RADIOLOGICAL ASSESSMENT OF MINERAL SANDMINING IN AUSTRALIA

G.C. Mason, S.B. Solomon, M.B. Cooper, M.A. Wilks
Australian Radiation Laboratory
Lower Plenty Road Yallambie Melbourne
Victoria Australia 3085

INTRODUCTION

Australia is a major producer and exporter of minerals derived from sandmining operations. The most significant minerals are ilmenite, rutile, zircon and monazite. All of these contain small quantities of thorium-series and uranium-series radionuclides, with monazite, being the most active by far, containing 6-7% thorium-232.

The minerals occur naturally as small grains in beach sand. Mine sites on the West coast lie on pre-historic beach sands, several kilometres from the present coastline, and mining is typically by mobile earthmoving equipment such as scraper or bucketwheel. On the East coast, mine sites are near the coastline or on offshore islands and some of the mining is by underwater dredge. A primary concentration process at the mine site removes the debris by screening and much of the silica sand by wet gravity separation. There is little of radiological significance to this point in the process, as the concentration of radionuclides in the ore as mined is very low.

The primary concentrate, which typically may contain about 1% monazite, is transported to a secondary, or dry, separation plant, which is often remote from the mine site. It is during the secondary separation process that radiation exposures can become significant, principally from inhalation of radioactive dust and irradiation by gamma rays.

MINERAL SEPARATION

Separation of the primary concentrate into the various mineral products exploits differences in their densities and electrical and magnetic properties (Fig. 1). Differences in electrical conductivity permit some minerals to be separated in high, non-uniform electric fields; differences in magnetic susceptibility allow others to be separated in high magnetic fields. Differences in density allow both wet and dry gravity separation. All of these processes, apart from wet sedimentation, require a very dry process material for efficient separation. The feed to the separation equipment is in a spatially dilute form to allow each grain to feel the effect of the applied electric or magnetic field, or for efficient separation using gravity. As the efficiency of any one stage is rather poor, many stages may be required, and incompletely separated streams are recirculated for repeated passes, to reach an acceptable purity of mineral product.

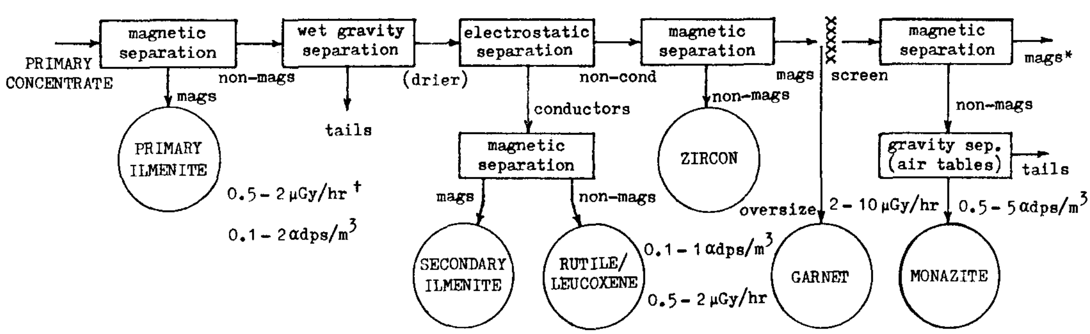
A consequence of the machine handling of hundreds of tonnes per day of mineral ores in the manner described above is that copious dusts are raised containing radioactive minerals which may be inhaled by plant workers. An additional exposure pathway arises from external radiation, especially near the monazite separation stages and in the monazite product store. A very approximate indication is given in Figure 1 of typical absorbed dose rates and gross alpha activity concentrations in air. Conditions vary from plant to plant, but where all or most of the separation processes are housed in the one building, activity concentrations can be similar throughout - a feature that is facilitated by the open interior design of many plants.

RADIOLOGICAL ASSESSMENT

The Australian Radiation Laboratory has conducted on-site measurements of absorbed dose rates, dust concentrations in air, particle size distributions, and radon and thoron and daughter concentrations at several of the major sandmining operations in Australia. A detailed report is in preparation, but some general observations are reported here, based on a representative subset of the data. The major pathways for occupational exposure have been identified as inhalation of dust containing thorium-series and uranium-series radionuclides, and external radiation, with only small contributions from radon, thoron and their daughter products.

Radon and thoron and daughters

Radon daughter concentrations are typically around 1 mWL or less at most locations, with thoron daughter concentrations in the range 1-10 mWL. Inside a monazite store containing bulk (unbagged) monazite the thoron daughter concentration near the breathing zone (1.8 m from the ground) was measured at 15 mWL. This is nearly two orders of magnitude smaller than the Derived Air Concentration (DAC) for thoron daughters of 1200 mWL [1].



*at some sites a xenotime stream may proceed from here

†the figures given are indicative only

Figure 1. Schematic illustration of a secondary separation process.

Radon concentrations up to 200 Bq m^{-3} were measured, with thoron concentrations in the latter stages of the secondary separation plant reaching 1200 Bq m^{-3}. In the store referred to above, thoron concentrations up to 5000 Bq m^{-3} were measured (one fiftieth of the DAC [1]). Ventilation is generally good, and equilibrium ratios (F-factors) are extremely low. Low thoron and thoron-daughter concentrations were not unexpected, as the short half-life of thoron does not permit significant diffusion of thoron from the mineral matrix. The thoron emanation coefficient has been estimated at about 1% or less [2].

External radiation

Absorbed dose rates increase through the separation process, being smallest, around 1 μGy hr^{-1}, in the initial stages (ilmenite section) and rising to around 10 μGy hr^{-1} or more near monazite extraction equipment and monazite bagging or binning operations. In areas where monazite product is stored, absorbed dose rates may reach 100 μGy hr^{-1} or more, depending on the exposure geometry - several times the pro-rata exposure rate permitted for a 2000-hour working year. Clearly, occupation of storage areas requires control. Access to storage areas is normally limited to storage and retrieval operations.

Employees working in secondary separation plants wear personal dosemeters. Most employees receive less than 5 mSv per year from external radiation, but some may receive up to 20 mSv in a year [3]. While the latter figure is below the current occupational limit of 50 mSv in a year, it will be necessary to review the working environment of those most exposed in the light of the recent trend towards controlling time-averaged, long-term exposures to less than 15 mSv per year [4],[5].

Radioactive dusts

Workplace dusts have been sampled at many locations in several dry separation plants. Gross alpha activity concentrations in air range from 0.02 to 50 alpha decays per second per cubic metre (αdps m^{-3}). The activity concentration values form an approximately lognormal distribution. The few measurements at the extreme upper end of the range almost certainly include material that is not normally considered as 'airborne dust' or 'inhalable' dust. A quantity of large particle size material is thrown from the separation equipment during processing. Although this rapidly reaches a vertical terminal velocity, some of it, depending on the location of the sampler, can be drawn into the sampler and retained on the filter paper. The presence of this large particle material confounds both activity concentration measurements and particle sizing studies, and consequently 'area sampling' results should be interpreted with caution. Whenever possible, personal sampling should be used to assess occupational exposure to workplace dusts.

Particle size distributions for airborne dusts have been measured using two different cascade impactors. Sizing measurements were made with a baffle placed some distance above the impactor to prevent large particle material falling vertically into the inlet. Consequently, the particle size distribution above about 20 µm is not known for samples in air. Activity Median Aerodynamic Diameters (AMADs) range from 2 to 12 µm, and an overall average value of about 6 µm, with rather large uncertainty, seems appropriate for the purposes of dose estimation. Similar values have been obtained independently [6].

There appears to be a significant difference in mean alpha activity concentrations in air between operations on the West coast (~1 αdps m^{-3}) and on the East coast (~0.1 αdps m^{-3}). The largest personal sampler concentration measured in a limited survey of workers on site was 3 αdps m^{-3}, during one shift at a West coast dry separation plant.

Taking an AMAD of 6 µm and the recommendations of the International Commission on Radiological Protection concerning calculation of DACs [7], the DAC for monazite dust based on an annual limit of 50 mSv is about 0.9 αdps m^{-3}. Many of the concentrations measured exceeded this value, especially at the West coast sites. Inhalation of radioactivity in dust during mineral sands processing is clearly a very significant exposure pathway. Fortunately, occupancy of the high activity sections of the plant is low and, for extremely dusty procedures, dust masks are worn. However, a routine monitoring program including personal dust sampling is strongly recommended in secondary separation plants, especially if adherence to a 15 mSv annual average is to be demonstrated.

REFERENCES

[1] ICRP Publication 32, 'Limits for Inhalation of Radon Daughters by Workers', Pergamon Press, Oxford, 1981

[2] Kerrigan G.C. and Dallimore P., 'Thoron emanation', State X-ray Laboratory of Western Australia (unpublished), 1983.

[3] Watson I.D. and Taylor R.K., Radiat. Prot. in Australia 2, 17, 1984.

[4] National Radiological Protection Board, 'Interim Guidance on the Implications of Recent Revisions of Risk Estimates and the ICRP 1987 Como Statement', NRPB Publication GS9, 1987.

[5] International Commission on Radiological Protection, Statement from the 1987 Como Meeting of the Commission, to be published in Annals of the ICRP.

[6] Hewson G.S., 'Particle Size Distributions of Radioactivity in Mineral Sands Separation Plants', to be published in Radiat. Prot. in Australia.

[7] ICRP Publication 30, 'Limits for Intakes of Radionuclides by Workers', Pergamon Press, Oxford, 1979.