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Appendix A: Technical Note: Introduction to Radiation

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INTRODUCTION TO RADIATION

All matter is made of atoms. Atoms are made up of protons and neutrons in a nucleus, and electrons orbiting around the nucleus. Some atoms are unstable and breakdown, giving off energy in the form of radiation. These are known as radioactive atoms or radionuclides.

Different radionuclides emit radiation at different rates. The breakdown (or decay) of radionuclides reduces the number remaining, so that the amount of radiation emitted continually reduces. The time taken for one half of the radionuclides to decay away is known as the 'half life'. Each radionuclide has its own half-life that can range from fractions of a second to billions of years.

When a radionuclide decays, the new atom formed may itself be radioactive, which might in turn decay to another radionuclide, and this can continue until a stable element is reached. When this occurs, the chain of radioactive decays is called the 'decay series' or 'decay chain'.

Radionuclides are ubiquitous and naturally occurring, existing everywhere in the environment, in food, air, water, soils and rocks. For example, uranium is a naturally occurring heavy metal and is widespread in Earth's crust, with an average concentration of about three parts per million (ppm). Since, radionuclides exist naturally in all materials, it is usual to only define a material as "radioactive" when the concentration of a radionuclide in the material exceeds a certain level.

Radiation emitted from radionuclides is known as ionising radiation because it ionises material through which it passes. This means that radiation produces charged particles called ions as it passes through matter.

There are three types of radiation emitted by naturally occurring radioisotopes:

- Alpha radiation consists of alpha particles (two neutrons and two protons) and has a very short range in air (a few centimetres), depositing their energy quickly. They are unable to penetrate the outer skin later, but can be hazardous when inhaled or ingested.
- Beta radiation consists of high-energy electrons. They have moderate penetration, typically about one metre in air and a few millimetres in water or tissue.
- Gamma radiation is not a particle but an electromagnetic wave similar to light and X-rays but of much higher energy. Gamma rays are generally able to penetrate up to several centimetres of metal or 10 cm of concrete, and usually pass right through the human body.

Exposure to radiation only can occur when there is an exposure pathway between the radioactive material and the person exposed. This can occur in two ways: external (where the source of radioactivity is outside the body) and internal (where the source of radioactivity is inside the body – for example in inhaled air).

Describing radioactivity and exposure to radiation can be difficult. In general, there are two ways used – one refers to how much radioactivity is in a material (or how radioactive it is), and the other refers to the resultant exposure from the radioactivity (this is also referred to as a "dose").

The amount of radioactivity is described by its 'activity' and is measured in the unit of becquerel (Bq), which is the amount of radioactive material that produces one radioactive decay per second. The activity concentration is the amount of radioactivity in a unit mass (or volume) of material and is measured in becquerels per gram (Bq/g) or per litre (Bq/L).

Dose refers to the amount of radiation received at a point or to a person. Dose is also a relative measure of the effect (or 'detriment') of radiation on the human body and is measured in the units of Sieverts (Sv) and takes into account of different types of radiation and different exposure situations. The sievert is quite a large unit of measure, and doses are usually expressed in millisieverts (mSv), thousandths of a sievert.

Due to radiation being very common in nature, everyone is exposed to natural radiation throughout their life. This radiation comes from the rocks and soil of the earth, the air we breathe, water and food we consume, and from cosmic radiation from space. Natural background can vary considerably in different places in the world. While the world average is 2.4 mSv/y, the typical range is quoted as 1–10 mSv/y (UNSCEAR 2000).

In addition to natural background exposure, some people around the world are regularly exposed to radiation in their work (other than in the nuclear industry), and from leisure activities (such as flying) and in medical procedures.

Table 1 shows the average annual dose for a range of different jobs.

Table 1. Occupational radiation exposures (in addition to natural background levels)

Source/practice	Average annual effective dose (mSv)
Nuclear fuel cycle	1.8
Industrial uses of radiation	0.5
Medical uses of radiation (doctors/nurses)	0.3
Air crew (from cosmic radiation)	3.0
Mining (other than coal)	2.7
Coal mining	0.7
Source: UNSCEAR 2000b	

Another major source of radiation exposure to the general public is medical exposure. Radiation is used extensively for diagnosis (such as x-rays) and treatment of disease. The average annual radiation dose from diagnostic medical procedures in developed countries is approximately 1.2 mSv/y (UNSCEAR 2000).

The acute health effects of radiation exposure (both internal and external) are well known. At high doses (several sieverts) significant numbers of cells may be killed, leading to the breakdown of the organ or tissue, and possibly resulting in death. The doses required for these effects are similar to those received by Chernobyl fire-fighters.

At lower doses, chronic health effects may arise from cells that are damaged by the radiation but not killed. This may be the initiating event for development of a cancer.

Several studies have found an increased risk of cancer among people exposed to moderate doses of radiation (UNSCEAR 2000). The studies show that the risk increases as the radiation dose increases.

In general, none of the studies has been able to measure increases in cancer risk from exposures to low doses of radiation (below about 50 mSv), however, it is conservatively assumed that there is an increased risk.

The studies and their results form the basis of the setting of radiation standards for exposure of workers and the general public.

The premier international body for radiation protection is the International Commission on Radiological Protection (ICRP). The limits recommended by the ICRP have generally been adopted around the world.

Dose limits form only one 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 risks associated with the radiation exposure.
- **Optimisation**, radiation doses received should be as low as reasonably achievable, economic and social factors being taken into account (the ALARA principle).
- **Limitation**, individuals should not receive radiation doses greater than the recommended limits.

The effective annual dose limits recommended by the ICRP are 20mSv for a designated radiation worker and 1mSv for a member of the public.

The radiological protection of the non-human living environment (being plants and animals) has, up until recently, been thought to be assured by ensuring that humans have been protected. In recent times this approach has been changed and it is now appropriate for a radiological assessment of non-human biota (NHB) to be conducted. International standards exist to conduct this assessment as detailed in Appendix D.

Appendix B: Technical Note: Estimate of Radon Sources

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ESTIMATES OF RADON SOURCES FOR

THE AUSTRALIAN ZIRCONIA LTD, DUBBO ZIRCONIA PROJECT (DZP)

INTRODUCTION

The aim of this technical note is to provide estimates of the potential radon releases from operations at the Proposal.

A summary of the estimated emissions can be seen in the following table and are detailed after the table.

Source Of Radon	Value (rounded)	Units
Open Pit Mine	0.6	$Bq.m^{-2}.s^{-1}$
Broken Ore Stockpiles in mine	8288	$Bq.s^{-1}$
Waste Rock	0.26	$Bq.m^{-2}.s^{-1}$
Solid Residue Storage Facility (1)	1.13	$Bq.m^{-2}.s^{-1}$
Solid Residue Storage Facility (2)	0.09	$Bq.m^{-2}.s^{-1}$
Salt Encapsulation Cell	0	$Bq.m^{-2}.s^{-1}$
Liquid Residue Storage Facility	0.0002	$Bq.m^{-2}.s^{-1}$
Processing Plant	51	$Bq.s^{-1}$

ASSUMPTIONS AND WORKINGS

All assumptions are based on an operation at full production and maximum size of facilities.

Mine Emissions (in Pit Emissions)

Estimates of emissions are based on published rates provided by BHP Billiton for its Olympic Dam mine (BHP 2009). This work showed that radon was emitted from the surfaces of ore containing uranium at the following rate;

$$5Bq(Rn).m^{-2}.s^{-1} \text{ per } 1000ppm \text{ uranium in ore} \qquad (1)$$

1000ppm of uranium in ore corresponds to approximately $12.4Bq.g^{-1}$ of the U^{238} isotope and equation *(1)* becomes;

$$5Bq(Rn).m^{-2}.s^{-1} \text{ per } 12.4Bq.g^{-1} \text{ of } U^{238} \qquad (2)$$

The ore contains $1.48Bq.g^{-1}$ of U^{238} (ANSTO 2012), therefore for the ore, there will be;

$$\frac{5}{12.4} \times 1.48Bq(Rn).m^{-2}.s^{-1} = 0.6Bq(Rn).m^{-2}.s^{-1} \qquad (3)$$

Mine Emissions (from Broken Ore Stockpiles)

BHP Billiton (Arup 2009) estimated that the radon emission from broken ore stockpiles was conservatively 5 times higher than emissions from unbroken in situ material. This is due to the higher surface area from which radon can be emitted.

It was assumed that a nominal stockpile of broken ore would always be present in either the pit or on the surface. The size of the stockpile was estimated based on the mining rate of 1.1mtpa and an assumption that there would be three blasts per week. It was assumed that material would not necessarily accumulate, but would be mostly removed to the processing plant for immediate processing.

Based on these assumptions, there would be a stockpile with maximum capacity of approximately 8,000t. If a specific gravity of 1 is used, then this would equate to a rectangular stockpile with dimensions of 10m x 20m x 40m, which gives an emanating surface area of 2,800m^2.

Using the calculated radon emission rate for unbroken ore and the factor for broken ore, the estimated radon emission rate is;

$$0.6Bq{\cdot}m^{-2}{\cdot}s^{-1} \text{ (from } (3)\text{) x 5 x } 2{,}800m^2 = 8{,}400Bq.s^{-1} \qquad (4)$$

[Note: This is a total emission rate and is not dependent upon the area. If the stockpile is considerable larger than the one calculated here, then the surface area estimate can be modified in equation *(4)* to reflect this.

Waste Rock

It is assumed that the waste rock conservatively contains 10ppm of naturally occurring uranium. (Note that the Australian average uranium in soil concentration is approximately 3ppm). Using the same assumption as for ore (see equation (1) above), the radon emanation can be calculated as follows;

$$5Bq(Rn).m^{-2}.s^{-1} \text{ per 1000ppm uranium in ore} \qquad (1)$$

$$10\text{ppm uranium in material gives } 0.05\ Bq.m^{-2}.s^{-1} \qquad (5)$$

The waste rock will be broken ore, therefore using the BHP 2009 assumption of a 5 fold increase in emanation due to the larger surface area in broken material, the estimated emanation rate is as follows;

$$0.05Bq.m^{-2}.s^{-1} \text{ x } 5 = 0.25Bq.m^{-2}.s^{-1} \qquad (6)$$

Solid Residue

In estimating the emanation of radon from the solid residue facility, two estimates of radon emanation rates have been provided.

The first estimate is considered to be the most conservative and is from the USEPA (US EPA 1986). The relationship is seen as follows;

$$1Bq(Rn).m^{-2}.s^{-1} \text{ per } Bq(Ra).g^{-1} \text{ in residue} \quad (7)$$

ANSTO (ANSTO 2012) notes that the solid residue will contain Ra^{226} at a concentration of $1.13Bq.g^{-1}$. Based on the EPA relationship, the radon emanation rate is calculated to be;

$$1.13Bq(Rn).m^{-2}.s^{-1} \quad (8)$$

The second estimate of radon emanation from solid residue is based on the work of BHP Billiton (BHP 2009). This work used actual samples of radon emanation from tailings (solid residue) and determined the following relationship;

$$0.08\ Bq(Rn).m^{-2}.s^{-1} \text{ per } Bq(Ra).g^{-1} \text{ in solid residue} \quad (9)$$

Using the ANSTO (ANSTO 2012) solid residue Ra^{226} concentration of $1.13Bq.g^{-1}$, the calculated emanation rate is;

$$0.08Bq(Rn).m^{-2}.s^{-1} \text{ per } Bq(Ra).g^{-1} \times 1.13\ Bq(Ra).g^{-1} = 0.09Bq.m^{-2}.s^{-1} \quad (10)$$

Comparison of the results from the two methods shows more than an order of magnitude difference. Both estimates of the radon emanation rate have been provided in the summary table. For the purposes of modelling impact, it is recommended that the more conservative USEPA derived figure is used, despite it being very conservative.

Liquid Residue

Radon emissions from liquids are generally recognised to be low (SENES 2011). However, for the purposes of completeness, estimates have been provided. Estimates of emanation from liquor ponds on tailings systems are provided in SENES 2011 giving the following relationship;

$$0.00212Bq(Rn).m^{-2}.s^{-1} \text{ per } Bq(Ra).L^{-1} \quad (11)$$

ANSTO (ANSTO 2012) provides an estimate of the Ra^{226} concentration in liquor of 0.11 Bq/l. Using these figures an estimate of radon emanation can be calculated as follows;

$$0.00212Bq(Rn).m^{-2}.s^{-1} \times 0.11Bq(Ra).L^{-1} = 0.00023Bq(Rn).m^{-2}.s^{-1} \quad (12)$$

Processing Plant

To calculate the emission of radon during processing, it is assumed that all contained radon in the ore is released to the atmosphere as the ore is processed. This is a conservative assumption as some radon will remain contained.

It is also assumed that the ore is in secular equilibrium (a fair assumption for newly mined ore) which means that the activity concentration of radon will be the same as the activity concentration for uranium, being 1.48Bq.g^{-1}.

Based on a production rate of 1.1mtpa and a radon activity concentration of 1.48Bq.g^{-1}, the quantity of contained radon is;

$$1.1 \times 10^9 g.y^{-1} \times 1.48 Bq.g^{-1} = 1.63 \times 10^9 Bq.y^{-1} \quad (13)$$

If this radon is released uniformly across the whole year, then the emanation rate is;

$$1.63 \times 109 Bq.y^{-1} \times (\text{seconds in a year})^{-1} = 51.6 Bq.s^{-1} \quad (14)$$

Salt Encapsulation Cells

ANSTO (ANSTO 2012) indicates that the evaporated salts will contain 2 Bq.kg^{-1} of Ra^{226}. This is considered to be very low. UNSCEAR (UNSCEAR 2000) reports a worldwide average concentration range for Ra^{226} in soil of 17 – 60 Bq.kg^{-1}.

The estimate emission of radon from these cells is considered to be zero.

CONCLUSIONS

The estimates have been provided here for the purposes of air quality modelling.

REFERENCES

BHP, 2009, *Olympic Dam Expansion Draft Environmental Impact Statement 2009*, BHP Billiton

SENES, 2011, 'Radon Emissions from Tailings and Evaporation Ponds', *Uranium Recovery Licensing Workshop, 2011,* Steve Brown and Doug Chambers, SENES Consultants Limited

UNSCEAR, 2000, *Report to the General Assembly, Annex B: Exposures from natural radiation sources*, United Nations Scientific Committee on the Effects of Atomic Radiation

ANSTO, 2012, *A Report to Australian Zirconia Limited on Dubbo Zirconia Project, Radionuclide Assessment* (Report in Draft)

USEPA, 1986, *Final Rule for Radon-222 Emission from Licensed Uranium Mill Tailings*, US EPA, (Background Information Document), EPA 520/1-86-009, 1986

Appendix C: Dose Conversion Factors

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Inhalation dose conversion factors for public exposure and particle size of 1µm [ICRP 2012]

Radionuclide	**Dose Conversion Factors (Sv/Bq)**
U^{238}	8.00E-06
U^{234}	9.40E-06
Th^{230}	1.40E-05
Ra^{226}	3.50E-06
Pb^{210}	1.10E-06
Po^{210}	3.30E-06
Th^{232}	2.50E-05
Ra^{228}	2.60E-06
Th^{228}	2.40E-04
Ra^{224}	3.40E-06
Pa^{231}	3.40E-05
Ac^{227}	7.20E-05

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Appendix D: Non-human Biota Assessment

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Papari Radiation Services
Radiation Protection in Mining and the Environment

RADIOLOGICAL EFFECTS ON NON-HUMAN BIOTA ARISING FROM THE DUBBO ZIRCONIA PROJECT

A report prepared for

JRHC Enterprises Pty Ltd

by

Philip Crouch BSc(Hons) PhD MARPS

PAPARI RADIATION SERVICES

May 2013

Papari Radiation Services ABN 96 088 095 019
20 Kidney St URAIDLA SA 5142 AUSTRALIA
+61 8 8390 3005 Mob 0439 842 263 xcrouch@tne.net.au

EXECUTIVE SUMMARY

An assessment of the potential for radiological effects on the terrestrial environment resulting from dust emissions from the operation of the Dubbo Zirconia Project has been conducted using the ERICA assessment tool. The assessment is based on deposition of radionuclides in dust from the project into the environment, and presumes that there are no aquatic pathways for contaminant transport.

Outside the 6 g/m^2/month dust deposition contour there is negligible risk of radiological harm to any of the "reference organisms". Within that contour, and particularly in areas (if any) where deposition exceeds 17 g/m^2/month, this assessment has indicated that dose rates may be above screening levels. However further review of those organisms that may exceed the screening level indicates that none of them are particularly sensitive to the effects of ionizing radiation, and are unlikely to be affected by the deposition rates expected from this project.

CONTENTS

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1. INTRODUCTION

Australian Zirconia Ltd (AZL) proposes to develop the Dubbo Zirconia Project in central New South Wales, for the extraction of zirconium and rare earths. It is proposed to mine the ore body at a rate of 1 Mt per year, and the current proposal is for a project life of 20 years. Processing will include grinding, addition of sulphuric acid, roasting and leaching. Processing wastes will be stored in a lined facility, and waste water evaporated [1].

This report concerns the potential radiological effects of the proposed operations on non-human biota (NHB) in the terrestrial environment. It is concerned only with the dispersion of radionuclides into the environment through airborne pathways. It is presumed that the operation will be conducted under "no-release" conditions so that no project related radionuclides reach surface or groundwater, and so there is no potential effect on aquatic organisms.

2. THE ERICA TOOL

The Environmental Risk from Ionising Contaminants (ERICA) assessment tool was developed under the European Commission to provide a method of assessing the impact of radiological contaminants on the natural environment [2][3]. The tool contains two major data sources. The first, the database FREDERICA, contains information on the effects of radiation exposure on populations, and includes data on four main "endpoints": morbidity, mortality, reproduction and mutation [4]. The second is a collection of databases that allows estimation of the radiation doses that will accrue to biota from radiological contaminants in their environment.

The International Commission on Radiological Protection (ICRP) has recommended that environmental radiological effects should be assessed on a series of "reference organisms", and these are incorporated into the ERICA tool [5]. Where endangered species or habitats may potentially be affected, additional assessment may be required.

The starting point for an ERICA assessment is the radionuclide concentrations of the medium in or on which the reference organisms are living, in this case soil. This allows the external dose rate for the organisms to be derived, and in addition "concentration factors" from the ERICA database are used to calculate the radionuclide concentrations in the organisms, and hence the internal dose rates to those organisms.

The assessment process can be carried out in three "tiers". Tier 1 is a simple highly conservative assessment, designed to easily identify situations that can be considered of negligible radiological concern. Tier 2 is used where a Tier 1 assessment indicates that there may be organisms at risk, and allows the use of more realistic and less conservative parameters to allow the estimation of dose rates to the organisms. These dose rates are then assessed against a screening dose rate to determine if there is a likelihood that populations may suffer harm. Tier 3 is not a screening tier but is designed to provide guidance in further investigation of situations where Tier 2 indicates that there may be a significant concern of radiological harm to the environment.

The default screening dose rate adopted by ERICA is 10 µGy/h. This dose rate (described as the "predicted no-effect dose rate", PNEDR) was derived from the dose estimated to give a 10% effect (ie to one of the end points: morbidity, mortality, reproduction and mutation) to 5% of the species present, by applying a safety factor of 5. This screening rate is thus expected to protect the most radiosensitive organisms likely to be present in an environment [6]. The ERICA tool allows other

screening dose rates to be adopted. For example several organisations have suggested that no measureable effects would be observed for dose rates of 40 µGy/h (terrestrial animals) and 400 µGy/h (terrestrial plants) [7][8][9] The ERICA tool presents the results as the dose rates to the organisms, and also in terms of the "Risk Quotient": the ratio of the dose rate to the screening rate. Dose rates and risk quotients are presented both for the "expected value" and a "conservative value". The default conservative value is three times higher than the expected value and represents the value at which there is only a 5% chance that the calculated dose rate exceeds the screening level. This then represents a further level of conservatism.

The results of an ERICA assessment can them be described in terms of three dose rate bands[2]:

- $RQ_{Expt} > 1$ (i.e. expected dose rate > 1)
  Screening dose is exceeded. Further assessment is needed.
- $RQ_{Cons} > 1$ but $RQ_{Exp} < 1$ (ie expected dose rate 3.3 – 10 µGy/h)
  Substantial probability that screening dose rate is exceeded. Assessment should be reviewed.
- $RQ_{Cons)} <1$ (ie expected dose rate <3.3 µGy/h)
  Low probability that screening dose rate will be exceeded. Environmental risk is arguably negligible.

A disadvantage in using the ERICA tool for Australian situations is that many of the parameters are derived from temperate northern hemisphere conditions. The most obvious is the case of kangaroos. ICRP has recommended a "large mammal", as one of the set of reference animals which should be considered and deer were chosen because of their widespread occurrence (in the northern hemisphere), and the large amount of radioecological data available for them [5]. In Australia the equivalent niche (grazing mammal) is filled by kangaroos, but the radioecological data for them is relatively sparse [10]. For the purposes of this assessment, the kangaroo is assumed to have the same radiological parameters as the deer. As will be noted below, this assumption is not likely to affect the overall conclusions of the assessment.

3. ENVIRONMENTAL RADIONUCLIDE CONCENTRATIONS

The only pathway of significance in this assessment is dispersion of project generated radioactive dust. As noted above, waterborne pathways are not considered, and the only other pathway of potential significance is the dispersion of radon. However radon being gaseous is widely dispersed in the environment and does not "settle out", hence it and its immediate decay products will not accumulate in the vicinity of the project.

Atmospheric dispersion modelling has been conducted for the project, and as part of this dust deposition contours have been calculated. Figures 1 and 2 show these contours: Figure 1 for year 5 of the project, and Figure 2 for year 15. Differences between the two plots are minor.

To estimate the increase in soil radionuclide concentrations as a result of this dust deposition, the first step was to calculate the radionuclide concentrations of the dust. The ore that is proposed to be mined has been analysed for uranium and thorium, with average activity concentrations of U-238 series radionuclides of 1.5 Bq/g and 2 Bq/g for the Th-232 series (assumed in equilibrium in both cases).

The sources of dust are listed in Table 1. It will be noted that over 60% of the dust is ore dust from mining, with over 33% from soil and overburden, and minor contributions from processing and processing waste. For the purposes of this assessment the conservative assumption that all dust is "ore" will be made.

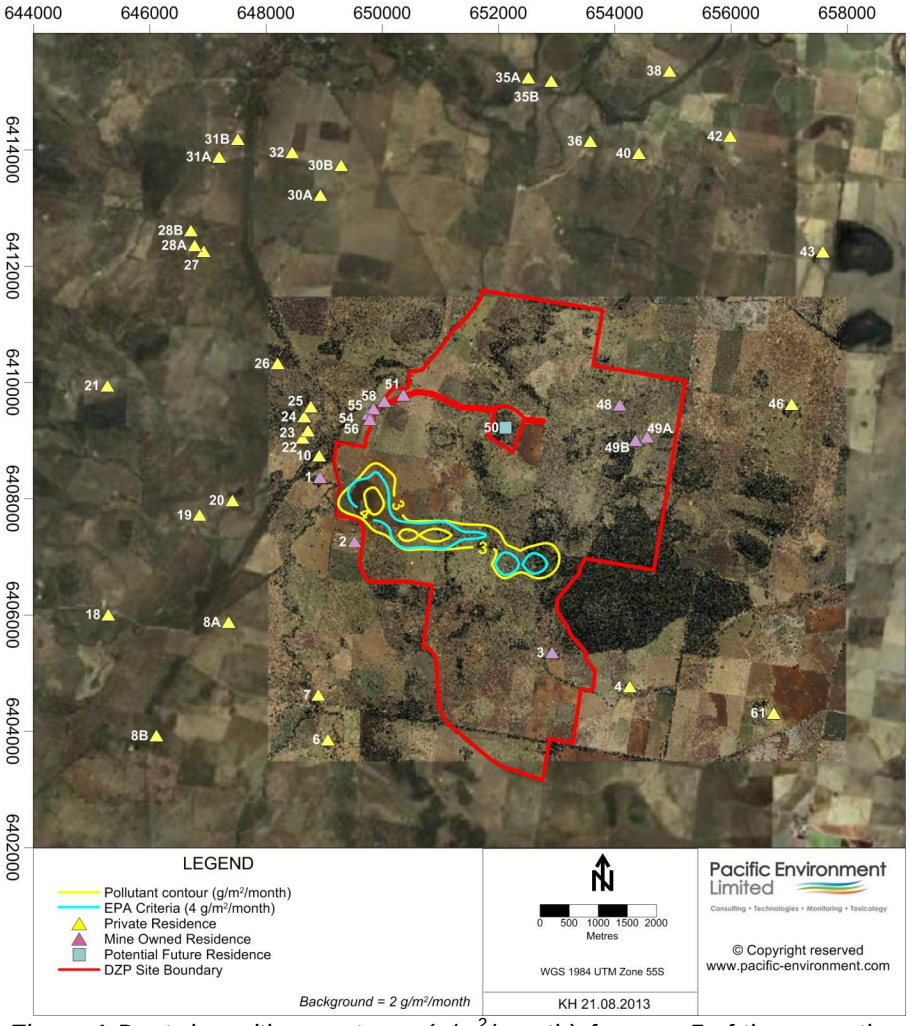

Figure 1 Dust deposition contours (g/m^2/month) for year 5 of the operation

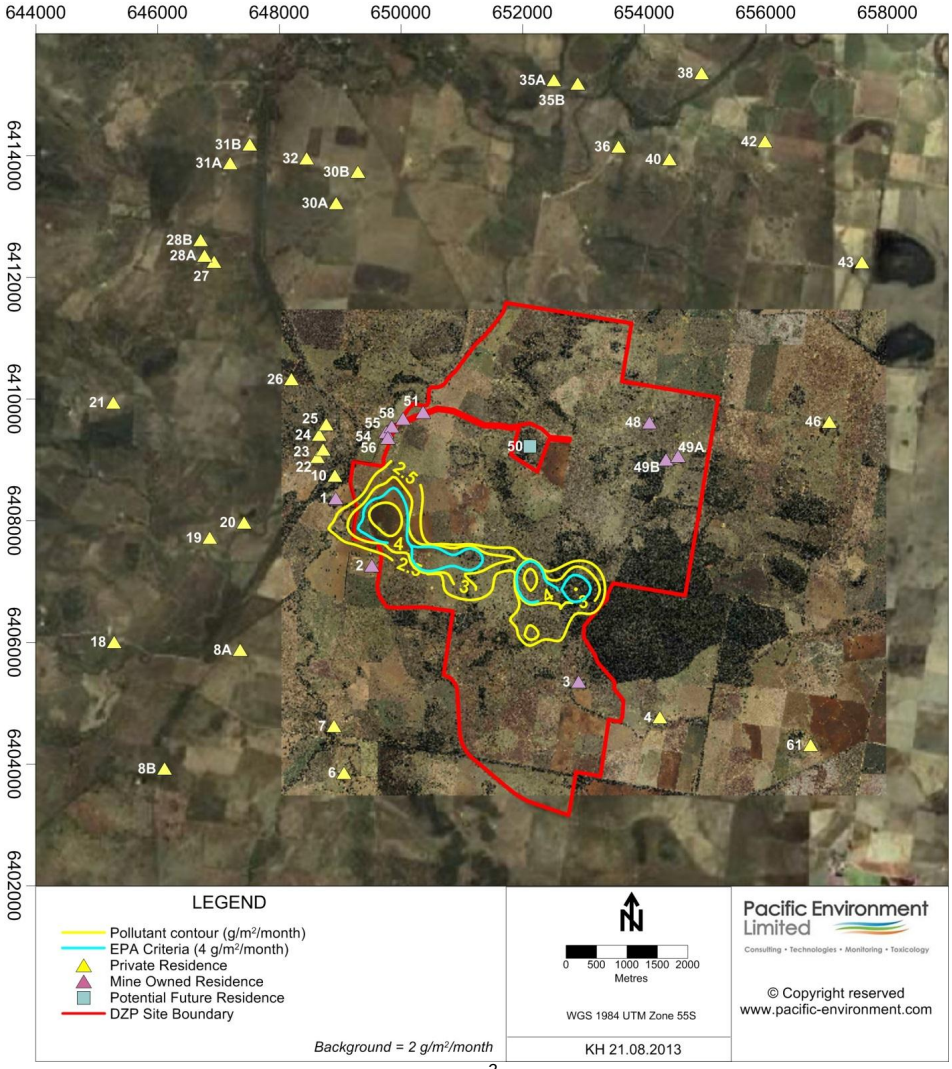

Figure 2 Dust deposition contours (g/m^2/month) for year 15 of the operation.

	Source	Annual emission (kg/y)	Relative contribution (%)
Area Sources	Soil	378064	32.
	Overburden	13480	1.2
	Ore	719400	61
	Waste	26534	2.3
Point sources	Ore Mill	8760	0.75
	Ore Pre	8760	0.75
	Zr Dryer	8760	0.75
	Nb Dryer	4380	0.37
	FeNb Stack	4380	0.37
Total		1170000	100

Table 1 Dust sources (kg/y)

After depositing on the soil surface, dust will mix with the soil through a combination of physical, chemical and biological processes. For the purposes of this assessment, it was assumed that the mixing depth was 10 mm, which is consistent with measurements in SE Australia and in grasslands [11]. The soil density was assumed to be 1.5 t/m^3.

For a location where dust deposition from mining was 10g/m^2/month, the amount of dust deposited over a 20 year mining period would be 2400g/m^2. This will result in an increase in soil radionuclide concentrations by 240 Bq/kg for each uranium series radionuclide and 320 Bq/kg for each thorium series radionuclide.

A Tier 1 assessment was conducted, using the soil radionuclide concentrations derived above for the10 g/m^2/month dust deposition contour. The result of this assessment was that the conservative value for several organisms (was above the

10 µGy/h screening level, and accordingly a Tier 2 assessment was conducted.

The Tier 2 assessment again used 10 g/m^2/month dust deposition level and used the ERICA default values for concentration ratio, and the 10 µGy/h screening level. The resulting derived dose rates are shown in Table 2.

Organism	**Dose Rate (µGy/h)**	**Dose Rate (µGy/h)**
	(expected value)	(conservative value)
Lichen & bryophytes	62.5	188
Detritivorous invertebrate	5.8	17.5
Soil Invertebrate (worm)	4.4	13.2
Flying insects	4.4	13.1
Grasses & Herbs	4	11.9
Shrub	3	9.1
Gastropod	2.6	7.7
Bird	1.5	4.6
Amphibian	1.5	4.5
Bird Egg	1.5	4.4
Reptile	1.5	4.4
Mamman (Rat)	1.5	4.4
Mammal (Deer)	1.1	3.2
Tree	0.7	2

Table 2 Derived dose rates for the reference organisms based on a dust deposition rate of 10g/m^2/month

The expected dose rates for all organisms are significantly below the screening level (10 µGy/h) with the exception of lichen and bryophytes, while the conservative values of 4 (detritivorous invertebrate, soil invertebrate, flying insect and grasses and herbs) were above the screening level.

4. DISCUSSION

4.1 Lichen and Bryophytes

The conservative dose rate derived for lichen and bryophytes is approximately 19 times the screening level (at a deposition rate of 10 g/m^2/month), and is more than fifteen times higher than any other organism. The reason for this is likely to be that lichens (in particular) do not have a well developed root system, and derive most of their nutrients from dust falling upon them. Consequently they might be expected to receive a higher dose from the fallout of mine and processing dusts than is the case for other organisms.

To investigate the consequences of this higher dose rate, the radiosensitivity of the group was considered. In fact they are extremely radioresistant: a threshold no- effect dose rate has been estimated at approximately 125,000 µGy/h, with some diversity reduction observed at 1.1 Gy/h [7] . These dose rates are over 10,000 times the default screening dose rate used in ERICA, and indicate that no effect at all would be expected from any doses that are potentially achievable in uranium mining. Lichen and bryophytes can therefore be considered not to be at any significant risk.

4.2 Non-vertebrates and plants

At 10 g/m^2/month the (expected) dose rates to non-vertebrate and plant groups (other than lichens and bryophytes) are approximately 4-5 µGy/h or less and the conservative dose rates are approximately 12 – 18 µGy/h, The expected dose rate is thus about one half of the screening level while the conservative dose rate is about 50% above the screening level.

These groups can be considered the critical organisms, in the sense that if doses to members of these groups are assessed to present a negligible risk, then all other reference organisms will also be protected.

4.3 Vertebrates

All vertebrate groups gave expected doses of less than 2 µGy/h at the 10 g/m^2/month deposition contour, approximately one half that of the invertebrate groups, and less than 20 % of the screening level. Thus at any level of deposition, the vertebrates will be not be at risk if the non-vertebrates are protected.

It is relevant to comment on the use of “deer” to represent the likely doses to kangaroos. The (conservative) dose that is derived for deer is less than one third of that of the “critical organisms” noted above. The choice of “deer” to represent “kangaroos” would have to underestimate the kangaroo doses by an approximate factor of three for the conservative kangaroo dose to exceed the screening level at the 10 g/m^2/month contour. It should also be noted that many kangaroo species range widely, and thus would be expected to only spend a fraction of their time in the potentially affected areas, which would significantly reduce average doses that they might receive from project emissions.

4.4 Affected areas

The maximum expected dose rate for a reference organism (excepting lichen and bryophytes), in areas receiving dust fallout less than 10 g/m^2/month is approximately 5.8 µGy/h. Thus to exceed the screening level, a dust deposition of approximately 17 g/m^2/month would be required. From Figures 1 and 2 it would appear that the area receiving greater than 17 g/m^2/month is a narrow strip approximately 5 km long and less than 1 km wide.

However using conservative estimates the maximum dose rate is 17.5 µGy/h, and this is equivalent to a deposition rate of about 6 g/m^2/month. This represents an area approximately 5 km long by 1 – 2 km wide.

Thus outside the 6 g/m^2/month deposition contour, all organisms have conservative dose rates below the screening level and are thus considered to be at negligible risk. Inside this area, and particularly in areas above 17 g/m^2/month dose rates may be above screening levels, and so there may be some associated risk, and additional assessment may be required.

4.5 Additional assessment

Further information was sought on the radiosensitivities of the four groups for which the conservative dose rates were above 10 µGy/h at the 10 g/m^2/month deposition contour (detritivorous invertebrate, soil invertebrate, flying insect and grasses and herbs). UNSCEAR [7] notes that adult invertebrates in general are quite resistant to radiation, but that juvenile stages and reproductive effects may be apparent at lower doses. However these effects seem to only become apparent at dose rates greater than 50 – 100 µGy/h, and for example bark beetles showed no effect on reproduction at 10 000 µGy/h.

UNSCEAR [7, paragraph 104] also notes that chronic dose rates of less than 400 µGy/h should have only slight effects in sensitive plants (particularly pinus species) and would be unlikely to produce any significant deleterious effects in the wider range of plants present in natural plant communities. This dose rate is about 30 times the conservative dose rate derived for grasses and herbs, and indicates that effects are very unlikely.

More generally, as noted above the IAEA, the US DOE and UNSCEAR have suggested that at levels of 40 µGy/h for terrestrial animals and 400 µGy/h for plants, no measureable population effects would occur. The values derived above (other than for lichen and bryophytes, discussed above) are well below these screening levels.

In the long term (after closure of operations) mixing of deposited radionuclides with soil is expected to continue, with a consequent reduction in concentrations in the surface soil. The doses to the reference organisms would therefore be expected to reduce over time.

5. CONCLUSIONS

Using the conservative model, the risk of radiological harm is assessed as "negligible" for all reference organisms (with the exception of lichen and bryophytes) at points where dust deposition is less than 6 g/m^2/month. Using the non-conservative estimates, the risk is "negligible" at the 17 g/m^2/month deposition contour. Lichen and bryophytes are very resistant to radiation, and no effects are expected at any dust deposition level.

An initial review of those organisms that are assessed to receive doses above the screening dose rate indicates that none of them are particularly sensitive to radiation, and are unlikely to be significantly affected by the deposition rates expected for the project.

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Appendix E: Waste Classification

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Technical Note: Waste Classification

Introduction

The aim of this technical note is to provide advice on the classification of wastes containing radioactivity that would be generated by the Dubbo Zirconia Project (DZP), proposed by Australian Zirconia Ltd (AZL) and to be located approximately 25km south of Dubbo, NSW. The aim is to determine the classification of the solid and liquid waste streams in accordance with the *NSW Waste Classification Guidelines* produced by the Department of Environment, Climate Change and Water (DECCW, 2008). In this assessment, only the radiological characteristics have been assessed.

Four main waste streams, being three solid waste streams and one liquid waste stream, would be produced by the DZP. Two of the solid waste streams are to be combined for final disposal, giving two solid waste streams and one liquid waste stream. The assessment conservatively assesses each of the individual waste streams as shown in Table 1.

Table 1: AZL Waste Streams

Waste Stream	Solid/Liquid	Quantity Produced
Combined Process Residues	Solid	3,924 tonnes per day
FeNb Slag	Solid	11.2 tonnes per day
Combined Waste Liquor	Liquid	1,9676 m^3 per day
Evaporated Waste Liquor Combined Salt (Combined Salt)	Solid	1,000 tonnes per day

As part of the testwork for the DZP, radionuclide analysis of the four waste streams in Table 1 was undertaken by ANSTO with results reported in the EIS prepared to assess the impacts of the DZP (RWC, 2013). The results for solids are shown in Table 2, and the results for the liquid waste stream are shown in Table 3. Note that the radionuclide analysis undertaken by ANSTO does not include all radionuclides that may be present in a material. This is due to difficulties in measurement and the ability to infer levels from other results. For the assessment in this technical note, radionuclides that have not been analysed, but which may be present in the waste streams, have been included. The concentrations for these radionuclides have been inferred from existing results. (For example, radionuclides with short half lives will be in equilibrium with parent radionuclides and isotopes of the same element would behave identically.)

Table 2: Radionuclide Analysis of Solid Waste Streams

Waste Stream	Radionuclide Concentration (Bq/g)																
	U^{238}	U^{234}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}	Th^{232}	Ra^{228}	Th^{228}	Ra^{224}	Pb^{212}	U^{235}	Th^{231}	Pa^{231}	Ac^{227}	Th^{227}	Total Activity
Combined Residues	0.045	0.045	1.04	1.13	1.08	1.09	1.4	1.5	1.4	1.5	1.5	0.002	0.025	0.025	0.037	0.025	11.8
FeNb Slag	0.42	0.42	3.5	0.37	0.47	0.35	4.6	0.49	4.6	0.49	0.49	0.02	8.7	8.7	0.66	8.7	43.0
Combined Salt	4.5	4.5	0.36	0.002	0.17	0.062	0.47	0.002	0.47	0.002	0.002	0.18	0.006	0.006	0.013	0.006	10.8

Table 3: Radionuclide Analysis of Liquid Waste Stream

Waste Stream	Radionuclide Concentration (Bq/L)																
	U^{238}	U^{234}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}	Th^{232}	Ra^{228}	Th^{228}	Ra^{224}	Pb^{212}	U^{235}	Th^{231}	Pa^{231}	Ac^{227}	Th^{227}	Total Activity
Combined Waste Liquor	266	266	21.2	0.11	10.1	3.7	27.9	0.14	27.9	0.14	0.14	10.64	0.37	0.37	0.74	0.37	636

(Note that the quantity of radionuclides appears to be higher in the liquid waste compare to the solid waste. This is due to the volume differences when presenting the concentration data. The convention is to present the solid concentration units as Bq/g, while the liquid concentration units are Bq/L)

Basis of Assessment

The waste material is assessed against the requirements outlined in the following;

- The radiation control regulation as seen at the following web address: http://www.legislation.nsw.gov.au/maintop/view/inforce/subordleg+52+2013+cd+0+N
- "NSW Waste Classification Guidelines Part 3: Waste Containing Radioactive Material" (Department of Environment and Climate Change, 2008) (referred to as the guideline)

A summary of the requirements in the guideline is as follows (note that *italicised* words have specific meaning in the references);

1. Step 1 – reference must be made to the Radiation Control Act 1990 and the Radiation Control Regulation 2013
2. Step 2 – If a material (solid or liquid) exceeds a combined *specific activity* of 100Bq/g and contains more than the *prescribed activity* of a radioactive element, is considered to be a **hazardous waste**.
3. Step 3 – If a material (solid or liquid) contains less than 100 Bq/g, then the *total activity ratio* and *specific activity ratio* must be calculated, based on the radionuclide group and the prescribed activity. (The group and prescribed activity for the relevant radionuclides are presented in table 4 and the formulas to calculate *total activity ratio* and *specific activity ratio* are provided.)

Table 4: Prescribed Activity for relevant Radionuclides

	Radionuclides Relevant to this Assessment	Prescribed Activity
Group 1 Radionuclides	U^{234}, Th^{230}, Ra^{226}, Po^{210}, Pb^{210}, Ra^{228}, Th^{228}, Pa^{231}, Ac^{227}, Th^{227}	40kBq
Group 2 Radionuclides	Ra^{224}, Pb^{212}	400kBq
Group 3 Radionuclides	Th^{231}	4MBq
Group 4 Radionuclides	U^{238}, Th^{232}, U^{235}	40MBq

Total Activity Formula (Formula 1)

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

A1, A2, A3, A4 are the total activity of group 1 to group 4 radionuclides as shown in Table 4, referenced to a 1kg sample

Specific Activity Formula (Formula 2)

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

SA1, SA2, SA3, SA4 are the specific activity of group 1 to group 4 radionuclides as shown in Table 4, referenced to a 1g sample

(Note that for a solid, the *total activity ratio* is equal to the *specific activity ratio*)

4. Step 4 – Where the ratios are greater than one, solid wastes would be classified as **restricted solid wastes** and government advice on liquid wastes must be obtained.
5. If the ratios are less than one, then the waste is classified according to other properties of the material.

Assessment – Solid Waste

- Are any of the solid wastes classified as *hazardous waste*?

Table 2 shows that the total specific activity for all solid wastes does not exceed 100Bq/g, therefore the solid wastes are not classified as *hazardous waste*. (Note that due to the quantity of the waste streams, the prescribed activity levels would be exceeded. However, the requirement for a hazardous waste is that both the specific activity of 100Bq/g and the prescribed activity levels are exceeded.)

- Are any of the solid wastes classified as *restricted solid waste*?

The requirement for a *restricted solid waste* is that the *total activity ratio* (TAR) and the *specific activity ratio* (SAR) be calculated and exceed 1. The TAR and SAR are calculated using the actual activities of radionuclides in each waste stream (shown in Table 2), the prescribed activities of the relevant radionuclides (shown in Table 4) and Formula 1 and 2 above.

Table 5 shows the total activity (in Bq/kg) of radionuclides in each group for each type of waste.

Table 5: Total Activity for relevant Radionuclides

	Total Activity for Each Radionuclide Group (Bq/kg)		
	Combined Residues	**FeNb Slag**	**Combined Salt**
Group 1 Radionuclides	7,372	28,260	5,591
Group 2 Radionuclides	3,000	980	4
Group 3 Radionuclides	25	8,700	6
Group 4 Radionuclides	1,447	5,037	5,150

To calculate the TAR, the total activity (in Bq/kg) of radionuclides in each group is multiplied by the relevant factor as shown in formula 1 and then added. The results can be seen in Table 6. For SAR, the total specific activity is in units of Bq/g which can be obtained by dividing the total activity by 1,000. Formula 2 is then applied. The results can be seen in Table 6.

Table 6: TAR and SAR for Solid Waste Streams

Solid Waste Stream	TAR	SAR
Combined Residues	7.7	7.7
FeNb Slag	28.5	28.5
Combined Salt	5.6	5.6

All solid waste streams are therefore classified as *restricted solid wastes* because the TAR and SAR results are greater than 1.

Assessment – Liquid Waste

- Is the liquid waste stream classified as *hazardous waste*?

Table 3 shows that the total specific activity for the liquid waste stream is 636Bq/L. If it is assumed that the liquid has a density of 1kg/L, then the average specific activity of the liquid is equivalent to 0.64Bq/g. This is does not exceed 100Bq/g, therefore the liquid waste stream is not classified as *hazardous waste*. (Note that due to the quantity of the waste stream, the prescribed activity levels would be exceeded. However, the requirement for a hazardous waste is that both the specific activity of 100Bq/g and the prescribed activity levels are exceeded.)

- Is the liquid waste stream classified as *restricted waste*?

The requirement for a *restricted waste* is that the *total activity ratio* (TAR) and the *specific activity ratio* (SAR) be calculated and exceed 1. The TAR and SAR are calculated using the actual activities of radionuclides in the waste stream (shown in Table 3), the prescribed activities of the relevant radionuclides (shown in Table 4) and Formula 1 and 2 above.

Table 7 shows the total activity (in Bq/kg) converted from Bq/L of radionuclides in each group for the liquid waste.

Table 7: Total Activity for relevant Radionuclides

Combined Liquid Waste	Total Activity for Each Radionuclide Group (Bq/kg)
Group 1 Radionuclides	330
Group 2 Radionuclides	0.28
Group 3 Radionuclides	0.37
Group 4 Radionuclides	304

To calculate the TAR, the total activity (in Bq/kg) of radionuclides in each group is multiplied by the relevant factor as shown in Formula 1 and then added. The results can be seen in Table 8. For SAR, the total specific activity is in units of Bq/g which can be obtained by dividing the total activity by 1,000. Formula 2 is then applied. The results can be seen in Table 8.

Table 8: TAR and SAR for Liquid Waste Streams

Solid Waste Stream	TAR	SAR
Combined Waste Liquor	0.33	0.33

The Total Activity Ratio and Specific Activity Ratio results are less than 1, therefore the Combined Waste Liquor stream is not classified as a *restricted waste*.

Conclusion

The radiological assessment of the process waste streams shows that the solid waste streams are classified as restricted solid waste and the liquid waste is not classified as either a hazardous waste or a restricted liquid waste.

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Appendix G: Glossary

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Activity
A measure of the level of radioactivity of a radionuclide in a unit called Becquerel.

Alpha radiation
Consists of alpha particles (two neutrons and two protons) and has a very short range in air (a few centimetres), depositing their energy quickly. They are unable to penetrate the outer skin later, but can be hazardous when inhaled or ingested.

Becquerel (Bq)
The Standard International (SI)unit of measurement of radioactive activity defined as one radioactive disintegration per second.

Beta radiation
Consists of high-energy electrons. They have moderate penetration, typically about one metre in air and a few millimetres in water or tissue.

Decay Product
The product of the spontaneous radioactive decay of a nuclide (a type of atom). A nuclide such as U^{238} decays through a sequence of steps and has a number of successive decay products associated with it in a decay series.

Dose equivalent
A measure of the radiation dose to tissue where an attempt has been made to allow for the different relative biological effects of different types of ionising radiation. Units are Sieverts (Sv).

Dose
The radiation energy absorbed in a unit mass of material.

Electron
A negatively charged particle that rotates around the nucleus of the atom, and is a component of all atoms.

Equilibrium Equivalent Concentration (EEC)
The concentration of Rn^{222} in equilibrium with its decay product.

Gamma radiation
A form of electromagnetic radiation similar to light or x-rays, distinguished by its high energy and penetrating power.

Impact
An effect, either positive or negative, that occurs due to the presence of an external entity.

Ionising radiation
Radiation which interacts with matter to add or remove electrons from the atoms of the material absorbing it, producing electrically charged particles called ions.

Isotope
Forms of a chemical element having the same number of protons but different numbers of neutrons.

Mineralised zone
An area of enriched mineralisation.

Occupational Dose
Radiation dose received by a person which occurs in the course of that person's work.

Particulate emission
Dust or particulates that are emitted as a result of an activity.

Member of Public

Any person other than a radiation worker who may be affected or impacted by radiation or radioactive emissions from an activity.

Radiation

Electromagnetic waves or quanta, and atomic or sub-atomic particles, propagated through space or through a material medium.

Radiation Dose

A relative measure of the energy deposited in human tissue by radiation.

Radiation Worker

Any person who works, whether full time, part time or temporarily, for an employer and who has recognized rights and duties in relation to occupational radiation protection.

Radioactive Decay Chain

The name given to the progression of naturally occurring radionuclides that occur as a result of radioactive decays.

Radioactive material

Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

Radionuclide

Any nuclide (isotope of an atom) which is unstable and undergoes natural radioactive decay.

Radon Decay Products (RnDP)

The short lived radioactive decay products of Rn^{222}

Sievert (Sv)

The SI derived unit of dose equivalent. It attempts to reflect the biological effects of radiation as opposed to the physical aspects.

Thoron Decay Products (ThDP)

The short lived radioactive decay products of Rn^{220}

TLD

Thermoluminescent dosimeter badge which measures gamma radiation exposure.

Total Suspended Particulates (TSP)

Airborne dusts, particles or aerosols that are generally less than 100µm in diameter.