Curtin University

NORM Management Guidelines

Health and Safety

CONTENTS

TABLES

1. INTRODUCTION

1.1. Purpose

The mining and mineral processing industry has legislation, codes of practice and safety guides for the use of Naturally Occurring Radioactive Material (NORM). Most of these rules and guidance materials are based around the extraction and processing of large quantities of ore. However, there is comparatively little guidance for other industries, such as the tertiary education sector, where NORM could be used in a research or teaching environment. When projects are undertaken in conjunction with the mining industry, these relevant legislation, codes and guidelines should be adhered to. The NORM management guidelines for Curtin University are not intended to replace those codes and guidelines, but rather supplement them, and in particular provide guidance on situations where there may be the need for regulation or radiation protection measures.

The purpose of these guidelines is therefore to assist University staff in understanding their requirements under legislation and to promote a University-wide safe management practice in the usage and storage of NORM that is clear and consistent across all areas of the University, while remaining flexible to account for different work practices and different levels of risk. These guidelines will also provide advice on the type of radiation protection measures that may be required and to achieve an acceptable level of risk to persons arising out of specific activities.

1.2. Scope

These guidelines will be applicable to all Curtin University campuses and will apply to all NORM as defined under section 1.4. Unless otherwise specified, the recommendations in these guidelines should be followed whenever the activity concentration in the material of any radionuclide exceeds the exempt thresholds as defined under section 2.2.1.

1.3. Structure

This guide is structured as follows: Section 2 provides information related to the initial stage of acquiring NORM and the relevant assessments and checks that must be completed prior to bringing it onto campus or starting activities in the field. Section 3 describes how NORM should be stored, managed and handled while within the University's possession. Section 4 describes considerations related to the disposal of NORM.

1.4. Definitions

1.4.1. RSC

Curtin University's Radiation Safety Committee, which monitors the performance of the University RSO.

1.4.2. RSO

Curtin University's Radiation Safety Officer is a legislated role that coordinates radiation activities at Curtin University to ensure compliance with the Radiation Safety Act 1975 and other regulations.

1.4.3. RSS

Heads of Schools or Area Managers may nominate a Radiation Safety Supervisor to act on their behalf in matters related to radiation safety in their area.

1.4.4. NORM

Naturally Occurring Radioactive Material is the term used to describe materials containing radionuclides that exist in the natural environment. Long-lived radioactive elements of interest include uranium, thorium and potassium, and their radioactive decay products, such as radium and radon.

1.4.5. TENORM

Technologically Enhanced Naturally Occurring Radioactive Material is a term that is sometimes used to define naturally occurring radioactive materials that may have experienced some kind of technological enhancement. Human activity can

enhance NORM so that its composition, concentration, availability or proximity to people is altered. For the purpose of these guidelines whenever the term NORM is used it will include TENORM, unless specified otherwise.

1.4.6.Work area

Work Area, for the purpose of this document, is a broad term that can cover a School, Institute, Discipline, Centre, geographical location or any other collection of units/locations as agreed by the Head(s) of School with responsibility for resources included therein.

1.5. Authorised personnel and responsibilities

There are various personnel across the University with responsibilities related to radiation, including the University Radiation Safety Officer (RSO), the Radiation Safety Committee (RSC), local Radiation Safety Supervisors (RSS) and Radiation licence holders. In addition, all staff and students must adhere to the requirements and report any safety, health or security concerns. A full description of responsibilities related to radiation safety can be found in the Radiation Safety Manual.

2. ACQUISITION OF NORM

2.1. Dealing with suppliers

Where possible, details about the NORM should be obtained from the supplier prior to any arrangements for shipping to University premises. The pre-purchase checklist from Health, Safety and Emergency Management (HSEM) can be used in these circumstances to assist during the acquisition. The details of the material should include the isotopic composition, the specific activity and the total amount of material. This information should be supplied in writing to the University, and the relevant RSS for the work area should be notified and provided with a copy of this information. Once the information has been received the work area, in conjunction with the relevant RSS, should ascertain the specific activity, as described in subsection 2.3, to help determine the appropriate controls.

In the absence of any information from the supplier about the specific activity, an initial assessment of the hazard must be made, as described under subsection 2.4. When liaising with the supplier it is also necessary to make arrangements for final disposal, see subsection 4.2. Note, where the activity from the supplier is measured in Curies (Ci) it can be converted to Becquerels (Bq) according to the following: 1 Ci = 3.7×10^{10} Bq.

2.2. Categorisation of NORM

For the purpose of these guidelines NORM shall be categorised according to its mass or specific activity and be described as either exempt, negligible or low specific activity.

2.2.1.Exempt NORM

If the material cannot be categorised as exempt via the above method the specific activity must be determined. The NORM will be categorised as exempt if the specific activity in the uranium decay chain or the thorium decay chain is known to be, or reasonably expected to be, less than 1 Bq/g, or the activity concentration of Potassium-40 is known to be, or reasonably expected to be, less than 10 Bq/g (ARPANSA Code: Radiation protection in planned exposure situations).

In addition, regardless of the specific activity, if the total amount of NORM material acquired by a work area is less than 50 grams, that material will be categorised as exempt. This figure is derived from an approximation of the exempt activity under Schedule V of the Radiation Safety General Regulations 1983 combined with the highest specific activity under Appendix I of these guidelines, and includes of a margin of error to help the University stay within its institutional limits.

If the NORM is categorised as exempt, the material will not be considered as NORM for the purpose of these guidelines and no further actions are required. Where the mass of the material exceeds 50 grams, the specific activity should be determined as described under section 2.3, or steps taken as described under section 2.4.

2.2.2.Negligible specific activity NORM

Where the specific activity exceeds the values specified in section 2.2.1 but is less than 30 Bq/g it shall be considered to have negligible specific activity. Any material with a specific activity in this bracket is considered to have sufficient specific activity to warrant controls under the ARPANSA Code for radiation protection in planned exposure situations, but is not considered radioactive under the WA Radiation Safety Act 1975 (Regulation 5(1)(a)). As such, subsections 3.4 and 3.5 in these guidelines do not apply for material in this category. All other subsections will apply.

2.2.3.Low specific activity NORM

Where the specific activity exceeds 30 Bq/g it shall be considered to have low specific activity. This terminology is consistent with that for NORM under the Code of Practice for the Safe Transport of Radioactive Material 2008. For this category of material, all of the sections in these guidelines will apply. The risk assessment should be conducted with reference to the radiation exposure limits of radiation workers and members of the public (as described in subsections 3.4 and 3.5).

2.3. Determining the specific activity

The specific activity should be determined by one of the following methods:

- i) Reference to the supplier's information about the material;
- ii) Measurement via an isotopic characterisation technique (such as ICP-MS); or
- iii) Referring to Appendix I, and assuming the highest listed specific activity for the relevant material.

In situations where the samples are acquired without being able to determine the specific activity (for example, collecting from a field site), an initial assessment of the hazard, as described in subsection 2.4, must be made to adopt some interim controls prior to the specific activity determination.

2.4. Initial assessment where specific activity unknown

For NORM it is often difficult to determine the specific or total activity when first coming into contact with the material, for example, when collecting from the field. Under such circumstances an initial estimate of the hazard should be made on site so that appropriate interim controls can be adopted prior to determining the specific activity via one of the methods in subsection 2.3.

Table 1: Controls required for NORM prior to determination of specific activity.

Activity levels	Required controls prior to determination of specific activity
Under 2 times average background at 1cm from sample surface.	No further controls required.
Over 2 times average background at 1 cm from sample surface, but under 25 times average background at the surface of the container in which the NORM is placed.	Procedures should be adopted that ensure handling time is minimised. Materials must be stored and transported in containers. The container must have the marking 'UN2910' clearly written on the outside, together with the contact details of the person responsible for those materials.
Over 25 times average background at the surface of the container in which the NORM is placed.	Procedures should be adopted that ensure handling time is minimised. The materials must be stored in a container that is sealed, such that in the event of an accident it is unlikely that the material would be released. Those sealed containers should have shielding that reduces the measured radiation to 25 times background at the surface of the container. The container must have the marking 'UN2910' clearly written on the outside, together with the contact details of the person responsible for those materials.

A radiation detector suitable for detecting gamma radiation, such as a scintillation counter, should be used to measure the activity relative to background. Any units can be chosen (e.g. counts per second, Sieverts per hour, etc.), as long as the same units are used for both the background and the NORM sample measurements. An average background check for

the detector should be conducted and the result recorded. Natural background can vary considerably so this background check must be conducted far from the field site to ensure activity levels from rock/sand/soil in the local area do not affect the reading. The purpose is to determine how much higher the activity levels of the sample are with respect to average background, not local background.

Measurements of the materials should be undertaken with the same detector and compared to the previously determined average background level. If the activity measurement is greater than twice the background, interim controls must be put in place as described in Table 1. The samples must then be placed in a container suitable for transport, and radiation measurements must be taken again by placing the detector at the surface of the container, then referring back to Table 1 for the appropriate controls.

2.5. Risk assessment

A risk assessment must be conducted for all NORM above exempt levels, which must be in addition to any risk assessment addressing other risks such as chemical and physical risks. This risk assessment must be made with reference to the hierarchy of safety controls i.e., elimination, substitution, isolation, engineering, administrative, PPE. Consideration must be given to dust suppression/extraction, ventilation, separation distance, shielding, work practices, training, PPE, risk monitoring, work surfaces, spills management and record keeping.

The risk assessment should also reflect the expected storage and working practices as described in the remainder of this section and in section 3. NORM can present both an internal and external radiation hazard, so the risk assessment should account for both. Information about risk assessments can be found at the Health, Safety and Emergency Management (HSEM) website. More comprehensive information about exposure pathways and NORM risks can be found in RPS 15, Management of Naturally Occurring Radioactive Material (NORM) safety guide (2008).

The risk assessment must be carried out by the personnel who will be working with the NORM. It is not necessary to work under a radiation licence in order to complete the risk assessment, although this risk assessment must be conducted in liaison with the RSS for the work area to ensure all relevant personnel will be made aware of the work. The risk assessment should show that the ALARA principle (As Low As Reasonably Achievable) is being applied with respect to minimising radiation exposure to personnel, and can do so by referring to Safe Work Procedures that demonstrate how this exposure is minimised. Additional information and templates can be found on the HSEM website.

2.5.1. Exposure pathways

Consideration should be given to potential internal exposure, for which the most common modes of entry to the body are inhalation and ingestion. When considering inhalation, it is important to take into account the potential build-up of Radon, which is a daughter radionuclide of radium and present in most rocks, soils and minerals which are naturally occurring radionuclides. These internal exposures can result from the decay of radionuclides within the body where radionuclides usually enter the body via inhalation, ingestion, and wounds, and by absorption through the skin.

Alpha radiation has the greatest effect for internal exposures, because its relatively high energy and low penetrating power means that all the energy of the alpha particle is deposited in a short distance when it passes through tissue. External exposures occur when the radiation source is outside the body. Gamma radiation has the greatest external exposure effect, while Beta radiation presents both an internal and external concern. Doses from external exposure depend on factors such as the duration of the exposure, proximity to the radiation source, the radionuclide concentration, and the presence of shielding material.

Doses resulting from internal exposures can depend on the radionuclide concentration(s) in air, food, water or materials being handled, the duration of the exposure, and the rate of intake of material into the body and the chemical form of the materials being handled.

2.5.2. Risks when handling NORM

In some industries, dry separation techniques are used to separate minerals. These procedures have the potential to generate high concentrations of airborne dust containing NORM, which can pose an inhalation risk.

Handling of materials containing NORM can result in the deposition of contaminated material on the skin or on clothing. For solids the main issues are deposition of dust on clothing and exposed skin. Where liquids are being handled, splashing onto clothing and exposed skin can be an issue. Material deposited on clothing can be transferred to the hands by rubbing. The radiological risk associated with this pathway can be significantly reduced by following good hygiene procedures, such as washing the face and hands before eating, and removing contaminated clothing before leaving the workplace.

2.6. Project approval

Projects involving NORM categorised as negligible or low specific activity, must be approved by the University RSO prior to the commencement of radiation activities. Radiation project approvals are administered via InfoEd. Personnel involved in the project must create and submit a project application, together with their safe work procedures. In some cases it is necessary to seek approval from Government Regulators or make alterations to a facility. As such, it would be prudent to make the project application many months in advance of the commencement of work to allow for these other possible delays.

3. TRAINING, STORAGE AND HANDLING OF NORM

3.1. Storage

The findings of the risk assessment should be considered when determining a suitable storage location. In poorly ventilated areas the build-up of radon levels can be a cause for concern. As such, the area must be ventilated sufficiently to prevent the build-up of Radon. The minimum outdoor fresh air flow per unit of total floor area should be at least 3 litres per second per square metre (AS/NZS 2982.2010).

Except in unusual circumstances, storage of NORM wastes/residues should not be considered as a long term management option, because the very long half-lives of 238U, 235U and 232Th would not lead to significant reduction in exposures over typical storage timeframes. Storage may require the construction of permanent or semi-permanent facilities with means of restricting access. Waste should be dealt with in accordance with section 4.

3.2. Training

All NORM must be stored in a secure location that can be accessed by authorised personnel only. To become authorised an individual must have radiation safety training and must have the permission of the local RSS. Training may consist of familiarity with relevant risk assessments and safe work procedures or may be a more formal training program, depending on the extent of the hazards. The RSS, in consultation with the University RSO, will determine the level of training required for any particular location within their work area, and will maintain a list of authorised personnel for that location.

3.3. Handling

Handling NORM sometimes has the potential to generate high concentrations of airborne dust, which can pose an inhalation risk. Controls should be put in place to ensure any potential inhalation or ingestion is minimised. This should be done by taking into account the nature and frequency of the material being used, and should be documented in the risk assessment. Machinery used for dry separation of minerals should be enclosed with dedicated dust extraction systems to keep dust levels in air breathed by workers to a minimum. For larger volumes of material working with a dust extraction hood should be considered as these hoods may be better than fume cupboards for dealing with large amounts of dust. Where materials are transported in dry form, spraying with water should keep dust levels in work areas at acceptable levels.

3.4. Monitoring of low specific activity NORM

The area surrounding the secure location must be surveyed whenever new material is introduced to the location. An estimate must be made of the amount of time personnel spend occupying the surrounding area to this location and this must be compared with the dose limits to members of the public in the Radiation Safety (General) Regulations 1983. Any individual occupying space outside the secure location must not be in a position where they may record a radiation dose level in excess of 20 µSv/hr, 250 µSv/week or 1000 µSv/year (Schedule I(3)).

If the secure location is large enough to be occupied by personnel (e.g. a storeroom), then the interior of the location must be surveyed whenever new material is introduced to the location. An estimate of the amount of time authorised personnel spend occupying this space must be made and compared with the dose limits in the Radiation Safety (General) Regulations 1983. If only radiation workers have access to the secure location, they must not be in a position where they may record a radiation dose level in excess of 1.25 mSv/month or 6 mSv/year (Regulation 15 & Schedule I(1)). These radiation workers should also wear a radiation badge. If the location can also be occupied by individuals who are not radiation workers, then the general public limits above will apply.

3.5. Occupancy factor for low specific activity NORM

An occupancy factor can be applied to assist in estimating the amount of time personal are exposed to radiation. Occupancy factors are routinely used in radiotherapy situations and are applied to reflect a more reasonable assessment of an individual's dose in areas that are not always occupied on a full-time basis. The estimated dose to an individual is then the potential dose as measured via a radiation survey multiplied by the occupancy factor. These occupancy factors can be used for any areas including those containing the NORM material or rooms/areas adjacent to the storage areas. The occupancy factors in these guidelines are modelled on NCRP 151, and are given in Table 2.

Table 2: Occupancy factors for different locations.

Location	Occupancy factor
Areas occupied full-time by an individual, e.g. administrative or clerical offices, receptionist areas	1
Corridors, employee lounges, staff rest rooms, classrooms	1/5
Toilets, storage areas, outdoor areas with seating, unattended waiting areas, janitors' closets	1/20
Outdoor areas with only transient pedestrian or vehicular traffic, unattended parking lots, vehicular drop off areas, stairways, unattended elevators	1/40

3.6. Inventory stock-take

The RSS will conduct an annual inventory check of the materials in accordance with the requirements of the National Regulator, the Australian Safeguards and Non-proliferation Office (ASNO) and submit this to the University RSO at the relevant time. The RSO will collate all information from across the University and correspond with the Regulator to ensure the University meets its compliance requirements.

For low specific activity material it will also be necessary to notify the RSO via an amendment in InfoEd any time there is an increase in the total activity of material present in a location.

4. MANAGEMENT AND DISPOSAL OF NORM WASTE

4.1. Management

The modern definition of a waste is a material for which there is no foreseeable use. The general approach is therefore to minimise waste production and utilise residues as much as possible. This is particularly applicable to NORM and wastes/residues resulting from processing of NORM, where large volumes of material with relatively low concentrations of radionuclides are frequently involved.

The appropriate approach to the management and disposal of NORM wastes can depend on factors such as radionuclide concentrations in the waste, the physical form of the waste (solid, liquid or gas) and the chemical form of the waste. Environmental impact can be limited by reducing the mobility of the waste. This can be done by solidification of liquids and/or the use of engineered barriers.

4.2. Return to supplier

The first preference for disposal is to arrange for the material to be sent back to the supplier when the material is no longer required. Where possible the final disposal should be organised with the supplier when the material is first acquired. If it is not possible to arrange for the material to be returned, a disposal plan should be devised in accordance with the guidelines in this section, and then included in the project application (subsection 2.6).

4.3. Negligible specific activity disposal

Negligible specific activity material is not considered radioactive under the Radiation Safety Act, so does not have to be disposed of as radioactive material. The RSS in consultation with the RSO will determine a suitable disposal route with reference to the chemical or physical risk assessment for the material.

Where the material has been enhanced such that it is considered TENORM as described in section 1.4.5, the material may be subject to disposal requirements from the Australian Safeguards and Non-proliferation Office (ASNO). To be compliant with ASNO requirements the RSS in consultation with the RSO must describe how the material will become practically irrecoverable. This should be stated on the relevant ASNO application to dispose of nuclear materials.

4.4. Low specific activity disposal

Low specific activity NORM is considered Radioactive under the Radiation Safety Act 1975 and must be disposed of in accordance with the requirements of the WA Radiological Council. Waste in this category must be transferred to the Curtin University Radioactive Waste Store, so that final disposal can be arranged by the University RSO and the relevant Regulators notified. Waste must be packaged in containers that can be lifted and carried comfortably by a single individual. The quantity and type of material should be listed on the outside of the container together with the name and contact details from the user group.

Where the NORM is to be disposed of in accordance with Radiological Council requirements the RSS must make arrangements with the RSO to access the University disposal route for radioactive materials. The RSO will determine the cost of the disposal and the RSS will provide the relevant cost centre to be charged.

REFERENCES

These guidelines are informed by the following:

a) Radiation Safety Act 1975.
b) Radiation Safety (General) Regulations 1983. Provides legal exposure dose thresholds (Schedule I(3) for general public).
c) ARPANSA RPS 1: Recommendations for limiting exposure to ionizing radiation (1995), and National standard for limiting occupational exposure to ionizing radiation.
d) ARPANSA RPS 2: Code of Practice for the Safe Transport of Radioactive Material (2008).
e) ARPANSA RPS 9, Code of Practice and Safety Guide Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005). This code and guide covers waste rock, process tailings, and products containing elevated concentrations of naturally occurring radionuclides.
f) ARPANSA RPS 15, Management of Naturally Occurring Radioactive Material (NORM) safety guide (2008). This guide provides safety information for NORM primarily associated with mineral extraction and processing. Supplements the Mining Code.
g) ARPANSA RPS C-1: Code for radiation protection in planned exposure situations.
h) NCRP 151 – Structural shielding design and evaluation for megavoltage x-ray and gamma-ray radiotherapy facilities.
i) Naturally Occurring Radioactive Materials (NORM) in Australian Industries - Review of Current Inventories and Future Generation, Malcolm B. Cooper (2005).
j) AS 2243.4 Ionizing radiations.
k) AS/NZS 2982 Laboratory design and construction.
l) Code of practice for the near-surface disposal of radioactive waste in Australia (NHRMC, 1992). Applies to bulk NORM residue disposal.
m) Review of Current Inventories and Future Generation by Malcolm B. Cooper (2005).

APPENDIX I

These estimates of specific activities are taken from Naturally Occurring Radioactive Materials (NORM) in Australian Industries - Review of Current Inventories and Future Generation by Malcolm B. Cooper (2005).

Summary of NORM in Australian Industries and Materials

Category of NORM I. raw material II. product(s) III. residues/ waste/by-products	Scale of mining/production and waste generation in Australia (estimated)	Typical radionuclide concentrations	Waste management or by-product use
MINERAL SAND MINING AND PROCESSING I. Ore II. Heavy minerals III. a. Tails from primary separation b. Oversize from secondary sepn. c. Tails from secondary sepn. d. Dust from secondary sepn. e. Solids from synthetic rutile f. Kiln solids	I. 3.5 $Mt.a^{-1}$ II a. 2.5 $Mt.a^{-1}$ Concentrate b. 2 $Mt.a^{-1}$ Ilmenite/Rutile c. 390 $kt.a^{-1}$ Zircon d. 80$kt.a^{-1}$ Monazite concentrate e. ** $kt.a^{-1}$ Synthetic rutile III a. 30 $Mt.a^{-1}$ b. 40 $kt.a^{-1}$ c. 400 $kt.a^{-1}$ d. 20 $kt.a^{-1}$ e. ** $kt.a^{-1}$ f. ** $kt.a^{-1}$	I. 0.02-0.3 $kBq.kg^{-1}$Th, 0.03-0.12 U II a. 0.3-3 $kBq.kg^{-1}$ Th, <0.1-0.8 U b. 0.2-2 $kBq.kg^{-1}$Th, <0.1-0.6 U c. 0.6-1.2 $kBq.kg^{-1}$Th, 1-4 U d. 40-250 $kBq.kg^{-1}$Th, 6-30 U e. <0.2-1.5 $kBq.kg^{-1}$Th, <0.1-0.3U III a. <0.2 $kBq.kg^{-1}$Th, <0.1 U b. 0.3-8 $kBq.kg^{-1}$Th, 0.6-2.0 U c. 0.8-24 $kBq.kg^{-1}$Th, 0.1-12 U d. 1-20 $kBq.kg^{-1}$Th, 0.1-6 U e. <0.2-1.5 $kBq.kg^{-1}$Th, <0.1-0.3 U f. 0.1-1.2 $kBq.kg^{-1}$Th, 0.1-1.2 U	IIIa. Landfill disposal in mined out area IIIb. To IIIf. Dilution with inert solids, then landfill disposal
TITANIUM PIGMENT PRODUCTION I. Rutile/Synthetic rutile II. Titanium pigment III. a. Neutralised slurries b. Solids from effluent treatment c. Liquid effluent	I. as above II. 185 $kt.a^{-1}$ titanium pigment III. a 200 $kt.a^{-1}$ b. 200 $kt.a^{-1}$ c. **	I. as above II. < 0.01 $kBq.kg^{-1}$Th, <0.01 U III a. 1.2 $kBq.kg^{-1}$ Th, 0.35 U b. 0.8-1.4 $kBq.kg^{-1}$ Th, 0.3-0.5 U c. < 0.1 kBq.kg Th, < 0.1 U	IIIa. Landfill disposal IIIb. Landfill disposal IIIc. Ocean discharge
ZIRCONIUM AND CERAMICS INDUSTRY I. Zircon II. Zirconia, Refractory materials, ceramics, glazes III. a. Sludge b. Chlorinator residues c. Dust d. Slag	I. as above II. ** III. **	I. as above II. ** III. **	

Note: ** information not currently available to author

Category of NORM I. raw material II. product(s) III. residues/ waste/by-products	Scale of mining/production and waste generation in Australia (estimated)	Typical radionuclide concentrations	Waste management or by-product use
ALUMINA PRODUCTION I. Bauxite II. Alumina III. Red mud	I. 58 $Mt.a^{-1}$ bauxite II. 17 $Mt.a^{-1}$ alumina III. > 20 $Mt.a^{-1}$ red mud	I. 0.7 kBq.kg Th, 0.2 U, 0.06 ^{40}K II. n.d. Th, n.d. U III. 1.4 $kBq.kg^{-1}$ Th, 0.4 U, 0.16 ^{40}K	III. Landspreading
COPPER MINING AND PROCESSING I. Copper ore II. Copper concentrate/refined metal III. a. Tails from flotation b. Dust from smelter c. Slag from smelter	I. 20 $Mt.a^{-1}$ II a. 800 $kt.a^{-1}$ Primary copper products b. 520 $kt.a^{-1}$ refined copper III a. **$kt.a^{-1}$ b. **$kt.a^{-1}$ c. **$kt.a^{-1}$	I. ** II a. ** III a. $Bq.kg^{-1}$ Th, $Bq.kg^{-1}$ U b. $Bq.kg^{-1}$ ^{210}Pb, ^{210}Po c. $Bq.kg^{-1}$ Th, $Bq.kg^{-1}$ U	IIIa. Disposal in tailings dam with U tails
TANTALUM/TIN MINING AND PROCESSING I. Tantalum ore II. a. Tantalum concentrate b. Tin III. a. Tantalum tails b. Tin slag	I. 2.5 $Mt.a^{-1}$ II. a. 2.5 $kt.a^{-1}$ b. ** $kt.a^{-1}$ III. a. ** $kt.a^{-1}$ b. ** $kt.a^{-1}$	I. < 10 $Bq.kg^{-1}$ Th, < 60 $Bq.kg^{-1}$ U. II. a. 7.5 – 75 $kBq.kg^{-1}$, U + Th III. a. ** b. **	IIIa. Landfill disposal
IRON SMELTING I. Iron ore II. Iron (+steel) III. a. Furnace slag b. Dust	I. 200 $Mt.a^{-1}$ II. 8 $Mt.a^{-1}$ III. a. 3.1 $Mt.a^{-1}$ b. ** $kt.a^{-1}$	I. 20 – 30 $Bq.kg^{-1}$ III. a. b. < 100 $kBq.kg^{-1}$ ^{210}Pb and ^{210}Po	III. Processed into industrial products, road construction, concrete manufacture III. On-site storage

Category of NORM I. raw material II. product(s) III. residues/ waste/by-products	Scale of mining/production and waste generation in Australia (estimated)	Typical radionuclide concentrations	Waste management or by-product use
PHOSPHATE INDUSTRY I. Phosphate rock II. Fertilisers,Phosphoric acid III. a. Phosphogypsum b. Calcium fluoride c. Furnace slag and dust d. Scale	I. 2 $Mt.a^{-1}$ (local rock) II. a. 4 $Mt.a^{-1}$ superphosphate b. 100 $kt.a^{-1}$ acid (< 1993) c. ADP III. a. 250 $kt.a^{-1}$ (<1993) b. 90% of ore c. 1% of ore as dust and 85% as slag	I. <0.01-0.2 $kBq.kg^{-1}$Th, <0.1-1.9 U II. a. 0.01-0.06 $kBq.kg^{-1}$Th, 0.5-2.2 U, 0.1-1.0 ^{226}Ra (incl. ADP) b. < 0.01 $kBq.kg^{-1}$Th, 1.2-1.5 U, 0.3 ^{226}Ra III. a. <0.01 $kBq.kg^{-1}$Th, 0.01-0.02 U, 0.28 - 0.35 ^{226}Ra, 0.32-0.44 ^{210}Pb d. <0.01 $kBq.kg^{-1}$Th, 0.01-0.2 U, 0.01-3.9 ^{226}Ra, 0.03-1. ^{210}Pb	III a. Stockpiled on site Plasterboard manufacture (10%)
OIL AND GAS PRODUCTION I. Natural oil and gas II. Purified oil and gas III. a. Sands and sludge b. Soft scales c. Hard scales and film	I. ** III a. 200 tonnes b. ** c. 1-2 tonnes	III a. < 0.01 $kBq.kg^{-1}$Th, < 0.01 U, 0.1-10 ^{226}Ra, 0.05-4 ^{228}Ra, 0.01-1 ^{210}Pb b. <0.01-0.07 $Na.kg^{-1}$Th, < 0.01 U, 0.1-10 ^{226}Ra, 0.05-4 ^{228}Ra, 0.01-1 ^{210}Pb c. < 0.01 $Bq.kg^{-1}$Th, <0.01-0.5 U, 0.1-100 ^{226}Ra, 0.1-40 ^{228}Ra, 0.1-300 ^{210}Pb	III a. Landfill Ocean discharge
COAL-FIRED POWER GENERATION I. Coal II. Electrical power III. a. Fly ash b. Bottom ash	I. a. 52 $Mt.a^{-1}$ Black coal b. 67 $Mt.a^{-1}$ Brown coal III a. 13 $Mt.a^{-1}$ fly ash b. 1 $Mt.a^{-1}$ bottom ash	I a. 0.005-0.05 $kBq.kg^{-1}$Th, 0.01-0.05 U 0.01-0.5 ^{40}K b. 0.005 $kBq.kg^{-1}$ Th, 0.01 U, 0.02 ^{40}K II a. 0.02-0.2 $kBq.kg^{-1}$ Th, 0.02-0.19 U 0.04-0.3 ^{210}Pb, 0.1-0.8 ^{40}K b. 0.05-0.19 $kBq.g^{-1}$ Th, 0.05-0.2 U, 0.005-0.08 ^{210}Pb, 0.04-0.10 ^{40}K	III Cement and brick manufacture Road construction Mine site rehabilitation Landfill

Category of NORM I. raw material II. product(s) III. residues/ waste/by-products	Scale of mining/production and waste generation in Australia (estimated)	Typical radionuclide concentrations	Waste management or by-product use
WATER TREATMENT I. Surface or bore water II. Purified potable water III. a. Sludge b. Resins and cartridges	I. 1400 GL III. 100 $kt.a^{-1}$	I. < 1 $Bq.L^{-1}$ ^{228}Ra, < 1 $Bq.L^{-1}$ ^{226}Ra II. ** III. **	IIIa. Landfill disposal or landspreading b. Landfill disposal
BUILDING MATERIALS I. a. Raw materials b. By-product wastes II. Bricks, cement, plasterboard, ceramic tiles	I b. 15 % Phosphogypsum recycled, 10% Fly ash II. **	I. b. As above II. Concrete - 0.001-0.24 $kBq.kg^{-1}$Th, 0.001-0.25 ^{226}Ra,.005-1.5 ^{40}K Bricks – 0.001-0.2 $kBq.kg^{-1}$Th, 0.01-2.2 ^{226}Ra, 0.01-1.6 ^{40}K Plasterboard - <0.01-0.05 $kBq.kg^{-1}$ Th <0.01-0.7 ^{226}Ra, 0.025-0.1 ^{40}K Ceramics - 0.02-0.2 $kBq.kg^{-1}$ Th, 0.03 - 0.2 ^{226}Ra, 0.16-1.4 ^{40}K	