

Australian Government

Australian Radiation Protection and Nuclear Safety Agency

Proposed Expansion of the Australian National Radiation Dose Register to the Mineral Sands Mining and Processing Industry

Sarsha Collett, Robert Guilfoyle, Ben Paritsky and Richard O'Brien

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Foreword

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is a Commonwealth Government agency charged with the responsibility for protecting the health and safety of people and the environment from the harmful effects of radiation. ARPANSA has, among other functions, a responsibility for promoting uniformity of radiation protection and nuclear safety policy and practices across jurisdictions of the Commonwealth, States and Territories.

Radiation protection of workers requires the maintenance of radiation dose records to aid assessment of compliance with occupational dose limits, and to support efforts to reduce radiation health risk to individuals through the continued improvement (optimisation) of work practices. While mineral sands operators in Australia are responsible for monitoring, assessing and recording the radiation dose to workers, as well as for reporting the results to the relevant state or territory authority, there is currently no national system for providing dose histories to mineral sands workers and no easy means for tracking the radiation dose to workers who move between different operations, industries, or jurisdictions.

A best practice approach for recording occupational exposures to radiation involves the collection and long-term storage of records in a centralised database. ARPANSA maintains the Australian National Radiation Dose Register (ANRDR), which is a centralised database designed for the collection and long-term storage of radiation dose records for workers who are occupationally exposed in the Australian uranium mining and milling industry. All current operating uranium mines in Australia are actively providing dose records to the ANRDR. ARPANSA is now seeking to expand the ANRDR to include other occupationally exposed workers. Beyond uranium mining this would initially include workers occupationally exposed to ionising radiation in the mineral sands mining and processing industry.

This technical report presents the findings of a review undertaken by ARPANSA to assess the current status of dose record management practices in the mineral sands industry. The purpose of this report is to provide information and recommendations that will assist ARPANSA, regulatory authorities, and operators in establishing the legal and practical requirements for the proposed implementation of the ANRDR to occupationally exposed workers in the mineral sands mining and processing industry.

Carl-Magnus Larsson CEO of ARPANSA

27 February 2014

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Executive Summary

This technical report presents the findings of a review undertaken by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) to assess the current status of dose record management practices in the mineral sands mining and processing industry, and identify legislative and other issues relating to the disclosure of workers' dose records to the Australian National Radiation Dose Register (ANRDR). The purpose of this report is to provide information and recommendations that will assist ARPANSA, regulatory authorities, and operators in establishing the legal and practical requirements for proposed expansion of the ANRDR to cover occupationally exposed workers in the mineral sands industry.

Based on the findings presented in this report, ARPANSA has assessed that existing practice for the management of radiation dose records in the Australian mineral sands industry could be improved to ensure record keeping practices meet international best practice. In the context of this report, a best practice approach for recording and maintaining occupational dose records for workers in the mineral sands industry involves the collection and long-term storage of radiation dose records in a centralised database, such as the ANRDR. It is considered that the ANRDR, when adopted and implemented, will allow for a single uniform national approach to the management of radiation dose records for the mineral sands industry and ensure that records remain available to workers.

In order to assist the mineral sands industry to improve the existing practice for maintaining radiation dose records and facilitate implementation of the ANRDR, ARPANSA makes the following five key recommendations:

- Recommendation 1: That ARPANSA works cooperatively with industry and regulatory authorities to establish processes and working arrangements for obtaining dose data directly from mineral sands operators.
- Recommendation 2: That consideration should be given by all states and territories to uniformly adopt the Safety Guide for *Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing* (RPS 9.1) (ARPANSA 2011) into their legislative framework and guidance notes governing personal data collection. This would facilitate consistency in personal data collected across mineral sands operations to ensure radiation doses can be linked to individual workers.
- **Recommendation 3:** That consideration should be given by all mineral sands operations currently using paper-based record keeping practices to develop systems for managing dose records in a digital format. Digital record keeping practices would help to ensure the longevity of radiation dose records for workers in the mineral sands industry.
- **Recommendation 4:** That ARPANSA, relevant regulatory authorities, and the mineral sands industry work cooperatively to develop dose record reporting processes and working arrangements to ensure that industry reporting requirements are effective and efficient in optimising worker protection efforts.
- Recommendation 5: That ARPANSA, in partnership with industry, review the current categories assigned to workers with the objective of developing a list of typical mineral sands work area categories to ensure a more consistent approach to worker categorisation across operations and jurisdictions.

ARPANSA will form a coordinating body consisting of relevant mineral sands industry and regulatory representatives to strengthen support for the ANRDR and guide implementation activities to ensure that future decisions for expansion of the ANRDR are in-line with industry practice and the regulatory framework for radiation protection and mining.

1. Introduction

1.1 Background

In mineral sands mining and processing operations, workers may be exposed to ionising radiation from naturally occurring radionuclides in mineral ores and processed materials. If occupational exposures are below regulatory concern, the practice may be exempt from regulatory control of radiation protection, but otherwise such exposures should be monitored, assessed, and recorded in accordance with the *Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing* (RPS 9) (ARPANSA 2005).

International Safety Standards (IAEA 2011a) require that records of individual occupational doses of workers are kept and made available to the relevant regulatory authority and to individuals. This requirement has been adopted in Commonwealth, State and Territory legislation across Australia. Internationally, it is considered to be best practice to strengthen the application of this requirement by establishing a central dose register to make provisions for establishing, maintaining, and retrieving records of occupational exposure. Canada (Zielinski et al. 2008) and many European (Frasch et al. 2001) countries have established comprehensive central registers for recording occupational doses.

In 2008 an Australian government initiative, in cooperation with industry, launched the development of the Australian National Radiation Dose Register (ANRDR). Established in 2010, the ANRDR is a centralised database designed for the collection and long-term storage of radiation dose records for workers who are occupationally exposed to radiation in the Australian uranium mining and milling industry. The ANRDR is administered by ARPANSA as part of its role to protect the health and safety of people and the environment from the harmful effects of radiation, and to promote uniformity of radiation protection.

Consistent with this role and to ensure that operation of the ANRDR meets the best practices of the more established national dose registers in Canada and Europe, ARPANSA is seeking to expand the ANRDR beyond uranium mining to include workers occupationally exposed to ionising radiation in the mineral sands mining and processing industry. To evaluate the feasibility of expanding the ANRDR beyond uranium mining, a comprehensive review of the Australian mineral sands mining and processing industry to get a better understanding of the legal requirements and practical considerations for implementation of the ANRDR to the mineral sands industry.

1.2 Objective

The objective of this report is to provide information and recommendations that will assist ARPANSA, regulatory authorities, and operators in establishing the legal and practical requirements for implementation of the ANRDR to occupationally exposed workers in the mineral sands mining and processing industry.

1.3 Scope of the review

The scope of the mineral sands review was to:

- identify relevant mineral sands operations in Australia to assess the number and types of workers monitored for occupational radiation exposure
- assess the status of the reporting and monitoring systems in place for the management of dose records for occupationally exposed workers in the mineral sands industry

- identify legislative issues impacting on disclosure of dose records to ARPANSA for the purpose of the ANRDR
- provide recommendations that will:
 - inform future decisions for expansion of the ANRDR in-line with privacy legislation and the regulatory framework for radiation protection and mining, and
 - establish cooperative arrangements with relevant state and territory governments and industry to strengthen support for the ANRDR expansion.

The radiological health impact of mineral sands mining on the public or the environment is not included in the scope of this report.

1.4 Report overview

The methodology for this review comprised four stages:

- Stakeholder analysis the review commenced with identification of the key industry and government stakeholders in the mineral sands industry.
- Desktop research a review was performed of the key existing data and literature currently available on mineral sands mining and radiation protection considerations that apply to the industry in Australia, and where relevant, internationally.
- Data collection the data collection phase was conducted in consultation with key industry and regulatory stakeholders. The content of this report is largely based on two information sources:
 - Industry survey an electronic survey was circulated to currently operating mineral sands mining and processing operations in Australia. The purpose of the survey was to determine how radiation dose records are managed for occupationally exposed workers in the mineral sands industry.
 - Legislative review ARPANSA performed a review of the relevant legislation in each jurisdiction relating to radiation protection and mining. The purpose of the review was to identify the legislative issues impacting on radiation dose history reporting arrangements and provide options for establishing the legal requirements for implementation of the ANRDR to the mineral sands mining and processing industry.
- Analysis and reporting following the research, data collection and consultative phases, an analysis was undertaken of industry dose record management practices, regulatory framework, legislative barriers and major issues impacting on radiation dose history reporting arrangements and possible means for addressing these.

Following the introduction, the report is structured as follows:

- Chapter 2 provides an overview of the mineral sands mining and processing industry in Australia.
- Chapter 3 summarises the radiation protection considerations that apply to the mineral sands industry, in particular the sources of exposure to workers, and radiation doses received by workers.
- Chapter 4 describes the current regulatory framework for radiation protection and mining in the mineral sands industry, including an overview of the relevant legislation, privacy issues relating to the disclosure of dose records to the ANRDR, and the different jurisdictional requirements for recording and keeping occupational dose records.

- Chapter 5 describes the management of radiation dose records, including international best practice, an overview of the ANRDR, and the current status of radiation exposure data management practices in the mineral sands industry in Australia.
- Chapter 6 presents the key findings of the review, including recommendations, practical considerations, the proposed approach and expected benefits for expansion of the ANRDR to the mineral sands industry.
- The report is supplemented by six appendices which present additional information on the following topics:
 - Appendix A Radionuclides in the uranium and thorium decay series
 - Appendix B Mineral sands operations in Australia
 - Appendix C Overview of alpha, beta and gamma radiation
 - Appendix D Radiation dose concepts
 - Appendix E Doses attributed to workers
 - Appendix F Australian jurisdictional requirements for record keeping and reporting
 - Appendix G Stakeholders consulted
 - Appendix H Stakeholder survey questions.

2. Mineral Sands Mining in Australia

2.1 Background

The term 'mineral sands' refers to ores containing heavy minerals with a specific gravity greater than 3 (WACME 1999). Mineral sands deposits were formed millions of years ago from weathering and erosion of the Earth's surface. A combination of wave action (alluvial systems) and wind action (aeolian systems) carried and concentrated the heavy minerals into beach and dune deposits. The principal components of heavy mineral sands are rutile, ilmenite, zircon, and monazite. The geological processes that formed these mineral sands also led to the incorporation of naturally occurring **radionuclides**, uranium and thorium, in the minerals.

The naturally occurring radionuclides of the uranium-238 (U-238) and thorium-232 (Th-232) decay series are the **sources** of **radioactivity** in the heavy minerals. Usually these naturally occurring radionuclides are present at only trace levels (approximately 10-50 parts-per-million). However the presence of U-238 and Th-232 in the ores means that workers involved in the extraction and processing of these minerals can be exposed to **ionising radiation**. For example, **mining** and processing of heavy mineral sands increases the potential for workers to be exposed to ores, products, or **waste** streams containing higher concentrations of U-238 and Th-232 than the naturally occurring levels. Appendix A provides more information about the various radionuclides in the U-238 and Th-232 decay series.

2.1.1 Mineral sands resources and production

Australia is rich in mineral sands resources with deposits located in most states and territories. Mineral sands deposits occur along the eastern coast from central New South Wales to northern Queensland, and in Western Australia. In addition, ancient beach deposits are found in Victoria, New South Wales and South Australia. The major companies currently producing mineral sands in Australia include:

- Iluka Resources (Western Australia, South Australia and Victoria)
- Cristal Mining Australia (Western Australia & New South Wales)
- Doral Mineral Sands (Western Australia)
- Tronox (Western Australia)
- Murray Zircon (South Australia)
- Sibelco Australia (Queensland).

Appendix B presents more detail on those mineral sands mining and processing **operations** in Australia that provided information to the development of this report. It should be noted that some of the operations listed are scaling down operations, while several other mineral sands projects other than those listed in this report are currently being proposed in Australia.

Heavy mineral sand deposits are mined for their ilmenite, rutile, leucoxene, and zircon content. Ilmenite, leucoxene, and rutile are titanium bearing minerals used mainly as **feedstock** for the production of titanium dioxide pigments. Zircon is a zirconium bearing mineral used for the manufacture of ceramics and refractories and also in a range of industrial and chemical applications. Monazite is a rare earth bearing mineral found within heavy mineral sand deposits in Australia. Monazite is rich in thorium and is not widely exploited in Australia due mainly to the very limited market for monazite. Australia is a major producer of heavy minerals, supplying more than 60% of the global demand for rutile and synthetic rutile, and more than 50% of the demand for zircon. Australia was the largest producer of rutile and zircon in 2011, producing 474 kilotonnes (kt) of rutile and 762 kt of zircon (Geoscience Australia 2013). Australia supplies 4% of the global demand for titanium dioxide pigment, producing approximately 160 kt of titanium dioxide pigment in 2011 (Australian Mines Atlas 2012). Australia's production of mineral sands is shown in Figure 1.



Figure 1: Australia's Production of Mineral Sands in 2011.

Geoscience Australia provides an indication of the extent of mineral resources available for extraction, with the main focus being on Economic Demonstrated Resources (EDR). EDR is a measure of the size and quality of the resource and its economic viability. In terms of Australia's ranking in world share of EDR, Australia's EDR of rutile (53%) and zircon (50%) represented the world's largest economic resource in 2011 (Geoscience Australia 2013). In addition, Australia's share of ilmenite (15%) is ranked second largest in the world behind China (31%). Australia's world share of mineral sands resources and production is shown in Figure 2.





2.1.2 Mineral sands mined in Australia

In Australia, mineral sand ores are mined and processed to produce two core product streams; titanium bearing minerals (in the form of rutile, ilmenite and leucoxene), and zircon.

2.1.2.1 Titanium bearing minerals

Titanium bearing minerals are used mainly as feedstock for the world's titanium dioxide pigment industry. The key titanium bearing minerals of commercial importance are:

- a) Ilmenite (FeTiO₃) is a mixed oxide of titanium and iron with an equivalent titanium dioxide (TiO₂) content of 34–69% (IAEA 2012). Ilmenite is an economically important mineral due to its titanium content. Ilmenite is upgraded to synthetic rutile (TiO₂) for use as feedstock for subsequent production of titanium dioxide pigment. Downstream processing of ilmenite and other heavy minerals is discussed in Section 2.2.3.
- b) Rutile (TiO₂) is a naturally occurring titanium dioxide with an equivalent TiO₂ content of 93-96.5% (IAEA 2012). Rutile and synthetic rutile (from ilmenite) are processed to produce titanium dioxide pigments for use in the manufacture of paint, paper, plastics, ink, ceramics and many other products. Synthetic rutile production is discussed further in Section 2.2.3.1.
- c) Leucoxene (Fe₂O₃·TiO₂) is formed through extensive weathering of ilmenite which removes iron and increases the titanium content resulting in an equivalent TiO₂ content of 70-90% (IAEA 2012). Leucoxene is largely used as feedstock for the production of titanium dioxide pigment. Titanium dioxide pigment production is discussed in greater detail in Section 2.2.3.2.

Titanium dioxide and other titanium-containing products are essentially free of radioactivity, however the titanium bearing minerals and the various feedstocks derived from them contain trace quantities of uranium and thorium and their radioactive decay products (IAEA 2012). These radionuclides tend to follow the solid waste stream during processing; as a result, the titanium dioxide pigments produced do not have detectable levels of radioactivity. Typical radionuclide concentrations for uranium and thorium in products and waste arising from mineral sand extraction and processing are discussed further in Section 3.2.

2.1.2.2 Zircon

Zircon (ZrSiO₄) is the major zirconium bearing mineral mined in Australia. Due to its hardness and high melting point, zircon is used for the manufacture of ceramics, glazes, glass, refractories, foundry sands and a wide range of industrial and chemical applications. Zircon has economic importance as a raw material and also as feedstock for the manufacture of zirconia (ZrO_2). Zirconia and zircon are also used for the manufacture of zirconium metal is not currently produced in Australia.

The zircon mineral contains trace amounts of radionuclides from the U-238 and Th-232 decay series within the mineral structure (Iluka 2010). Zircon products may contain elevated levels of thorium if the monazite is not completely removed during the secondary separation process. **Secular equilibrium** (hereafter referred to as equilibrium) typically exists between the radionuclides within their respective decay series, meaning that all of the radionuclides in the decay series have similar **activity concentrations** to each other. However, during the manufacture of zirconia from zircon, the **decay chain** equilibrium present in the zircon feedstock is significantly disrupted, resulting in higher concentrations of radionuclides in zirconia (Cooper 2003). Typical radionuclides in some of the process materials involved in the production of zirconia from zircon are shown in Table 3.

2.2 Mineral sands mining and processing

2.2.1 Mineral sands mining

Mining of mineral sands ores is carried out either by dry mining methods or wet dredging techniques. Dry mining methods use earth moving equipment to extract ore located above the water table. The ore is then transported (in slurry form) to a **concentrator** plant for separation and processing. Dredge mining, or wet mining, is best suited to ore reserves below the water table. Dredging involves cutting the ore under the surface of a pond and using a bucket well and suction to pump the ore in **slurry** form to a concentrator for separation and processing.

2.2.2 Processing of mineral sands

Recovery of the various heavy minerals from the ore takes place in two main stages:

- i. The primary separation process step is the production of a **heavy mineral concentrate** (HMC) using a wet gravity separation technique. The ore is washed through a series of spiral separators that utilise sizing and gravity differentiation to separate the heavy minerals from the accompanying clay, quartz sand and rock. The concentrate obtained from this process contains a mix of valuable heavy minerals as well as other non-valuable heavy mineral components and waste. The primary separation process produces a heavy mineral concentrate with a typical composition of 73% ilmenite, 20% zircon, 5% rutile, 1% leucoxene, 1% monazite and less than 1% xenotime (IAEA 2007a). The HMC is stockpiled before being transported to the dry separation plant for secondary processing. A flow chart of the typical steps involved in mineral sands mining and processing is shown in Figure 3.
- ii. The secondary separation process utilises a series of dry extraction techniques to further separate the individual minerals. Dry separation processes exploit the physical properties (magnetic susceptibility, electrical conductivity and density) of each mineral to produce the various mineral products. The physical properties of the heavy minerals discussed in this section are shown in Table 1. The dry separation techniques applied to the HMC involve various magnetic and electrostatic separators. Early in the process, ilmenite is separated from the other heavy minerals due to its high magnetic susceptibility. Electrostatic separators are then used to separate the conductive minerals such as rutile, leucoxene and residual ilmenite from the non-conductive minerals, such as zircon and monazite. Small remaining quantities of non-valuable heavy minerals and contaminants are then removed by further magnetic and electrostatic separation techniques.

Mineral	Chemical Formula	Magnetic Susceptibility	Electrical Conductivity	Specific Gravity	TiO ₂ Content (%)
Ilmenite	FeO [·] TiO ₂	High	High	4.5 - 5.0	34 - 69
Rutile	TiO ₂	Low	High	4.2 – 4.3	93 - 96.5
Zircon	ZrSiO ₄	Low	Low	4.7	N/A
Leucoxene	Fe_2O_3 ·Ti O_2	Semi	High	3.5 – 4.1	70 - 90
Monazite	(Ce,La,Th,Nd,Y)PO ₄	Semi	Low	4.9 – 5.3	N/A

Table 1: Physical properties of heavy minerals (adapted from Iluka 2009, IAEA 2007a, IAEA 2012).

2.2.3 Downstream processing of mineral sands

Downstream processing of mineral sands involves chemical treatment of the materials produced in the primary and secondary separation processes described in Section 2.2.2 to produce materials such as synthetic rutile, zirconia and titanium dioxide pigment. A detailed description of downstream processing techniques is outside the scope of this report, but is given elsewhere (IAEA 2007a, IAEA 2012).

2.2.3.1 Synthetic rutile production

Synthetic rutile, also known as 'upgraded ilmenite', is a chemically modified ilmenite which has had most of the non-titanium components removed. In Australia, synthetic rutile is produced by the Becher process (IAEA 2012) which involves chemical treatment of ilmenite to remove iron oxides and produce a high percentage titanium oxide feed material for subsequent production of titanium pigment. The synthetic rutile product has an equivalent titanium dioxide content of 88-94% (IAEA 2012). In the Becher process, usually only a small proportion of the thorium and uranium content of ilmenite is removed from the process stream via the **residues**, with the majority passing through to the synthetic rutile product. An important change to the Becher process has been the development of the synthetic rutile enhancement process (SREP) which uses various leaching methods to produce a high grade synthetic rutile product with lower radionuclide concentrations than that achieved using the Becher process.

2.2.3.2 Titanium dioxide pigment production

Titanium dioxide pigment is produced via one of two methods; the chloride process and the sulphate process. In Australia, titanium dioxide pigment is extracted from rutile and synthetic rutile using the chloride process. In this process, rutile is reacted at high temperatures with chlorine gas, to form titanium tetrachloride (TiCl₄) gas, which is then converted to titanium dioxide by oxidation (IAEA 2012). A wide range of **titaniferous** feedstocks (ilmenite, rutile and leucoxene) can be used to produce titanium dioxide pigment, however the chloride process typically requires feedstocks of high grade (high TiO₂ content), such as rutile and synthetic rutile.

2.2.3.3 Zirconia production

In Australia, zirconia (ZrO_2) is produced by high temperature fusion of zircon $(ZrSiO_4)$. In this process, zirconia is produced by dissociation of zircon into its components zirconia and silica at a temperature of 1800 degrees Celsius or more, followed by chemical purification of the separated zirconia component (IAEA 2007a).





2.3 Waste production

Mining and processing of heavy minerals gives rise to products, residues and wastes. Residues are those materials that have potential for utilisation, whereas a **waste** is a material for which there is no foreseeable use (ARPANSA 2008b). The generation and handling of residues and wastes during the extraction and processing of mineral sands can result in radiation **exposure** to workers. Radiation exposure arising from waste production is discussed in Section 3.2.

2.3.1 Waste generated during mining and the primary separation process

Apart from the mining **overburden**, most of the waste arising from the mining and primary processing of the mineral sands is in the form of oversize material (rocks, etc.), sand **tailings**, and clay **fines** (Cooper 2003). These waste materials are usually returned to the mined out pit for disposal, after drying if necessary, or used for construction of on-site gravel roads, tailings dam walls, etc. Where wet dredging techniques are used, waste slurries are returned directly to the dredging pond for disposal (WACME 1999).

2.3.2 Waste generated during the secondary separation process

Waste materials generated during the secondary separation process consist mainly of tailings, oversize solids, dust extracted from the dry separation plant extraction systems, particulates collected from stack discharges and clay fines removed from the separation plant water system (IAEA 2011b). The solids, dust and particulate waste are returned to the mine site and either stockpiled for possible future reprocessing or dumped into mined out pits. In some cases selected streams such as monazite-rich tailings may be blended with other solid waste streams before disposal into the mined out pits. The clay fines are transported to drying dams before disposal into the mine pit (WACME 1999).

The radioactivity levels in waste material generated during the secondary separation process depend mainly on the monazite content of the original ore (Cooper 2003). Typical activity concentrations for uranium and thorium in waste arising from mineral sand mining and processing methods are presented in Section 3.2.

2.3.3 Waste generated during downstream processing

Downstream processing of the heavy minerals produces waste in various forms, including inert solids, iron oxide solids, slurries and oversize solids from the product drying kilns, neutralised acid effluent solids and non-magnetic fines (Cooper 2003). This waste material is collected from the various processes either as dry solids, or slurries that have to be dried prior to disposal. Solids are neutralised, washed, and separated from the liquids, then dried before final disposal in specifically constructed tailings dams. Liquid effluent is treated and discharged to a containment pond or surface water body. Solids from the effluent treatment are occasionally disposed of in landfill.

Typical activity concentrations for uranium and thorium in waste arising from the production of synthetic rutile, zirconia and titanium dioxide are presented in Section 3.2 in Table 2, Table 3, and Table 4 respectively.

2.4 Transport

Often mineral sands ore is processed at a different location from where it is mined. This results in transport of minerals and wastes being a significant component of mining and production. Mineral sands ore, heavy mineral concentrate, tailings and other wastes, and final products are transported to and from the mine site and mineral separation plant, and to customers via road, rail and sea. Exposures to workers who are involved in the transportation of mineral sands ore, concentrate, products and tailings are discussed further in Section 3.5.

3. Occupational Exposure to Radiation in the Mineral Sands Industry

3.1 Background

The methods involved in the extraction, separation, and downstream processing of heavy mineral sands produce a large number of product, residue, and waste streams. The original ores contain radionuclides from the uranium-238 (U-238) and thorium-232 (Th-232) series that are in approximate equilibrium. However, extraction and processing of the heavy mineral sands can disturb the equilibrium, which can cause the activity concentrations of the radionuclides in the different product, residue and waste streams to vary significantly (Long et al. 2012). In addition, processing of the heavy minerals may affect the composition of the radionuclides leading to additional possible exposure pathways to workers.

A number of pathways can result in exposures to workers in mineral sands mining and processing operations. Pathways for which measures for occupational radiation protection require consideration are those involving external exposure to gamma radiation, and internal exposure via the intake of radionuclides, and inhalation of **radon** and **thoron** gases and **progeny** (ARPANSA 2011). In the context of this report, a **worker** implies a radiation worker. A radiation worker is someone who is exposed to ionising radiation as a normal part of their work - some workers may be inadvertently exposed in the course of their work, even though they do not handle radioactive materials.

3.2 Ionising radiation in the mineral sands industry

In the context of radiation protection, the term **NORM** is used to describe situations where human activities have increased the potential for exposure to ionising radiation from materials containing naturally occurring radionuclides like uranium and thorium in comparison to the situation where those materials were left undisturbed. For example, mining and processing of heavy mineral sands increases the potential for workers to be exposed to ores, products, or waste streams containing higher concentrations of the radioactive **isotopes** U-238 and Th-232 (and their radioactive decay products – see next paragraph) in comparison to the naturally occurring situation.

Isotopes of the naturally occurring radioactive elements uranium and thorium carry excess energy and are unstable. When these radioactive isotopes (radionuclides) break down, or undergo radioactive decay, they spontaneously emit ionising radiation in the form of **gamma rays**, **alpha particles** and **beta particles** and form decay products which are also radioactive. Furthermore, when these new radionuclides undergo radioactive decay, they create further decay products which are also radioactive. This process is repeated until the decay process results in the formation of a stable nuclide. The appendices provide more detailed information about alpha, beta and gamma radiation (Appendix C), and the various radionuclides in the U-238 and Th-232 decay series (Appendix A).

The rate at which spontaneous nuclear transformations occur in a given amount of a radioactive material is known as its **activity** and is expressed in a unit called the **becquerel** (Bq). An important quantity is the activity concentration which is the amount of activity per unit of volume, in units of becquerels per kilogram (Bq/kg) for the context of this report. Typical radionuclide activity concentration and thorium in products and waste arising from mineral sand extraction and processing in Australia and world-wide comparison values are given in Table 2.

Apart from those heavy minerals that contain uranium and/or thorium within the mineral structure (e.g. zircon, ilmenite and rutile), the radioactivity level in waste material depends mainly on the monazite content of the original ore, which can vary considerably depending on the location of the

ore body (Cooper 2003). Monazite is a phosphate mineral containing rare earth elements, thorium (between 5 and 7%), and uranium (between 0.1 and 0.3%) (Hewson 1997). With the decreased interest in thorium, monazite in many cases is considered a waste product and is typically separated from other products and disposed of with tailings.

		Activity Concentration (Bq/kg)			
Stage of	Material	Australia ¹ (V	VACME 1999)	World (I	AEA 2012)
Operation		Uranium	Thorium	Uranium	Thorium
	Ore	30 - 120	20 - 280	30 - 200	200 - 1,000
Mining and Primary	Heavy mineral concentrate	<100 - 800	300 - 3,000	100 - 2,000	300 - 8,000
Separation	Sand tailings	<100	<200	10 - 20	50 - 100
	Oversize	<100	<200	120	200
	Ilmenite	<100 - 400	200 - 2,000	30 - 400	40 - 2,000
	Leucoxene	200 - 600	300 - 3,000	200 - 800	300 - 3,000
	Rutile	<100 - 300	<200 - 1,400	<100 - 700	60 - 400
	Zircon	1,000 - 4,000	600 - 1,200	1,000 - 4,000	500 - 1,000
Processing Plant	Monazite concentrate	6000 - 30,000	40,000 - 250,000	6000 - 40,000	140,000 - 250,000
Separation	Xenotime	N/A	N/A	50,000	60,000
	Oversize	600 - 2,000	300 - 8,000	600 - 1,900	300 - 2,600
	Tailings	100 - 12,000	800 - 24,000	100 - 10,000	1000 - 20,000
	Clay slimes	~ 400	~ 2400	400	2000
	Mill dust and stack particulates	100 - 6,000	1000 - 20,000	100 - 6,000	2000 - 20,000
	Synthetic rutile	<100 - 300 ²	<200 - 1500 ²	90 - 700 ²	$100 - 1900^2$
Processing Plant	Iron oxide and other inert solids	<300 ²	<400 ²	<1,000 ²	<1,000 ²
– Synthetic Rutile	Neutralised and non-magnetic solids	100 - 1,200 ²	200 - 7,000 ²	<1,000 ²	<1,000 ²
	Kiln solids	<100 - 600 ²	100 - 1,200 ²	N/A	N/A

Table 2:	Typical radionuclide activity concentrations in products and waste from mineral sand mining and
	processing (adapted from WACME 1999 and IAEA 2012).

Notes: 1. The Australian data presented in this table were almost exclusively collected in Western Australia.

2. Secular equilibrium of the respective uranium and thorium series cannot be assumed for the production of synthetic rutile or materials related to synthetic rutile.

Typical radionuclide activity concentrations in some of the process materials involved in the production of fused zirconia from zircon sand are shown in Table 3. The radionuclide concentrations are higher when baddeleyite (naturally occurring zirconia) feedstock is used. For zirconia produced in Australia, the radionuclide concentrations are consistent with the values given in Table 3.

	$\mathbf{P}_{\mathbf{r}}$						
		Кас	lionuclide Ad	ctivity Conce	ntration (Bq	/ Kg)	
	Uranium-238 Series				Tho	orium-232 Se	ries
Process Material	U-238	Ra-226	Pb-210	Po-210	Th-232	Ra-228	Th-228
Zircon sand feedstock	3,400 - 4,100	3,400 - 4,100	3,400 - 4,100	3,400 - 4,100	560 - 610	540 - 610	540 - 610
Zirconia product	1,900 - 5,200	400 - 2,450	150 - 300	160 - 300	570 - 1,200	270 - 800	470 - 900
Silica by-product	950 - 2,000	57,600	2	2	10 - 100	870	220
Silica waste	1,500	1,500	10,000	10,000	600	600	600



Notes: 1. These are indicative values only.

2. Radionuclide not present in this process material.

In titanium dioxide production, traces of uranium and thorium and radioactive progeny (decay products) are present in the original rutile and synthetic rutile minerals. These radionuclides tend to accumulate in the solid waste stream(s) during processing. Titanium dioxide pigments generally do not contain detectable levels of radioactivity. Typical radionuclide concentrations in the solid waste are given in Table 4 (WACME 1999).

Table 4:Typical quantities and radionuclide concentrations in titanium dioxide pigment production
(adapted from WACME 1999).

Material	Uranium-238 ¹ (Bq/kg)	Thorium-232 ¹ (Bq/kg)
Titanium dioxide pigment	Not detectable	Not detectable
Neutralised residue slurry	350 (wet)	1,200 (wet)
Solid waste from liquid effluent treatment	300 - 500 (dry)	800 - 1,400 (dry)

Note: 1. Based on mass concentrations of uranium and thorium. However, secular equilibrium of the respective uranium and thorium series is not maintained throughout processing.

The main radionuclides contributing to gamma exposure in the production of titanium dioxide pigment are actinium-228 (Ac-228), lead-212 (Pb-212) and thallium-208 (Tl-208) from the Th-232 decay series and lead-214 (Pb-214) and bismuth-214 (Bi-214) from the U-238 decay series (IAEA SRS 76) (see Appendix A).

3.3 Sources of exposure to workers

Sources of radiation exposure to workers during a normal working day in the mineral sands industry will vary with the methods that are used to mine and process the heavy mineral ores. In general, exposure to ionising radiation can occur in three main ways, namely:

- external gamma radiation
- intakes of radionuclides associated with airborne dust
- inhalation of radon gas and radon progeny.

Exposure to workers in the Australian mineral sands mining and processing industry is primarily due to external exposure to gamma radiation, and internal exposure through inhalation of long-lived alpha emitters associated with airborne dust (Alexander et al. 1993, Hartley 2001, Cassidy 1990).

3.3.1 External gamma radiation

Workers can be exposed to external gamma radiation from bulk materials. This becomes important in the extraction of the raw materials, packaging and storage of products, management of processing wastes and residues, and transport of raw materials and products. Another potential source of external exposure to the worker is from contamination on surfaces. This can be an issue in processing plants where there is potential for spills of material and for build-up of loose material on floors and equipment surfaces.

Exposures during maintenance, refurbishment, and decontamination work can also give rise to **doses** to workers from external gamma radiation, unless controls are applied. Controls for reducing doses to maintenance workers include limiting exposure times, measurement and recording of exposure rates and doses received, and good occupational hygiene practices. Dose assessment of maintenance workers may be based on personal dosimetry or on a consideration of dose rate measurements and time spent working (IAEA 2012). Clothing and tools may need to be checked for contamination at the end of the maintenance operation to prevent the spread of contamination and to reduce the potential for further exposure. Wastes generated by these maintenance operations should be collected and disposed of under controlled conditions.

Additionally, exposure to the external gamma radiation can also occur in the process of operation and maintenance of radiation density gauges containing caesium-137, as each heavy mineral processing plant cannot be successfully operated without accurate measurement of the density of transported materials in different points of the process.

3.3.2 Intakes of radionuclides

Another important mode of exposure for workers is internal exposure following intakes of radionuclides via inhalation or ingestion, particularly of dust suspended in the air from sand separation and processing. Much of the processing of mineral sands involves the handling of fine, dry material. This can lead to high airborne dust concentration in processing plants, unless measures are taken to prevent dust re-suspension or reduce airborne dust concentrations. Machines that handle dry materials are fitted with dust covers in modern processing plants. These covers significantly reduce the levels of airborne dust. In other areas where there is potential for re-suspension of dust, ventilation and spraying are two common methods of controlling airborne dust levels.

Inhalation of radioactive gases (other than radon and thoron and their progeny) can also be a source of exposure. Kiln processing or smelting operations can result in the volatilisation of polonium and lead isotopes. These are generally removed by scrubbers in the stacks used to vent off-gases. Another potential pathway for inhalation of dust occurs during maintenance, refurbishment and

decontamination work. Respiratory protective equipment may be required if there is potential for airborne dust generation during this work.

Personal contamination may pose an external gamma radiation risk, but it is more likely to pose an ingestion risk, particularly if contamination gets on the hands and the worker then eats or smokes. This problem can be easily managed by applying standard occupational health and hygiene procedures in workplaces.

3.3.3 Inhalation of radon gas and radon progeny

Workers can be internally exposed to radiation through the inhalation of radon and thoron gases, and radon and thoron decay products, which are all members of the respective uranium and thorium decay series. Radon and thoron can be released from process materials during extraction and processing, particularly when material is being crushed. Under good ventilation conditions, internal exposure from inhalation or radon and thoron is typically negligible as the levels of radon and thoron are generally consistent with natural background (Hewson and Hartley 1990, IAEA 2007, Hewson 1993). However, there is potential for dose estimates from radon and it's progeny to be higher with the revision of dose conversion factors for assessment of radon exposure in line with recommendations of the International Commission on Radiological Protection (ICRP) (ICRP 2009).

3.4 Radiation doses received by Australian mineral sands workers

3.4.1 Exposure of workers in the Australian mineral sands mining and processing industry

3.4.1.1 Historical doses

Radiation doses to workers in the mineral sands mining and processing industry were previously much higher than they are today (IAEA 2011b). Changes to legislation and the publication of recommendations of the ICRP on the control of radiation and setting of dose limits for workers (ICRP 1977, ICRP 1979) and *the Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores* (CoA 1987) prompted research into **occupational exposure** in these industries in the 1980s and 1990s. This research resulted in many improvements in dust control and radiation protection **practices** (Cassidy 1990).

Typical doses to workers during the mining and wet processing stages are of little radiological concern, due to the low concentration of radionuclides at these stages (Hewson 1990, Marshman and Hewson 1994, Carter 1993). It is the mineral separation and processing stages where the risk of radiation exposure to a worker is likely to be higher. The typical sources of exposure were mentioned in Section 3.3 and usually involve exposure to radiation through external gamma radiation, and internal exposure through inhalation of long-lived alpha emitters associated with airborne dust (Alexander et al. 1993, Hartley 2001, Cassidy 1990).

Hewson and Hartley (1990) reported that approximately 15% of workers in the Western Australian mineral sands industry exceeded an annual radiation dose of 15 mSv (the relevant investigation level at that time) by the late 1980s. The same authors also reported that a small proportion of the workers received annual doses approaching or exceeding the statutory limit of 50 mSv¹. By 1992, the annual doses to workers in the Western Australian mineral sands industry had reduced to approximately 8 mSv (Marshman et al. 1994). Both these studies noted that the internal dose contributed 80-90% of the total, but also noted that the estimates of internal dose were likely to be subject to considerable uncertainties.

¹ Radiation dose limits and concepts have changed over time. The history of radiation dose limits and concepts are covered in more detail in Appendix D.

Cassidy (1990) also recognised that internal doses resulting from the inhalation of dusts are conservative estimates, and that previously, due to the assumptions made in the calculation, the doses may have been overestimated by at least a factor of two, and possibly by a factor of ten.

3.4.1.2 Dose mitigation

While the presence of elevated levels of radionuclides in this industry has been long appreciated, early protective and regulatory measures were focussed on control of external radiation exposure in circuits where monazite was being concentrated and bagged. Intake of radioactive dust was only recognised as a potentially significant source of exposure in the early 1980s, following a national review, and acceptance of ICRP Publication 30 (ICRP 1979). This resulted in the application of **derived air concentration** (DAC) values for thorium an order of magnitude lower than those previously used in the industry (Hewson and Terry 1995, Hewson 1997).

Dust control has been recognised as an important step in reducing radiation doses to workers (Cassidy 1990). Methods of dust control include:

- reduction of dust at the source
- containment of any dust generated such that it does not become airborne
- removal of suspended dust from the air by ventilation or similar methods
- providing personal protective equipment in the form of masks or similar devices.

Another major change to radiation protection practices was the recommendation of ICRP Publication 60 (ICRP 1991), to reduce the occupational dose **limit** from 50 mSv per year, to 20 mSv (per year) averaged over five calendar years, with a maximum of 50 mSv in any one year. This was formally adopted in Australia with the publication of *Recommendations for Limiting Exposure to Ionising Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionising Radiation (1995)* (ARPANSA 2002). The reasoning and methodologies behind these dose limits and how they have changed over time is described in Appendix D.

3.4.1.3 Doses to current workers

Doses to workers have decreased over time with the introduction of reduced dose limits, improved dust control techniques, and better radiation protection practices. However, it has been recognised that without appropriate control measures, significant radiation exposures can be received from external gamma radiation exposure and from inhalation of long-lived alpha emitters associated with dust (Hewson and Hartley 1990).

Analysis of data from **ARPANSA**'s Personal Radiation Monitoring Service (PRMS) shows that average external gamma doses to workers in the mineral sands industry have decreased over time (ARPANSA 2013), as demonstrated in Figure 4 and Appendix E.



Figure 4: Mineral sands worker doses by category and year (ARPANSA 2013).

These PRMS data are similar to estimates of total effective dose to workers in zircon milling and processing plants of 5.5 mSv per year, with the potential dose from inhaled zircon being estimated at 3.3 mSv per year (Hartley 2001). The data are also consistent with published international data (Righi et al. 2005, IAEA 2007a).

A review of radiation management plans published in Australia (Bemax 2007, Iluka 2007, Matilda Minerals 2005, SEMF 2008) show a range of estimated occupational doses, all well below the statutory dose limits. Estimated doses will differ from one site to another due to the nature of the mine and the nature of the ore. Typical estimated doses to Australian workers range from 0.5 mSv to 3.2 mSv per year for external doses (Bemax 2007, Iluka 2007, Matilda Minerals 2005, SEMF 2008). Estimated doses from inhalation of dust can also vary between sites, and between worker roles. Conservative estimates of dose from the inhalation of dust can vary from as low as 0.06 mSv per year to as high as 10.7 mSv (Iluka 2006) per year for workers in mineral separation plants.

3.5 Radiation doses to workers involved in the transport of mineral sands

3.5.1 Background

Transport of primary concentrate, heavy mineral concentrate (HMC), intermediate products and tailings is important in terms of radiation protection of workers in the mineral sands mining and processing industry, particularly when Mineral Separation Plants (MSP) are not co-located with the mine sites. These materials contain low quantities of radionuclides, and there exists a risk of exposure to the transport workers.

A report was prepared for ARPANSA by Calytrix Consulting (Calytrix 2008), which studied the radiation exposure of transport workers in the Australian mineral sands mining and processing industry. This report studied 16 transport routes, and identified that all doses to workers were very low. It was noted that all materials transported were exempt from the ARPANSA *Code of Practice for the Safe Transport of Radioactive Material* (ARPANSA 2008a). Transport modes studied were via road, rail, and sea. The four main transport routes studied included:

- transport of 'primary' concentrate to a 'secondary' concentrator
- transport of HMC from mine sites to the separation plants
- transport of final product from a separation plant to a wharf
- transport of final product to a customer overseas.



Figure 5: Truck used for transporting ore.

3.5.2 Exposure pathways in transport

Road, rail and sea transport were identified as key modes of transport in the mineral sands industry. These three modes offer potential risks of exposure to the transport workers involved.

Some typical scenarios for external gamma and internal dust exposure are:

- exposure while loading a truck with a front loader from a stockpile of HMC, waste or product
- exposure from a loaded truck while inside driver's cabin
- exposure from storage bins on a loaded railway wagon
- exposure from storage bins on a loaded train from inside the locomotive operator's cabin
- exposure during train loading and unloading
- exposure from material in a loaded cargo hold on a ship

- exposure during loading and unloading of a ship
- exposure from stored materials prior to loading at a wharf.

3.5.3 Doses to workers from transport

Maximum estimated doses to workers studied in the Calytrix report are summarised in Table 5. The maximum dose to a worker was to a truck driver transporting HMC to the plant and returning to the mine site with tailings, which was estimated to be 0.6 mSv per year. While this estimated dose was much higher than the estimated doses for other routes, it is still less than the public dose limit of 1 mSv per year.

Material Transported	Mode of Transport	Highest Estimated Exposure (mSv/year)
	Road	0.60
Heavy Mineral Concentrate	Rail	0.23
	Sea	0.20
Zircon	Road	0.13
ZIICOII	Sea	0.17
Ilmonito/Sunthotic Dutilo	Road	0.15
innenite/synthetic Kuthe	Sea	0.12

Table 5:Summary of the results of the study on doses to transport workers (adapted from Calytrix 2008).

The estimated doses in the Calytrix report can be compared to estimated doses from a brief review (Iluka 2007) of recently published radiation management plans and transport plans for currently operating Australian mineral sands mining and processing operations. Typical doses to transport workers were found to be very low, so even though transport doses may be considered, the dose values are rarely estimated in radiation management plans. A typical estimation of doses to transport workers as included in a radiation management plan is listed in Table 6.

Table 6:Estimated doses to transport workers at an Australian mineral sand mining and processing
operation (Iluka 2007).

Exposure Pathway	Annual Effective Dose (mSv)
Deixer	0.26 (Heavy Mineral Concentrate)
Driver	0.11 (Mineral Separation Plant waste)
Loading/Unloading	0.18 (Heavy Mineral Concentrate)
	0.04 (Mineral Separation Plant waste)

4. Radiation Protection Regulatory Framework

4.1 Background

As discussed in Chapter 3, workers in the mineral sands mining and processing industry may potentially be exposed to radiation levels greater than the public dose limit of 1 mSv per year. The radiation protection framework for the mining and processing of radioactive ores in Australia is complex. Australia has nine jurisdictions, each of which have their own Acts, regulations, codes of practice and guidelines governing the safe operation of mining and processing practices with respect to radiation protection. There are no mining or processing operations that are relevant to this report in the Australian Capital Territory, so details about the radiation protection regulatory framework in that jurisdiction have been omitted.

ARPANSA leads the development of standards, codes of practice, and guidelines to support radiation protection and nuclear safety in Australia. These documents are often based on documents published by international organisations such as the **IAEA** and the ICRP. The adoption by the Commonwealth government of guidelines published by these international bodies ensures that international best practice can be readily achieved. The documents published by ARPANSA are intended to be used by the states and territories in Australia to develop their own regulatory frameworks for radiation protection purposes within their jurisdiction. Figure 6 illustrates the process for the development of regulatory frameworks for radiation protection in Australia.

UNSCEAR	ICRP	IAEA	Australia
Reviews and assesses the scientific evidence and reports on levels and health effects of exposure to ionising radiation	Evaluates radiation risks and establishes the protective measures based on the scientific evidence and value judgements	Establishes international standards for Government for global nuclear safety and security to protect people and the environment from ionising radiation	ARPANSA works cooperatively with state and territory regulators to promote national uniformity and develop codes of practice and guidance based on international best practice

Figure 6: Development of the Australian radiation protection framework based on international best practice.

4.2 Relevant legislation

While based on international best practice and ARPANSA guidance, the regulatory framework for radiation protection in Australia can differ significantly between jurisdictions. Each state and territory has their own Acts and regulations concerning radiation protection. This presents challenges for national uniformity due to differences in legislative and regulatory requirements across the different jurisdictions. Table 7 lists the relevant Acts and regulations, by jurisdiction, regarding radiation protection in the Australian mineral sands industry.

Jurisdiction	Regulatory Authority	Relevant Legislation and Regulations
Commonwealth	Australian Radiation Protection and Nuclear Safety Agency	Radiation Protection Series 1: Recommendations for Limiting Exposure to Ionizing Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionizing Radiation (republished 2002) Radiation Protection Series 9: Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005)
		Radiation Protection Series 9.1: Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing (2011)
New South Wales	New South Wales Environment Protection Authority New South Wales	Radiation Control Act 1990
	Department of Trade and Investment	Radiation Control Regulation 2013
Northern Territory	Department of Health	Radiation Protection Act 2012 Radiation Protection Regulations 2012
Queensland	Department of Natural Resources and Mines	Mining and Quarrying Safety and Health Act 1999 Mining and Quarrying Safety and Health Regulation 2001
South Australia	Environment Protection Authority South Australia	Radiation Protection and Control Act 1982 Radiation Protection and Control (Ionising Radiation) Regulations 2000
Tasmania	Department of Health and Human Services	Radiation Protection Act 2005 Radiation Protection Regulations 2006
Victoria	Department of Health	Radiation Act 2005 Radiation Regulations 2007
Western Australia	Department of Mines and Petroleum Radiological Council of Western Australia	Mines and Safety Inspection Act 1994 Mines and Safety Inspection Regulations 1995 Radiation Safety Act 1975 Radiation Safety (General) Regulations 1983

Table 7:Relevant legislation and regulations for radiation safety for the mining and processing of ores in
Australian jurisdictions.

4.3 **Privacy issues**

The ANRDR collects some personal information in order to accurately match the dose information with the correct worker. This information is listed in Section 5.3.5 (Figure 10). All data are managed in accordance with the *Privacy Act 1988*. ARPANSA may only disclose records containing personal information under certain circumstances. Access to personal information can only be obtained via a written request from the individual to whom it relates. On confirmation of identity, the worker will be provided with a copy of the relevant dose history report. Once new data are uploaded to the ANRDR, a high dose check is performed. If a worker has exceeded any of the relevant annual dose limits, ARPANSA will disclose a copy of the individual's radiation dose history report to the appropriate state or territory authority and to the employer. ARPANSA can only disclose dose history records to state and territory regulatory authorities if a worker has exceeded an occupational dose

limit. ARPANSA may also produce statistics to demonstrate industry trends and to compare with industries overseas. All published statistics will be de-identified.

In addition to imposing limitations in relation to the disclosure of dose histories, Commonwealth privacy legislation also imposes obligations on ARPANSA in relation to matters such as:

- the use of dose histories for purposes other than the purposes for which they were obtained
- the storage and security of dose histories
- the provision of information about records containing dose histories
- the alteration of such records and the checking of accuracy of such records.

4.4 Disclosure of dose data to the ANRDR

4.4.1 Disclosure of dose data in the Australian uranium mining and milling industry

Currently, dose data are collected from uranium mining operations in two jurisdictions; the Northern Territory and South Australia. In the Northern Territory, amendments were made to the Radiation Protection Act and Radiation Protection Regulations to require Ranger mine, as a prescribed mining site, to report dose records to the ANRDR on a quarterly basis. These amendments also require workers to be informed in writing of the types of information being reported to ARPANSA. These records must be reported to ARPANSA within six weeks of the end of a quarter. This is enforced by the Department of Health, Northern Territory.

In South Australia, amendments were made to the radiation management plans for the relevant mine sites to require the disclosure of radiation dose data to the ANRDR. Conforming to a site radiation management plan is a regulatory licence condition, and therefore enforced by the relevant regulatory authority, in this case the Environment Protection Authority South Australia.

4.4.2 Disclosure of dose data in the Australian mineral sands industry

ARPANSA performed a review of the regulatory framework for radiation protection in the mineral sands industry to determine the legislative issues impacting on the disclosure of dose records, and provide options for establishing the legal requirements for implementation of the ANRDR to the mineral sands mining and processing industry. This review focussed on the current (July 2013) Acts and regulations applicable in each jurisdiction. Based on the interpretation of the regulatory framework, recommendations could be made as to how mining operations in each jurisdiction could work with their regulatory authority in order to provide dose data to the ANRDR. ARPANSA's interpretation of the Acts and regulations relevant in each jurisdiction are described below.

4.4.2.1 New South Wales

Amendments to the *Radiation Control Act 1990* were made in 2013, which included the regulation of radiation protection in the mining of radioactive ore. This means that for the purposes of regulating radiation protection in the mining of radioactive ores, the Department of Trade and Investment is the authority which administers the Radiation Control Act and regulations. The regulations specify that a record must be kept for each occupationally exposed worker, and the type of information it should contain.

The regulations do not specify how often these records should be reported to the regulatory authority, or whether these records could be disclosed to ARPANSA. In the future, mining workplaces may be required to have a radiation management plan if the minerals on site contain a level of radioactivity which could pose a health hazard (New South Wales Department of Trade and

Investment, 2013). It may be possible to include a condition in the radiation management plan, or to alter the radiation or mining licence conditions to provide dose records to the ANRDR.

In terms of the *Mining Act 1992*, conditions can be imposed on an **operator** in a new mining lease to disclose dose records to the ANRDR. Conditions cannot be imposed on a current mining lease; however, the Minister responsible for the *Mining Act 1992* may amend any conditions in a mining licence upon renewal.

Under section 125(1)(a) of the *Mining Act 1992*, the Minister may cancel a mining lease in certain limited circumstances, including on request from the holder of the mining lease to the Minister to do so. Consequently, with the agreement of the operator, the Minister could cancel and re-issue the operator's mining licence on the same terms, but attaching a condition requiring the operator to provide workers' dose histories to ARPANSA for inclusion in the ANRDR.

4.4.2.2 Northern Territory

Radiation protection in the Northern Territory is administered under the *Radiation Protection Act* (2012) and the Radiation Protection Regulations (2012), which are enforced by the Department of Health, Northern Territory. The regulations only apply to prescribed mining sites. Currently, the Ranger uranium mine is the only prescribed mining site. The regulations require the reporting of dose data, in the form as listed in the ANRDR Data Transfer Specifications, to ARPANSA no more than 6 weeks after the end of a quarter. To allow for mineral sands mining and processing sites to report radiation dose records of occupationally exposed workers, the sites would have to be listed as prescribed sites in the Radiation Protection Regulations (2012).

4.4.2.3 Queensland

Radiation protection in the mining and processing industry in Queensland is administered under the *Mining and Quarrying Safety and Health Act 1999* and Mining and Quarrying Safety and Health Regulations 2001 by the Queensland Department of Natural Resources and Mines. However, mining licences are issued under the *Mineral Resources Act 1989* (MRA).

Under section 276(4) of the MRA it is possible for the Minister to impose on an operator's mining lease a condition requiring the operator to provide workers' dose histories to ARPANSA but for this to occur the agreement in writing of the operator holding each relevant mining lease would be required.

However, the objectives of the MRA are not about ensuring the health and safety of workers, but for mining activities and managing impacts other than environmental conditions, which are regulated under conditions of an Environmental Authority.

ARPANSA has been advised that radiation doses received by workers involved in mineral sands mining are occupational health and safety matters that would come under the *Mining and Quarrying Safety and Health Act 1999* (MQSH). The Queensland government would encourage the mineral sands mining operations in Queensland to voluntarily provide any personal monitoring data to the ANRDR and also include that expectation in the government's guidance notes on mineral exploration and other guidance notes on mineral extraction and processing where NORM is involved.

4.4.2.4 South Australia

In South Australia the control of activities related to radioactive substances, and the protection of health and safety of people against the harmful effects of radiation is regulated by the Environment Protection Authority of South Australia, under the *Radiation Protection and Control Act 1982*, and the Radiation Protection and Control (Ionising Radiation) Regulations 2000. The South Australian government is currently reviewing the *Radiation Protection and Control Act 1982*.

Under section 36 of the *Radiation Protection and Control Act 1982*, it would be possible for the Minister to impose on each operator a condition requiring the operator to provide workers' dose histories to ARPANSA for inclusion in the ANRDR. However, regulation 24 of the Radiation Protection and Control (Ionising Radiation) Regulations 2000 (SA Regulations) specifically prohibits the disclosure of employee dose histories unless one of the exceptions in regulation 24 applies. An exception under regulation 24 is where the disclosure is approved by the Minister (sub-regulation 24(d)).

In order to ensure that the conditions of the licence requiring disclosure of dose histories to ARPANSA comply with the regulations, the Minister may impose a condition that the operator disclose dose histories to ARPANSA, except where prohibited by regulation 24, and approve all disclosures of dose histories to ARPANSA under sub-regulation 24(d).

If the disclosure of dose histories was required by SA Regulations, then the regulation 24 prohibition on disclosure would not apply. Amendments to the SA Regulations would be subject to the approval of the relevant Department and Minister.

Uranium mines in South Australia are required to provide data to ARPANSA by a clause in their radiation management plans, which must be adhered to under a licence condition. Data provision from mineral sands sites in South Australia could occur in the same way.

4.4.2.5 Tasmania

The *Radiation Protection Act 2005* and Regulations 2009 are administered by the Department of Health and Human Services in Tasmania.

The Director of Public Health may, under section 22 of the *Radiation Protection Act 2005* (the Tasmanian Act), issue a licence subject to specified conditions. Section 22(3) lists types of conditions that may be imposed; however, this list does not limit the conditions that the Director of Public Health may impose. A new licence may be issued which contains a condition requiring the operator to provide dose histories for inclusion in the ANRDR.

In relation to existing licences, the Director of Public Health could amend licences and conditions specified in them under section 28 of the Tasmanian Act. The Director of Public Health may only make such an amendment if they are satisfied that is it necessary to do so to protect persons or the environment from the harmful effects of radiation emitted from the source to which the authority relates. The Director of Public Health may also amend the licence on request from the operator if the Director of Public Health is satisfied that the amendment of the licence would not, or would not be likely to, result in the failure to protect persons or the environment from the harmful effects of radiation emitted from the authority relates.

A further option in relation to existing licences would be for the Director of Public Health to wait until the expiration of each licence and to impose new conditions upon licence renewal. As licences issued by the Tasmanian radiation regulator are renewed annually, a condition requiring disclosure of dose records can be imposed when the licence is renewed.

Section 59 of the Tasmanian Act prohibits persons who are involved in the administration of the Tasmanian Act from disclosing certain information; however, it does not apply to operators. This section would not prevent operators from disclosing data to the ANRDR.

4.4.2.6 Victoria

The *Radiation Act 2005* and Radiation Regulations 2007 are administered in Victoria by the Department of Health. To conduct a radiation practice within Victoria, which includes the mining and processing of radioactive material, requires a management licence.

Under section 47 of the Victorian Act, the Secretary of the Department of Health may impose any condition he/she considers appropriate on a management licence. The Secretary is permitted under section 65 of the Victorian Act to vary the conditions of a management licence on his or her own initiative, by notifying the licence holder in writing.

Therefore, it would be possible under section 65 of the Victorian Act for the Secretary to impose on a management licence held by an operator a condition requiring the operator to provide workers' dose histories to ARPANSA for inclusion in the ANRDR.

4.4.2.7 Western Australia

Unlike other industries in Western Australia where workers are occupationally exposed to radiation, radiation safety of the mineral sands industry is not regulated by the Radiological Council of Western Australia. Radiation safety of workers in the mining industry, including the mineral sands industry, is regulated by the Department of Mines and Petroleum (DMP) under the *Mines Safety and Inspection Act 1994*, and Regulations 1995. There are, however, some areas of overlap in the responsibilities under the Mines Safety Inspection Act and regulations, and the Radiation Safety Act 1975 and Radiation Safety (General) Regulations 1983. A Memorandum of Understanding between the DMP and the Radiological Council of Western Australia was signed in 2012 to clarify the overlap in regulations, and to establish the Radiation Liaison Committee (RLC). The RLC facilitates communication between the Radiological Council and the DMP in relation to areas of mutual responsibility, including appointments of statutory radiation safety officers; review and consideration of radiation management and radioactive waste management plans; review and consideration of reports and notifications; compliance and inspections, mine closure, decommissioning and rehabilitation; and other authorisations as the RLC sees fit.

One option for the provision of data to the ANRDR by operators of mining and processing facilities in Western Australia is that the WA Radiological Council may, under section 36 of the *Radiation Safety Act 1975* (the WA Act), impose on particular licences or registrations granted or effected under section 33 of the WA Act, a condition requiring the operator to provide workers' dose histories to ARPANSA for inclusion in the ANRDR.

This may occur in a similar way as in South Australia, where a condition in the radiation management plan is altered, with the approval of the relevant regulatory authority, to allow for the operator to report dose records to the ANRDR.

4.5 Requirements for record keeping and reporting radiation dose records

The National Standard for Limiting Occupational Exposure to Ionizing Radiation (ARPANSA 2002) (hereafter called RPS 1) serves to identify the provisions which are to be made in the regulations of states and territories for the control of occupational exposure to radiation, including the specification of occupational exposure dose record keeping and reporting practices. It is recognised that due to the differing legislative frameworks in each state and territory that the requirements for keeping and reporting radiation dose records vary across jurisdictions. However, it is expected that implementation of the provisions contained in RPS 1 (ARPANSA 2002) will be nationally consistent.

RPS 1 (ARPANSA 2002) specifies employers' responsibilities, including the requirement to keep records relating to occupational exposure, and to provide these records to the appropriate authority. The following extract from RPS 1 (ARPANSA 2002) describes the requirement for record keeping, which is consistent with international best practice (IAEA 2011a):

Requirements for record keeping: Part 14.2 of RPS 1 (ARPANSA 2002)

"Records of doses assessed to have been received by an employee, including details of monitoring results and dose calculation methods, as required by the appropriate authority, shall be kept during the working life of the employee and afterwards for not less than 30 years after the last dose assessment and at least until the employee reaches, or would have reached, the age of 75 years. When an operation terminates, the employer shall pass to the appropriate authority the retained records of doses assessed to have been received by employees and any other records specified by the appropriate authority."

As RPS 1 (ARPANSA 2002) sets fundamental requirements for safety, other documents are developed, such as Codes of Practice and Safety Guides, to provide practice-specific guidance on achieving the requirements set out in RPS 1. Two key documents have been developed for the mining and **mineral processing** industries:

- The Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (ARPANSA 2005) (hereafter called RPS 9) sets out the mandatory requirements necessary for the control of occupational radiation exposures. It is intended that RPS 9 can be incorporated into regulatory instruments, such as conditions attached to licences or mining tenements as appropriate.
- The Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing (ARPANSA 2011) (hereafter called RPS 9.1) provides further information and guidance to assist industry and regulatory authorities in meeting the objectives and requirements of RPS 9 (ARPANSA 2005).

The purpose of RPS 9 (ARPANSA 2005) and RPS 9.1 (ARPANSA 2011) is to foster uniform outcomes in radiation protection in the mining and processing industries, or more specifically, to promote a nationally consistent approach to monitoring, assessing and recording occupational exposures to radiation for operations involving mining and processing of uranium and mineral sands.

Keeping proper records and providing appropriate reports relating to radiation monitoring and dose assessment are important aspects of a radiation protection program. RPS 9.1 (ARPANSA 2011) notes that the relevant regulatory authority will specify the reporting requirements for each operation within its jurisdiction, according to the applicable legislation. In addition, it is recommended that doses are reported by calendar quarter² and provided to the ANRDR to facilitate maintenance of national records (ARPANSA 2011).

- Quarter 1 1 January to 31 March
- Quarter 2 1 April to 30 June
- Quarter 3 1 July to 30 September
- Quarter 4 1 October to 31 December

² A calendar quarter represents the period of time covered by the data. The quarter numbers as defined in the ANRDR Data Transfer Specifications are:



Figure 7: The Code of Practice RPS 9 (ARPANSA 2005) and the Safety Guide RPS 9.1 (ARPANSA 2011) developed for mining and mineral processing operations.

Furthermore, records retained by an employer should preserve enough information that foreseeable enquiries concerning a worker's exposure history can be readily answered; this includes the collection of personal information. RPS 9.1 (ARPANSA 2011) lists the type of personal information that should be collected in association with a worker's radiation dose record:

Requirement for personal data collection: Section 7 of RPS 9.1 (ARPANSA 2011)

The record for each employee for whom individual dose assessments are made should include the following items, as appropriate:

- a unique identifier for the individual
- the full name, gender and date of birth of the individual
- records of any formal declaration of pregnancy, any revocations of such declarations, and notifications of the conclusion of a pregnancy.

Although RPS 9.1 (ARPANSA 2011) outlines the types of personal data that should be collected, there is still some inconsistency in the regulatory requirement across different jurisdictions for the type of personal data collected for each worker due to the differing legislative frameworks that exist in each state and territory.

Table 8 provides a summary of the requirements for recording personal data and reporting occupational dose records in each of the Australian jurisdictions with respect to the mineral sands industry. Appendix F provides more detailed information about the Australian jurisdictional requirements for record keeping and reporting in the mineral sands industry.
Jurisdiction	Requirement for Recording Personal Data	Reporting Requirement
New South Wales	Full name, gender, date of birth, current address, date of commencement (and cessation) of employment	No legislated requirement for reporting to a regulatory authority ¹
Northern Territory	Include information required by clause 7.1.2 of RPS 9.1 (ARPANSA, 2011)	The operator of a mining site must report to ARPANSA quarterly ¹
Queensland	No current record keeping requirements	No legislated requirement for reporting to a regulatory authority ¹
South Australia	Full name, gender, date of birth, current address, date of commencement (and cessation) of employment	No legislated requirement for reporting to a regulatory authority ¹
Tasmania	Personal radiation monitoring is required but no specific requirements for personal data collection	No legislated requirement for reporting to a regulatory authority ¹
Victoria	Personal radiation monitoring is required and dose assessments to be kept for at least 30 years after the last dose assessment or until the person reaches, or would have reached the age of 75 years	No legislated requirement for reporting to a regulatory authority ¹
Western Australia	Personal radiation monitoring is required in accordance with radiation management plans, but no specific requirements for personal data collection	The manager of a mine must ensure that dose assessments are reported to the State Mining Engineer in a form and at intervals approved by the State Mining Engineer

Table 8.	Summary	of the	Australian	iurisdictional	requirements for	record keeping	and reporting
Table o.	Summar	yor the	Australiali	julisuictional	requirements for	record keeping	z anu reporting.

Note: 1. Jurisdictions where a reporting requirement is not specified in the relevant legislation, reporting requirements may be captured in the licence conditions for individual operators.

5. Management of Radiation Dose Records

5.1 Background

Radiation exposures to workers in the mineral sands mining and processing industry that are subject to a radiation protection regulatory framework should be monitored, assessed, and recorded in accordance with the *Code of Practice for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing* (ARPANSA 2005). Recording and maintaining occupational exposure records are important aspects of a radiation protection program, to demonstrate compliance with occupational dose limits and facilitate optimisation of the effectiveness of monitoring procedures and programs. Records retained by an employer should preserve sufficient information that foreseeable enquiries concerning a worker's exposure history may be readily answered.

5.2 International best practice

International Safety Standards (IAEA 2011a) require that records of individual occupational doses of workers are kept and made available to the relevant regulatory authority and to individuals.

IAEA International Safety Standard for Records of Occupational Exposure (IAEA 2011a)

Requirement 25 of the International Safety Standard outlines the responsibility of employers to assess and record occupational exposures. A summary of paragraphs 3.103 to 3.107 which prescribe the requirements for employers to maintain records of occupational exposure is as follows:

- Employers shall maintain records of occupational exposure for every worker for whom assessment of occupational exposure is required.
- Records of occupational exposure for each worker shall be maintained during and after the worker's working life, at least until the former worker attains or would have attained the age of 75 years, and for not less than 30 years after cessation of the work in which the worker was subject to occupational exposure.
- Records of occupational exposure shall include information on:
 - the general nature of the work in which the worker was subject to occupational exposure
 - information on dose assessments and data upon which the dose assessments were based
 - dates of employment
 - records of any assessments of doses due to actions taken in an emergency or due to accidents or other incidents.
- Employers shall provide workers with access to records of their own occupational exposure and make arrangements for the retention of exposure records for former workers.
- Employers shall provide the regulatory body with access to workers' records of occupational exposure and facilitate the provision of copies of workers' exposure records to new employers when workers change employment.
- If employers cease to conduct activities in which workers are subject to occupational exposure, they shall make arrangements for the retention of workers' records by the regulatory body or a State registry.

This requirement has been adopted in Commonwealth, state and territory legislation across Australia. Internationally, it is best practice to strengthen the application of this requirement by establishing a centralised national dose register to collect individual dose history records of occupationally exposed workers. Canada (Zielinski et al. 2008) and many European (Frasch et al. 2001) countries have established very comprehensive national registers for recording occupational doses. Centralising occupational dose records is important for the long-term security of individual workers' dose histories, especially considering the complex radiation protection regulatory framework that exists in Australia. In 2008, an Australian government initiative launched the development of a national dose register to ensure practices for managing occupational dose records are consistent with international best practice. This register, called the Australian National Radiation Dose Register (ANRDR), is discussed further in Section 5.3.

5.3 The Australian National Radiation Dose Register (ANRDR)

5.3.1 Development of the ANRDR

The ANRDR is a centralised database designed for the collection and long-term storage of radiation dose records for workers who are occupationally exposed in the Australian uranium mining and milling industry. The development of the ANRDR began as a result of a recommendation made in a report from the Uranium Industry Framework Steering Group in 2006 (UIF 2006).

Recommendation 12 of the Uranium Industry Framework Steering group stated that:

"The Australian Government should work with relevant state and territory governments to establish cooperative arrangements with industry to ensure that permanent records of the radiological dose history of uranium industry individuals are collected, maintained and retrievable."

As a result of this recommendation, the Department of Resources, Energy and Tourism (DRET)³ and ARPANSA launched the development of the ANRDR.

The ANRDR is administered by ARPANSA as part of its role to protect the health and safety of people and the environment from the harmful effects of radiation, and to promote uniformity of radiation protection. Consistent with this role, the ANRDR provides a single uniform national approach to the management of radiation dose records for uranium mine workers and ensures the longevity of records beyond the working life of a uranium mining operation, so that records remain available to workers.

5.3.2 Objectives of the ANRDR

The key objectives of the ANRDR are to:

- record and track the lifetime radiation dose of workers
- assure long-term maintenance of dose records
- provide dose histories to workers
- notify regulators and employers when an individual has exceeded their annual (or 5 year average) dose limits
- produce annual statistics and trends.

³ On 18 September 2013, the functions of the Department of Resources, Energy and Tourism were transferred to the Department of Industry.

5.3.3 Benefits to workers and industry

The ANRDR provides benefits to both workers and industry alike. For workers, it provides assurance that radiation dose records are maintained and retrievable into the future, including when companies cease to operate. It allows the tracking of a worker's radiation dose throughout their career, to assess compliance with occupational dose limits, including in situations where a worker moves between different operations, or between different industries (e.g. between mineral sands mining and uranium mining), or between different jurisdictions. Workers can request a report of their radiation dose history which will contain all past doses received while working in occupationally exposed mining and processing industries in Australia, and while registered with the ANRDR.



Figure 8: Occupationally exposed workers who are monitored for radiation exposure.

For mine operators, the information contained in the ANRDR will assist in informing better work practices and improve safety for occupationally exposed workers in Australia. Analysis of the ANRDR data can provide information on industry-level statistical data on radiation doses received by workers which will assist in the optimisation of radiation protection for workers in the Australian mining industry. The ANRDR also facilitates reporting of statistical data to international bodies such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Atomic Energy Agency (IAEA) to make possible comparisons on the overall radiation safety performance of Australia against other countries.

5.3.4 How the ANRDR works

The ANRDR is a computer-based system that incorporates a secure web-based portal (Figure 9) and a database for the consolidation and long-term storage of records. The operators can upload data files (in accordance with the ANRDR Data Transfer Specifications developed for uranium mine operators) containing workers' radiation dose records through this web portal. All worker records are held in compliance with the requirements of the *Privacy Act 1988*. Operators, acting through a nominated contact person (e.g. the worksite radiation safety officer) can access the web portal to register a worksite, upload data, and view industry-level statistical reports.

Australian Government Australian Radiation Protection and Nuclear Safety Agency	1721/2011
Velcome to the Australian National Radiation Dose Register	
he Australian Government is committed to the safety and long-term wellbeing of uranium work	Please login to the ANRDR website
he Australian National Radiation Dose Register is designed to track uranium workers' dose acords throughout their career in the uranium industry. This will allow individuals to move betwi ompanies, states and territories with the knowledge that their radiation dose is being recorded tored on a single national database. This register has been developed by, and is operated and naintained by, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).	een Usemame:
his portal is to be used as a means of submitting workers' radiation dose histories to the regis nd to facilitate communication with the administrators of the Australian National Radiation Dos legister.	ster, se <u>Forgotten Username and/or Password2</u>



The ANRDR collects information on quarterly assessed radiation doses for occupationally exposed workers for each of the three main exposure pathways (i.e. external gamma radiation, intakes of radionuclides, and inhalation of radon gas and radon progeny). This is compatible with current industry practice of monitoring, assessing, and recording worker doses for each pathway and the time periods over which doses are calculated and reported. Quarterly assessed radiation doses for mineral sands workers will be integrated in the register to compare with annual and five year occupational dose limits specified in RPS 1 (ARPANSA 2002). A dose to a worker in excess of the occupational dose limit will be flagged and reported to the relevant state or territory authority for further inquiry.

The ANRDR does not absolve operators from their responsibility to also maintain radiation dose records for workers. However, it will help to ensure the longevity of records beyond the working life of a mining or processing operation and that records remain available to workers. Workers can request a report of their lifetime radiation dose history. This report will contain all doses reported to the ANRDR from current or past employment in Australia. Dose information can be requested by completing a form provided on the ARPANSA website. The service is provided free of charge by the Australian Government.

5.3.5 Type of information collected

The ANRDR collects information on doses received both externally and internally. These dose data are sourced from personal monitoring, as well as other monitoring and dose assessments calculated on-site. Company data and personal information are also collected to match a dose to the correct worker. A summary of the type of information collected is included in Figure 10.

All personal and radiation dose information is kept strictly confidential, and is handled according to the *Privacy Act 1988*.



- Full name
- Date of birth
- Gender
- Employee number
- Place of employment
- •Employee work classification
- Dates employed

COMPANY DATA

- •Trading name
- •Worksite
- •ABN
- Operator details
- •Worksite details
- •Commencement of operation
- Dose parameters

DOSE DATA

- •External gamma
- Inhalation of:
- radioactive
- particulates
- radioactive gases and vapours
- Ingestion
- •Wound
- •Extremity doses

Figure 10: Type of information collected for the ANRDR.

5.3.6 Current status of the ANRDR

The ANRDR has been open to receive dose records from uranium mining and milling operators since 1 July 2010. The ANRDR has been successfully implemented to all four operating uranium mines in Australia: Olympic Dam, Beverley and Honeymoon in South Australia, and Ranger in the Northern Territory. The ANRDR currently holds radiation dose records for more than 31,300 registered workers. A summary of the data currently held in the ANRDR database from the uranium mining industry is provided in Table 9. ARPANSA staff data have also been included in the ANRDR to test the suitability of the ANRDR for accepting dose histories from non-uranium mining occupational groups.

Table 9:The total number of records currently registered in the ANRDR from the uranium mining and
milling industry.

Mine	Year Included in the ANRDR	Total Number of Records	Data Collected
Olympic Dam	October 2010	29,290	Q1 2004 – Q3 2013
Beverley	January 2011	1,046	Q1 2001 – Q2 2013
Ranger	July 2012	811	Q1 2010 – Q3 2013
Honeymoon	February 2014	177	Q1 2011 – Q3 2013

Note: 1. Data correct as of 12/02/2014

5.3.7 Worker outreach program

ARPANSA has launched a worker outreach program to educate workers in the uranium mining and milling industry of the existence of the ANRDR. Its aim is to inform workers on the capabilities and benefits of the ANRDR and to encourage workers to check their radiation dose history. A brochure and poster series has been developed to be distributed to mine sites (Figure 11). ARPANSA is working with the mine sites to integrate this information into site inductions and radiation safety training programs.



Figure 11: Posters developed for the worker outreach program.

5.3.8 Future of the ANRDR

Now that the ANRDR has been successfully implemented to all operating uranium mines in Australia, ARPANSA intends to publish annual statistics showing industry sector trends and comparisons to assist in the optimisation of radiation protection practices for workers.

ARPANSA is currently investigating options for future expansion of the ANRDR to cover other occupationally exposed workers. Given that the existing database has been designed for the uranium mining industry, expansion to cover other forms of mining and processing of radioactive ores, such as mineral sands, is a potential next, readily achievable step in this direction.

The success of the ANRDR relies on cooperative arrangements between Government and industry. Implementation of the ANRDR has been strongly supported by the uranium mining industry and it is expected that there will be high uptake and acceptance following entry into the mineral sands industry. Over the next 12 to 18 months, expansion efforts will focus largely on establishing cooperative arrangements with the mineral sands industry and regulatory authorities to strengthen support for the ANRDR, including developing the necessary legislative and practical requirements to guide implementation of the ANRDR.

In addition, the ANRDR database and associated systems require further development to ensure the database is capable of accepting dose data from non-uranium operations. Development of the ANRDR database is planned for 2014 and will be informed by results from the survey completed by mineral sands operators presented in Section 5.5.

Ultimately, expansion of the ANRDR to cover all occupationally exposed workers in Australia would be a desirable outcome and would ensure that the operation of the ANRDR is consistent with the best practice implementations of the more established international dose registers. However expansion of the ANRDR beyond the mining industry will be dependent on ARPANSA securing additional funding.



Figure 12: Proposed timeline for expansion of the ANRDR to the mineral sands industry.

5.4 Mineral sands industry review

5.4.1 Purpose of the mineral sands industry review

All mineral sands mining and processing operations in which workers may be potentially exposed to significant ionising radiation doses from materials containing naturally occurring radionuclides (NORM) are required to maintain a suitable personal monitoring program to ensure occupational exposures on site are kept well below legislated limits. Occupational dose reporting to a regulatory authority is governed by the relevant state/territory jurisdiction in which the operation lies. Guidelines for promoting a nationally consistent approach to monitoring, assessing, and recording occupational doses in mining and mineral processing exist in the form of the RPS 9.1 publication (ARPANSA 2011). However, mining operators are not legally bound by the guidelines published by ARPANSA, and as such, different radiation monitoring methodologies, dose assessment and recording practices exist across mining operations and jurisdictions. The purpose of the mineral sands industry survey was to gather information on how dose reporting and data management occurs across different operations and jurisdictions. The survey are presented in Section 5.5.

5.4.2 Methodology for conducting the mineral sands industry review

The review commenced with identification of the key industry and government stakeholders in the mineral sands industry (Appendix G). Government stakeholders were identified from ARPANSA's records and relevant legislation. Industry operators were identified through Geoscience Australia and relevant state/territory mining and radiation industry regulators. Once the mineral sands operators were identified, the ANRDR contacted each of the operators by phone to determine whether they maintain a personal radiation monitoring program, and who the responsible contact person is.

The thirteen operators who confirmed that they monitor their staff for occupational exposure were requested to participate in an online survey. Part 1 of the survey consisted of a range of multiple choice and short answer questions concerning radiation exposure to workers, data management, and record keeping practices. Part 2 referred to the organisation's participation in the ANRDR, and record provision either to the ANRDR or to a regulatory authority. A complete list of the survey questions are presented in Appendix H. The results of the survey are discussed in Section 5.5.

A review of the relevant state/territory legislation was conducted focussing mainly on personal data collection, disclosure of data to the ANRDR, and privacy issues. This primarily involved desktop research of the relevant Acts and regulations and ARPANSA's interpretation of the legislation.

5.5 Current status of radiation exposure data management practices

The ANRDR team conducted an online survey of the mineral sands industry that formed part of the research for this technical report. The survey was circulated to all thirteen currently operating mineral sands operations that monitor their workers for radiation exposure. Both mine sites and processing plants were included in the survey, which revealed the gamut of ways in which radiation dose records are managed in the mineral sands industry. The results of the survey are discussed below.

5.5.1 Personal radiation monitoring services

The three main personal radiation monitoring services used by mineral sands operations across Australia to monitor external exposures are listed below alphabetically:

- Australian Radiation Services (ARS)
 - National Radiation Laboratory (New Zealand)
- Landauer Australasia
- The ARPANSA Personal Radiation Monitoring Service (PRMS).

The National Radiation Laboratory is not used by any of the mineral sands operators directly but is outsourced by ARS to fulfil some of their work.

5.5.2 Types of radiation and exposure scenarios

Workers employed in the mineral sands industry may potentially be exposed to a variety of radiation types and exposure pathways. Radiation exposure from NORM, as in the case of external gamma exposure from radioactive ores and inhalation of radioactive dust are the most common exposure types associated with the industry. Other types of exposure from man-made sources may also occur, such as density gauges (Caesium-137) that may be used on site.





Figure 13 represents all the radiation types and exposure scenarios appropriate for mineral sands workers, as nominated by the operators in the mineral sands industry survey. All the major scenarios are represented in the responses, including external exposure from gamma emitting isotopes, internal exposure from various gamma and alpha emitting isotopes via ingestion, and inhalation of particulates and gases.

As expected, exposure to external gamma radiation is the principal exposure scenario for all thirteen mineral sands operations surveyed. These exposed workers are monitored by personal dosimeters issued by one or more of the monitoring services listed in Section 5.5.1. Furthermore, ten (77%) of the respondents cited that their workers may be exposed to radioactive airborne substances and five (38%) stated that ingestion of radioactive substances may occur.

Seven (54%) operations calculate or estimate doses that are not captured by their radiation monitoring service. Three operators indicated that they estimate doses due to inhalation of radioactive particulates, one operator calculates external gamma doses, and three operators assess both.

Recommendation 1:

That ARPANSA works cooperatively with industry and regulatory authorities to establish processes and working arrangements for obtaining dose data directly from mineral sands operations (not from a third party, such as a monitoring service) to ensure that all exposure pathways are included in the dose assessment record reported to the ANRDR.

5.5.3 Personal data collection

Correct and accurate personal data collection is important for the ANRDR to be able to conclusively match a dose record with the correct worker. Across all of the mineral sands operations surveyed, the documentation of workers' full names is the only consistency demonstrated in the collection of personal data for storage with personal dose records, as demonstrated in Figure 14. The personal data parameters listed in Figure 14 are the parameters required by the ANRDR.





Date of birth and gender were collected by eleven (85%) of the organisations, while period of employment was recorded by just over half. Although the latter parameter may not be directly linked to personal dose records, it is likely that these data are recorded by human resources and could be retrieved and supplied to the ANRDR if required. A unique identifier was attributed to workers at only five (38%) operations. The majority of mineral sands operators employ a relatively small workforce (<50 workers) which may explain why the workers are not issued with unique identifiers. There appears to be no uniformity in the collection of personal data across the industry, with each worksite establishing their own practices and procedures for dose record management, according to the applicable legislation. In most jurisdictions, the legislation for personal data collection and record keeping for personal dosimetry is insufficient, as demonstrated in Appendix F.

Recommendation 2:

That consideration should be given by all states and territories to uniformly adopt the Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing (RPS 9.1) (ARPANSA 2011) into their legislative framework and guidance notes governing personal data collection. This would facilitate the maintenance of national records within the ANRDR.

In accordance with RPS 9.1 and International Safety Standards, it is recommended that the following personal data be recorded for workers for whom individual dose assessments are made:

- a unique identifier for the individual
- the full name, gender, and date of birth for the individual
- the date on which the individual was entered into the database.

5.5.4 Dose record management practices

Most operators use a combination of digital and paper formats for managing occupational exposure records, as shown in Figure 15. It is worth noting that two operators employ exclusively paper-based record keeping practices for managing dose records.

Digital record keeping will ensure the long term survival of historical data attributed to individual workers past, present and future, as well as provide the opportunity to observe trends and statistics within the industry.



Figure 15: Current industry radiation dose record management practices.

Operators that maintain digital record keeping practices are able to export data in a variety of file formats, some of which include XML (extensible markup language), CSV (comma separated variable), XLS (Excel spread sheet), PDF (portable document format), and MS Access (Microsoft Access). CSV and XML are the two most common file formats that operators can use for data export with three and four operators, respectively.

At present, uranium mining operators report data to the ANRDR in CSV format, according to predetermined specifications. As part of our pursuit for improvement and innovation, the ANRDR may look at changing the data upload file format to XML to provide more flexibility in the type of information that can be included in the file. Notwithstanding, the ANRDR recommends a uniform approach to dose data record management and file formats.

Recommendation 3:

That consideration should be given by all mineral sands operations currently using paperbased record keeping practices to develop systems for managing dose records in a digital format. This would ensure dose record management practices are consistent with international best practice and would facilitate implementation of the ANRDR.

Furthermore, it is desirable that digital occupational dose records are in a format compatible with the ANRDR. ARPANSA will develop data transfer specifications for mineral sands operators to facilitate the submission of dose records to the ANRDR.

5.5.5 Historical data collection

The ANRDR survey has revealed that a significant number of mineral sands operations maintain historical dose data, as shown in Figure 16. In fact, 85% of operations hold data for more than five years, while 31% retain data for more than 20 years.



Figure 16: Number of years for which data is maintained.

The number of workers monitored by each site varies considerably, as shown in Figure 17. The majority of sites monitored fewer than 50 workers for radiation exposure, however, some sites monitored up to 250 workers over the past year.





Furthermore, mineral sands operators retain an abundance of historical dose records from the commencement of their operations. Figure 18 demonstrates that there are historical records for up to 6600 workers in the mineral sands industry. This is important because many of these workers have potentially changed employers and/or relocated to a different jurisdiction, in which case their dose histories may not have accompanied them to their new place of employment. It is well known that the Australian mining industry has a dynamic workforce, due to factors such as strong employment growth and rate of job turnover, which can facilitate the movement of workers between employers, jurisdictions and mining industries (AWPA 2013).



Figure 18: Number of workers for which historical data exists.

5.5.6 Record keeping for multiple sites

Mineral sands organisations commonly operate multiple sites. These sites may operate mining or processing facilities only, or a combination of both. According to the survey responses, nine (69%) operators are part of an organisation with multiple sites. Of these, four (44%) manage their dose records separately, and not in a central, organisation-wide database.

Further to the large amount of historical data that is held by the mineral sands organisations, as discussed in Section 5.5.5, the fact that some sites manage their own dose records is further justification for the consolidation of data into a centralised database. This will facilitate intra/inter-organisational dose comparison and will enable the ANRDR to produce industry-wide statistics in the form of annual reports.

5.5.7 Provision of dose records to regulatory authorities

Currently, eleven mineral sands operators provide dose record data to the relevant regulatory authority. The frequency at which an operator reports dose data to a regulatory authority varies across the industry. However, annual reporting is the most common reporting frequency, with nine operators reporting data annually. The remaining two operators report data on a bi-annual and quarterly basis.

Typically, radiation monitoring services provide personal dose reports to operators in the mineral sands mining and processing industry on a 12 week basis. As mentioned previously, subsequent reporting of dose data by an operator to a regulatory authority typically occurs on an annual basis. Ideally, dose data would be reported to the ANRDR on a quarterly basis, however the practice of annual reporting would still be consistent with ANRDR requirements if the dose data were provided by calendar quarter.⁴

Data are reported to regulatory authorities in a range of formats. The most common reporting format is an annual report, as shown in Figure 19. All four operators in Western Australia report via BOSWELL, an assessment and reporting database designed specifically for mining and mineral processing operations in Western Australia that use or handle NORM. As BOSWELL is an MS Access database, it is also Excel compatible.

It is important to note that in some jurisdictions, doses are reported as averages for 'workgroups', and not for individual workers.



Figure 19: Current dose data reporting formats.

Recommendation 4:

That ARPANSA, relevant regulatory authorities, and the mineral sands industry work cooperatively to develop dose record reporting processes and working arrangements to ensure that industry reporting requirements are effective and efficient in optimising worker protection efforts and facilitate the maintenance of national records within the ANRDR.

In accordance with Section 7 of RPS 9.1, mineral sands mining and processing operations should report occupational radiation dose records to the ANRDR by calendar quarter.

- Quarter 1 1 January to 31 March
- Quarter 2 1 April to 30 June
- Quarter 3 1 July to 30 September
- Quarter 4 1 October to 31 December

⁴ A calendar quarter represents the period of time covered by the data. The quarter numbers as defined in the ANRDR Data Transfer Specifications are:

5.5.8 Mineral sands worker categories

The mineral sands industry survey responses demonstrate that worker categorisation varies greatly within the industry. Some operators maintain highly specific categories relevant to the type, size, and geographical location of their operation. One operator does not currently undertake categorisation, possibly due to the small size of its workforce. Another operator utilises only two categories, possibly due to the nature of work performed at the site. For all others, some similarities in categorisation have been identified. Some workers have more than one category classification and may have their badges counted in more than one category. Common worker categories are listed in Table 10. Categories that were not common to at least two operators have not been included in this list.

Table 10: Common worker categories.

Worker category	No. of Organisations
Dry plant operator	7
Engineering maintenance - dry plant	7
Laboratory	6
Administrative services	5
Miscellaneous (electrical, mechanical, metallurgist, geologist	5
Wet plant operator	4
Mine site (and concentration plant)	4
Technical services	4
Transport	3
Synthetic rutile plant	2
Earth-moving equipment	2

Recommendation 5:

That ARPANSA, in partnership with industry, review the current categories assigned to workers with the objective of developing a list of typical mineral sands work area categories to ensure a more consistent approach to worker categorisation across operations and jurisdictions.

6. Findings of this review

This chapter presents the key findings and recommendations of the review that will assist ARPANSA, regulatory authorities, and operators in establishing the legal and practical requirements for proposed implementation of the ANRDR to the mineral sands mining and processing industry.

6.1 Justification for implementation of the ANRDR to the mineral sands industry

Radiation protection of workers requires the maintenance of radiation dose records to aid assessment of compliance with occupational dose limits and to support efforts to reduce radiation health risk to individuals through the continued improvement (optimisation) of work practices. While mineral sands operators in Australia are responsible for monitoring, assessing and recording the radiation dose to workers, as well as for reporting the results to the relevant state or territory authority, there is currently no national system for providing dose histories to mineral sands workers and no easy means for tracking the radiation dose to workers who move between different operations, or between different industries (e.g. between mineral sands mining and uranium mining), or between different jurisdictions.

ARPANSA's review of the mineral sands mining and processing industry has highlighted the following points which provide justification for establishing a system for recording workers' dose records in a national database:

- Personal information there is little consistency in the type of personal information collected across mineral sands operations. Recording the workers' full name, date of birth, and a unique identifier (such as an employee number) in an occupational exposure dose record would serve to link the radiation dose record to the worker. The ANRDR will assist in establishing uniformity in personal data collected across mineral sands operations to ensure radiation doses can be linked to individual workers.
- Dose record management practices most operators use a combination of digital and paper formats for managing occupational exposure records, with some operators employing exclusively paper-based record keeping practices. Digital record keeping practices will help to ensure the long term survival of workers' radiation exposure data. The provision of dose records to the ANRDR will help to ensure the longevity and security of radiation dose records for workers in the mineral sands industry.
- Historical data mineral sands operations maintain a significant amount of historical data; this
 practice is consistent with international and national standards for retention of occupational
 exposure records. The provision of dose records to the ANRDR will allow tracking of a worker's
 radiation dose throughout their career and ensure compliance with record retention
 requirements, particularly in situations where companies cease to operate.
- Centralised records mineral sands companies commonly operate across multiple sites, and sometimes across different jurisdictions. However many operators do not have a system in place for managing dose records in a centralised database. The provision of dose records to the ANRDR will ensure that exposure data are maintained within a single storage location, which will assist in facilitating intra/inter-organisational dose comparisons and reporting of industry-level statistics and trend data.

6.2 Implementation of the ANRDR to the mineral sands industry

6.2.1 Options for establishing the legal requirements

As discussed in Chapter 4, ARPANSA performed a review of the regulatory framework for radiation protection in the mineral sands industry to determine the legislative issues impacting on the disclosure of dose records to the ANRDR. Based on ARPANSA's interpretation of the relevant legislation, the most suitable options for establishing the legal requirements for implementation of the ANRDR to the mineral sands industry in each jurisdiction are summarised in Table 11 below.

Table 11:Options for establishing the legal requirements for implementation of the ANRDR to the mineral
sands industry.

Jurisdiction	Option	Regulatory Notes
New South Wales	Impose a condition of licence	A condition that requires the operator to disclose workers' dose histories to ARPANSA may be imposed but only on new mining leases. For existing mining leases, the condition may be imposed when the leases are renewed, or an operator can request the Minister to cancel and re-issue the mining lease with a new condition.
Northern Territory	Include mineral sands operations as prescribed sites in the NT legislation	The requirement in the NT legislation for dose records from the Ranger uranium mine to be disclosed to the ANRDR may be extended to the relevant mineral sands mining and processing sites by prescribing the site in the NT legislation.
Queensland	Include requirement in the new guideline documents on radiation protection from NORM	The Queensland Government is currently updating the NORM guideline documents on mining and processing activities, which could include a requirement for operators to provide workers' dose records to ARPANSA.
South Australia	Impose a condition of licence	A condition requiring the disclosure of workers' dose records to ARPANSA may be imposed, but the Minister must approve the disclosure.
Tasmania	Impose a condition of licence	A condition that requires the operator to disclose workers' dose histories to ARPANSA may be imposed on new licences. For existing licences, the condition may be imposed when the licences are renewed (licences are renewed
Victoria	Impose a condition of licence	annually), or upon request from an operator. A condition requiring the operator to provide workers' dose records to ARPANSA may be imposed on each new and existing management licence held by an operator.
Western Australia	Impose a condition of licence	A condition may be imposed on licences or registrations requiring the operator to provide workers' dose records to ARPANSA.

6.2.2 Recommendations

While a new legislative framework is not required, this report has made recommendations on how existing practice can be improved to facilitate the maintenance of national records within the ANRDR and ensure management of radiation dose records in the Australian mineral sands industry meets best practice. The central recommendations relate to:

- working cooperatively with industry and regulatory authorities to establish processes and working arrangements for obtaining dose data directly from mineral sands operators
- establishing uniformity in personal data collected across mineral sands operations to ensure radiation doses can be linked to individual workers
- developing systems for managing dose records in a digital format
- ensuring that dose record reporting processes and working arrangements are effective and efficient in optimising worker protection efforts
- reviewing the current worker categorisation to develop standardised worker categories across jurisdictions to improve comparability of exposure data.

The diagram below (Figure 20) provides a summary of the recommendations presented in Chapter 5 for proposed expansion of the ANRDR to the mineral sands industry.





6.2.3 Practical considerations

While international standards can provide theoretical guidelines for establishing a national register to collect dose history records of occupationally exposed workers, procedures need to be based on practical considerations. Proper operation and maintenance of a national register requires that an adequate information system be in place to provide consistency in data collection and recording, and allow for valid dose comparisons. Furthermore, reliable and convenient processes are required to receive data from operators to minimise the administrative burden on industry, and to ensure that quality data are received in a timely manner to optimise worker protection efforts.

To ensure that future decisions for expansion of the ANRDR take into consideration industry practice as well as the regulatory framework for radiation protection and mining, it is essential that ARPANSA establishes cooperative arrangements with the relevant state and territory governments and industry. Mineral sands operators who participated in the survey have shown support for ARPANSA to form a coordinating body consisting of relevant mineral sands industry and regulatory representatives to guide implementation of the ANRDR to the mineral sands industry.

6.2.4 Proposed approach

Management of dose records necessitates a holistic approach, which allows for the uniform collection of data across jurisdictions and different industries. ARPANSA's proposed approach for implementing the ANRDR to the mineral sands industry will closely follow the approach taken for the uranium mining industry. It is proposed that the collection, storage and retrieval of dose data from the mineral sands industry occur as follows:

- The state/territory regulator will establish a legislative requirement (or alternative) on the relevant mineral sands operations to:
 - collect and disclose their worker dose histories to ARPANSA for the purpose of the ANRDR
 - inform workers of the types of information being reported to ARPANSA.
- The worker's radiation dose exposure will be recorded by the operator as required by state/territory radiation regulations.
- The operator will release the information to ARPANSA by calendar quarter for incorporation in the ANRDR at a frequency agreed to by the operator and regulatory authority.
- ARPANSA will store the information and the database software will identify situations where it appears that a worker has exceeded the occupational dose limits for exposure as prescribed by the state/territory legislation.
- In situations where a worker has transferred jurisdictions, ARPANSA will notify the relevant state/territory regulators if a worker has exceeded the radiation exposure limit.
- The worker can request his/her dose history directly from ARPANSA.

Due to privacy issues, it should be noted that ARPANSA will only release dose information to a worker on their request and to the relevant state/territory regulator at the time of the potential breach of dose limits. If the worker has changed his/her place of employment this could result in data which were initially collected in relation to an individual working in one jurisdiction being released to a regulator in a different jurisdiction. Furthermore, ARPANSA will only release dose information directly to an operator if signed consent by the worker is provided to ARPANSA.

The dose information will also be collated by ARPANSA for statistical purposes and this information will be available to the operators and regulators in order to monitor exposure trends in mineral sands mining and processing workers. However, this statistical information will not disclose the names or any other personal data that would be capable of identifying individual workers.

Figure 21 below represents the ANRDR in conceptual form, with an emphasis on the flow of information (data) into and out of the ANRDR system.



Figure 21: Information flow into and out of the ANRDR system.

6.3 Expected benefits of the ANRDR to the mineral sand industry

6.3.1 Permanent records for workers

The ANRDR will help to safeguard the longevity and security of radiation dose records beyond the working life of a mineral sands mining and processing operation. Workers whose records are collected and stored in the ANRDR would benefit from the assurance that their radiological dose records are stored and maintained over the long-term and will remain retrievable into the future.

6.3.2 Optimise radiation protection for workers

The ANRDR not only serves to record exposure histories and facilitate identification of doses that may exceed occupational dose limits, but can also be used as a tool to assist the mineral sands industry in establishing dose constraints and continuing to improve the effectiveness of radiation protection practices. Analysis and reporting of ANRDR trend data to industry and the international community will allow for the identification of good radiation protection practices, and of deficiencies and the need for action.

6.3.3 Uniformity of radiation protection

Expansion of the ANRDR will also promote uniformity of radiation protection in the mineral sands mining and processing industry. The information collected, stored and maintained by the ANRDR will provide a solid statistical and scientific basis to support an evidence-based approach to identifying industry trends and assessing compliance with occupational dose limits. This will allow the development of uniform best practice in all Australian regulatory jurisdictions in radiation protection through the optimisation of work practices in the mineral sands industry.

6.3.4 Promote international best practice

Implementation of the ANRDR to the mineral sands industry will allow the production of annual statistics to identify industry sector trends and enable comparison with international dose trends. This will ensure that doses to workers in Australian mineral sands operations are assessed on the basis of best international methods and guidance. Furthermore, expansion of the ANRDR to the mineral sands industry is the first phase of a proposed multi-phase expansion to include all individuals occupationally exposed to ionising radiation in Australia. This proposal is in-line with ensuring that the ANRDR operation is consistent with the best practices established by existing international dose registers.

6.3.5 Promote industry engagement

Expansion of the ANRDR will promote engagement with key industry and regulatory stakeholders which is essential for establishing uniform practices and the continuing improvement of worker radiation health and safety in the mining industry. Working with industry will ensure that mineral sands workers are adequately monitored, protected from, and informed about the occupational risks of exposure to ionising radiation.

6.4 Concluding remarks

The data collected from operators for this report reflects practices in the Australian mineral sands mining and processing industry in early 2013. The trends, if left unchecked, may create a greater diverging approach to record keeping. In addition, the state and territory legislative approach will change with time; however the issues impacting on the disclosure of dose records to the ANRDR are likely to remain the same in Australia for years to come.

To date, the proposed expansion plans for implementation of the ANRDR to the mineral sands industry have been strongly supported by operators and regulatory authorities. The process for implementation of the ANRDR to the mineral sands industry will commence after release of the findings and recommendations from the review to key stakeholders. Successful implementation of the ANRDR to the mineral sands industry will be dependent on various factors, including:

- ARPANSA's ability to maintain cooperative arrangements with state/territory regulators, industry groups and operators
- individual jurisdictions having the necessary legislation in place for the provision of dose records to ARPANSA
- individual mineral sands operations having the capacity and capability to establish policies and procedures to support submission of data to the ANRDR
- development of the ANRDR database and associated systems to ensure the database has the capacity to accept data from mineral sands mining and processing operations.

Glossary

Where available, these definitions are taken from publications referenced in this report including publications in the ARPANSA Radiation Protection Series and publications of the International Commission on Radiological Protection; otherwise they are based on the IAEA Safety Glossary (IAEA 2007b).

Activity: The number of spontaneous nuclear transformations taking place per second for a quantity of radionuclide. Activity is given in units of becquerel (Bq).

Activity concentration: The amount of activity per unit volume, per unit mass or per unit area, whichever is appropriate to the situation. In this report, activity concentration is given in units of Bq/kg.

Alpha particle: A charged particle, consisting of two protons and two neutrons, that is emitted by the nucleus of a radionuclide during radioactive decay (α -decay).

Becquerel (Bq): Name for the SI unit of activity, equal to one transformation per second.

Beneficiation: The process of separating minerals from each other, by mechanical or chemical processes.

Beta particle: An electron or positron emitted by the nucleus of a radionuclide during radioactive decay (β -decay).

Concentrator: Employs a gravity separation process using a series of water fed spirals to separate the heavy minerals from the lighter sand.

Decay chain: A series of radionuclides, each of which (except for the first, or parent) is formed as a result of the radioactive decay of the previous member of the chain.

Derived air concentration (DAC): A limit on the activity concentration in air of a specified radionuclide, calculated such that an individual breathing air with constant contamination at the DAC while performing light physical activity for a working year, would receive an intake corresponding to the annual limit on intake for the radionuclide in question. For radiation workers, it is normal to assume a breathing rate of 1.2 cubic metres per hour and a working year of 2000 hours; however this can vary between sites.

Disposal: The emplacement of waste in an approved facility without intention of retrieval. Disposal may also include the approved direct discharge of effluent (e.g. liquid waste) into the environment with subsequent dispersion.

Dose: A generic term which may mean absorbed dose, equivalent dose or effective dose depending on context.

Effective dose: A measure of dose which takes into account both the type of radiation involved and the radiological sensitivities of the organs and tissues irradiated. The unit of effective dose is J kg⁻¹, with the special name sievert (Sv).

For a more detailed explanation, please see: Appendix D.2.7 Effective dose.

Equilibrium: See secular equilibrium.

Equivalent dose: A measure of dose in organs and tissues which takes into account the type of radiation involved. The unit of equivalent dose is $J \text{ kg}^{-1}$, with the special name sievert (Sv).

For a more detailed explanation, please see: Appendix D.2.4 Equivalent Dose.

Exposure: Either; the circumstance of being exposed to radiation, or a defined dosimetric quantity now no longer used for radiation protection purposes.

(The context in which the word is used should avoid ambiguity).

Feedstock: Raw material fed into a process for conversion into something different. For example, rutile and synthetic rutile are used as feedstock in the production of titanium dioxide pigment.

Fines: Very small particles found in mining and milling, typically less than approximately 10 microns in diameter.

Gamma ray: Ionising electromagnetic radiation emitted by a radionuclide during radioactive decay or during a nuclear (isomeric) transition.

Heavy mineral concentrate: The commercially valuable material produced after primary separation of the ore using a wet gravity separation technique has occurred.

IAEA: International Atomic Energy Agency.

ICRP: International Commission on Radiological Protection.

Ionising radiation: Radiation which is capable of causing ionisation, either directly (for example: for radiation in the form of gamma rays and charged particles) or, indirectly (for example: for radiation in the form of neutrons).

Isotope: A variant of a chemical element that has the same number of protons in the nucleus but differs in the number of neutrons.

Limit: The value of a quantity used in certain specified activities or circumstances that must not be exceeded.

Mineral processing: All activities associated with the processing of minerals to produce a physical or chemical concentrate and/or mineral product, including primary processing, secondary processing, and downstream processing.

Mining: All activities associated with the extraction of minerals from the ground.

NORM: Radioactive material containing no significant amounts of radionuclides other than naturallyoccurring radionuclides, and for which the original radionuclide concentrations or exposures have been altered by human action.

Occupational exposure: Exposure of a person to radiation which occurs in the course of that person's work and which is not excluded exposure.

Operation: An instance of a practice; a particular human activity which may result in exposure to ionising radiation and to which a program of radiation protection applies.

Operator: Any person or entity responsible for a mining or mineral processing operation which may lead to exposure to ionising radiation.

Overburden: Rock or soil overlying a mineral deposit.

Practice: Any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or modifies the network of exposure pathways from existing sources, so as to increase the *exposure* or the likelihood of exposure of people or the number of people exposed.

Progeny: Radionuclides that result from radioactive decay of a parent radionuclide.

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

Radiation weighting factor: A modifying factor which is applied to an organ or tissue absorbed dose to yield equivalent dose and which depends on the type and energy of the radiation to which the organ or tissue is exposed. It is denoted by the symbol w_{R} .

Radionuclide: A species of atomic nucleus which undergoes radioactive decay; a radionuclide is identified either by its elemental symbol with the mass number of the nuclide as a superscript (e.g. ²³⁵U) or, as in this technical report, by its elemental name followed by the mass number (e.g. uranium-235).

Radon: Used generically, all isotopes of the element radon, having atomic number 86, but typically used to refer to the radioactive gas radon-222.

Residue: By-product from mineral sands processing that can be used in the production of materials in other industries.

Scenario: A postulated or assumed set of conditions in which exposure can occur.

Secular equilibrium: A state in which the activities of all radionuclides in a decay chain are equal. This occurs when the half-life of the original radionuclide is much longer than the half-life of the decay product.

Sievert: The special name for the unit of radiation dose, J kg⁻¹. It is denoted by the symbol Sv.

Slurry: A mixture of ore and water.

Source: Anything that may cause radiation exposure — such as by emitting ionising radiation or by releasing radioactive substances or materials — and can be treated as a single entity for protection and safety purposes.

Source, natural: A naturally occurring source of radiation, such as the sun and stars (sources of cosmic radiation) and rocks and soil (terrestrial sources of radiation).

Tailings: The materials left over after the process of separating the valuable fraction from the worthless fraction of an ore.

Thoron (radon-220): A radioactive gas produced by the decay of thorium-232. Thoron has a half-life of 55.8 seconds that decays to polonium-216 by alpha decay.

Tissue weighting factor: Multiplier of the equivalent dose to an organ or tissue used for radiation protection purposes to account for the different sensitivities of different organs and tissues to the induction of stochastic effects of radiation. It is denoted by the symbol w_T .

Titaniferous: Containing titanium.

Waste: Material remaining after ore has been processed for which no further use is foreseen.

Waste, radioactive: Material that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the relevant regulatory authority, and for which no further use is foreseen.

Worker: The term used to denote any person who performs work, whether full time, part time or temporarily, on behalf of an *operator* and who has recognised rights and duties in relation to occupational radiation protection.

Appendix A Radionuclides in the Uranium and Thorium Decay Series



Figure 22: Uranium-238 decay series.

Uranium-234 (U-234), uranium-235 (U-235), and uranium-238 (U-238) are the three naturally occurring uranium isotopes. Uranium-238 is the most stable and most abundant of the three. It decays to thorium-234 (Th-234) by alpha decay or spontaneous emission with a half-life of 4.47×10^9 years.

Uranium-235, which accounts for only 0.7204% of naturally occurring uranium, is the only uranium isotope that is fissionable in its natural state.

One of uranium's decay products is radon-222 (radon), a radioactive gas that decays to polonium-218 by alpha decay. Radon is exhaled from the ground and builds up in confined spaces with poor ventilation such as basements, buildings, and underground mines. Radon is potentially dangerous to humans because when inhaled, radiosensitive lung tissue is exposed to alpha radiation. Alpha radiation poses no external hazard to the body because it does not penetrate the skin, but can damage internal organs if the alpha decay occurs inside the body. Although radon's 3.82 day half-life is relatively short, radon decays to other radioactive isotopes (radon progeny) that can attach to dust, posing an additional hazard if the dust is subsequently inhaled.



Figure 23: Thorium-232 decay series.

Almost all thorium found on earth consists of thorium-232 (Th-232), the most stable of the thorium isotopes. Thorium-232 comprises around 0.0007% of the earth's crust and decays to radium-228 by alpha decay with a half-life of 1.40×10^{10} years, or three times the age of the earth. Thorium is approximately three times more abundant than uranium in the Earth's crust and is mainly refined from monazite as a by-product of mineral sands and rare earth metals extraction.

One of thorium's decay products is radon-220 (thoron), a radioactive gas with a half-life of 55.8 seconds that decays to polonium-216 by alpha decay. Thoron, like radon (described above in the uranium-238 decay series) can pose a hazard when it or its progeny are inhaled.

Due to the very long half-lives of their parents, the radionuclides of the uranium and thorium decay chains exist in secular equilibrium. This equilibrium can be disturbed by some physical or chemical separation processes. A recent study by ARPANSA focussing on NORM in different types of mining (Long et al. 2012) has found that mineral sands processing caused a significant disturbance in equilibrium, contrary to almost all other types of mining tested where no disturbance was observed.

Appendix B Mineral Sands Operations in Australia

The table below provides a list of currently operating minerals sands mining operations in Australia that monitor workers for occupational exposure to radiation (as identified by ARPANSA).

Table 12:Mineral sands operators in Australia who monitor workers for occupational exposure to radiation
(information provided to ARPANSA by mineral sands operators in early 2013).

Company	Region
	ineBioli
Cristal Mining Australia	Southwest Region
Doral Mineral Sands	Southwest Region
Iluka Resources	Perth Basin
Tronox	Southwest Region
SOUTH AUSTRALIA	
Iluka Resources	Eucla Basin
Murray Zircon	Murray Mallee Region
VICTORIA	
Iluka Resources	Murray Basin
NEW SOUTH WALES	
Cristal Mining Australia	Murray Basin
(formerly Bemax Resources)	
QUEENSLAND	
Currumbin Minerals	Southeast Region
Sibelco Australia	North Stradbroke Island
TASMANIA	
SEMF Pty Ltd	Fraser Beach

Appendix C Overview of Alpha, Beta and Gamma Radiation

Isotopes of the naturally occurring radioactive elements uranium and thorium carry excess energy and are unstable. When these radioactive isotopes breakdown, or decay, to make new radioactive isotopes, they give up some of their excess energy in the form of alpha particles, beta particles and gamma rays. Alpha, beta and gamma radiation have different penetration ranges in air and in solid matter, and therefore affect biological tissue differently. The figure below presents a simple overview of the penetrative properties and biological effects of alpha, beta and gamma radiation.



Alpha particles (α) are doubly charged helium nuclei emitted from radionuclides such as uranium, thorium, and radium during alpha decay. Alpha particles are highly ionising because they are relatively large, slow, and have a double positive charge. Because of this, alpha particles are brought to rest by a few centimetres of air, or less than a tenth of a millimetre of living tissue. Alpha radiation can, however, be hazardous if the alpha decay occurs inside the body.

Beta particles (β) are negatively charged particles, identical to electrons, emitted from some radionuclides during beta decay. Beta decay commonly occurs in natural radioactive decay chains following one or more alpha decays. Being less ionising than alpha particles, beta particles can travel up to several metres in air and can penetrate several millimetres of skin or tissue. Nonetheless, beta particles can be stopped by a thin sheet of metal, plastic, or a block of wood. Beta radiation does not normally penetrate beyond the top layer of skin. However, beta radiation can be hazardous if the beta decay occurs inside the body.

Gamma rays (y) are photons (i.e. high energy electromagnetic radiation) emitted by some radionuclides following radioactive decay. Gamma rays have high energy but no mass or charge, and are able to penetrate a considerable distance (centimetres or more) in many kinds of materials, including human tissue. Gamma radiation can therefore deliver significant doses to internal organs from radiation sources outside the body. Very dense materials, such as steel or lead, are commonly used as shielding to slow or stop gamma rays.

Figure 24: Penetrative properties and biological effects of alpha, beta and gamma radiation.

Appendix D The History of Radiation Dose Concepts

D.1 Background

When discussing radiation exposure to workers it is useful to be able to quantify the exposures and the potential detriment to organs, tissue and the whole body. The International Commission on Radiological Protection (ICRP) released some key publications which discuss these quantities and the concepts of dose limitation:

- ICRP Publication 26: Recommendations of the International Commission on Radiological Protection (hereafter called ICRP 26) was published in 1977 and was used by Australia and the mineral sands industry to determine the doses to workers (ICRP 1977)
- ICRP Publication 60: 1990 Recommendations of the International Commission on Radiological Protection (hereafter called ICRP 60) was later released to update dose concepts and weighting factors based on better scientific understanding of the mechanisms of interaction of radiation with the body (ICRP 1991)
- ICRP Publication 103: The 2007 Recommendations of the International Commission on Radiological Protection (hereafter called ICRP 103) further updated these dose concepts (ICRP 2007).

The names and definitions of some concepts have changed over time due to the progression of scientific knowledge on radiation exposures to the body. This may lead to confusion between the terms used in ICRP 26 and the terms used in ICRP 60 and ICRP 103. What was known as 'dose equivalent' in ICRP 26 is analogous to '**equivalent dose**' in ICRP 60 and ICRP 103. What was known as 'effective dose equivalent' is analogous to 'effective dose' in ICRP 60 and ICRP 103.

D.2 Radiation dose concepts

The radiation dose concepts described below were defined by the ICRP in publications 26, 60 and 103.

D.2.1 Absorbed dose

Absorbed dose is defined as

$$D = \frac{d\overline{\varepsilon}}{dm}$$

where $d\varepsilon$ is the mean energy imparted by ionising radiation to matter of mass dm. The unit of absorbed dose is joule per kilogram (J kg⁻¹) and its special name is the gray (Gy).

Absorbed dose alone is insufficient to predict the severity or probability of deleterious effects on health resulting from tissue irradiation. ICRP 26 recommended the use of a quantity called dose equivalent, which is described below.

D.2.2 Dose Equivalent

Prior to 1991, dose equivalent was commonly used to describe doses to organs. The quantity dose equivalent was defined to more accurately describe the effect of a particular type of radiation upon a given organ. This quantity weights the absorbed dose by a Quality Factor, *Q*, which is related to the relative biological effectiveness of different types of radiation.

Dose equivalent (H), at a point in tissue, is the product of absorbed dose D, Quality Factor (Q), and the product of all other factors used in weighting the absorbed dose (N).

$$H = DQN$$

N was defined as 1, and later not included in calculations of dose equivalent. The unit of Dose Equivalent was the **sievert** (Sv).

D.2.3 Relative Biological Effectiveness

The Relative Biological Effectiveness (RBE) is the ratio of biological effectiveness of one type of ionising radiation relative to another, given the same amount of absorbed energy. The concept is that different types of radiation have different effects on tissue, even if they result in the same amount of absorbed dose.

This concept of RBE is related to the quality factor, *Q*. Prior to 1991 the quality factor of a type of radiation was used to weight the absorbed dose to more accurately calculate a quantity called dose equivalent, *H*.

A list of quality factors by radiation type can be found in Table 13, as listed in ICRP 26.

D.2.4 Equivalent Dose

The publication of ICRP 60 in 1991 introduced a new concept to describe dose to organs called equivalent dose, H_T . This quantity is analogous to the dose equivalent quantity described earlier. This quantity is a measure of dose in organs and tissues which takes into account the type of radiation involved. The equivalent dose is the absorbed dose averaged over a tissue or organ and weighted for the type of radiation involved and its biological effectiveness. Equivalent dose takes into account a weighting factor called the radiation weighting factor, w_R .

The equivalent dose in tissue is given by the expression:

$$H_{T} = \sum_{R} w_{R} . D_{T,R}$$

where $D_{T,R}$ is the absorbed dose averaged over the tissue or organ T, due to radiation R.

The unit of H_7 is the same as for absorbed dose, J kg⁻¹, and is expressed in units of sievert (Sv). Equivalent dose is still used today; however the values for w_R have changed over time.

D.2.5 Radiation weighting factor, w_R

Values for radiation weighting factors are mainly based on experimental data of the RBE for various types of radiation at low doses. The concept was introduced in ICRP 60 to replace the Quality Factor (*Q*) concept, and it was altered slightly in ICRP 103 to better allow for the spectrum of neutron energy. A summary of quality factors and radiation weighting factors as published by ICRP is in Table 13, Table 14 and Table 15 below.

Table 13: Approximate Quality Factors recommended by ICRP 26 for internal and external radiation (ICRP 1977).

Radiation Type	Quality Factor, Q
X rays, γ rays and electrons	1
Neutrons, protons and singly-charged particles of rest mass greater than one atomic mass unit of unknown energy	10
Alpha particles and multiply-charged particles (and particles of unknown charge), of unknown energy	20

Table 14: Radiation weighting factors in ICRP 60 (ICRP 1991).

Radiation Type and Energy Range	Radiation Weighting Factors, w _R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons, energy < 10 keV	5
10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 Mev to 20 MeV	10
> 20 MeV	5
Protons, other than recoil protons, energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Table 15: Radiation weighting factors in ICRP 103 (ICRP 2007).

Radiation Type	Radiation Weighting Factors, w _R	
Photons	1	
Electrons and muons	1	
Protons and charged pions	2	
Alpha particles, fission fragments, heavy ions	20	
Neutrons	A continuous curve as a function of neutron energy	

D.2.6 Whole body dose

Typically, when a person is exposed to radiation, more than one organ or tissue is exposed. Often it is more appropriate to talk about a dose to the whole body, rather than to a particular organ or tissue. For prevention of stochastic, or long-term effects of radiation on the body, ICRP 26 set an annual dose equivalent limit for uniform irradiation of the whole body ($H_{wb,L}$) of 50 mSv. This dose limitation concept is based on the principle that the risk should be equal whether the whole body is irradiated uniformly or whether there is non-uniform irradiation. This condition would be met if:

$$\sum_{T} w_{T} H_{T} \leq H_{wb,L}$$

where w_T is a weighting factor for tissue *T* (see Section D.2.8) representing the proportion of stochastic risk resulting from harm to tissue *T* to the total risk, when the whole body is irradiated uniformly, and H_T is the annual dose equivalent in tissue *T*. Whole body dose therefore takes into account the different radiobiological sensitivities of the organs and tissues, and the RBE of the different types of radiation.

Prior to 1991 this whole body dose was called effective dose equivalent. After 1991, with the publication of ICRP 60, this quantity was called effective dose, *E*.

D.2.7 Effective dose

Effective dose is a measure of dose which takes into account both the type of radiation involved and the radiological sensitivities of the organs and tissues irradiated. The effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body. The unit of effective dose is joule per kilogram (J kg⁻¹) and is typically expressed in units of sievert (Sv). It is given by the expression:

$$E = \sum_{T} w_{T} . H_{T} = \sum_{T} \sum_{R} w_{T} . w_{R} . D_{T,R}$$

The equation for effective dose is very similar to the previous expression for effective dose equivalent.

D.2.8 Tissue weighting factor, w_T

The tissue weighting factor, W_{T} is an important concept in terms of determining a whole body dose. The rationale is that different organs are affected in different ways when the body is exposed to uniform irradiation. Over time these values have changed as a result of further research into the radiation sensitivities of different organs. A summary of tissue weighting factors as published by the ICRP can be found in Table 16 and Table 17 below.

T '	Tissue Weighting Factor, w_{τ}			
lissue	Publication 26 (1977)	Publication 60 (1991)		
Bone Surfaces	0.03	0.01		
Bladder	-	0.05		
Breast	0.15	0.05		
Colon	-	0.12		
Gonads	0.25	0.20		
Liver	-	0.05		
Lungs	0.12	0.12		
Oesophagus	-	0.05		
Red bone marrow	0.12	0.12		
Skin	-	0.01		
Stomach	-	0.12		
Thyroid	0.03	0.05		
Remainder	0.30	0.05		
TOTAL	1	1		

Table 16:ICRP recommendations for tissue weighting factors in ICRP 26 and ICRP 60 [as reported in Annex B
of ICRP 103 (ICRP 2007)].

Table 17: Tissue weighting factors, W_T , in ICRP 103 (ICRP 2007).

Organ/Tissue	Number of Tissues	w _T	Total Contribution
Lung, stomach, colon, bone marrow, breast, remainder	6	0.12	0.72
Gonads	1	0.08	0.08
Thyroid, oesophagus, bladder, liver	4	0.04	0.16
Bone surface, skin, brain, salivary glands	4	0.01	0.04

D.2.9 Committed equivalent dose

Radionuclides taken into the body can decay for some time after the intake. In addition, the radionuclides can become distributed throughout the body by biokinetic processes, and some radionuclides are preferentially accumulated in specific tissues. Therefore, the important parameters for purposes of internal dosimetry are the integrated dose to a tissue and the integrated dose to the whole body over a specified time interval after intake. For this reason the dose resulting from internal exposure is referred to as *committed dose*. Committed dose is the lifetime dose from an intake of radionuclides, and this total lifetime dose is attributed to the person at the time of intake. Due to the nature of internal doses from intakes of radionuclides, both the radiological decay and biological decay (e.g. excretion from the body) of the radionuclides need to be taken into account. The combined radiological and biological half-life is called the effective half-life and will differ depending on the radionuclides and organs in question.

The equivalent dose rate in tissue *T* due to absorption of all types of radiation by tissue *T* is denoted by $dH_T(t)/dt$ and is given by

$$\frac{dH_{T}(t)}{dt} = \sum_{R} W_{R} \cdot \frac{dD_{T,R}(t)}{dt}$$

where w_R is the radiation weighting factor for radiation of type *R* (assumed to be time-independent), and the intake is assumed to occur at time (t) = 0. Values of w_R have been recommended by the ICRP (ICRP 1979, ICRP 1991, ICRP 2007) and can be found inTable 13, Table 14, and Table 15.

The committed equivalent dose over a 50 year period post-intake is then given by

$$H_{50,T} = \sum_{R} w_{R} \int_{0}^{50} \frac{dD_{T,R}(t)}{dt} dt$$

D.2.10 Committed effective dose

The committed effective dose rate is given by $\frac{dE}{dt}(t) = \sum_{\tau} w_{\tau}$. $\sum_{R} w_{R}$. $\frac{dD_{\tau,R}(t)}{dt}$,

and the committed equivalent dose over a 50 year period post-intake is then given by

$$\boldsymbol{E}_{50} = \sum_{T} \boldsymbol{w}_{T} \cdot \sum_{R} \boldsymbol{w}_{R} \cdot \int_{0}^{50} \frac{d\boldsymbol{D}_{T,R}(t)}{dt} dt$$

D.2.11 Dose limitation

Initially, dose limits for occupational exposures to ionising radiation were set at values which would prevent non-stochastic effects and limit the occurrence of stochastic effects to an acceptable level. ICRP 60 discusses the concept of limitation as a means of establishing a level of dose above which the consequences for the individual would be regarded as unacceptable.

ICRP 26 (ICRP 1977) recommended dose-equivalent limits for occupational exposure. This publication recommended an annual dose-equivalent limit of 50 mSv for uniform irradiation of the whole body. This limit for whole body irradiation was based on the various tissue weighting factors, and the recommendations that non-stochastic effects would be prevented by applying a dose-equivalent limit of 0.5 Sv in a year to all tissues, except the lens of the eye, for which the Commission recommended a limit of 0.3 Sv in a year.

Dose limits were revised in 1991 with the publication of ICRP 60. The effective dose limit for occupational exposure was set at a reduced level of 20 mSv averaged over five years with the further provisions that the effective dose should not exceed 50 mSv in any single year. A summary of these dose limits is given in Table 18.

Table 18: Recommended dose limits (ICRP 1991).

Application	Occupational Dose Limit
Effective Dose	20 mSv per year, averaged over defined periods of 5 years, with the further provision that the effective dose should not exceed 50 mSv in any single year
Annual equivalent dose in	
the lens of the eye	150 mSv
the skin	500 mSv
the hands and feet	500 mSv

Dose limits remained mostly unchanged with the publication of ICRP 103 (ICRP 2008). However in 2011 the ICRP released *Statement on Tissue Reactions* (ICRP 2011) which recommended a change to the annual equivalent dose limit of the lens of the eye. The revised dose limit reduced the annual equivalent dose limit to the lens of the eye to 20 mSv a year, averaged over defined periods of 5 years, with no annual dose to exceed 50 mSv.

D.2.12 Dose limitation in the Australian Context

The dose limits and concepts used in Australia are all based on international best practice and guidance from international bodies. The current radiation protection system is based on the information gathered by international organisations which feed into Australian regulations. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) is a committee of Government nominated experts from around the world who gather the basic information on radiation exposure and effects. The International Committee on Radiological Protection (ICRP) is an independent scientific advisory body that utilises these data to make recommendations on the best way to implement radiation protection. The International Atomic Energy Agency (IAEA) then utilises the ICRP recommendations to develop material suitable for incorporation into international and national regulation. A key IAEA document is the International Basic Safety Standards for Radiation Protection and Safety of Radiation Sources (IAEA 2011a).

Individual countries, including Australia, utilise the IAEA Safety Standards to provide the basis for regulation. In Australia, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is responsible for taking the international regulations and adapting them to a format suitable for adoption in Commonwealth regulations. The states and territories, in turn, use the Commonwealth regulations as a basis for implementing their own regulations. The end result is that the Australian radiation protection system, including dose limits, is directly traceable to the most current international recommendations.

In 1980, a document was published by the National Health and Medical Research Council (NHMRC) titled *Recommended Radiation Standards for Individuals Exposed to Ionising Radiation (NHMRC 1981)*. This document was based on the recommendations in ICRP 26 (ICRP 1977) and set out the dose limits for Australian occupationally exposed workers.

In 1995, the NHMRC, in conjunction with the National Occupational Health and Safety Commission (NOHSC), published the *Recommendations for Limiting Exposure to Ionising Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionising Radiation*. This document was based on the revised ICRP recommendations published in ICRP 60. This document was later republished as Radiation Protection Series 1 (RPS 1) (ARPANSA 2002).
At the time of preparation of this report, ARPANSA had begun the process of revision of the Australian standards set out in RPS 1 to reflect the revised recommendations published in ICRP 103. When published, the *Fundamentals for Protection Against Ionising Radiation* together with the proposed *Code of Practice for Radiation Protection in Planned Exposure Situations as Applied to Workers, the Public and the Environment* will supersede RPS 1.

Appendix E Doses Attributed to Workers

Table 19:Annual external doses to workers in the Australian mineral sands mining and processing industry as
reported by PRMS (ARPANSA 2013).

	2004			2008			2012		
Worker Category	Avg (mSv)	Max (mSv)	Wearers	Avg (mSv)	Max (mSv)	Wearers	Avg (mSv)	Max (mSv)	Wearers
Wet Plant Operator	1.770	1.770	1	0.309	0.525	5	0.147	0.730	32
Dry Plant Operator	1.034	6.384	114	0.513	9.490	193	0.389	7.650	166
Miscellaneous	0.497	2.263	70	0.419	3.160	168	0.353	3.015	146
RSO	0.422	0.639	4	0.155	0.990	9	0.077	0.330	11

The data shown in Table 19 and illustrated in Figure 4 was provided by the ARPANSA Personal Radiation Monitoring Service (PRMS) and is only representative of operators that use PRMS as their personal monitoring service. This previously unpublished data refers to external gamma doses only, and was generated according to the parameters specified below:

- only operators with a centre type of 80 (mineral sand mining) were considered
- all monitors that were worn by registered persons for at least part of that year were included
- for monitors where the wearing start date or the wearing stop date falls outside of the year, the dose value was pro-rated on the number of days relevant to the year in question
- in the cases where wearers had been reported under more than one occupation type, they were effectively treated as two people
- the required data were extracted selecting only those occupation types required. There were other occupation types, and a large number of people with no occupation type who were excluded.

Appendix F Australian Jurisdictional Requirements for Record Keeping and Reporting

F.1 Background

Each jurisdiction in Australia has different provisions for radiation protection. These provisions also identify the requirements for record keeping in relation to dose records for workers and the reporting requirements. Below is a table which highlights the relevant requirements within the radiation protection legislation in each Australian jurisdiction and whether these requirements are consistent with the minimum personal data requirements for the ANRDR. These details are correct as of the date of the publication of this report.

Table 20: Requirements for record keeping and reporting.

Jurisdictional Requirement for Record Keeping and Reporting	Comments
COMMONWEALTH	
 Clause 7.1.2 in the Radiation Protection Series 9.1: Safety Guide for Monitoring, Assessing and Recording Occupational Radiation Doses in Mining and Mineral Processing (2011) states that the record for each employee for whom individual dose assessments are made should include the following: a unique identifier for the individual the full name, gender and date of birth of the individual the date on which the individual was first entered into the database if not included in the current database, a pointer or reference to where earlier dose records for the individual may be found the categorisation of the individual's work area (as a controlled area or supervised area) and, where appropriate, designation of the employee 	Requirements are consistent with the minimum personal data requirements for the ANRDR.
NEW SOUTH WALES	
 The Radiation Control Regulation 2013 state that for each person for whom a personal radiation monitoring device is issued, the record must contain the following personal information: the full name, sex and date of birth of the occupationally exposed person the current home address of the occupationally exposed person or, if the person is no longer employed by the employer, the person's last known home address the date of commencement of employment (and, if applicable, the date of cessation of employment) as an occupationally exposed person 	Regulations do not specify a requirement to record a unique identifier. In practice, operators may record a unique identifier on individual dose records. In this case, industry practice would be consistent with the minimum personal data requirements for the ANRDR. Regulations do not specify a reporting requirement to a regulatory authority. However, a reporting requirement may be imposed in the licence conditions.
NORTHERN TERRITORY	
<u>Record Keeping:</u> The <i>Radiation Protection Act 2012</i> states that the personal radiation exposure record for a radiation worker must:	Record keeping and reporting requirements are consistent with the minimum personal data

Jurisdictional Requirement for Record Keeping and Reporting	Comments
 include the information required by clause 7.1.2 of the Safety Guide (ARPANSA, 2011) to be kept for an employee be kept in a form and manner consistent with Part 7 of the Safety Guide be kept for the period required by clause 7.1.2 of the Safety Guide 	requirements for the ANRDR.
<u>Reporting:</u> The operator for a mining site must give radiation exposure information to the CEO of ARPANSA in accordance with the ANRDR Data Transfer Specification within 6 weeks from the end of each quarter as defined in clause 8.2 of the ANRDR Data Transfer Specification.	
QUEENSLAND	
 The Mining and Quarrying Safety and Health Regulation 2001 states that the site senior executive must ensure: the mine has a system to provide for the safe management of the 	Relevant legislation does not specify record keeping and reporting requirements.
radiationthe system is complied with	The Department of Natural Resources and Mines is currently developing guidance notes on NORM mining and processing, which will specify the requirements for record keeping and reporting.
	Reporting requirements not specified in the regulation.
SOUTH AUSTRALIA	
The <i>Radiation Protection and Control (Ionising Radiation) Regulations</i> 2000 state that a personal radiation exposure record must contain the following information:	Relevant legislation does not specify a requirement to record a unique identifier.
 the full name, sex and date of birth of the radiation worker the current home address of the radiation worker, and if no longer employed by the specified employer his or her last known home address the date of commencement of employment (and if applicable the date of cessation) as a radiation worker 	In practice, operators may record a unique identifier on individual dose records. If this is the case, industry practice would be consistent with the minimum personal data requirements for the ANRDR.
	Reporting requirement not specified in the regulations.
TASMANIA	
The <i>Radiation Protection Act 2005</i> states that radiation monitoring be carried out by the holder of the authority, and that the Governor may make regulations for the purposes of the Act in relation to (sections	Relevant legislation does not specify personal data requirements.
 radiation protection measures radiation monitoring required to be carried out by persons all matters relating to the protection from the harmful effects of radiation of persons working in an industry or business where they are exposed to radiation that occurs naturally in the environment the records to be kept and returns to be made by persons and the inspection of the records 	If industry practice is not consistent with the minimum personal data requirements for the ANRDR, the Governor could prescribe a requirement in the regulations, or details of personal data requirements could be specified in the operator's radiation management plans.

Jurisdicti	onal Requirement for Record Keeping and Reporting	Comments		
managendeta reco sour	nent plans must contain the following information: hils of record-keeping requirements including details of the ords that will be kept of movement of any mobile radiation free in the radiation practice	Reporting requirement not specified in the regulations.		
VICTORIA	A			
The mano 2005 stat • A re- rece worl year reac	datory radiation safety requirements of the <i>Radiation Act</i> the that the management licence holder must ensure that: cord is kept of the radiation doses assessed to have been trived by each occupationally exposed person during the king life of the person and afterwards for not less than 30 rs after the last dose assessment and at least until the person thes, or would have reached, the age of 75 years.	Relevant legislation does not specify personal data requirements. Reporting requirements not specified in the regulations.		
WESTER	N AUSTRALIA			
The Radio employer • Keep • Inclu	ation Safety (General) Regulations 1983 state that the r of a radiation worker shall: p a continuing personal file relating to the radiation worker. ude in the personal file the results of all personal monitoring the radiation worker carried out in accordance with these	Relevant legislation does not specify personal data requirements. If industry practice is not consistent with the minimum personal data requirements for the ANRDR, details of personal data requirements could be specified in the operator's radiation management plans		
regu The <i>Mine</i> manager at the mi	llations. <i>es Safety and Inspection Regulations 1995</i> states that the of a mine must ensure that records are kept and maintained ne of:			
 mon dose any man 	hitoring results e assessments other information required to be kept under the radiation hagement plan	The regulations state that reporting of dose assessments to a regulatory authority must occur. No specific		
The regulations also state that the records of assessed doses:		must be approved by the		
 are l are l are s emp 	readily accessible kept for the duration of employment sent to the State mining engineer upon the cessation of oloyment of that employee	regulatory authority.		
Furtherm	nore, the regulations state that:			
 the report apprivation the man 	manager of a mine must ensure that the following matters are orted to the State Mining Engineer in a form and at intervals roved by the State Mining Engineer — results of the monitoring program approved in the radiation nagement plan.			

Appendix G Stakeholders Consulted

WESTERN AUSTRALIA
Cristal Mining Australia
Department of Mines and Petroleum
Doral Mineral Sands
Iluka Resources
The Chamber of Minerals and Energy (WA) Radiation Industry Group
Radiological Council
Tronox
SOUTH AUSTRALIA
Environment Protection Authority
Iluka Resources
Murray Zircon
VICTORIA
Department of Health
Iluka Resources
NEW SOUTH WALES
Cristal Mining Australia
Division of Mineral Resources and Energy, Department of Trade and Investment
Environment Protection Authority
ACT
ACT Health Protection Services, Health Directorate
ACT Health Protection Services, Health Directorate QUEENSLAND
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health Sibelco Australia
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health Sibelco Australia
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health Sibelco Australia NORTHERN TERRITORY Department of Health
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health Sibelco Australia NORTHERN TERRITORY Department of Health Matilda Zircon Resources
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health Sibelco Australia NORTHERN TERRITORY Department of Health Matilda Zircon Resources TASMANIA
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Currumbin Minerals Department of Natural Resources and Mines Queensland Health Gueensland Health Sibelco Australia NORTHERN TERRITORY Department of Health Matilda Zircon Resources TASMANIA Department of Health and Human Services
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Currumbin Minerals Department of Natural Resources and Mines Queensland Health Sibelco Australia NORTHERN TERRITORY Department of Health Matilda Zircon Resources TASMANIA Department of Health and Human Services SEMF Pty Ltd
ACT Health Protection Services, Health Directorate QUEENSLAND Currumbin Minerals Department of Natural Resources and Mines Queensland Health Gueensland Health Sibelco Australia NORTHERN TERRITORY Department of Health Matilda Zircon Resources TASMANIA Department of Health and Human Services SEMF Pty Ltd OTHER
ACTHealth Protection Services, Health DirectorateQUEENSLANDCurrumbin MineralsDepartment of Natural Resources and MinesQueensland HealthSibelco AustraliaNORTHERN TERRITORYDepartment of HealthMatilda Zircon ResourcesTASMANIADepartment of Health and Human ServicesSEMF Pty LtdOTHERDepartment of Resources, Energy and Tourism (DRET)
ACTHealth Protection Services, Health DirectorateQUEENSLANDCurrumbin MineralsDepartment of Natural Resources and MinesQueensland HealthSibelco AustraliaNORTHERN TERRITORYDepartment of HealthMatilda Zircon ResourcesTASMANIADepartment of Health and Human ServicesSEMF Pty LtdDepartment of Resources, Energy and Tourism (DRET)Geoscience Australia
ACTHealth Protection Services, Health DirectorateQUEENSLANDCurrumbin MineralsDepartment of Natural Resources and MinesQueensland HealthSibelco AustraliaNORTHERN TERRITORYDepartment of HealthMatilda Zircon ResourcesTASMANIADepartment of Health and Human ServicesSEMF Pty LtdDepartment of Resources, Energy and Tourism (DRET)Geoscience AustraliaMinerals Council
ACTHealth Protection Services, Health DirectorateQUEENSLANDCurrumbin MineralsDepartment of Natural Resources and MinesQueensland HealthSibelco AustraliaNORTHERN TERRITORYDepartment of HealthMatilda Zircon ResourcesTASMANIADepartment of Health and Human ServicesSEMF Pty LtdDepartment of Resources, Energy and Tourism (DRET)Geoscience AustraliaMinerals CouncilRadiation Health Committee (RHC)

Appendix H Stakeholder Survey Questions

This survey was conducted on-line. While the questions below remain the same, the format and layout may have differed from the way it was presented to stakeholders.

- 1. Please enter your name (open ended response)
- 2. Please enter your organisation (open ended response)
- 3. Please enter the name of your mining operation (mine site or processing facility) (*open ended response*)
- 4. Which radiation monitoring service does your organisation use? (select more than one option if appropriate)
 - a. ARPANSA Personal Radiation Monitoring Service (PRMS)
 - b. Australian Radiation Services (ARS) Personal Radiation Monitoring Service (PRMS)
 - c. Landauer Australasia
 - d. Global Dosimetry Solutions
 - e. Global Medical Solutions Australia
 - f. National Radiation Laboratory (New Zealand)
 - g. None
 - h. Other (please specify)
- 5. What types of radiation doses are workers exposed to in your organisation? (select more than one option if appropriate)
 - a. External gamma doses
 - b. External neutron doses
 - c. Inhalation of radioactive particulate
 - d. Inhalation of Rn-222 progeny
 - e. Inhalation of Rn-220 progeny
 - f. Inhalation of radioactive gas and vapour
 - g. Ingestion of radioactive material
 - h. Doses to the extremities (hands and feet)
 - i. Internal doses from the intakes of radioactive material via a wound
 - j. Other (please specify)
- 6. Does your organisation estimate or calculate doses that aren't captured by your radiation monitoring service?
 - a. Yes
 - b. No
- 7. Which doses are calculated or estimated? (Select more than one option if appropriate)
 - a. External gamma doses
 - b. External neutron doses
 - c. Inhalation of radioactive particulate
 - d. Inhalation of Rn-222 progeny
 - e. Inhalation of Rn-220 progeny
 - f. Inhalation of radioactive gas and vapour
 - g. Ingestion of radioactive material
 - h. Doses to the extremities (hands and feet)
 - i. Internal doses from the intakes of radioactive material via a wound
 - j. Other (please specify)

- 8. What personal data are collected and stored with radiation dose records for workers? (select more than one option if appropriate)
 - a. Full name
 - b. Date of birth
 - c. Gender
 - d. Period of employment
 - e. Employee number (unique identified)
 - f. Other (please specify)
- 9. How does your organisation manage radiation dose records? (select more than one option if appropriate)
 - a. Database
 - b. Spread sheet
 - c. Paper Records
 - d. Other (please specify)
- 10. If your records are held in a digital format, to what file format can the data be exported? (select more than one option if appropriate)
 - a. CSV
 - b. XML
 - c. Other (please specify)
- 11. How many years of radiation dose records does your organisation hold? (select one)
 - a. 0 5 years
 - b. 5 10 years
 - c. 10 15 years
 - d. 15 20 years
 - e. 20 25 years
 - f. 25 plus years
- 12. Does your organisation have multiple mineral sands mining or processing sites?
 - a. Yes
 - b. No
- 13. How are the records for radiation exposure to workers managed?
 - a. All workers' records are managed in a central location within the organisation
 - b. Workers' records are managed separately depending on which location the worker is employed (i.e. separate databases or spread sheets per worksite)
- 14. The responsibility of radiation record management sits with:
 - a. A central radiation safety officer, or radiation safety group for the entire organisation
 - b. One radiation safety officer, or radiation safety group for each worksite
- 15. Over the past year, approximately how many workers were monitored by your organisation/ worksite?
 - a. 1-50
 - b. 50-100
 - c. 100-250
 - d. 250-500
 - e. 500-1000
 - f. 1000 plus

- 16. Including historical data, approximately how many workers in total have been monitored by your organisation/worksite since operations commenced?
 - a. 1-50
 - b. 50-100
 - c. 100-250
 - d. 250-500
 - e. 500-1000
 - f. 1000-2500
 - g. 2500-5000
 - h. 5000 plus
- 17. In terms of maintaining radiation dose records, how are workers categorised? Please provide a list of categories below. This list may include categories as defined by your radiation monitoring service. Examples may include Miner, Wet Plant Operator, Dry Plant Operator, Radiation Safety Officer, Office Worker, Concentrator Worker, Refinery Worker, etc. (*open ended response*)
- 18. Do you have any additional comments? (open ended response)
- 19. Do you currently provide dose record information to a state/territory radiation or mining regulatory authority?
 - a. Yes
 - b. No
- 20. Which state/territory radiation or mining regulatory authority is dose record information reported to? (*open ended response*)
- 21. In what format is the data reported (Excel spread sheet, annual report, txt file, etc.)? (*open ended response*)
- 22. How frequently do you provide dose record information to the state/territory regulatory authority? (*open ended response*)
- 23. Do you perceive any barriers to expansion of the ANRDR to the mineral sands mining and processing industry in Australia and/or to mining and processing operations in your state/territory? (*open ended response*)
- 24. Would you be interested in attending a workshop on the ANRDR to discuss expansion efforts to the mineral sands industry and implementation issues? It is likely that the workshop would also be attended by other radiation safety officers in the mineral sands mining and processing industry in Australia.
 - a. Yes
 - b. No
- 25. Do you think it would be beneficial for ARPANSA to form a coordinating body of relevant industry and regulatory representatives to guide implementation of the ANRDR to the mineral sands industry?
 - a. Yes
 - b. No

26. Do you have any additional comments? (open ended response)

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