to radionuclide in dust concentration

The following method was used:

- It was assumed that all dust emitted from the project is mineralised material containing 239 ppm uranium.
- It was assumed that the uranium is in secular equilibrium with its decay products (the most conservative assumption).
- Pure U^{238} contains 12,400 Bq/g (meaning 1,000,000 ppm U^{238} equals 12,400 Bq/g).
- In naturally occurring uranium, the most abundant radioisotope is U^{238}.
- Therefore 1 Bq/g of U^{238} equates to approximately 80 ppm uranium.
- Therefore 239 ppm uranium is equivalent to 3 Bq/g of U^{238}.
- Since the radionuclides are in secular equilibrium, the activity concentration of the decay products would be 3 Bq/g.
- Increase in U^{238} concentration in the soil.

Dose assessment

When calculating the radiological dose from inhalation of radionuclides in dust, the total suspended solids (TSP) figure is used.

Radon Decay Product (RnDP) Factors

1.2 mSv/mJ [ARPANSA, 2005]

Assume 2.4 mSv/mJ (pending advice from ICRP regarding the revised RnDP dose conversion factor).

Appendix B: References

ARPANSA, 2002	*Recommendations for Limiting Exposure to Ionizing Radiation (1995)*, Radiation Protection Series. Canberra. RPS 1.
ARPANSA, 2005	*The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing* Radiation Protection Series. Canberra. RPS 9.
ARPANSA, 2008	*Management of Naturally Occurring Radioactive Material (NORM)*. Radiation Protection Series. Melbourne RPS 15.
ARPANSA, 2012	*Understanding Radiation*, Radiation Protection, [http://www.arpansa.gov.au/radiationprotection/basics/understand.cfm] accessed: 020616
ARPANSA, 2014a	*Fundamentals for Protection Against Ionising Radiation*, RPS F-1
ARPANSA, 2014b	*Code of Practice for the Safe Transport of Radioactive Material*. Melbourne. Radiation Protection Series. Canberra. RPS 2.
Australian Uranium Association, 2011	*Radiation Workers' Handbook*, Radiation Control in the Mining & Mineral Processing Industry [http://www.aua.org.au/Content/RadiationSafety.aspx] accessed: 250613
BHP Billiton, 2009	*Olympic Dam Expansion Draft Environmental Impact Statement 2009*, Appendix S Uranium and Radiation, BHP Billiton, Adelaide, South Australia
ERA, 2014	*Appendix 8: Radiation Assessment of the Ranger 3 Deeps underground mine Draft Environmental Impact Statement*, 3 October 2014 http://www.energyres.com.au/operations/reserves-resources/ranger-3-deeps/draft-environmental-impact-statement/
ICRP, 1977	*Recommendations of the ICRP*, Publication 26. Ann. ICRP 1 (3)
ICRP, 2007	*The 2007 Recommendations of the International Commission on Radiological Protection,* ICRP Publication 103, Ann. ICRP 37 (2-4),
ICRP, 2015	[http://www.icrp.org/admin/Summary%20of%20April%202015%20Main%20Commission%20Meeting%20Sydney.pdf] accessed: 020616
Kinhill, 1997	*Olympic Dam Expansion Project – Environmental Impact Statement,* Kinhill Engineers, 1997
Palabora, 2013	*Worker Exposure from a Copper Mining and Beneficiation Facility, AJ* van der Westhuizen, Palabora Mining Company Limited. Proceedings of an International Symposium Beijing, China, 22–26 April 2013, IAEA
Safe Work Australia 2013	*Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants,* Safe Work Australia, April 2013
Thomson, J. E. and O. J. Wilson, 1980	*Calculation of Gamma Ray Exposure Rates from Uranium Ore Bodies*, Australian Radiation Laboratory
World Nuclear Association, 2014	World Nuclear Association website: [http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/uranium-mining-overview.aspx] accessed: 211116