Management of NORM in Australia

Peter Burns[a], Alan Melbourne[a], Richard O'Brien[a]

[a]Australian Radiation Protection and Nuclear Safety Agency, 619 Lower Plenty Road, Yallambie, Victoria 3085, Australia

Abstract. The system of radiation protection was developed with the primary intention to control risks from man-made sources, which have in general been reduced to levels that are very small compared to the other hazards of life. The same risk and dose criteria cannot however be applied with the same vigour to naturally occurring sources without imposing a significant burden on society. One of the intentions of the 2007 Recommendations of ICRP is to allow more flexibility in the system which should make it easier to deal with exposures where human activity has enhanced the concentration of radionuclides in materials. Within the new system the principle of optimisation of protection is now considered as the primary tool in radiation protection. The level of protection should be the best under the prevailing circumstances, maximising the margin of benefit over harm. In order to avoid severely inequitable outcomes of this optimisation procedure, there should be restrictions on the doses or risks to individuals from a particular source using dose or risk constraints and reference levels. The optimisation process is an iterative process requiring regular review. Where optimisation becomes a matter for the regulatory authority, the focus should not be on specific outcomes but rather on processes, procedures, and judgements. Australia has developed a Safety Guide on the Management of Naturally Occurring Radioactive Material (NORM) in industries where enhanced levels of radioactive materials are produced in products, wastes or residues. The Safety Guide describes the broad regulatory decision-making framework of exclusion and exemption and a graded approach to managing radiological risks. A series of annexes address the application of this guidance to the oil & gas industry, the bauxite/aluminium industry and the phosphate industry.

KEYWORDS: NORM, Australia, management,

1. Introduction

Just over one hundred years ago, not long after the discovery of X-rays, ionizing radiation was also found to emanate from some rocks and minerals. We now know that all materials contain these naturally occurring radioactive materials and that everyone on earth is exposed to them to some degree. We also know that human actions can enhance the level of exposure to natural sources and that exposures to these sources covers a wide range.

By the 1950s it was apparent that while compliance with dose limits would prevent deterministic health effects, chronic exposure to low levels of radiation could cause adverse health effects such as leukaemia, solid cancer and hereditary effects. The International Commission on Radiological Protection (ICRP) [1] strongly recommended that in view of the unsatisfactory nature of much of the evidence that every effort be made to reduce exposures to all types of ionizing radiations to the lowest possible level.

This recommendation gradually evolved into the ALARA principle and more recently into the principle of optimisation. The ICRP in its 2007 recommendations [2] now considers this principle the primary tool in radiation protection, particularly when dealing with exposures to natural sources of radiation.

The system of radiation protection was developed with the primary aim of controlling risks from man-made sources, which have in general been reduced to levels that are very small compared to the other hazards of life. The same risk and dose criteria cannot however be applied with the same rigour to naturally occurring sources without imposing a significant burden on society. One of the intentions of the 2007 Recommendations of ICRP is to allow more flexibility in the system which should make it easier to deal with exposures from naturally occurring sources, particularly those where human activity has enhanced the concentration of radionuclides in materials.

2. NORM in Australia

Many industries in Australia process materials that contain enhanced levels naturally occurring radioactive materials (NORM). A report was recently prepared for the Radiation Health and Safety Advisory Council of the Australian Radiation Protection and Nuclear Safety Agency on the range of industries involved and types of materials in which enhanced levels of NORM may be present [3]. Depending on the industry and the process involved enhanced levels may be found in products, by-products or waste streams. The following areas were considered:

- Mining and mineral processing, including the mineral sand industry, alumina production, tantalum mining, tin smelting, copper production
- Downstream processing of heavy minerals, including titanium pigment production, and zirconium products
- Phosphate ores used for the production of phosphoric acid and fertiliser and the use of phosphogypsum as fertiliser and soil conditioner or in building materials
- Fossil fuels use, including oil and gas production, coal-fired power stations
- Metal smelting industries, including tin smelting, pig iron production
- Ceramics and building materials
- Water treatment and purification.

Industries were examined and a brief description of the industry itself produced, including the processes involved and the types of residues generated, together with an overview of the origin and nature of the radioactivity associated with the raw materials, products, by-products and the residues. Information on the quantities of materials and residues arising in various industrial processes was provided and a summary of the volume of materials processed and the contamination levels in raw materials, products, by-products and residues generated was presented. The mineral sands industry is usually subject to regulation and reliable information on volumes and concentrations is available. However for some industries it was not possible to provide comprehensive information due to the lack of readily available data. In general there was a lack of published information on radionuclide content of materials and/or solid residues for the industrial processes in Australia. Detail could only be gained by inference based assessments on the current annual production levels and knowledge that the industry has been operating for a certain period of time.

Table 1 presents a summary of the relative quantities and activity concentrations for residues and by-product materials from various industries. Industries were grouped in terms of quantities of material produced annually and activity concentration levels. There were three categories for quantity produced: small (<1 kt), medium (1-100kt) and large (>100 kt) and three categories of activity concentration: low (<1,000 $Bq.kg^{-1}$), moderate (1,000 – 20,000 $Bq.kg^{-1}$) or high (>20,000 $Bq.kg^{-1}$).

From Table 1 it can be seen that generally the NORM residues that are produced in very large quantities, such as fly ash, alumina “red mud”, and metal smelting slags, and mineral processing tailings, are confined to the group classified as being of low activity. For materials with high activity concentrations only those waste materials that have a quite low annual production rate, such as oil scales and metal smelting dust, fall into this category. The exception to this is monazite concentrates and tailings. However it is important to note that monazite residues arise in an industry that is already subject to radiation protection regulations because of the potential for significant occupational exposures in the industry.

NORM materials typically comprise raw process materials, products, by-products and recycled materials, waste and other residues. Concentration ranges given in the Table are for individual long-lived radionuclides of the natural uranium and thorium series, e.g. U-238, Ra-226, Pb-210, Th-232 and Ra-228. By comparison Australian soils typically contain natural uranium and thorium with concentrations ranging from 5 to 60 $Bqkg^{-1}$.

Table 1. **Q**uantities and activity concentrations for residues from various industries in Australia

Radionuclide Content (Bq kg^{-1})	Quantity Produced Annually		
	Small (< 1 kt)	**Moderate (1 kt - 100 kt)**	**Large (> 100 kt)**
0 – 1000	Oil (sands and sludge) Oil (hard scales and films)	Synthetic rutile Ceramics Sand blasting materials Oversize from secondary mineral sands separation	Alumina residues (red mud) Coal ash (bottom ash & fly ash) Titanium dioxide pigment, slurries & solids Tantalum and Copper tailings Ores (coal, bauxite, iron ore) Heavy minerals (concentrate, ilmenite, rutile, zircon) Furnace and metal smelter slags Phosphogypsum Phosphate fertilisers Water treatment sludge Building materials & building/demolition waste
1000 – 5000	Oil (sands and sludge) Oil (hard scales and films)	Tantalum products Oversize from secondary mineral sands separation Dust from secondary mineral sands separation Phosphoric acid	Heavy minerals (concentrate, ilmenite, rutile, zircon) Superphosphate & phosphate rock Alumina residues (red mud) Solids from effluent treatment (titanium dioxide pigment production)
5000 – 20000	Oil (sands and sludge) Oil (hard scales and films)	Dust from secondary mineral sands separation. Tantalum concentrate	Tails from secondary mineral sands separation
> 20000	Zircon dusts Copper smelter dusts Oil hard scales and films	Monazite concentrates Monazite tailings Tantalum concentrate	Tails from secondary mineral sands separation

In Australia in recent years several industries have come to attention either because of the volumes of NORM produced or because of the activity concentrations in the wastes generated. These include the mineral sands, aluminium, coal, oil and gas industries as well as the use of by-products from these industries in the building industry. A brief outline of these industries is given below.

2.1 Mineral Sands

Australia is a major producer of heavy minerals extracted from mineral sands. Waste materials are usually returned to the mine site for blending with mine sand tailings and disposed of into the mine pit. Some material may be recycled or used as road base, as is the case with kiln discharge oversize material, and, in the case of the neutralised acid effluent solids, as fertiliser in the agriculture industry.

2.2 Aluminium Production

Bauxite is mined on a large scale in Australia and is refined to produce alumina. Annual production is approximately 16 million tonnes. The main solid residues are sand residue and mud residue (commonly termed red mud) with 1-2 tonnes of red mud produced for every 1 tonne of alumina produced. Red mud is commonly disposed of by spreading in layers over large areas covering the waste with sand and revegetating.

2.3 Coal

Approximately 120 million tonnes of black and brown coal is consumed annually in Australia and typically 5 to 30% remains as ash after burning. Fine ash is collected by the electrostatic precipitators, fabric filters and flue gas scrubbers. The heavier, more refractory mineral matter settles as bottom ash or slag. Most of the waste is generated as fly ash with approximately 13 Mt of fly ash and bottom ash produced a year. Approximately 30% of bottom and fly ash is sold for industrial uses such as cement-extender in concrete, for road making, or other applications such as mine site rehabilitation. Volatile radionuclides such as polonium-210 and lead-210 tend to accumulate in the fly ash while the more refractory elements, such as uranium and thorium, accumulate in the bottom ash and slag.

2.4 Oil and Gas

Sand and oily sludge from off shore oil and gas reservoirs are removed during treatment and solids deposit on the internal surfaces of production equipment. The oily sludges and sand separated at an early stage of the process comprise the bulk of the solid waste with a volume of about 200 m^3 per year. Disposal of sludge is carried out in an on-shore landfill or dumped at sea directly from the production platform. Scales on equipment are low in volume with accumulations of 1 – 2 tonnes annually. Equipment with NORM scales is either cleaned for re-use within the industry or stored awaiting approval for scrap metal smelting, disposal or other recycling options.

2.5 Ceramics and Building Materials

Industrial by-products and recycled industrial residues and wastes are often used as raw materials for the building industry. The main waste types used in production of building materials are:

- fly ash from coal burning used in concrete production and brick making, approximately 10% of ash generated in Australia,
- phosphogypsum from the phosphate industry used as a substitute for natural gypsum in the manufacture of plasterboard (this practice does not occur in Australia),
- bottom ash from coal burning and furnace slag from metal smelters is used for road construction.

Generally, the radionuclide concentration in the final material will be lower than that of the original by-product because of the presence of other inert material in the particular building material.

3. The System of Radiation Protection

In 1990 the system of radiation protection set out by ICRP imposed controls on those activities that changed radiation exposure [4], called practices or interventions. Developments in radiation protection over the last twenty years led the ICRP to revise its recommendations and these are set out in ICRP 103. The new system now applies to all sources and all individuals exposed to radiation. After considering all conceivable circumstances of exposure three types of exposure situations were identified.

- Planned Exposure Situations
- Emergency Exposure Situations
- Existing Exposure Situations

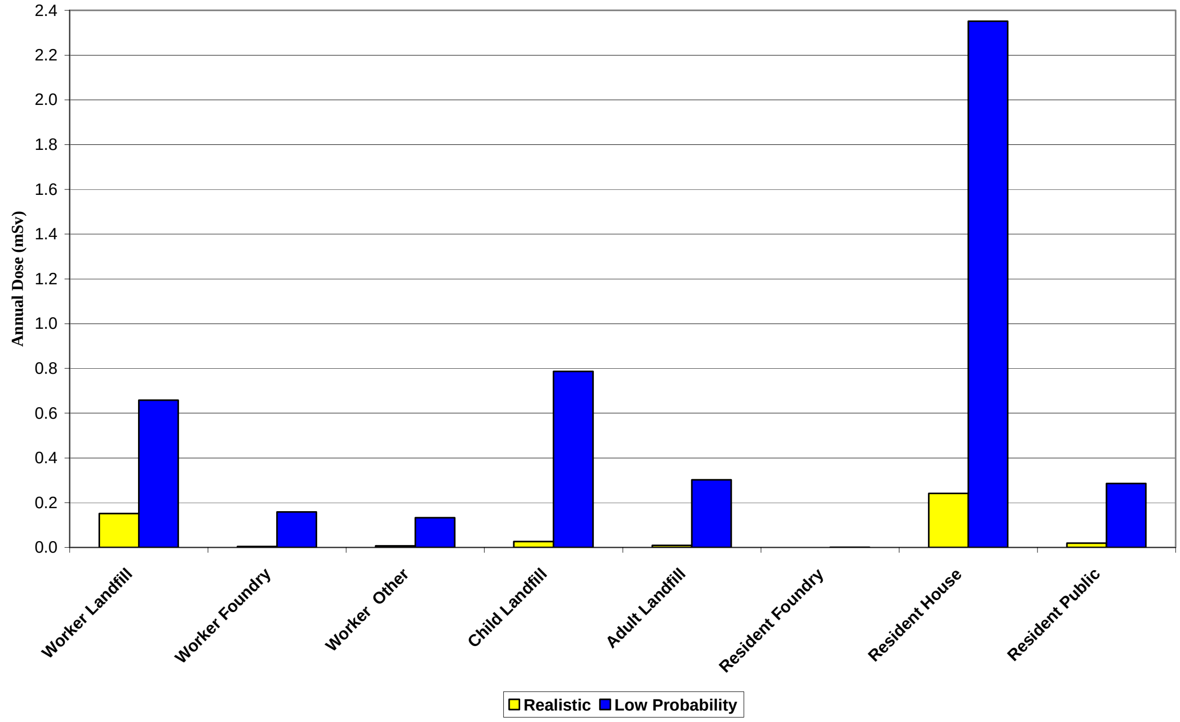
It is now clear that some existing exposure situations involving exposure to naturally occurring radioactive materials should be treated similarly to those from anthropogenic sources, in particular industries that enhance naturally occurring radionuclides in their product streams or their waste streams, resulting in potential or actual exposures to workers and members of the public.

Some radiation exposures are essentially unamenable to control such as cosmic rays and normal exposures to naturally occurring radionuclides. These exposures are generally excluded from the provisions of the radiation protection system. Sources that are not excluded may however be exempted from some or all requirements of the system of protection.

Exemption levels determined for man-made radionuclides by the International Atomic Energy Agency in its Basic Safety Standards, BSS 115 [5] are based on a criterion of an annual risk of death in the range 10^{-6} to 10^{-7}, which translates into an annual dose of 10μSv per year. A problem that arises for naturally occurring radionuclides is that normal exposures can result in doses and risks one hundred to one thousand times those mandated for man-made sources.

The ICRP and the IAEA (Safety Guide RS-G 1.7) [6] have attempted to work around this problem when deriving activity concentration limits for bulk materials containing naturally occurring radioactive materials applying $1Bqg^{-1}$ for alpha emitters and $10Bqg^{-1}$ for beta emitters. Details of scenarios are given in IAEA Safety Series Report 44 [7] for workers at landfill, foundries and other scenarios; and for residential exposures of children and adults from landfill, from living next to a foundry, from house construction and in a public place. Doses were calculated for ^{226}Ra for an activity concentration of $1Bqg^{-1}$. Doses are generally well above the $10μSva^{-1}$ criterion for most scenarios, with a highest dose of $2.35mSva^{-1}$ for the residential housing scenario (Fig 1).

Figure 1. Doses for realistic and low probability scenarios for exposure to bulk materials contaminated with $1Bqg^{-1}$ of ^{226}Ra



The problem that this poses is that exposures from natural sources will be managed at risks approximately one hundred times higher than those for man-made sources. This paradox presents a major difficulty in developing a system to regulate exposures from NORM and explaining it to members of the public.

Within the new system the principle of optimisation of protection is now considered as the primary tool in radiation protection. The principle is stated as: the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economic and societal factors.

The level of protection should be the best under the prevailing circumstances, maximising the margin of benefit over harm. In order to avoid severely inequitable outcomes of this optimisation procedure, there should be restrictions on the doses or risks to individuals from a particular source using dose or risk constraints and reference levels.

Constraints and reference levels are key parts in the optimisation process that will ensure appropriate levels of protection under the prevailing circumstances and should not be used or understood as prescriptive regulatory limits. The optimisation process is an iterative process requiring regular review. Where optimisation becomes a part of the regulatory process, the focus should not be on specific outcomes for a particular situation, but rather on processes, procedures, and judgements.

4. Management of Naturally Occurring Radioactive Material

Australia has developed a Safety Guide on the Management of Naturally Occurring Radioactive Material (NORM) [8]. The Safety Guide describes the broad regulatory decision-making framework of exclusion and exemption and is based on the system set out in IAEA Safety Report 49 [9]. A series of annexes address the application of this guidance to specific industries in which NORM may be a potential issue. The annexes developed for this edition discuss the oil & gas industry, the bauxite/aluminium industry and the phosphate industry.

In most NORM industries radionuclides are present in the products, wastes or residues in relatively low concentrations; however large volumes of wastes and residues are produced. Proper management of wastes and residues is important in restricting potential exposures from NORM and a range of control measures are needed to manage the wide variety of materials that might be produced. The optimisation principle is particularly important for the management of residues as doses to the public can be comparable to background radiation levels and may exceed the public dose limit. If doses cannot be easily reduced without significant expense the associated level of risk may be acceptable provided that stakeholders have been properly informed and that the situation is kept under periodic review. Establishing clear and open procedures for optimisation of protection for the management of NORM is important.

Regulation of NORM has to be subjected to a graded approach consistent with the optimisation principle. The scope of regulation, including exclusion and exemption criteria, needs to be carefully considered if regulation is not to apply to all human activities. Under the current system of radiation protection many exposures from naturally occurring radioactive materials are excluded from regulation even though exposures are above the public dose limit. Deciding on criteria that would require regulatory oversight cannot be decided by the universal application rigid reference levels or dose constraints.

Some exposures to NORM can be classified as planned exposure situation. In these situations ICRP recommends that dose constraints for public exposure should be set in the less than 1mSv band while dose constraints for occupational exposures should be set in the 1 - 20mSv band.

For existing exposure situations, that is situations that already exist when a decision on control has to be taken, it is recommended that reference levels be applied within the1-20 mSv band to restrict doses to the public. This recommendation applies to exposures from natural sources including radon and to exposures resulting from previous operations in industries that enhanced naturally occurring sources. The result of an assessment may be that action to reduce exposures is not warranted, depending on the controllability of the source of exposure and the prevailing economic, societal and cultural circumstances. An endpoint for the optimisation must not be set a priori as the optimised level of protection will depend on the situation and past experience with the management of similar situations.

In its 2007 recommendations the ICRP recommends that in most existing situations for NORM residues, it is desirable to reduce exposures to levels that are close or similar to situations considered as 'normal' and, whenever practicable, values for the reference levels should be set at the lower end of the 1 to 20 mSv band.

5. Graded Approach to Managing NORM Residues

For most industries engaged in processing materials management of NORM wastes and residues is the most important for restricting radiation exposures to members of the public. Solid residues are initially stored on site, usually in stock piles or in tailings dams, and some wastes are buried on site in near-surface burial facilities. Other residues are on-sold as by-products and are used in a variety of applications such as landfill, concrete extender, plasterboard, building materials, soil conditioners, rail ballast, road fill or recycled as scrap metal. The end application has a significant impact on the potential doses to members of the public and is the main reason why reference levels citing activity concentrations for particular radionuclides cannot be universally applied.

Regulation of NORM requires a graded approach based on the principle that regulatory effort should be proportional to radiological risk. Initially a screening assessment of the potential radiological impact of the operation should be carried out. As a result of this screening assessment, the regulator may grant an unconditional exemption or require that a more detailed environmental impact assessment and safety assessment be carried out. Following this more detailed assessment, the regulator may then grant conditional exemption or require registration or licensing of the operation. The process to determine the optimal level of regulatory response is set out below.

5.1 Notification

The Regulatory Authority may, on the basis of previous or international experience with a particular type of operation, contact a new or existing industry, and request a screening assessment if they believe there is a potential for radiation impacts. Ideally however it should be the responsibility of the operator to notify the regulator that an operation involves naturally occurring radioactive materials. The process of notification provides a record for the Regulatory Authority of the intended operation and any decision to either exempt the operation, where it is clear that exposures and activity concentrations will not exceed the relevant exemption criteria, or to proceed with a screening assessment.

5.2 Screening assessment

Upon receiving a notification, the Authority may require an initial screening risk assessment to be made to estimate:

- the magnitude doses to workers or members of the public;
- the level of optimisation of radiation protection;
- the long term impact of any residues on the environment in the case of disposal;
- the impact of residues that may be recycled;
- the impact of manufactured items containing NORM.

Due to the wide variability of NORM operations the screening assessment should be specific to the particular operation and should be negotiated between the operator and regulator. The assessment may be based on existing information relating to the operation, its processes and waste/residue management methods, or be based on an agreed monitoring program to provide more data. Possible outcomes of the screening assessment include unconditional exemption, conditional exemption plus periodic review, registration, licensing and a requirement to develop a NORM management plan.

5.3 Unconditional exemption

Where doses are below the exemption criteria, and any other impacts are considered acceptable, the Authority may exempt the operation from further requirements. This would apply to those cases where it is clear that the potential for significant exposures is negligible even if there are changes to the process or the materials being handled.

5.4 Conditional exemption

Where the screening assessment confirms that the criteria for unconditional exemption cannot be met, but the doses to the workforce and members of the public are expected to be well below the relevant dose limits, a conditional exemption may be appropriate. There should be ongoing requirements for monitoring and reporting and/or periodic re-assessment against reference levels or dose constraints being applied as conditions of the exemption. In these situations the operator may be required to develop an appropriate NORM management plan, including provisions for re-assessment.

5.5 Registration/Licensing

Where an exemption is not granted, regulation may require the operator to hold an appropriate licence or registration. These authorisations would typically assign responsibilities and require a NORM management plan, including a radiation management plan and a radioactive waste management plan, to be implemented. The Authority may apply conditions to any registration or licence issued to define the particular requirements for ongoing monitoring and reporting, and, where appropriate, to specify the frequency of re-assessment of the status of the operation.

5.6 NORM management plan

When required an operator should develop a NORM Management Plan that would cover all aspects of the management of radiation exposures and radioactive waste. The NORM management plan should include:

- a description of all processes and in particular processes where doses may arise;
- a demonstration of compliance with relevant radiation protection standards;
- the relevant elements of a plan to manage radiation exposures;
- the relevant elements of a radioactive waste management plan;
- an assessment of the current or projected use of a material that may be recycled;
- an assessment of the potential impact of manufactured items containing NORM;
- appropriate monitoring and review programs;
- the relevant occupational health and safety issues;
- the relevant environmental protection issues;
- the definition of responsibilities for the operator/employer and employees;
- a process of review of the status of the operation in relation to continuing controls.

6. Conclusions

The extraction and processing of mineral ores containing low levels of naturally-occurring radionuclides can lead to the generation of products, by-products, wastes and residues containing elevated concentrations of these radionuclides. It is important that operators acknowledge that it is their responsibility to understand and manage the NORM issues relevant for their industry. These issues include radiological protection during extraction, processing, transport, storage and disposal of NORM.

In general, the activity concentrations in NORM are low although volumes might be high. A graded approach to regulation is required as in many cases unconditional or conditional exemption might be appropriate. Such a graded approach places emphasis on the need for optimisation of protection. The costs and benefits of introducing regulatory requirements need to be considered and compared with other options that would achieve the same objective. Development of a NORM management plan, including characterisation of materials, monitoring of radionuclide concentrations, and ongoing risk/dose assessments is an important management tool in determining the level of regulation required.

Public perception is important in any issue involving radioactive materials. Involvement of stakeholders is therefore an important consideration when assessing the optimisation of protection when utilising NORM, or disposing of NORM residues and wastes. There is a clear need for communication of the potential risks and benefits associated with proposals of this nature.

The Safety Guide developed in Australia incorporates three Annexes giving detailed information on the oil and gas, bauxite/aluminium and phosphate industries. It is anticipated that further Annexes will be developed in future on other industries dealing with NORM.

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