Managing naturally occurring radioactive material (NORM) in mining and mineral processing — guideline

NORM–4.2

Controlling NORM — management of radioactive waste

Government of **Western Australia**
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1. General information

1.1. Purpose

To provide recommendations on the safe management of radioactive waste that results from the mining and processing of minerals.

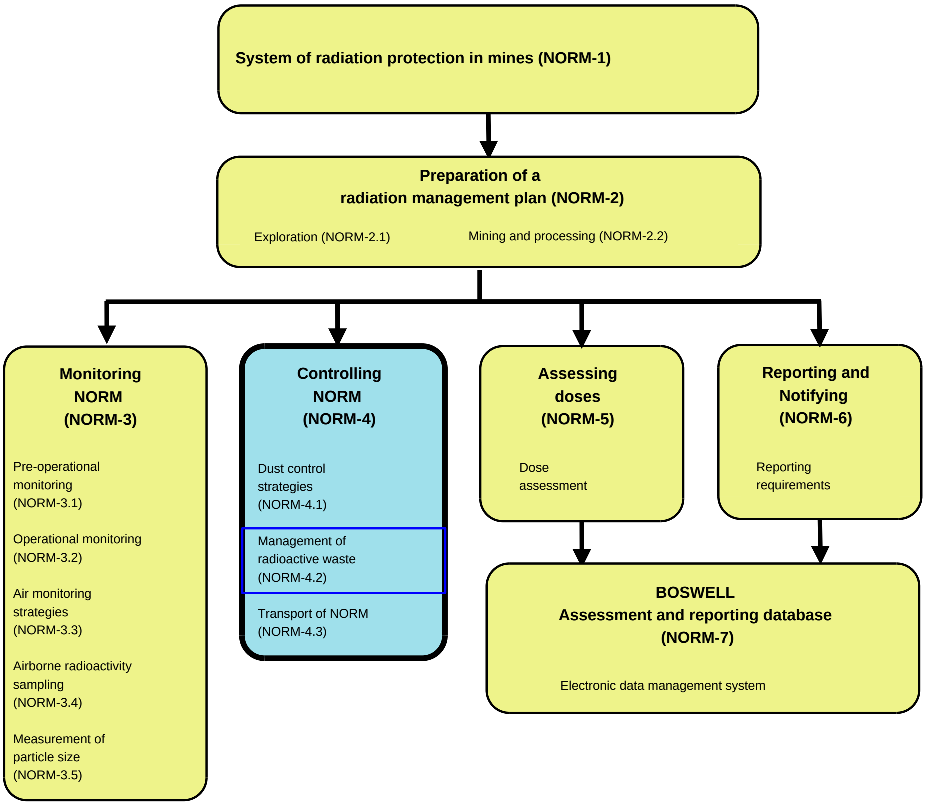
1.2. Scope

This guideline applies to all exploration, mining and mineral processing operations in Western Australia that use or handle naturally occurring radioactive material (NORM) and come within the scope of Part 16 of the Mines Safety and Inspection Regulations 1995 [1].

1.3. Relationship to other NORM guidelines

The flowchart in Figure 1.1 shows how the Radiation Safety Guidelines are arranged.

Figure 1.1.: Relationship to other NORM guidelines



2. Guidance

2.1. Introduction

The radioactive waste generated in mining and minerals processing operations, especially those involving naturally occurring radioactive material (NORM), typically contains low concentrations of radioactive material but is generated in very large volumes. The management methods usually involve waste disposal near the surface and in the vicinity of the mining and processing sites. In addition, the waste typically contains long-lived radionuclides, and this has important implications for its management because of the long time periods for which control will be necessary.

The preferred option for the disposal of the radioactive waste is that, where safe and practicable, radioactive waste is diluted with other mined material before it is finally disposed of in order to ensure that in the long term the use of the disposal site is not restricted.

This method, however, is only applicable in the situations where the secular equilibrium of both uranium and thorium decay chains is not disrupted (for example for tailings from heavy mineral sands physical separation). This method cannot be used for the disposal of uranium processing tailings and for any other waste generated in the process of chemical and/or thermal treatment of NORM.

Radioactive waste is typically generated at most stages of mining and mineral processing and typically includes mineral processing tailings, waste rock (or 'oversize'), scales, sludges, scrap material and process water, including leaching solutions. Rainfall runoff and seepage from stockpiles and areas of processing plants should also be managed.

Tailings storage facility typically receive the bulk of processing water, which is normally recycled, but some of it may be released into the environment through seeping or due to unusually high rainfall. The tailings storage facility (TSF), when dry, usually represent the main source of radon/thoron and dust emissions to the environment. Special containment arrangements are required for the disposal of tailings generated during chemical and/or thermal processing of uranium and thorium-bearing minerals – to ensure that environmentally mobile radionuclides are not released into the surrounding environment.

The disposal of contaminated equipment and materials also needs to be controlled. Where required, decontamination methods used are typically steam and high pressure water cleaning, mechanical cleaning, etc.

The waste from mining and minerals processing operations is often re-used in other industries. Examples include use of different slags in road construction, sands and ash in building materials such as cement, and gypsum in agricultural use as a soil conditioner. It is important to ensure that no material that is considered as radioactive waste is released from mining and mineral processing operations without sufficient dilution with non-radioactive constituents and only after the approval by the appropriate authority.

Certain types of waste material can be re-utilised for other applications after appropriate blending and a general guidance on the possibilities of the blending of radioactive waste for the re-use is provided in Appendix A on page 17.

The hazards posed by mining and mineral processing waste are often not limited to its radioactivity. The presence of other potentially toxic chemicals must be taken into account and often measures taken to protect the environment from other contaminants are sufficient for radiation protection as well.

Where appropriate, an institutional control over the waste disposal sites should be established to maintain control and/or knowledge of the site after closure. This may be achieved via the registration of the site in accordance with the *Contaminated Sites Act* [5].

2.2. Radioactive waste management plan

The Code of Practice [3] requires that in conjunction with the Radiation Management Plan (Guideline NORM–2.2 Preparation of a radiation management plan – Mining and processing), a specific Radioactive Waste Management Plan (RWMP) should be developed.

In developing the RWMP, all relevant pathways for dispersion of radionuclides and for radiation exposure of both employees and members of the general public should be considered.

The essential elements of the RWMP are:

1. An outline of the processes generating waste.
2. A description of waste including nature of material (chemical, physical and radiological), contaminants, and quantities and rate of production.
3. A description of the environment into which the waste will be discharged or disposed (climate, terrain, soils, vegetation, hydrology), including the baseline radiological characteristics.
4. Heritage (social and cultural) and land use (present and potential).
5. A description of the proposed system for waste management including the facilities and procedures involved in the handling, treatment, storage and disposal of radioactive waste.
6. Predictions of environmental concentrations of radionuclides and radiation doses to the public from the proposed waste management practice, including demonstration that the statutory radiation protection requirements will be met both now and in the future.
7. A program for monitoring the concentration of radionuclides in the environment and assessment of radiation doses to members of the public arising from the waste management practices.
8. Contingency plans for dealing with accidental releases and the circumstances which might lead to uncontrolled releases of radioactive waste in the environment.
9. Contingency plan to cover cases of early shutdown or temporary suspension of operations.
10. A schedule for reporting on the waste disposal operation and results of monitoring and assessments.
11. A plan for the decommissioning of the operation and associated waste management facilities, and for the rehabilitation of the site.
12. A system of periodic assessment and review of the adequacy and effectiveness of the RWMP to take account of potential improvements consistent with best practicable technology.

The RWMP should be further developed throughout the operational stage and should be reviewed whenever there is a significant change in the operation or of the waste management system, and at intervals similar to the Radiation Management Plan.

The following factors should be considered in the development of the RWMP:

1. The level of effluent control achieved and the extent to which environmental pollution and degradation are prevented in similar mining and mineral processing operations elsewhere in the world.

2. The total cost of the application or adoption of the technology relative to the environmental protection to be achieved by its application or adoption.
3. Evidence of detriment, or lack of detriment, to the environment after the commencement of the waste management/disposal operation.
4. The physical location of the operation.
5. The age of equipment and facilities and their relative effectiveness in reducing environmental pollution and degradation.

During the operational stage, the appropriate authority must be notified of:

- any changes to the operation which may alter the nature or quantity of waste generated;
- any proposal to change the waste containment system; and
- any unanticipated circumstances that may lead to a variation in performance of the approved RWMP.

These changes would not normally be put into effect until a required statutory approval has been issued.

2.3. Waste management practices and radiological protection

2.3.1. Mining and concentrating

Typically, the tailings from the mining and initial separation phase of the operation are of no radiological concern as most of the mineral would have been removed for downstream separation/processing. In most cases, the tailings can be returned to the mined out areas and the sites rehabilitated in accordance with the requirements of the appropriate authority.

Some waste rock (oversize) may, however, contain elevated concentrations of radionuclides and may need to be disposed of appropriately, typically by filling out the mining pit and/or underground workings.

The mineral is sometimes stockpiled on mine sites prior to transport to the processing sites, and these stockpiles may contain radioactive minerals in concentrations sufficient to produce elevated radiation levels. The stockpiles therefore need to be protected against unauthorised access and also against the possibility of the material spreading through wind saltation.

Since the mineral in the stockpile is usually dense, the saltation process will normally occur only at a high wind velocity. Where wind drift occurs, mineral grains and particles commonly accumulate in places where vegetation or other obstruction is located or where the wind velocity drops. Therefore, re-deposition usually takes place at fence lines or in grassed or vegetated areas. Where the wind velocity is high enough wind blown particles can destroy grass cover and denude lightly vegetated areas and appropriate precautions will be needed at stockpiles. Typically, simple shade-cloth fencing is sufficient to restrict the spread of the material. Ideally, stockpiles containing radionuclides in concentrations that require signposting of areas as 'supervised' and/or 'controlled' should be located on a concrete slab to simplify the clean-up operations.

For the disposal of underground tailings, provided that the probabilities of geological disturbance to the site and of human intrusion into the site are sufficiently low, no further controls may be necessary beyond recording details of the location and characteristics of the waste and monitoring the site for a limited period.

2.3.2. Separation and downstream processing

The tailings from the separation and downstream processing of minerals require appropriate management as they may contain radionuclides in concentrations that could give rise to unacceptable radiation levels. The disposal of such waste will depend on the method used to process the mineral and on the respective levels of radiation.

If the tailings are categorised as radioactive waste, disposal may be undertaken by returning the tailings to the mine pit (dispersed in the initial mine tailings, if possible, or stored with appropriate safeguards where future economic use is foreseen).

If no chemical/thermal treatment of the mineral takes place (e.g. in the case of separating the heavy mineral sands), the radionuclides in the tailings could be considered as remaining bound in the individual mineral grains, and the possibility of the contamination of groundwater by radionuclides from tailings is therefore not considered to be significant. In some cases however, small amounts of radium may be present in water and their removal may therefore be required.

Where any grinding, chemical and/or thermal treatment of minerals containing radionuclides takes place, additional safeguards must be implemented due to the fact that secular equilibrium in both uranium and thorium decay chains may be disrupted, resulting in an increased environmental mobility of radionuclides such as radium.

Cleaning of certain minerals prior to processing (such as, for example, cleaning of the heavy mineral sand grains) may produce finely powdered waste (slimes). The disposal of these slimes may require consideration from the radiation protection point of view, as they may have a significant uranium or thorium content. Collection in a specifically designated slimes pit and disposal with other tailings is usually suitable for those materials that are found to contain elevated uranium and thorium concentrations.

The equipment used in downstream processing of minerals may become contaminated by NORM (particularly with scales and sludge on the inside surfaces of pipes and vessels used in chemical and thermal processing) and will need to be either disposed of with the approval from an appropriate authority (typically at a mine site), or thoroughly decontaminated prior to any re-use.

2.3.3. Uranium processing tailings

Special considerations are required for the tailings generated in the processing of uranium ores.

The main characteristics of tailings from uranium processing are residual radioactivity and radon exhalation rates. Non-radiological issues that need to be taken into account include the geochemistry of the ore, any chemical contaminants added as part of the uranium extraction process and the acid generation potential of the material (which is related to the content of pyrites in the ore). Typically, the most important contaminants of concern are not the radionuclides but the chemical elements such as arsenic, nickel and other heavy metals, as well as organic residues from uranium extraction. Presence of non-radiological contaminants in uranium processing tailings may require much more comprehensive management than the control of the release of radionuclides. Another important factor is the particle size of tailings, as the lower grade ores require grinding to a very fine (5–10 μm) material prior to processing.

The most important radiological issue of uranium processing tailings is associated with the fact that they typically contain about 85% of the radioactivity contained in the original ore, as the long-lived decay products of uranium, thorium–230 and radium–226 are not removed during the extraction process. Also, all uranium is not recovered during processing and the tailings may also contain from 1 to 10% of uranium–238 initially present in the ore.

The solubility of thorium is very sensitive to a pH around 4 and neutralising acidic tailings to pH 4.5 will result in a very substantial reduction in the concentration of thorium in water. Unless the tailings are neutralised to above pH 4 prior to the disposal, the bulk of the thorium will remain in solution, and will contribute substantially to the total radioactivity of the process residue liquor.

Radium–226 is considered to be the most important contaminant of concern in the uranium decay chain, as it is the most serious potential health hazard resulting from uranium tailings, particularly if the tailings are misused as building material or construction fill.

Radium–226 present in tailings decays to the radioactive gas radon–222 and a fraction of this radon escapes from the tailings deposit into the atmosphere. Despite the fact that radon–222 has a comparatively short half-life of 3.8 days, it presents a long-term hazard, since the decay of radium–226 (half-life of 1,600 years) constantly produces new radon. In addition, the tailings also contain the predecessors of radium–226 in the decay chain including thorium–230, which decays with a half-life of 75,400 years, again constantly producing radium–226. The health hazard is associated with the fact that radon and its decay products can accumulate to substantial levels inside structures built on a radium-containing fill or built from material with relatively high radium–226 concentrations.

The level of radon exhalation from tailings depends on many factors, such as the method of waste management, the amount of waste, the concentration of radium–226, the rate of diffusion of the radon through the bulk solids, moisture content, temperature and atmospheric pressure. Therefore, a comprehensive assessment of each individual tailings storage facility is required in order to develop an appropriate management strategy.

For the purposes of dose assessments it is important to determine radium–226 and thorium–230 concentrations in the airborne dust and water; with thorium–230 concentrations being of more importance in dust due to the fact that the inhalation dose conversion factor for thorium–230 is over three times higher than the same factor for radium–226; and radium–226 concentrations being of more importance in water as the ingestion dose coefficient for radium–226 is over two times higher than the same factor for thorium–230 (please refer to the guideline NORM–5 Dose assessment for additional information).

An important non-radiological issue in the management of uranium processing tailings is the potential generation of acid. This process occurs when sulphide-containing minerals that are susceptible to oxidation in the presence of moisture and oxygen (such as pyrite) are present in the ore, waste rock and tailings. The oxidation and hydrolysis results in the formation of sulphuric acid, which then attacks the rock matrix and liberate metals and radionuclides. Once acidic seepage has commenced, the process can continue for decades, and even centuries, as the oxidation 'front' progresses through the tailings mass.

There are several ways of preventing and controlling acid generation, with the most common technique being the inhibition of oxidation by the use of saturated clay or wet covers as oxygen barriers. A very detailed and complicated modelling is required to design a cover which will be effective for each particular location, as the effectiveness of a particular cover depends on climate regime and net water balance in the area, and on the reactivity of the tailings material.

2.3.4. Tailings storage

The prime functions of a tailings storage facility (TSF) are the safe, long term storage of tailings with minimal environmental impact. Tailoring the design of a TSF to the site conditions, to ensure safety and minimise the environmental impacts, can lead to a reduction in total project costs.

'Guidelines on the Safe Design and Operating Standards for Tailings Storage' [9] have been prepared by the Department of Minerals and Petroleum to assist in the design, construction, management and decommissioning of TSFs in Western Australia so as to achieve efficient, cost effective, safe and

environmentally acceptable outcomes. The guidelines are intended to provide a common approach to the safe design, construction, operation and rehabilitation of TSFs, and to provide a systematic method of classifying their adequacy under normal and worst case operating conditions.

The approach adopted in these Guidelines recognises the desire of the mining industry to move towards self management by the use of a certificate of compliance for TSF design and a certificate of compliance for TSF construction.

The following Acts of Parliament currently govern safety and environmental issues of TSFs in Western Australia:

1. *Mines Safety and Inspection Act.*
2. *Mining Act.*
3. *Environmental Protection Act*:
    a) Part IV, Environmental Impact Assessment.
    b) Part V, Approval and License for prescribed premises.
4. *Rights in Water and Irrigation Act.*
    a) Part III, Control of Waters.

In some circumstances, TSFs may also be subject to additional legislation under the following:

1. *Aboriginal Heritage Act.*
2. *Soil and Land Conservation Act.*
3. *Conservation and Land Management Act.*
4. *Wildlife Conservation Act.*
5. *Land Administration Act.*
6. *Native Title Act.*
7. *Local Government Act.*

Among the aims of these guidelines is encouragement of the mining industry to take a longer term approach to the planning of TSFs. One of the factors critical to the final rehabilitation of a TSF is the management of the tailings deposition during the TSF operation. Without systematic tailings deposition and careful water management, the final rehabilitation could be very costly, and be required at a time when cash flow is limited or non-existent. Much of this challenge can be overcome by adequate planning, associated with good tailings management and the use of sound technical approaches early in the life of the facility.

It is recognised that not all of these guidelines may necessarily be applicable to all forms of tailings storage. A notable example is below ground storage of mineral sands tailings within mined out dredge ponds. In such circumstances the management of the operation should recognise and address the issues that are applicable to a particular tailings storage system.

2.3.5. Operating manual for tailings storage

Tailings management plans are an essential prerequisite for sound storage practice as most failures of tailings storage around the world result from inadequate management of the storage. The effective implementation of a management plan will not only result in a safer tailings storage facility (TSF), but will frequently reduce the overall costs associated with operation and closure of the facility.

'Guidelines on the Development of an Operation Manual for Tailings Storage' [10] have been prepared by the Department of Minerals and Petroleum to provide a consistent basis for the preparation of Operating Manuals for TSF in Western Australia. They provide both the technical basis for site-specific Operating Manuals and an administrative framework which meets the requirements of regulations currently covering the mining industry in Western Australia.

These Guidelines assume that a design has been carried out for the TSF in accordance with the *'Guidelines on the Safe Design and Operating Standards for Tailings Storage'* [9]. For pre-existing facilities where a formal design has not been carried out, it may be necessary to conduct additional investigation work to provide the necessary information for inclusion in the Operating Manual. The preparation of an Operating Manual should take into account the provisions that relate to TSF in the Acts of Parliament listed in Section 2.3.4 on page 6.

The Operating Manual should identify all areas of TSF management requiring consideration during the operating phase of the facility and outline a course of action if performance is inadequate. One of the aims of the Guidelines is to encourage the mining industry to take a longer term view of the storage of tailings, so each Operating Manual should also address the rehabilitation, closure and post-closure monitoring requirements of the TSF. A carefully prepared Operating Manual will form part of an overall management plan that encompasses all of these aspects while ensuring that TSF are rehabilitated and closed cost effectively so meeting public expectations relating to environmental performance.

2.3.6. Radiation protection of employees

A comprehensive radiation protection program should be in place to address all sources of occupational radiation exposure at the exploration, mining and/or mineral processing site, including radioactive waste management.

The following exposure pathways should be taken into account for the protection of employees:

1. External gamma and beta irradiation, including skin contamination.
2. Inhalation of dust and gases such as radon and/or thoron.
3. Ingestion.

2.3.7. Radiation protection of the public

Releases of radionuclides from radioactive waste to the environment during mining and processing operations and subsequent waste management activities may result in the radiation exposure of members of the public (airborne waste discharges such as stack emissions or fugitive dust should not be forgotten). However, since mining and processing NORM tailings will continue to present a potential hazard to human health after closure, additional analyses and measures may be needed to provide for the protection of future generations. Such measures should not be left until closure but should be considered and implemented throughout the design, construction, and operation stages of the mining and processing facilities.

Typically, processing (and on some occasions, mining) waste contains only naturally occurring radionuclides, but these radionuclides cannot be considered to be in their original states or concentrations, since their physical and chemical forms may have been altered substantially, and exposures may be influenced by the operation of the waste management facilities.

After the closure of operations, a combination of engineering and institutional controls may be used to achieve a level of radiation protection that meets the requirements of the appropriate authority. Institutional control consists of actions implemented to maintain control and/or knowledge of a waste site after closure. This control may be active (for example, by means of monitoring, surveillance, remedial work, fences) or passive (for example, by means of land use control, markers, records).

2.3.8. Contaminated Sites

As a measure of institutional control, the registration of the NORM waste disposal site in accordance with the *Contaminated Sites Act* [5] will be required. Sites are to be assessed in accordance with the requirements of the Department of Environment and Conservation (DEC). Summary guidance on the classification of sites is provided below, and is based on the mean dose to the member of the critical group of the members of the general public.

Table 2.1.: Contaminated sites.

UNRESTRICTED USE:
0.0 mSv/y < DOSE < 0.3 mSv/year
RESTRICTED USE:
0.3 mSv/y < DOSE < 1.0 mSv/year
REMEDIATION NECESSARY IN MOST CASES:
1.0 mSv/y < DOSE < 3.0 mSv/year
REMEDIATION NECESSARY IN ALL CASES:
DOSE > 3.0 mSv/y

When the classification of a particular site is considered, it is essential that the DEC and Radiological Council are consulted for further information and advice.

2.4. Decommissioning and rehabilitation

On the completion of their operation mining and mineral processing sites are required to be decommissioned to the satisfaction of the appropriate authority. The decommissioning plan will require approval prior to implementation.

Ideally, the occupied site and surrounding area should be returned to a state that existed prior to the commencement of mining and/or processing operations such that unrestricted future use is possible. Where the contamination of equipment or materials is such that achievement of a pre-operational state may not be possible, engineering solutions will be required.

Where future use of the land is restricted, rigidly enforced covenants on land use via the *Contaminated Sites Act* [5] and exclusion zones (where appropriate) should be put in place for the period required by the appropriate authority.

During the decommissioning phase, a number of activities and considerations should be in effect including:

- decontamination of equipment;
- disposal of reusable or recyclable materials;

- transport requirements;
- consideration of exposure pathways for employees, public and the environment;
- rehabilitation and re-vegetation of mining and/or processing sites and adjacent land; and
- future monitoring to demonstrate the adequacy of decommissioning procedures.

2.4.1. Forward planning

The planning for the decommissioning phase should commence during the design and construction phase and continue (with the progressive refinement of the plans) during the operational phase.

2.4.1.1. Baseline Environmental Data

Baseline data should include topographical surveys, an assessment of soil types on the surface and at depth, flora and fauna diversity and distribution, radiation surveys above the land surface, air and groundwater radionuclide surveys.

All potentially impacted land should be assessed including that is to be occupied by mine site, processing plant and office buildings, transport corridors, tailings facilities and adjacent land that is potentially a subject to wind blown contamination by mined and/or processed materials.

Further details on the range of baseline environmental data that may be required and on the methods of its collection are available in the guideline NORM–3.1 Pre-operational monitoring requirements.

2.4.1.2. Operational Planning

Criteria to be eventually met should be borne in mind during the operational phase to ensure that decommissioning stage is managed more easily. Consideration needs to be given to the ongoing disposal of tailings and waste, dispersal of radioactive materials during processing and transport, storage of concentrates, disposal of processing and decontamination waste, location of wastes used as landfill.

Adequate and secure documentation of every activity that impacts on decommissioning should be kept. Considering the lifetime of mining and processing operations electronic documentation by itself is unlikely to have adequate archival properties.

2.4.2. Regulatory requirements

Before abandoning a mining or processing operation, a final version of the Radioactive Waste Management Plan must be submitted to the relevant statutory authority for approval.

Ideally the surface gamma dose rate of the abandoned site should be no greater than background natural levels existing prior to the start of the mining or processing operation. This may be achieved in part by distributing the returned material in such a way that the radioactive content is as near as practical to that of the material originally mined in the area.

Documentation should include the locations in which radioactive waste is buried, dose rates above the final surface and a commitment to inspect and maintain the abandoned site for a certain period of time, to be determined by the appropriate authority.

2.4.3. Technical considerations

2.4.3.1. Buildings and Facilities

The following should be considered:

1. Detailed surveys of buildings and facilities will identify the need to decontaminate.
2. In some processes, surface contamination may adhere tenaciously to the substrate and may only be removed by chemical or physical means.
3. Suitable decontamination techniques include vacuuming, scrubbing, high-pressure water or steam jetting and sandblasting.
4. Sandblasting of relatively soft surfaces (wood, plastic, metal covered with a thick layer of paints, etc.) must be used with caution because of the possibility that 'micro-hammering' by sand particles can make surface contamination embedded in the surface of the equipment. In addition sandblasting may disperse radioactive material.
5. Slightly contaminated equipment (such as some tools and valuable materials) could be relocated to another site, if possible. These items will require removal of loose contamination before transport. The levels of surface contamination should be checked to ensure that adequate signage for vehicles is provided and statutory approval sought and obtained before the transport of contaminated objects from the site.
6. If the equipment cannot be decontaminated to the level below statutory limits (surface contamination monitoring should not be overlooked), it could be disposed of in the specially engineered pit either on-site or off-site. Further consultations with the appropriate authority will be required if this option will be considered.
7. As far as possible contamination should be removed from plant surfaces, equipment and pipework prior to demolition.
8. Interior structures, machinery and equipment that do not compromise the structural integrity of the building should be decontaminated as required and taken out from the processing plant.
9. As pipes, elevators, beams are likely to be cut into convenient sizes, cutting and demolition methods should be chosen carefully to control the release of dust into the atmosphere. Personal respiratory protection may be required for most activities.
10. During the decommissioning all radiation monitoring is to be conducted by a person competent in radiation monitoring and in the interpretation of results. This competent person must sign all radiation clearance documentation for material release. Detailed procedure for monitoring of both external gamma-radiation levels and alpha- and beta-surface contamination should be developed and submitted for approval to the appropriate authority.
11. Particular attention needs to be paid to the health and safety of employees involved in the decommissioning process. This includes adherence to prescribed exposure limits and protection from intake of radioactive substances.

2.4.3.2. Mine and Waste Disposal Site

The options for the decommissioning of the open pit mine depend on the stability of the walls of the mined out pits in the long term, safety considerations, possible future land uses and existing drainage patterns. For most tailings facilities, the physical stability represents the greatest hazard to the safety of employees, not the concentrations of radionuclides in a particular waste.

Options to be considered include:

1. The pit may be left as excavated but reworked to achieve flatter slopes for possible future use.
2. If the water table is close to the pre-mining surface or if the surface drainage flows to or through the pit, it may be difficult to keep the pit dry. Provided that the hydrological characteristics are suitable and approval is received from the appropriate authority, it may be beneficial to allow the pit to simply fill with water. An analysis should be carried out to assess the potential for transporting contaminants from the flooded pit to the environment.
3. Appropriate engineering controls should be provided so that radioactive material will not diffuse into the environment.
4. Where possible and appropriate, all tailings should be diluted with non-radioactive material to ensure that the radioactivity of the final blend does not exceed the radioactivity of the mined material.
5. Some consideration may need to be given to the pre-disposal management of the waste, such as, for example, 'fixing' of mobile radioactive components to inhibit release to the environment or to ensure that any release, if it does occur, is at a controlled, acceptably low rate.
6. Reliance on long-term active institutional controls should be minimised.
7. Requirements for the continuing maintenance of dams should be minimised.
8. Some controls should be in place to prevent the unauthorised removal of tailings, for example, signposting of areas and registration under the *Contaminated Sites Act* [5].
9. Facilities and procedures need to be in place for the monitoring and control of groundwater contamination and release of radioactive dust and radon into the atmosphere.
10. Surface profiling should be such as to avoid undesirable hydro-geological effects such as erosion.
11. It is desirable that vegetation does not have root systems that could penetrate through the topsoil and reach the tailings. This may result in the uptake of radionuclides by particular plants that would be unacceptable from the radiation protection point of view due to the possible consumption of this plants by fauna, including humans. This could also destabilise the waste in the event of climate changes.
12. It is recommended to carry out the study of local fauna to ensure that the tailings form the disposal facility are not brought back to the surface by burrowing animals and insects.
13. Typically, a half-metre layer of roller compacted clay-soil mixture will be effective in attenuating radon/thoron release to the atmosphere. Such a layer optimally profiled may also direct rainwater away from the tailings reducing the rate of dissolution of soluble components; and
14. It is recommended that the storage of tailings, which are already kept in tailings storage facilities, be re-assessed. If the current storage site is unsatisfactory due to the long-term physical stability, radionuclide concentrations or the mobility of radionuclides (including radon/thoron diffusion), or due to social considerations such as encroaching industrial or residential developments, then several options may be considered:
    a) Physical structure of disposal site may be reinforced.
    b) Tailings may be reprocessed.
    c) Tailings may be mixed with other material for permanent disposal.
15. When all other options are found to be unsatisfactory and there is a possibility of radiation exposure to members of the public (either directly or via intrusion in the future), it will be necessary to relocate the tailings to a more appropriate structure or location.

2.4.3.3. Neighbouring Properties

Neighbouring properties and transport corridors may have become contaminated by wind blown or water borne radioactive materials, or spillage. Low-grade material may have been also intentionally removed in the past from the mining and/or processing sites and used for fill or construction. During the decommissioning phase all neighbouring properties should be surveyed for radioactive contamination to ensure that they are restored to their pre-operational state or to the levels approved by the appropriate authority if pre-operational levels are not known.

A plan for the restoration should include:

- a legally binding agreement between the owner of the neighbouring property and the site operator, outlining the responsibilities, the timetable for actual work and financial arrangements;
- detailed results of radiometric surveys, including the description of radionuclides, their activity levels, the depth of contamination and resulting volume of contaminated material;
- a program for radiation protection of workers and members of the general public during the clean-up operation; and
- the means of controlling future unauthorised removal of material and the spreading of wind blown or water borne contamination from site to vicinity properties.

After remediation, the property should be re-surveyed thoroughly to verify that radiation exposure levels were reduced to acceptable levels.

2.4.4. Decommissioning radiation monitoring

To reduce the risk to employees, members of the public and the environment, dust control, air and water monitoring, site and/or personal radiation monitoring should be continued until the decommissioning process has been completed. The goals and requirements of these programs will be similar to those carried out during the operational phase.

These include:

1. Dust control programs and use of respiratory protective equipment may be required to reduce the risks associated with the generation of airborne dust. Performing as much dismantling as possible inside the buildings will minimise the release of dust into the environment.
2. The environmental radiation monitoring programs that were in place during the operational phase should be retained and, possibly, increased.
3. Occupational radiation monitoring program scope should depend on the number of employees on site.
4. A traffic control system should be established to control the movements of waste and potentially contaminated equipment and materials. All vehicles and equipment leaving controlled areas should be monitored and, if necessary, decontaminated to the statutory limits in order to prevent the spread of contamination off-site and to protect the public and the environment.

2.4.5. Post close-out radiation monitoring

The mining and/or mineral processing company will, for a number of years after completion of decommissioning, have to demonstrate to the appropriate authority that the closed out facilities are performing as designed and releases of radioactivity from the site are below the specified limits.

2.4.5.1. Environmental Monitoring

The following information should be included:

1. Possible release rates of radioactive contaminants such as tailings particles, leachates and radon/thoron gas to the environment should to be established.
2. A program for surface water sampling should depend on the proximity of the critical group of members of the public and possible exposure scenarios.
3. Groundwater monitoring bores should be placed with knowledge of the hydraulic gradient. At least two monitoring bores, up-gradient and down-gradient from the potential contamination source will be required.
4. Atmospheric monitoring points should be determined taking into account the proximity of the critical group of members of the public and meteorological data such as wind speed and direction. Locations should surround the potential contamination source and be located along the dominant annual wind vector downwind of the site.

2.4.5.2. Biological Monitoring

Biological monitoring should be required to determine if concentrations of contaminants are increasing in the environment as a result of atmospheric or water pathways, particularly in cases of decommissioning of the facilities where chemical/thermal processing of minerals took place (for example, at the sites where uranium ores were processed).

Samples of vegetation and, where applicable, aquatic organisms (e.g. mussels) and other fauna will need to be collected and radionuclides' concentrations determined.

2.4.5.3. Rehabilitation Monitoring

Surveillance monitoring should be carried out to determine if waste containment erosion control, re-vegetation and other remedial measures are effective.

2.4.6. Decommissioning documentation

At the completion of the decommissioning program, a final report should be submitted to the appropriate authority. This report should contain, as a minimum:

1. The exact location of radioactive waste disposal facilities (maps with recorded coordinates), depth of waste deposition, and the quantity and activity of material located at each facility.
2. Detailed description of waste containment facilities and expected levels of performance for both the liner material (clay, plastic, concrete) and the top cover (including its thickness).
3. A record of dose exposure of employees and dose estimates for members of the general public and the environment.
4. A summary of results obtained by all monitoring activities.
5. A record of measurements that confirm compliance with clean-up criteria.
6. A record of quality assurance audits and inspections.
7. A record of all relevant correspondence between operator and the appropriate authority.
8. Suggested improvements that could be incorporated into future similar activities.
9. A record of correspondence with the landowner and owners of neighbouring properties (where applicable).

2.4.7. Quality assurance (QA) program

The purpose of the QA program is to ensure that appropriate controls are in place so that performance objectives and technical requirements of the decommissioning are achieved. This program should be established before the decommissioning activities commence and must be used for all activities.

In general, a QA program should include the following considerations:

1. The authority and duties of those people and external organisations responsible for performing activities covered by a QA program should be clearly established. Such persons and organisations should have sufficient authority to be able to identify problems, initiate solutions and verify the implementation of solutions.
2. A documented design control system for waste disposal facilities should include the following :
   a) The measures to verify the adequacy of the design of the facility.
   b) The controls to ensure that the data used in the design work was collected in a defined and verifiable manner.
   c) The measures to verify and validate the computer software used in the design activities.
   d) The measures to ensure that verification is performed by individuals different from those who developed the original design.
   e) The positions and external organisations responsible for design verification should be listed.
3. Procedures must be established in order to clearly explain the sequence of actions to be performed in the preparation, review, approval and control of instructions and procedures.
4. Documents that contain site characterisation, planning, design, monitoring, maintenance and other requirements should be controlled to ensure that the directions are understandable and that the documents reach those responsible for the activities.
5. Measures should be established for identifying and controlling materials, equipment and field and laboratory samples.
6. A program should be established to ensure that all monitoring is performed in accordance with approved procedures.
7. Measures should be established to ensure that events such as monitoring results in excess of statutory limits, defects and malfunctions are promptly identified, reported and corrected.
8. Inspection results should be recorded.

2.4.8. Rehabilitation

The operator should not commence operations for decommissioning or rehabilitating of any waste management facility except in accordance with provisions of the approved waste management system as detailed in the Radioactive Waste Management Plan. The appropriate authority would determine when the decommissioning phase has been completed and the rehabilitation of the site may commence.

In accordance with the Code [3] a specific 'authorisation to rehabilitate' should be sought by operator from the appropriate authority.

The Code [3] specifies that inappropriate attempts at rehabilitation may influence the ability to achieve an acceptable final state. For this reason, rehabilitation operations should not be attempted without authorisation.

An application for authorisation to rehabilitate should include the following information:

1. The condition of the site to be rehabilitated, including the facilities and waste to be rehabilitated, levels of contamination, and quantities of waste.
2. Details of rehabilitation measures to be undertaken.
3. Management of waste generated during rehabilitation.
4. The anticipated final state of the site after rehabilitation, including estimates of the levels of residual contamination.
5. Details on ongoing monitoring and surveillance that will be required after rehabilitation.
6. Contingency plans, and plans for remediation of any defects in the rehabilitation that may become apparent.

Prior to rehabilitation, it is often useful to estimate the potential surface gamma radiation dose rate from a particular waste material prior to the disposal. The following equation [4] may be applied:

$$Dose\,rate\,in\,\mu Gy/hr = 0.042 \times A_{(^{40}K)} + 0.462 \times A_{(^{238}U)} + 0.604 \times A_{(^{232}Th)}$$

where:
$A_{(^{40}K)}$, $A_{(^{238}U)}$ and $A_{(^{232}Th)}$
are the specific activities in Bq/g for potassium–40, uranium–238 and thorium–232.

The result is an approximate estimation and can only be used during the planning stages of waste disposal (such as in an estimation of the depth of the disposal of the specific NORM waste), actual measurements should always be carried out to confirm the calculated value.

For most materials in the mining and mineral processing industry, the value for potassium–40 can be ignored, with the exception of the phosphate industry. In some cases where material contains predominantly radium–226 from the uranium–238 decay chain and almost no uranium (as in some scales and sludges), the value of radium–226 specific activity can be substituted for the uranium–238 in the calculation.

A. Appendix with guidance on NORM blending

This guidance falls under the scope of the Radiation Safety Act rather than the Mines Safety and Inspection Act as it deals with the blending of NORM prior to the disposal (contaminated sites) and also for the possible re-use of material. The Radiological Council must be contacted in every case by any proponent that seeks approval for the use of NORM in building products. This guidance has been based on other international guidance material on waste management and is provided on the basis that it has merit and may be useful to proponents in preparing a submission to the Radiological Council.

Typically, mining and mineral processing waste not containing environmentally mobile radionuclides can be blended with other materials to ensure that in the long term the use of the disposal site is not restricted [1]. The concentrations of radionuclides must be such that the final material is not classified as radioactive.

Ideally, the concentrations of uranium and thorium in the 'final waste' material should be the same as they were prior to mining and/or processing. The maximum acceptable concentrations that radionuclides could be diluted to and then dispersed in the ground without institutional control being considered are detailed in the Code of Practice [3] and are 1 Bq/g of thorium and/or uranium.

Some types of tailings generated by mining and mineral processing industry and containing naturally occurring radionuclides can be re-utilised for different applications, including those in the building and construction industry, in accordance with the following recommendations.

Several international documents provide guidance on the allowable levels of naturally occurring radionuclides in building materials. It is recommended that the values suggested in the EU publication RadPro–112 [6] are used as a basis for the guidance on levels of NORM in different materials, with additions from the documents from Poland [7] and China [8].

Two indexes are established:

1. External exposure index: $f_1 = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$
2. Internal exposure index: $f_2 = \frac{C_{Ra}}{200}$

Where: C_{Ra}, C_{Th} and C_K are the concentrations of radium–226, thorium–232 and potassium-40, respectively, expressed in Bq/kg. If both uranium and thorium decay chains in the material are in a secular equilibrium, the value for the concentration of radium–226 can be replaced by uranium–238, and the value for thorium–232 can be replaced by radium–228.

The index f_1 describes the content of NORM in a particular material and is calculated on the basis of concentrations of radium–226, thorium–232 and potassium–40.

The index f_2 limits the concentration of radium–226 due to the potential internal radiation exposure to radon–222 and its decay products.

Index f_1 is used in all cases, index f_2 – only in situations when it is known that radon exhalation rate from a particular material cannot be disregarded from the radiation protection point of view.

These indexes should be used only as screening tools for identifying of the likely use for particular materials. Additional approvals from an appropriate authority will be required in each case — based on a separate dose assessment carried out for scenarios where the material is used in a typical way.

Potential use of NORM has been classified in five groups and the limiting factors are as follows:

1. Material for buildings for human habitation. Application of the material is not restricted: $f_1 \leq 1$, $f_2 \leq 1$.
2. Decorative material (tiles, boards, etc.) for buildings for human habitation. Application of the decorative material is not restricted: $f_1 \leq 1$, $f_2 \leq 2$.
3. Decorative material (tiles, boards, etc.) for buildings for human habitation. Application of the decorative material is restricted to the external walls of a building: $f_1 \leq 3$, $f_2 \leq 5$.
4. Material is not recommended for buildings for human habitation. Application of the material is restricted to the underground parts of a building, including road and rail tunnels: $f_1 \leq 5$, $f_2 \leq 7$, and a thorough assessment of potential exposures will be required. The material can also be used as a base in road construction.
5. Material with values of $f_1 > 5$ and $f_2 > 7$ can only be used after a comprehensive dose assessment *and* a detailed environmental impact study – and only in situations where *both* the exposure of the members of the general public *and* the release of radionuclides into the environment are extremely unlikely. Examples of such situations are the construction of central parts of large bridge piers and sea shore erosion control applications (such as the construction of sea walls and/or artificial reefs – preferably in and around industrial ports).

Bibliography

[1] Part 16 –Radiation Safety, Mines Safety & Inspection Regulations, 1995.

[2] *Mines Safety & Inspection Act, 1994.*

[3] Code of Practice and Safety Guide: Radiation Protection and Radioactive Waste Management in Mining and Minerals Processing, Radiation Protection Series Publication No.9, Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 2005.

[4] Sources and Effects of Ionising Radiation; 2000 Report to the General Assembly, with Scientific Annexes, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 2000.

[5] *Contaminated Sites Act, 2003.* link

[6] Radiological Protection Principles concerning the Natural Radioactivity of Building Materials, European Commission, Radiation Protection 112, 1999 (This document will be superseded in the near future, with the issue of new EU Basic Safety Standards; the suggested values remain the same).

[7] Decree of the Council of Ministers of 3 December 2002 on requirements regarding the content of naturally occurring radioactive isotopes in materials used in buildings designed for people and livestock and also in waste materials used in the building industry and monitoring of the content of such isotopes, Dziennik Ustaw No. 220, Item 1850 (in Polish), 2002.

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A. Appendix – Guidance on NORM blending

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Ideally, the concentrations of uranium and throrium in the 'final waste' material should be the same as they were prior to mining and/or processing. The maximum acceptable concentrations that radionuclides could be diluted to and then dispersed in the ground without institutional control being considered are detailed in the Code of Practice [3] and are 1 Bq/g of thorium and/or uranium.

Some types of tailings generated by mining and mineral processing industry and containing naturally occurring radionuclides can be re-utilised for different applications, including those in the building and construction industry, in accordance with the following recommendations.

Several international documents provide guidance on the allowable levels of naturally occurring radionuclides in building materials. It is recommended that the values suggested in the EU publication RadPro-112 [6] are used as a basis for the guidance on levels of NORM in different materials, with additions from the documents from Poland [7] and China [8].

Two indexes are established:

a) External exposure index: $f_1 = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000}$

b) Internal exposure index: $f_2 = \frac{C_{Ra}}{200}$

Where: C_{Ra}, C_{Th} and C_K are the concentrations of radium-226, thorium-232 and potassium-40, respectively, expressed in Bq/kg. If both uranium and thorium decay chains in the material are in a secular equilibrium, the value for the concentration of radium-226 can be replaced by uranium-238, and the value for thorium-232 can be replaced by radium-228.

The index $f_1$describes the content of NORM in a particular material and is calculated on the basis of concenrtaions of radium-226, thorium-232 and potassium-40.

The index $f_2$limits the concentration of radium-226 due to the potential internal radiation exposure to radon-222 and its decay products.

Index $f_1$is used in all cases, index f_2 – only in situations when it is known that radon exhalation rate from a particular material cannot be disregarded from the radiation protection point of view.

These indexes should be used only as screening tools for identifying of the likely use for particualr materials. Additional approvals from an Appropriate Authority will be required in each case – based on a separate dose assessment carried out for scenarios where the material is used in a typical way.

Potential use of NORM has been classified in five groups and the limiting factors are as follows:

1. Material for buildings for human habitation. Application of the material is not restricted: $f_1 \leq 1$, $f_2 \leq 1$.
2. *Decorative* material (tiles, boards, etc) for buildings for human habitation. Application of the *decorative* material is not restricted: $f_1 \leq 1$, $f_2 \leq 2$.
3. *Decorative* material (tiles, boards, etc) for buildings for human habitation. Application of the *decorative* material is restricted to the external walls of a building: $f_1 \leq 3$, $f_2 \leq 5$.

4. Material is not recommended for buildings for human habitation. Application of the material is restricted to the underground parts of a building, including road and rail tunnels: $f_1 \leq 5$, $f_2 \leq 7$, and a thorough assessment of potential exposures will be required. The material can also be used as a base in road construction.

5. Material with values of $f_1 > 5$ and $f_2 > 7$ can only be used after a comprehensive dose assessment *and* a detailed environmental impact study – and only in situations where *both* the exposure of the members of the general public *and* the release of radionuclides into the environment are extremely unlikely. Examples of such situations are the construction of central parts of large bridge piers and sea shore erosion control applications (such as the construction of sea walls and/or artificial reefs – preferably in and around industrial ports).